FIRESENSE

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Abstract	This deliverable provides a reference set of user requirements, based on the outcome of WP2 (Identification of Requirements and System Specification). It is suitable for further enhancement, so that it can act as a reference guide for actors and suppliers. It includes four main sections namely: state of the art, user requirements groups and user questionnaires, user requirements, and field measurements.
Keywords	State of the art, Questionnaire analysis, User requirements, Field tests.

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1 Introduction

This deliverable provides a reference set of user requirements, based on the outcome of WP2 (Identification of Requirements and System Specification). It is suitable for further enhancement, so that it can act as a reference guide for actors and suppliers. It includes four main sections namely: state of the art, user requirements groups and user questionnaires, user requirements, and field measurements.

The state of the art section includes surveys on ten different subjects, which will constitute the basics of the FIRESENSE system given in Figure 2.1-1. In the *Sensors for Fire Surveillance and Optimization of Deployment* section, possible sensor technologies that the project plans to use are investigated. In addition, the camera technologies that the project plans to use in FIRESENSE are mentioned. In the *Weather Stations* section; various types of devices and sensor technologies used on them are described.

In the *Flame Detection Techniques and Video Smoke Detection Techniques* sections*, v*isible spectrum camera-based algorithms are investigated. Noteworthy algorithms in the literature are discussed with their advantages and shortcomings. In the next section, *Infrared Fire Detection*, a survey of the usage of infrared band instead of visible spectrum for fire (flame or smoke) detection is provided also given. Cameras that can be used in different IR bands are introduced and their properties are given. In addition, an analysis of which spectrum band should be used is included given and specific features are identified.

Another important problem to be dealt with in FIRESENSE is the transmission of the sensor data to the control center for further processing. Sensors used in FIRESENSE are low power devices, therefore transmission should be done in an energy efficient way. In section *Wireless Sensor Network Technologies for Fire Detection,* the ways of achieving this type of communication network are investigated. Several different hardware packages are investigated. Moreover possible network topology and factors affecting this topology are investigated.

The FIRESENSE system gathers several different types of information from sensors and cameras. While the sensors collect measurements of temperature, humidity, etc., the cameras collect images in different spectra. In the *Data Fusion* section, methods to fuse such different measurements are presented.

As fire ignition is detected using such techniques, the next phase is to estimate the propagation direction and speed of fire. In the *Fire Propagation Estimation and Visualization* section different fire spread models and factors affecting the spread that can be found in published literature are presented. Moreover, possible visualization technologies, which can be used to display the spread of fire in a user friendly and interactive manner, are mentioned.

In the *Commercial Fire Detection and Management Systems* section, existing commercialized indoor and forest fire detection systems are surveyed. The standards used in these systems are also presented. In *Related EU Projects* section, some related previous and on-going EU projects are reviewed.

Scientific issues and the advantages/disadvantages of the state of the art techniques are very important in designing the FIRESENSE system. On the other hand the importance of the user requirements is not to be underestimated. To understand the user requirements better, user groups have been established and questionnaires specifically adapted for these user groups were prepared. In section *User Requirements Group and User Questionnaires,* information on the established groups and an analysis of the results obtained using the questionnaires filled by the members of these groups are presented.

Final requirements for FIRESENSE system are then defined according to (i) Debates during the consortium meetings, (ii) State of the art investigation and (iii) the results of the questionnaires. In the *User Requirements* section the necessary requirements specifications and constraints for the different elements of the FIRESENSE system are categorized and provided in a tabular form.

In the last section, the planned field tests that will be implemented during the FIRESENSE development process are mentioned. These tests are divided into two: internal and external field test. The internal tests cover experiments and examinations in a controlled environment, while the external tests include controlled real fire experiments.

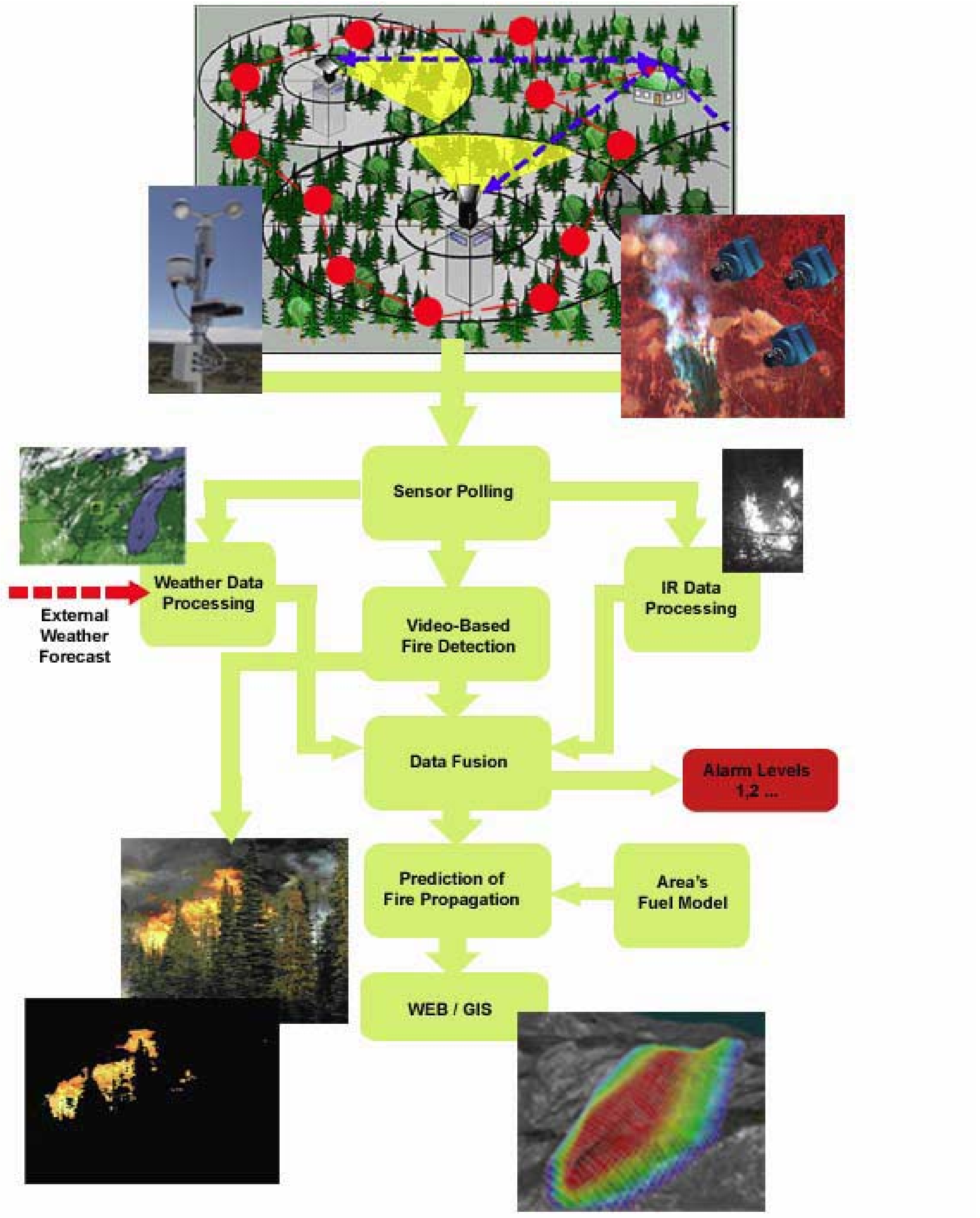


Figure 2.1-1: Overall system architecture of FIRESENSE

2 State of the Art

2.1 Sensors for Fire Surveillance and Optimization of Deployment

2.1.1 Introduction

There are nowadays two different types of sensors dedicated for fire surveillance, the cameras and the WSN (Wireless Sensor Network).

The first types of sensors are composed of cameras covering large areas between 40 to 50 km^2. The covering of large areas is realized with the help of Pan Tilt and Zoom systems. In this configuration the cameras with the lenses are expensive. The cameras are installed on the top of the masts, they are powered with power supplies and the images are sent thanks to the microwave links. The microwave links could reach ranges between 10 to 60 km depending on the LOS (Line Of Sight), the emitted power, the type of area (woods, urban) and the size of the antenna. The bandwidth usually operates between 50 and 100 Mbps. These nodes are referred to as high bandwidth sensors and are used to transmit several video signals. The real covered area will depend on the line of sight. Only large smoke areas could be detected without line of sight.

The line of sight and the early stage of the fire process problem could be solved with the second type of sensors. A new technology, called Wireless Sensor Network (WSN) is nowadays receiving more attention and starts to be applied in forest fire detection. The Wireless Network Sensors integrate on the same hardware the sensors, the data processing, the wireless networking and the batteries. Unlike cell phones WSN do not have the capability of periodic recharging. The sensors are devices capable of sensing their environment and computing data. The sensors sense physical parameters such as the temperature, the pressure and the humidity, as well as chemical parameters such as Carbon Monoxide, Carbon Dioxyde and Nitrogen Dioxyde. The sensors operate in a self-healing and self organizingwireless networking environment. One type of wireless technology is ZigBee which is a new industrial standard based on IEEE 802.15.4. This technology emphasizes low cost battery powered application and small solar panels. It is suited for low data rates and small range communications

2.1.2 State of the Art

2.1.2.1 Deployment example for fire surveillance and detection

The figure shows a representative example of sensor deployment integrating fixed and PTZ (Pan, Tilt and Zoom) multispectral cameras covering large areas with WSN covering specific areas or areas without LOS.

The gateway nodes are designed to process and store sensor readings from other nodes. The gateway nodes serve as an interface into other existing networks. All the data acquired from the PTZ cameras and the motes are sent to the control room with the help of a broadband microwave link (for example the Libra 5800).

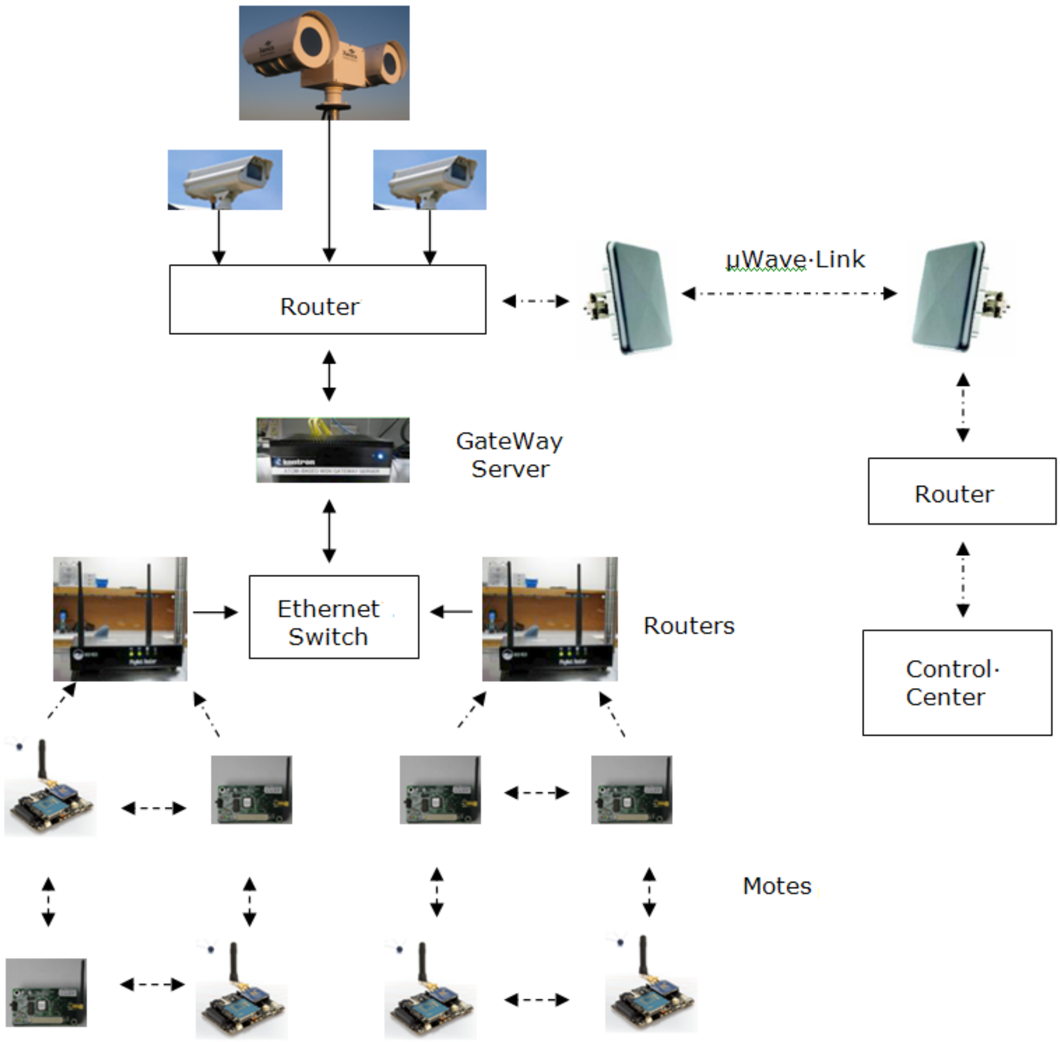


Figure 2.1-1: Sensor Deployment

2.1.2.2 Motes

Several generic sensor nodes such as the Mica2 Mote, the Imote2, the TelosB, the Iris, the Waspmote and the BTnode are available today. The term Mote refers to a general class of technology that aims to produce small robust and versatile sensors that can be easily deployed over a wide area. The figure hereunder illustrates the Mica2 mote.

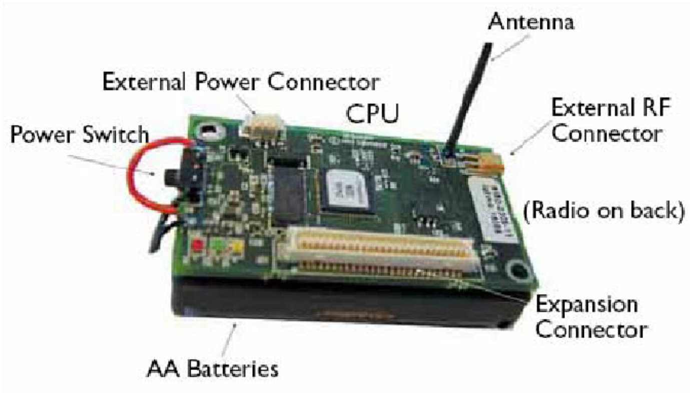
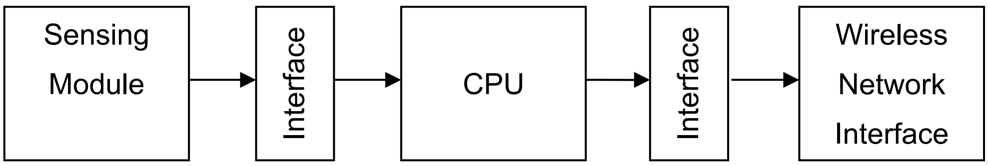


Figure 2.1-2:Mica2 Mote

The deployment of sensor nodes in a WSN can be accomplished using two types of methods. The first method deploys the nodes randomly. The second method, that we will adopt, distributes the nodes in fixed locations. These locations are identified with a GPS. The nodes that make up the WSN are comprised of four components:

1. Sensors
2. Wireless communications
3. Data Processing
4. Power Supply (Batteries, Solar Panel)



The sensory nodes can be in four different modes during their operation:

1. Transmitting a message
2. Receiving a message
3. Sensing an event (temperature, humidity, CO2, CO, NO2, PIR, …)
4. Sleeping

Each type of sensor has its advantages and disadvantages. A careful assessment of the environment will define the optimal configuration of the WSN (motes, mote deployment, the wireless communication, range between nodes, node distribution, and duration of battery life …) the cameras and the microwave link.

Example of MSP410CA mote battery life test:

Circuit	Mode	Current
PIR	Off	1 µA
PIR	On	300 µA
Radio	Off	1 µA
Radio	RX mode	8 mA
Radio at 1 mW	TX mode	16 mA
Processor	Sleep	15 to 20 µA
Processor	Active	8 mA
Serial flash memory	Write	15 mA
Serial flash memory	Read	4 mA
Serial flash memory	Off	2 µA

The masts with the sensors are designed to be deployed with low maintenance or human intervention and the WSN should be designed to be deployed without maintenance or human intervention. The sensor nodes are small and inexpensive but they are limited in power, in range, in memory, in data rate and computation capabilities. If nodes fail due to a fire or due to batteries the WSN topology may have to change and self organize quickly.

2.1.2.3 Main motes products

Figure 2.1-3: Example of mote packaging

These are examples of mote packaging including PIR (Passive InfraRed) sensors.

Figure 2.1-4: Eko Sensors for environmental monitoring from Crossbow Technology

Crossbow Technology has several environmental monitoring sensors (Soil Moisture, Soil Temperature, Soil Water Content, Ambient Temperature and Humidity, Leaf Wetness, Solar radiation). They provide also the Node, the gateway and a weather station suite.

Figure 2.1-5: Forest fire detection using wireless sensor networks from youtube from wireless distributed communications from libellium

Libelium seems to be the first company providing products for detecting forest fires using WSN with Waspmote. See http://www.libelium.com/libeliumworld/articles/101031032811.

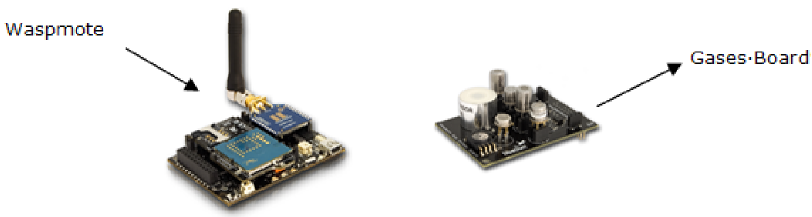


Figure 2.1-6: Libellium Waspmote with the gases board

In the forest fire detection application, the Waspmotes were deployed in strategic locations. Temperature, Relative Humidity, Carbon Monoxide and Carbon Dioxide are measured each 5 minutes. Each device is powered with rechargeable batteries and a solar panel.

More recently Dust Networks designed the DN2510, a mote on chip and the M2510 Mote Module and the mote packaging. See http://www.dustnetworks.com/.

Figure 2.1-7: Mote on a chip, Mote Module and Mote Packaging from Dust Networks

A overview of the cameras types and WSN for fire surveillance is described in the sensors chapter.

2.1.2.4 Minerva S200 Plus Triple IR flame Detector

The MINERVA S200 Plus flame detectors are Infrared solar blind and multi-channel infrared flame detectors with low power consumption and high false alarm immunity. It is a triple waveband infrared solar blind flame detector for optimum false alarm immunity. The properties of Minerva S200 are

- Unrivalled black body rejection over a wide range of source temperatures
- Range adjustable to 50 meters for a $0.1m^2$ petrol pan fire
- Discrimination of optical faults (dirty windows) from other faults by the built-in self test feature
- Housing designed for easy installation of cabling
- Flexible mounting and angular adjustment
- 2 x 20mm field cable entries
- IP66/67 housing designed for external use
- Rugged stainless steel ANC4 (316L) housing and stainless steel 316 mounting bracket
- Operating temperature range of -40 to + 80°C
- Variable response times and sensitivity settings
- Remote self test and range setting
- True window test in detection area (i.e. not in the edge of the window)
- Terminals provided for Remote LED connection where relevant
- ATEX and IECEx certified
- Approved to EN54 Pt10
- FM, DNV and LRS certified
- Very low power consumption (0.35mA)
- Models available with Conventional or Analogue Addressable interface (requires 2 core cable only)
- Models also available with relay or 4-20mA outputs
- Patented dual filter solar blindness for complete solar blindness
- 100° field of view on IS versions

- 90° field of view on Flameproof versions

A typical MINERVA sensor is shown in Figure 2.1-8.

Figure 2.1-8: Minerva Sensor

MINERVA S200 PLUS is available in both intrinsically Safe (EEx ia) and flameproof (EEx d) models. The intrinsically safe models are suffixed by the letter "i" or their ATEX Certified EEx version "ia". As part of an intrinsically safe circuit, it is suitable for zones 0, 1 and 2 where group IIC gases or lesser hazards can be continuously present in explosive concentrations. The flameproof models are suffixed by the letter "f" and are ATEX Certified EEx d IIC T6. The detectors are suitable for zones 1 and 2 where group IIC gases or lesser hazards can be intermittently present in explosive concentrations.

2.1.2.5 FireSentry Flame detector QuadBand Triple IR/vis FS24X

Firesentry sensors are highly sensitive to virtually all fires including Hydrogen Flames Resistant to artificial- and sunlight

- Built in (self) test (BIT)
- Suitable for indoor and outdoor applications
- FM and ATEX certified
- SIL 2 according to exida FMEDA report.
- Relay outputs, 4-20 mA output and RS-485 modbus output
- A test range of up to 5 meters (16 ft.) when tested with Test Lamp TL-2055X

The Explosion proof Flame detector QuadBand Triple IR/vis FS24X is suitable for the detection of Hydrocarbon fires such as wood, gasoline and natural gas but also non-Hydrocarbons such as Hydrogen and metals. Detection range: 0,1 m^2 n-Heptane at 60 meters (1 sq. ft. n-Heptane at 200 ft.). Applications: Gas- and Oil platforms, Tank farm, Aircraft hangars and Generator rooms. Firesentry sensor is shown in Figure 2.1-9.

Figure 2.1-9: Firesentry sensor

With the Test Lamp TL-2055X one can test the FS24X at a distance of more than 5 meters (16ft). So testing without scaffolding or lifts will save a lot of money.

2.1.2.6 *PIR Sensors for Flame Detection and Infrared Pyrometers for Temperature Estimation*

Infrared non-contact temperature measurement systems have been around since 1950's. Recent advances in electronics and optics provided low-cost temperature measurement and motion estimation devices based on pyrometry. The word pyrometry comes from the Greek word of “pyro” meaning fire. It may be possible to design low-cost wild fire detection sensors based on pyrometric infrared sensors.

Bilkent University conducted some experiments to test the possible use of Pyroelectric Infrared (PIR) sensors for flame detection. PIR sensors can detect IR radiation from 3 micron to 15 microns. They are widely used for motion detection and commercially available (less than 5 Euros). Normal PIR sensors produce binary outputs. We modified the circuitry of the sensor as shown in Figure 2.1-10 and were able to obtain a real-time signal as in expensive IR sensors.

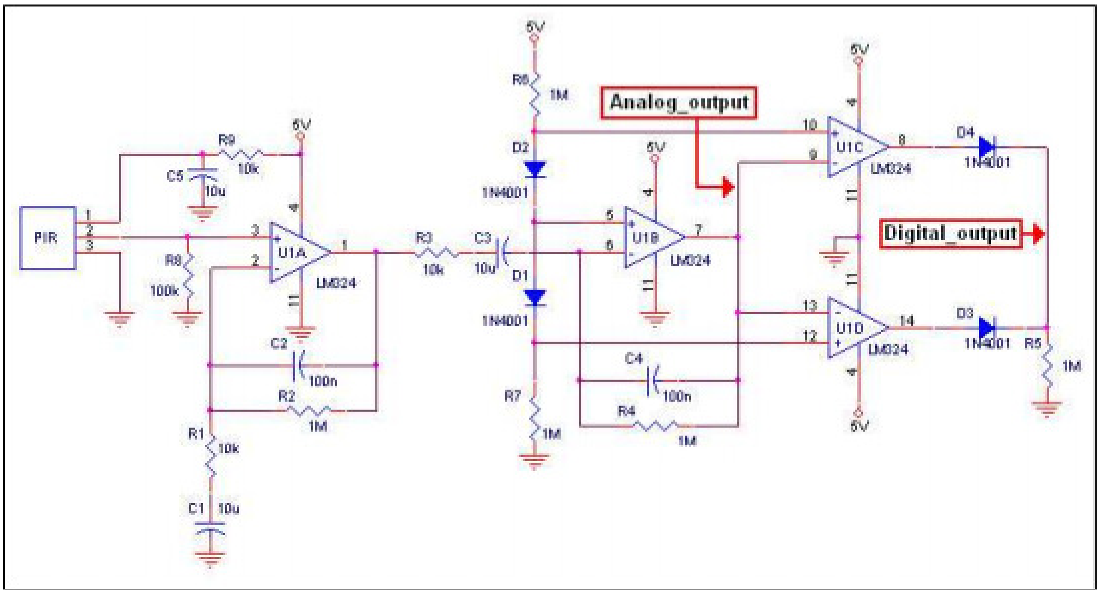


Figure 2.1-10: Modified version of PIR sensor circuitry

A typical background signal produced by the PIR sensor is shown in Figure 2.1-11. There are no moving objects in front of the sensor.

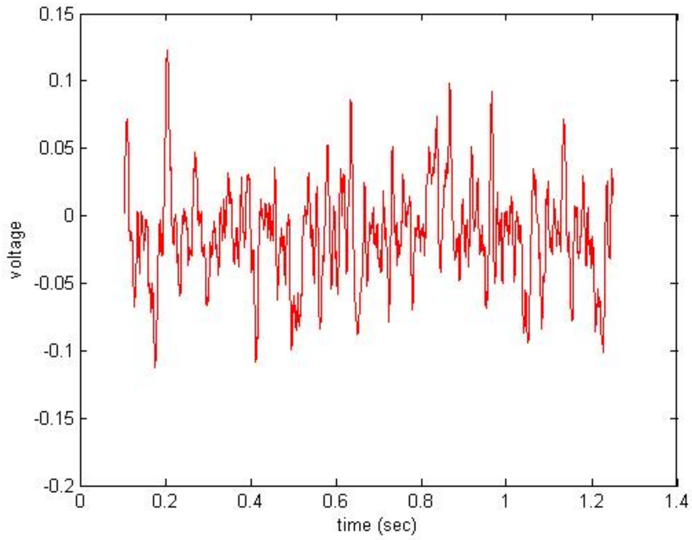


Figure 2.1-11: Background signal produced by PIR sensor

It is experimentally shown that it is possible to detect the existence of flames using PIR sensors. The Figure 2.1-12 shows the signal obtained from a PIR sensor, which is 5 meters away from a 50cm by 50 cm pan fire. The amplitude of this signal is ten times higher than the background signal shown in Figure 2.1-11.

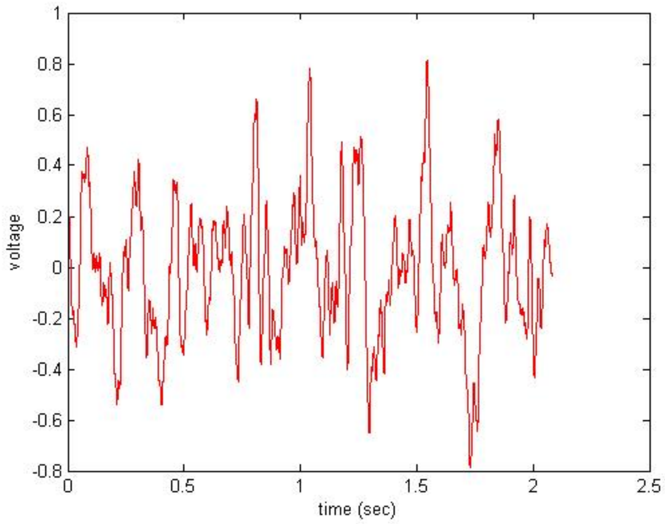


Figure 2.1-12: Signal produced by PIR sensor

It may not be possible to place regular high-cost IR sensors to fields or archaeological sites but it may be possible to place PIR sensors to archaeological sites. In fact, low-cost infrared thermometers are recently proposed for use in agricultural research [1]. Commercially available infrared thermometers use an optical system to collect infrared energy from a measured target area. This energy is used to calculate the target surface temperature. They are also called infrared pyrometers [2], [3], [4] because of the pyrometric measuring process. The optical system focuses the thermal radiation of the target object onto a detector. Temperature (T) of an object is related to the thermal radiation or irradiance J^* of the object through the Stefan–Boltzmann law.

$$J^* = \varepsilon \sigma T ,$$

where σ is called the Stefan-Boltzmann constant and ε is the emissivity of the object. This relation is used to estimate the temperature of an object from a distance. As a result, there is no need for direct contact between the pyrometer and the object, as in thermocouples and Resistance temperature detectors (RTDs). Commercial systems utilize with single wavelength, dual wavelength, and multi-wavelength designs depending on the application. In wildfire detection applications it may not be necessary to estimate the exact temperature around the sensor but it is necessary to determine the rate of sudden increase in temperature due to fire.

2.1.2.7 Thermocouples

A thermocouple is a temperature sensor consisting of two wires of dissimilar metals. The simple concept of a thermocouple is shown in Figure 2.1-13.

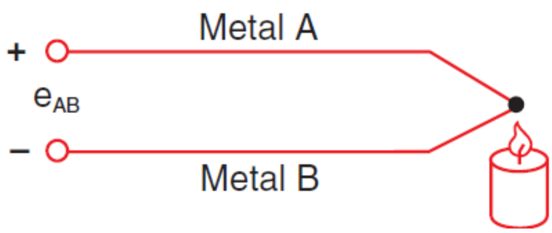


Figure 2.1-13: Basic concept of the thermocouple (Figure taken from [5])

The temperature gradient between the ends of the wires generates a small DC voltage (e_{AB}), which is directly proportional to temperature. The sensitivity of the thermocouple depends on the used materials. Such sensors are widely used in forest fire simulation studies. Usually, forestry engineers carve thermocouples in soil and record their temperatures in order to determine the speed of spread of the controlled fire. Unlike optical IR sensors, thermocouple based sensors cannot detect fire from long distances. This is the main problem with thermocouples because they can only detect flames or heat when the fire is very close to the sensor.

In the remainder of this section we review a commercially available thermocouple system, as shown in Figure 2.1-14.

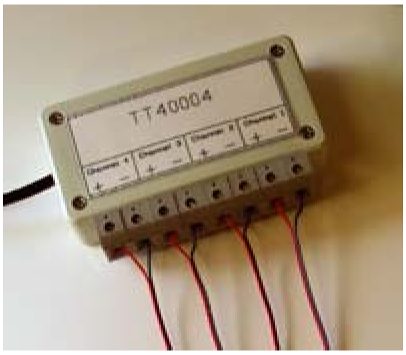


Figure 2.1-14: TT4 Multi-sensor thermocouple

The thermocouple TT4 [6] is factory calibrated in order to use any of the common material types, and is software selectable via a menu from the fire control center. The temperature range and the sensitivity of the sensor depend on the materials that are used in the production of the thermocouple. The materials used in design, their standard letter codes and the temperature ranges of these designs are given in Table 2-1.

Table 2-1: Thermocouple types and their basic properties

Type	materials	wire colours	output	temp range
Type E	Chromel/ Constantan		68µV/°C	-270 - 1100°C
Type J	Iron/ Constantan	red/white	52µV/°C	-40 - 750°C
Type K	Chromel/ Alumel	yellow/red	41µV/°C	-200 - 1200°C
Type T	Copper/ Constantan	blue/red	43µV/°C	-200 - 350°C

TT4 offers low cost thermocouple sensors. Therefore, these sensors can be used in application areas where the risk of sensor destruction is considerably high. Thus, TT4 thermocouples are ideal for applications in which the probe of the system is not recoverable such as temperature sensors carved in soil. By using the TT4 interface, users can build their own thermocouple.

Due to the built-in microprocessor unit, analog to digital conversion (e.g., raw voltages to binary values) is performed during the measurement and a calibration process is needed according to the type of the thermocouple. The digital/serial output is compatible with 3-wire Data bus protocol that enables the transfer of signals up to distances of 4 km without any loss in data and data quality.

Figure 2.1-15: TTT4 Multi-Sensor thermocouple and wires

TT4 technology provides:

- Plug & Play Operation
- Built in Microprocessor
- Digital/Serial Data Output
- Factory Calibration
- 4 Channel Capacity
- User made thermocouples (Optional)

- Compatibility with standard E,J,K,T thermocouples

The user can also adjust the length of each thermocouple in order to use it in a certain application. The thermocouple TT4 can communicate with its smart interface from a maximum distance of 10 meters.

In this section TT4 thermocouple is briefly reviewed. There are also other commercially available thermocouples [7],[8],[9].

Although thermocouples provide accurate, cheap and easy-to-use solutions, they can detect temperature, only at the sensor locations. In order to have an efficient temperature sensing system from the point of view of wildfire detection, each node (probe) of the sensing system must sense not only the changes at the probe location but also changes in the vicinity of the probe. Because of this pyrometric temperature sensors may be more valuable in fire detection than thermocouples and thermistors because they can estimate the temperature of an object from a distance.

2.1.2.8 Cameras

We will present here different types of day and night cameras.

Day Cameras:

- Color CMOS
- CCD
- Day – Night Cameras:
- LLLTV: Low Light Level TV
- ICMOS: Intensified CMOS
- EMCCD: Electron Multiplying Charge Coupled Device
- EBCMOS: Electron Bombarded CMOS
- CMOS: Complementary Metal Oxide Semiconductor
- NIR: Near InfraRed
- SWIR: Short Wave InfraRed
- MWIR: Middle Wave InfraRed
- LWIR: Long Wave InfraRed

In our application we will evaluate Color day, NIR, SWIR, MWIR and LWIR cameras for scientific analysis. This analysis will help us to extract and select the features for fire detection. For sensor cost reasons, image processing will be applied on color and LWIR cameras.

There are mainly four types of IR instrumentation. They can be classified in function of the spatial and spectral resolution.

		Spectral Resolution	
		No	Yes
Spatial Resolution	No	Radiation Thermometers	IR Spectrometers
	Yes	IR Cameras	Imaging Spectrometers

We will describe in the document of the trials the IR camera and imaging Spectrometers based on Xenics detectors and main players in fire detection thermal cameras.

2.1.2.9 Multispectral Cameras

	VIS	EMCCD I2CMOS	NIR	SWIR	MWIR	LWIR
VIS	Sarnoff Goodrich Raytheon		Sarnoff Goodrich Raytheon	Sarnoff Goodrich Raytheon		Sarnoff Goodrich Raytheon
EMCCD I2CMOS						Northrop Gruman
NIR	RIT		RIT			RIT
SWIR						
MWIR	FLIR					
LWIR	Elbit	FLIR Elcan				

Although there is extensive research in image fusion and in infrared image processing for fire detection there are nearly no available products. Opgal seems to be the only one who provides a multispectral image fire detection solution.

Other companies are providing hardware for image fusion at the pixel level. The most complete product is from Sarnoff and Goodrich. They are able to fuse 3 images. The image fusion is realized in real time with the Acadia processor.

It is at this stage applied in military applications only.

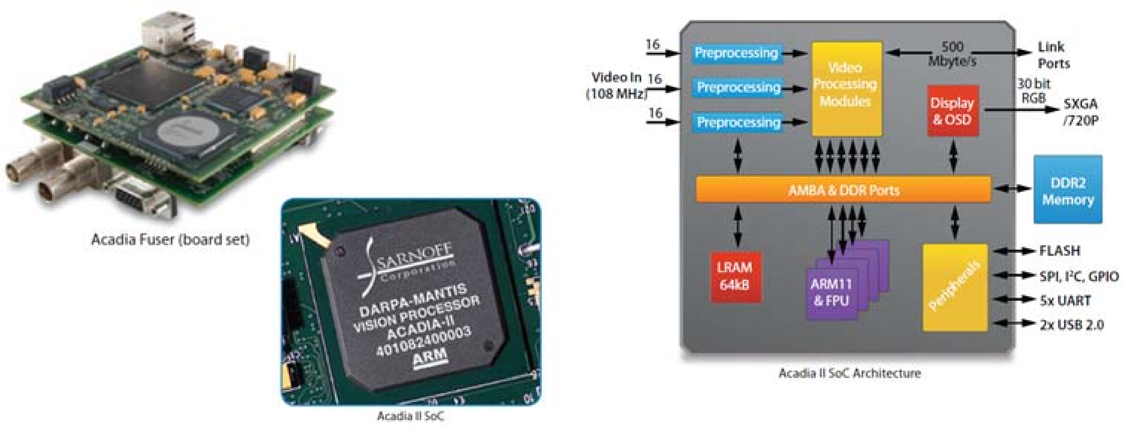


Figure 2.1-16: Image Fusion SOC from Sarnoff

The Equinox Company developed the DVP-4000 dual video processing board based on a FPGA.

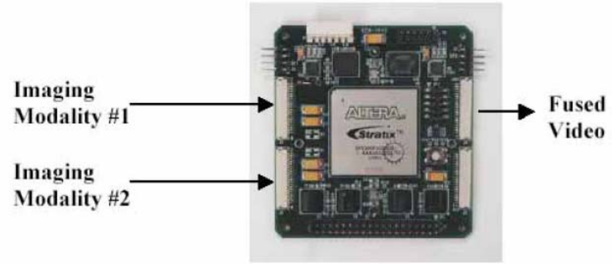


Figure 2.1-17: Compact Video Processing board DVP-4000 Equinox

Equinox used the fusion model from Waterfall solutions.

Figure 2.1-18: Compact Video Processing Board FP5500 from Imagize

2.1.2.10 Sensors Description

2.1.2.10.1 Raven 384 LWIR camera

The **Raven-384** is an infrared imaging camera from Xenics. The camera interface can be PAL/ NTSC video for regular CCTV security network or optional Ethernet for digital LAN. Standard delivery includes a common power supply and connecting cables. The detector of the Raven-384 has a medium resolution of 384x288 pixels.

Detector Specification	
Array type	Micro bolometer (a-Si)
Number of pixels and pitch	384x288; 25 µm pitch
NETD	80 mK
Array operability	>99.9 %

Operating temperature range	-40°C to 50°C			
Storage temperature range	-50°C to 85°C			
Lenses selection				
Lenses Part number	**Focal**	**HFOV**	**VFOV**	**Optional**
XC509-302	18 mm F/1	30°	23°	x
XC509-303	25 mm F/1	22°	16.5°	x
XC509-308	19 mm F/1.1	29,4°	21.5°	Included
XC509-309	60 mm F/1.25	9.2°	6.8°	x
XC509-3010	75 mm F/1	7.3°	5.5°	x
XC509-3011	100 mm F/1	5.5°	4.1°	x

Thermal Camera specifications	
Lens provided by default	
Longueur focale	19 mm f/1.1
Imaging performance	
Non Uniformity Correction (NUC)	DSP controlled, shutter less as option.
Interfaces	
Analog Output	PAL (CCIR) or NTSC (RS 170)
Camera Control	Optional Ethernet (TCP/IP
Power Requirements	
Power Consumption	3.4 W
Voltage	12 Volts
Physical Characteristics	
Dimensions	74x70x60 mm^3 (without lens)
Weight camera head without lens	< 500 g
Shock	70 G , 2 ms halfsine profile (without shutter)
Vibration	2 G (5 Hz to 500 Hz)
Humidity	5 % - 95 % non condensing

Product selector guide			
Sensitivity (NETD) @F/1	**Shutter**	**Frame Rate (Hz)**	**Analog Out**
Premium : >50 mK	x	50	PAL/NTSC
Base : ≥80 mK	-	50	PAL/NTSC
Base : ≥80 mK	x	50	PAL/NTSC
Base : ≥80 mK	-	9	PAL/NTSC
Base : ≥80 mK	x	9	PAL/NTSC

2.1.2.10.2 Arbel LWIR IR camera

The **Arbel** is an infrared imaging camera from Opgal.

Features	Description / Performance		
Focal Plane Array	Long Wave Microbolometer 384x288		
Spectral Band	8 – 14 µm		
Video Output	CCIR or RS-170		
NETD	<50°mK (with f#1 optics)		
Operating Voltage	9-28VDC		
Power Consumption	~ 2.2 W at steady state		
e-Zoom	x2 and x4		
Command and Control	RS 422 or RS 232 or PELCO D (Optional)		
Control Operation	Polarity, NUC, Image Flip, Manual Gain/Level, e-Zoom, Focus Corrections		
Number of Fields of view	2		
Dimensions	110x111x240 mm		
Mounting	4x M8X1.25		
Weight	< 2.2 Kg		
Environmental Qualification			
EMI/EMC	MIL-STD-461D		
Operating Temperature	-30°C -60°C		
IP Rate	IP 65; IP 67 optional		
Vibrations	MIL-STD 810E		
		NATO Target (2.3mx2.3m)	
	Field of view HxV (Deg)	**Detection (m)**	**Recognition(m)**
Wide FOV - 45 mm	12 x 9	2,000	690
Narrow FOV - 135 mm	4 x 3	6,200	2,000

2.1.2.10.3 Miricle Microcam LWIR IR camera

The **Miricle Microcam** is an infrared imaging camera from Thermoteknix.

Specification	
Sensitivity (f1.0 no lens)	384`M´ Model = <80mK 384`H´ Model = <50mK
Power consumption	<0.6 Watts
Supply	1.8V to 5.5V
Detector Material	ASi
Array Size	384x288 (Optional 320x240)
Pixel Count	110,592
Pixel Pitch	25µ
TEC-Less operation	Yes
NUC operation	Shutterless - No Shutter Present nor required
Spectral response	8-12um
Frame Rate	60 FPS
Video Output	Composite PAL / NTSC
Digital Zoom	x2 x4
Polarity invert	Yes
Image flip / rotate	Yes
Discrete Button inputs	4
Text overlay	Yes
Operating temperature	-20°C to +60°C
Weight (Excluding optics)	35g / 1.2oz
Typical Weight (Including 14.95mm F/1.3 lens)	74g / 2.6oz

2.1.2.10.4 Tau LWIR IR camera

The **Miricle Microcam** is an infrared imaging camera from Thermoteknix.

Product Configuration	Performance	Fire	Digital
Imager Features & Performance			
Thermal Imager	Uncooled VOx Microbolometer	Uncooled VOx Microbolometer	Uncooled VOx Microbolometer
FPA Formats	324 x 256	324 x 256 & 160 x 128	324 x 256 & 160 x 128
Full Frame Rate	30 Hz (NTSC); 25 Hz (PAL)	30 Hz (NTSC); 25 Hz (PAL)	30 Hz (NTSC); 25 Hz (PAL)
Exportable Frame Rates	7.5 Hz (NTSC); 8.3 Hz (PAL)	7.5 Hz (NTSC); 8.3 Hz (PAL)	7.5 Hz (NTSC); 8.3 Hz (PAL)
Input power	4.0 - 6.0 VDC	4.0 - 6.0 VDC	4.0 - 6.0 VDC
Power dissipation	<1 W	<1 W	<1 W
Sensitivity	<75 mk, <50 mk f/1.0	<85 mk, <60 mk f/1.0	<85 mk, <60 mk f/1.0
Time to Image, FFC Interval	<3.5 sec, <0.5 sec	<3.5 sec, <0.5 sec	<3.5 sec, <0.5 sec
Image optimization (BPR, NUC, & AGC'd video) Factory set, User selectable	Y	Y	Y
DDE	Y	Y	Y
Physical Attributes			
Size (w/ shutter)	1.75" x 1.75" x 1.18" (44.5 x 44.5 x 30.0 mm)	1.75" x 1.75" x 1.18" (44.5 x 44.5 x 30.0 mm)	1.75" x 1.75" x 1.18" (44.5 x 44.5 x 30.0 mm)
Size (shutterless option)	1.5" x 1.5" x 1.18" (38.1 x 38.1 x 30.0 mm)	1.5" x 1.5" x 1.18" (38.1 x 38.1 x 30.0 mm)	1.5" x 1.5" x 1.18" (38.1 x 38.1 x 30.0 mm)
4 WFOV lens options - 19 mm, 13 mm, 9 mm & 5 mm (160 only) sealed, iDLC coating	Y	Y	Y
4 WFOV options average mass	72 grams	72 grams	72 grams
NFOV lens options	25 mm (18°) 35 mm (13°) 65 mm (7°) 100 mm (4.6°)	–	–
Support Lens-less configurations	Y	–	–
Precision Mounting holes (M2X0.4) on 3 sides (2 per side)	Y	Y	Y
Sealable bulkhead mounting feature on lens barrel (M29X1.0) , WFOV only	Y	Y	Y
ROHS, REACH and WEEE Compliant	Y	Y	Y
Interfaces and Features			
CMOS, (60/30Hz, 14bit or 8bit)	Y	Y	Y
BT-656 (60Hz, 8 bit)	Y	Y	–
Legacy Photon LVDS (30Hz, 14bit or 8bit)	Y	Y	Y
Slow video (factory set)	Y	Y	Y
NTSC/PAL	Y	Y	–
Invert/Revert (analog and 8-bit digital)	Y	Y	Y
Polarity control	Y	Y	Y
2x & 4x Digital zoom	Y	Y	Y
Dynamic Zoom and Pan	Y	Y	Y
Scene Range	-40°C to +600°C	-40°C to +600°C	-40°C to +160°C
Dynamic Range Switching	–	Y	–
Temperature Measurement/spot meter	Y	Y	–
Temperature Isotherms	Y	Y	–
Symbology (256 Gray & 256 Color)	Y	Y	–
Color Pallets (LUTs)	Y	Y	–
Gamma Correction	Y	Y	–

2.1.2.10.5 SWIR XS-1.7-320 thermal infrared camera

The Short Wave Infrared (SWIR) cameras are based on InGaAs technology. They are perfectly suited for utilizing the night glow phenomenon. One of the advantages is that the nightglow is emitted equally by the entire sky, and at all geographical latitudes. The XS-1.7-320 unit is working up to 1.7 μm, and its analog video-out interface makes it an easy plug-and-play infrared camera system.

Detector Array Specifications	
Array type	InGaAs
Spectral band	Standard 0.9 till 1.7 μm
# Pixels	320x256
Pixels pitch	30 μm
Array cooling	Uncooled
Pixel operability	>99%
Camera Specifications	
Lens (included)	
Focal length	25 mm
Optical Interface	C-Mount (Broad selection of lenses available)
Imaging Performances	
Frame rate (full frame)	60 Hz over NTSC 50 Hz over PAL
Integration time	Snapshot
Interfaces	
Analog out	PAL or NTSC
Power Requirements	
Power consumption	<4 Watt
Voltage	12 V DC
Power Supply	12 V – 5 A
Physical Characteristics	
Ambient operating temperature	0 to 50 ˚C
Dimensions	50 x 50 x 50 mm^3
Weight camera head	225 g

Product selector guide		
Frame Rate (Hz)	**Analog Interface**	**ADC**
60 Hz	NTSC	14 bit
60 Hz	PAL	14 bit

2.1.2.10.6 IQ752 Visible camera

The product specified is an industrial grade, color, full-featured, high-speed day/night 2.0 megapixel network cameras with on-camera recording/playback capabilities. The product is designed to meet or industrial and surveillance applications requiring a low power, rugged video camera with IP network capability. The camera has a built-in web server and FTP server. It is IEEE 802.3af Power-over-Ethernet ready and can also be powered directly using 12-24 VDC or 24 VAC. The camera will include a NTSC/PAL analog public view output.

IQ752 Specifications	
Imager	CMOS
Optical Format	½ inch
Image Resolution	1600 (H) x 1200 (V)
Number of pixels	2 millions
Camera aspect ration	User configurable, not limited to 4:3 aspect ratio.
Frame Rate (ips)	20 images per second at full resolution
	20 ips at 4:3 aspect ratio
	27 ips at 16:9 aspect ratio
Minimum light to produce color image	0.2 lux (0.02 fc)
Minimum light to produce B&W image	0.05 lux (0.005 fc)
Connection	TCP/IP protocol video output via RJ-45 Ethernet connection. PAL/NTSC

2.1.2.10.7 Onca 640 MWIR camera

The Onca-640 uses advanced real-time image correction and is equipped with a 2D InSb or MCT array with 640x512 pixel resolutions. The Onca-640 camera offers 14-bit images at various frame rates. Two speed versions are available: a standard video rate version operating at 30 Hz and a high speed version with frame rates above 100 Hz full frame.

Detector Specifications		
Array Specification	Onca MCT	Onca InSb
Array type	MCT	InSb
Spectral band	3.7 to 4.8 µm	3.6 to 4.9 µm or 1 to 5 µm
# Pixels	640 x 512	640 x 512
Pixels pitch	15 µm	15 µm
Array operability	Stirling cooled	Stirling cooled
Sensitivity (NETD)	< 20 mK	< 20 mK

Pixel operability	> 99.5 %	> 99.5 %
Cold stop F number	f/2.5	f/3.0
Camera Specifications		
Camera Specification	**Onca MCT**	**Onca InSb**
Lens (included)		
Focal length	25 mm	
Optical Interface	Bayonet	
Imaging Performances		
Frame rate : Video Rate **High Speed**	30 Hz 120 Hz	30 Hz 100 Hz
Window of interest	Smallest window 1x132	Smallest window 1x138
Integration time	Snapshot	
Exposure time range	>1µs, adjustable to full range	
A/D conversion resolution	14 bits	
Interfaces		
Camera control	GigE Vision Serial channel Camera Link	
Image acquisition	GigE Vision : 14 bit full frame rate CameraLink: 14 bit full frame rate Analog Pal or NTSC	
Trigger	Trigger in and out; LVCMOS	
Graphic User Interface (GUI)	Xeneth Advanced	
Power Requirements		
Power consumption	<50 Watt at room temperature	
Voltage	24 V DC	
Physical Characteristics		
Camera cooling	Forced convection cooling	
Ambient operating temperature	0 to 50 ˚C	
Dimensions	190 x 170 x 250 mm^3	
Weight camera head	5.5 kg	
Hardware Specifications		
Filter wheel options	Start Stop mode	
# filters	4 filters, one blank, 25.4 mm diameter	
Shutter options	Blank position in filter wheel	
GPS time stamp	Can receive GPS data from Accutime Trimble Gold GPS receiver	

2.1.2.10.8 Meerkat PTZ - LWIR and VIS

The Meerkat PTZ is a versatile pan/tilt positioning system from Xenics that is user configurable for side mounting of payloads or 'over-the-top' traditional mounting of payloads. Two motors control the azimuth and elevation positioning. The slip ring allows 360 degrees rotation. The maximum speed in Azimuth is 60˚/second (depending on the load) and the maximum elevation speed is 30˚/second.Incremental pan and tilt encoders with 2048 resolution provide position feedback and are also used to provide ‘on-screen’ display of pan/tilt position in azimuth and elevation.

The pedestal weight is 9.5 kg without the cameras. The maximum tolerated side load is 22.6 kg and 18 kg on the supports. Electronic control supports Pelco-P or Pelco-D configuration protocol and is selected with DIP switches on the Control Electronics board. The cameras are dry nitrogen pressurized in the enclosure (tube) in order to protect the optics and avoid condensation.

Meerkat PTZ Specifications	
Parameters	
Voltage	12-28 V DC
Physical	
Side mounted balanced payload capacity	22.6 kg (sur le coté équilibré)
Over the top mount payload capacity	18 kg
Pedestal Weight	9.5 kg
Size	260 mm (wide) 203 (deep) 254 mm (height)
Operating Temperature Range without heater	0°C à 70°C
Operating Temperature Range with heater	-30°C à 70°C sans chauffage
Azimut and tilt amplitude	
Azimuth	360 degrees continuous
Tilt	-30 degrees à +60 degrees
Slip Ring	15 Slip Ring. 12 @ 2 A & 3 @ % A
Motor	Brushed Motors DC, 12 V DC
Tilt limit switches	Internal limit PWB top mounted in housing
Position Feedback (Pan & Tilt)	Incremental encoders; TTL, single ended output. 422/485 X,Y format. 2048 resolution; index pulse once per revolution
Rotation Speed	
Azimuth	60 degrees / second
Tilt	30 degrees / second

2.1.2.10.9 Galil PTZ - LWIR and Visible

The Galil is a day and night observation head PTZ system including the Arbel and Sony CCD camera.

Technical Data

Mechanism Parameters

	Night Camera		**Day Camera**	
Specifications	Thermal Camera Arbel		CCD Sony Camera FCB-EX1000\P	
FPA \ Image Sensor	Long wave microbolometer 384x288 \ 640x480		1/4-type EX-view HAD CCD	
Spectral Band	8 – 12 µm		Visible	
NETD	< 50°mK (with F#1 optics)			
Video Output \ Signal	CCIR or RS-170		NTSC (380k pixel) PAL (440k pixel)	
Operating voltage	9 – 28 VDC		6 – 12 VDC	
Power consumption	2.2 W steady state		1.6 W inactive \4.0 W active motors	
Control Operation	Polarity, NUC, Image Flip, Manual Gain/Level,e-Zoom, Focus Corrections		Auto, Manual, Priority mode, Bright, EV compensation, Backlight compensation, Slow AE	
Field Of View	Dual			
	Wide (45mm))	**Narrow(135mm)**	36x optical zoom, f=3.4 mm (wide) to 122.4 mm (tele), F1.6 to F4.5	
384x288	12.2° X 9.2°	4.1° X 3.1°		
640x480	20.2° X 15.1°	6.8° X 5.1°		
e-zoom	x2 and x4 \ continues zoom		12x (432x with optical zoom)	
Focus	Auto Focus corrections (640x480)		Auto (Sensitivity: normal, low), One-push AF, Manual, Infinity, Interval AF, Zoom trigger AF	
Image Processing	Enhanced Mode for improved detection			
Thermal Camera performance				
Targets	NATO (2.3mX2.3m)		Human (1.7mX0.5m)	
Range Performance	**Detection**	**Recognition**	**Detection**	**Recognition**
Wide FOV 45 mm	2000m	690m	830m	280m
Narrow FOV 135 mm	6200m	2000m	2500m	830m

System Parameters

Power Supply	12VDC
Storage Temperature\Humidity	-40°C - 60°C
Operating Temperature\Humidity	-32°C - 50°C
Power Requirements\Power Consumption	12VDC 6.4W (16.4W during CCD heaters operation)
Weight	7.35 Kg
IP Rate	IP66
Remote operation	Optima S\W interface
Dimensions	321mm (L) X 190mm (H) X 312mm (W)

Based on Internet search, the DualSec WarningEye based on the Galil PTZ seems to be the only long range (2 – 10 km) system available detecting automatically smoke and fires. The system could support 2 types of thermal engines, the DS 320 (EyeR25 45_135 mm DFOV, 320x240) and DS 640 (EyeR640 45_135 mm DFOV, 640x480)

Figure 2.1-19: PTZ Meerkat Multisensor control system

2.1.3 Conclusion and Remarks

Except the Libellium Waspmote WSN and the Opgal Galil PTZ LWIR and Visible cameras, there were no specific products giving a solution for fire detection. In this study we did not took into account the military product that could be adapted for fire detection. A large number of commercial infrared and visible cameras are available. Specific hardware should be added for the signal and image processing. This study was mainly based on information provided by internet.

2.1.4 References

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2.2 Weather Stations

2.2.1 Introduction

In the FIRESENSE Project, MARAC will develop prototype automatic meteorological stations (AMS) with the aim of collecting meteorological data (air temperature, relevant humidity, barometric pressure, wind velocity and direction) of the areas where they will be installed. All the data will be transmitted via Internet to the prediction computing station through several communication options including cell phone technology and GPRS network.

2.2.2 History

Early references to the weather can be found in the poems of ancient Greece and in the Old Testament of the Bible. Even older references can be signed out in the Vedas, the most ancient Hindu scriptures that were written around 1800 BC. Specific writings on the theme of meteorology and climatology are found in Hippocrates' 'Air water and Places', dated 400 BC, followed by Aristotle's 'Meteorologica'. To the early Greek Philosophers, climate means "slope" and referred to the curvature of the earth's surface which, due to the changing incidence of the sun's rays, gives rise to the variation of climate with latitude. Logical and reliable inferences on climate are to be found in the work of the Alexandrian philosophers Eratosthenes and Aristarchus.

With the onset of extensive geographical exploration in the 15th century, descriptions of the earth's climate and the conditions giving rise to specific climatic conditions started to emerge. The invention of meteorological instruments such as the thermometer in 1593 by Galileo Galilei and the barometer in 1643 by Evangelista Torricelli gave a greater impulse to the establishment of mathematical and physical relationships between the different characteristics of the atmosphere and, therefore, of relationships which could describe the state of the climate at different times and in the different places.

2.2.3 Classification

The requirements for observational data may be met using in situ measurements or remote-sensing (including space-borne) systems, according to the ability of the various sensing systems to measure the elements needed. The Global Observing System, designed to meet these requirements, is composed of the surface-based subsystem and the space-based subsystem. The surface-based subsystem comprises a wide variety of types of stations according to the particular application (for example, surface synoptic station, upper-air station, climatological station, and so on). The space-based subsystem comprises a number of spacecraft with on-board sounding missions and the associated ground segment for command, control and data reception.

Surface synoptic stations or weather stations are used for state weather measurements and predictions. Generally, a distinction is made between analog and digital weather stations as follows.

2.2.4 Analog Weather Stations

Analog weather stations can be found mostly in so-called weather cabins. These are small "boxes" made of wood or plastic (weather-resistant) in order to protect the weather instruments from rain and dirt, but also to ensure correct readings.

They are usually only designed for indoor use and their thermometers and hygrometers have errors of at up to 3 ° C air temperature and 20% relative humidity.

The above mentioned weather cabins (also called air cabins or lodges) consist of wind permeable walls and blades painted white on the outside, so the sun should not distort the temperature. The typical weather station is equipped with a psychrometer, maximum and minimum thermometers and a thermohygrograph.

Outside of the instrument shelter is also a rain gauge in the open sky, an anemoscope and an anemometer mounted. Some stations also measure the global radiation, sunshine duration, or special values such as evaporation or soil temperature.

The advantages for the analog weather stations are that they do not consume any electrical power, as well as their greater assessment comfort.

2.2.5 Digital Weather Stations

Digital weather stations have essentially the opposite advantages and disadvantages from their analog counterparts. They consist of two or more separate modules:

a) The base station, which receives the data and evaluates
b) The sensors for the measurement data and the associated transmission.

The sensors are attached to the desired measuring points in which they collect data and transmit it to the base station, which receives the data (either by cable or by radio) and displays them on a LCD screen. In addition, the data is usually stored for some time and can be recalled when needed.

Common communication methods include wired transmissions through serial data cable for example through RS232 / RS485 or Dial-up connections via analog, ISDN or wireless modems (GSM, GPRS). Increasingly, today's weather stations also use the Internet Protocol-based data paths. Thus, weather data is available online with high data rates via standardized protocols like FTP, HTTP, SNMP in local area networks (LAN) and wireless networks (WLAN) and worldwide via the Internet (DynDNS). Modern weather stations also send SMS directly. The sensors generally used are as follows:

- Thermometer (indoor and outdoor),
- Dew point (often indoor and outdoor),
- barometer (mostly indoor),
- rain gauge and anemometer (outdoor).

Automatic meteorological stations (AMS) are used to satisfy several needs, ranging from a simple aid-to-the-observer at manned stations to complete replacement of observers at fully automatic stations. It is possible to classify them into a number of functional groups; these frequently overlap each other, however, and the classification then begins to break down. A general classification could include stations that provide data in real time and those that record data for non-real-time or off-line analysis.

Real time AMS: A station providing data to users of meteorological observations in real time, typically at programmed times, but also in emergency conditions or upon external request. Typical real-time use of an AMS is the provision of synoptic data and the monitoring of critical warning states such as storms and river or tide levels.

Off line AMS: A station recording data on site on internal or external data storage devices possibly combined with a display of actual data. The intervention of an observer is required to send stored data to the remote data user. Typical stations are climatological and simple aid-to-the-observer stations.

2.2.6 Purpose of Automatic Meteorological Stations

Automatic meteorological stations are used for increasing the number and reliability of surface observations. This is achieved through:

(a) Providing data from new sites and from sites that are difficult to access and forbidden;
(b) Supplying data 24/7;
(c) Increasing the reliability of measurements by using sophisticated technology and modern, digital measurement techniques;
(d) Ensuring the homogeneity of the network by standardizing the measuring techniques;
(e) Satisfying new observational needs and requirements;
(f) Reducing human errors;
(g) Measuring and reporting with high frequency or continuously according to user requirements.

2.2.7 State of the Art

2.2.7.1 Sensors

As the measurements in AMS are controlled from long distances, careful selection of the sensors that will be used in the assembled station is vital. These should be robust, fairly maintenance-free, have no intrinsic bias or uncertainty in the way in which they sample the variables to be measured. All of the current developments, enhancing the performance of existing sensors have been considered and studied. While searching the market on this topic, we have come to the conclusion to reject analogue sensors (with outputs in the form of voltage, current, resistance or capacitance), as well as digital sensors (with digital signal outputs and information in bits or group of bits) and finally evaluated and selected the so-called "Intelligent sensor". Those state of the art sensors include a microprocessor performing basic data-acquisition and processing functions providing an output in serial or digital parallel form.

Some specific considerations for the AMS sensors are given below:

Atmospheric pressure: A wide variety of devices exists, mostly based upon the use of an aneroid capsule, vibrating wire, or quartz crystal which provide an output in electrical analogue or digital form. For digital sensors, reference is made to WMO (1992b). The main problems that have been carefully considered by MARAC, are the adverse effects of temperature, long-term drift, vibration and exposure. Temperature effects are severe and are not always fully compensated by built-in temperature compensation circuits. AMS pressure sensors have an intrinsic long-term drift in accuracy, typically less than 0.2 to 0.3 hPa every six months and therefore require regular calibration. Because of the vulnerability of most readily available pressure sensors to the effects of external exposure, it is common practice to house the pressure instrument within a sealed and thermo-stabilized small box inside the CPU enclosure.

Temperature: The most common types of thermometers used in an AMS are pure metal resistance thermometers or thermistors. The platinum resistance thermometer

(100 Ω at 0°C) shows very good long-term stability and can be considered as the preferred type of sensor.

Electrical thermometers usually have a short time-constant and, when sampled by fast electronic circuits, their output reflects high-frequency low amplitude fluctuations of the local temperature. Resistance thermometers also require linearization.

Of great concern was the proper protection of the sensors against the effects of radiation. A radiation shield adjusted to the size of the sensor has been selected in order to replace the common naturally ventilated Stevenson screen. For accurate measurements, we ventilate artificially the radiation shield with an air speed of about 3 ms^{-1}. The measuring system is identified as Pt100, 1/3 DIN.

Humidity: Although relatively low-cost resistance and capacitive sensors for direct relative humidity measurements are widely employed in automatic weather stations, they are still susceptible to poor performance in the presence of pollutants and require special protection filters. Dew-point meters, such as the saturated lithium chloride sensor and the chilled mirror sensor, are also used. The major drawback of lithium chloride sensors is their sensitivity to power failures.

The optical dew point meter is considered as the most promising technique but further investigations are required in order to develop a good automatic mirror cleaning device. A radiation shield adjusted to the size of the sensor has been selected also for the case of the humidity sensor.

Wind: The use of conventional cup or propeller anemometers with pulse or frequency output is wide spread and presents no particular technical problem other than that associated with icing in severe conditions. This complication can be overcome by heating the sensor in moderate icing conditions, but this results in a significant increase in electrical power consumption. It is recommended that for new cup and propeller anemometers, the response length should be smaller than 5 m and that, in new digital systems, the sampling frequency must be compatible with the filtering applied. In counting devices, this implies that the number of pulses over one counting interval is considered as one sample.

The use of conventional analogue instruments equipped with a potentiometer for wind direction measurements is also widespread in AMSs. Wind-vane devices with digital angle encoders, usually in one or the other form of Gray code, are increasingly used. Wind vanes with an undamped natural response length smaller than 10 m and a damping ratio between 0.3 and 0.7 are recommended. For vanes with digital encoders, a minimum resolution of 10 bits is required.

International Maritime Organization (IMO) [1] also recommends that, for new systems, it should be possible to report standard deviations of wind speed and direction with a resolution of 0.1 ms^{-1} and 10°, respectively.

The wind system that has been selected provides the most accurate and cost effective 2 axis wind measurement. The elimination of moving arts, together with a rugged stainless steel construction makes its maintenance free and requires no calibration. The heated head keeps the unit free from ice and snow, providing continuous use even in the most extreme weather conditions. It can be configured to the engineer's exact requirements, which may include analogue outputs, 10 Hz output, heating or sensor temperature. The external construction is of stainless steel 316 while all environmental standards are met.

- Moisture protection IP66 (NEMA4X)
- EMC BS EN 50081-1:1992 (Emissions class B)
- BS EN 50082-2:1992 (Immunity)
- FCC Class A
- Icing MILSTD 810E Method 521.1 Procedure 1

Precipitation: The most common rainfall-measuring equipment in a station is the tipping-bucket rain gauge. Gauges are rapidly clogged by debris such as leaves, sand or bird droppings;

For measurements of rain and snowfall below 0°C, different parts of the gauge must be heated properly. This can give rise to serious electrical power problems, in particular for battery-operated AMS as in our case, but it has already been considered in our study. Care has also been taken since heated gauges introduce errors due to evaporation losses. An achievable observing accuracy of 5-10 % is considered to be excellent. Accuracy is also improved as we surround the rain gauge with a proper windshield. The surface of the rain gauge is 400 cm^2, according to WMO recommendations and there is a gold plated special shaped tipping bucket that ensures that the rain gauge is emptied at each tip.

2.2.7.2 Data Logger Core

The rapid technological evolution of modern industrial data-acquisition and process-control systems opens up new possibilities for meteorological applications. The high degree of input/output modulation and flexibility, the drastically increased operating speed of microprocessors and, in particular, the availability of dedicated data-acquisition, process-control and telecommunications software makes this possible. Manufacturing meets all environmental standards as IP40 for moisture protection and EMC EN 50081-1 class B EN 50082-2 for electromagnetic conformity.

2.2.8 Key characteristics of the Developed AMS

- State of the art technology station using innovative architecture hardware on wide temperature range
- Reliable, quality evaluated and tested sensor platform performing precision measurement capability
- Lightning protection of the station
- Data Logger that measures the sensors, then processes, stores and transmits the data ensuring accurate and reliable performance
- Data transmission through cell phone and GPRS network
- Operation under severe conditions environment
- Long–term, remote operation using batteries and solar panel power focusing on lower power consumption
- Proper flexible firmware, managing and interrogating the sensors according to the needs of the project easily expandable for substantial sensors handling
- Suitable interface (also web) connecting the data logger with the appropriate protocol
- Conformity to ISO 9001:2008 production procedures as well as to European environmental regulations and standards

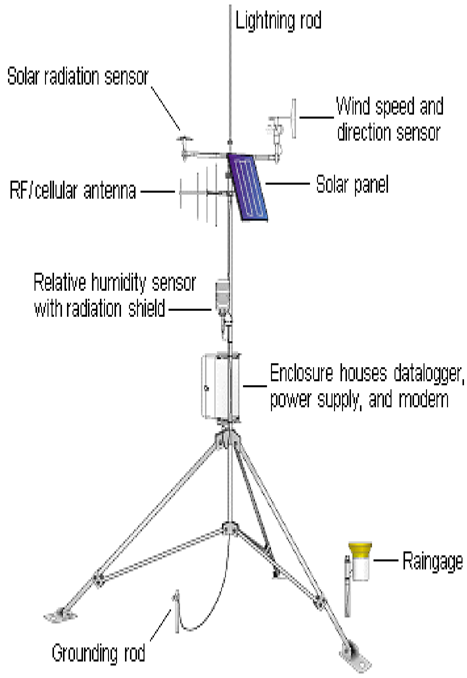
2.2.9 Networking

All the AMSs from MARAC may have the capability of being a part of a network of meteorological stations, each transmitting its processed data to a central network processing system. As the tasks to be executed by this central system are strongly related, and often complementary to the tasks of the AMSs, the functional and technical requirements of both the central system AMSs are designed for full coordination.

2.2.10 Hardware and Peripherals

The stations are basically configured as follows :

Configuration
Data Logger equipped with relative humidity and wind velocity and direction sensors
BOX IP-65 (0,60m x 0,60m x 0,22m)
Batteries 12V
Battery 24V
Rain Gauge
Air temperature , barometric pressure sensors
Solar Panels 1,57m x 0,95m



2.2.11 Sitting and installation

Choosing an appropriate site for an AMS is a very difficult matter and much research remains to be done in this area. The general principle is that a station should provide measurements that are, and remain, representative of the surrounding area, the size of which depends on the meteorological application.

As our AMSs have to operate unattended for long periods at sites with difficult access construction.

Security measures (against lightning, flooding, theft, vandalism, and so forth) have been also taken into account and the stations must, of course, be able to withstand severe meteorological conditions. As the cost of providing systems capable of operating under all foreseen circumstances at an automatic station is prohibitive; it is essential that, before specifying or designing an AMS, a thorough understanding of the working environment anticipated for the AMS has been obtained. A detailed analysis of the relative importance of the meteorological and technical requirements has already been carried out at the early stage of planning so that sites can be chosen and approved as suitable before significant installation investment is made.

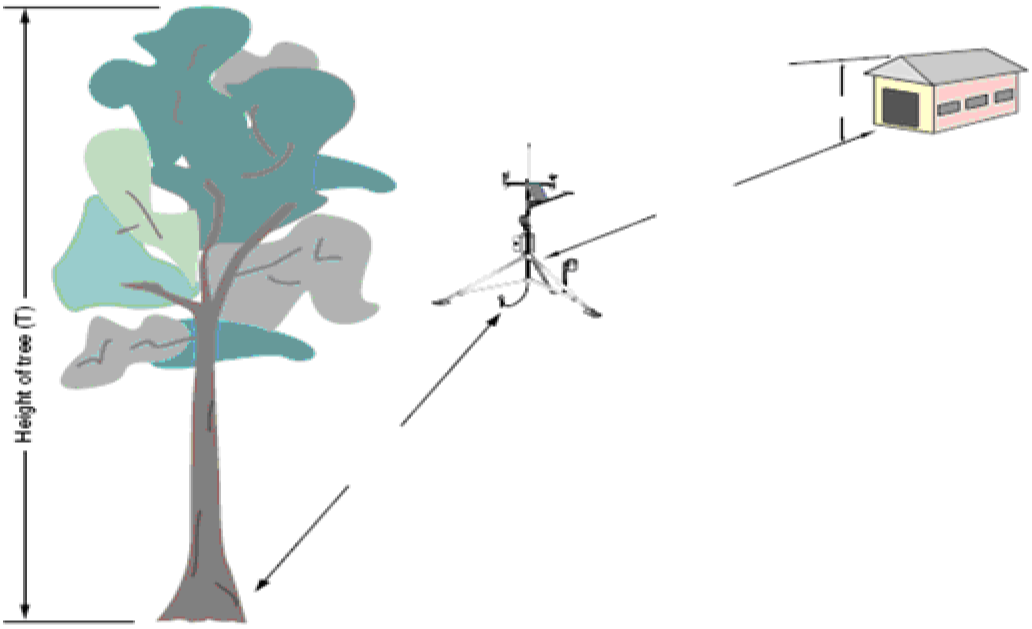


Figure 2.2-1: For geographically representative wind measurements, site the station well away from obstructions. Disturbed wind areas can also be avoided with a tower that is 2.5 times the height if the obstruction.

Wind, air temperature, and water vapor pressure measurements are affected by surface type and roughness, soil moisture, regional topography, and obstructions.

Figure 2.2-2: Installation: Heavy Duty Aluminum tower - Option A

Considering the severe condition harsh working environment of the AMS, deep consideration has taken action, on mounting of the stations. We are still processing the evaluation on two of the installation options of the AMS as shown on the photos above.

The meteorological stations that will be developed and pilot tested by MARAC, are not a ready commercial product but they will be created by assembling a number of different components in order to meet the project requirements and purposes.

Figure 2.2-3: Installation heavy duty frame – Option B

2.2.12 Conclusion and Remarks

Meteorological stations are continuously collecting meteorological data (air temperature, relevant humidity, barometric pressure, wind velocity and direction, rainfall/snowfall measurements) of the areas where they are installed. All the data are transmitted to FIRESENSE Control Room through several communication options including Wireless Data Network, cell phone technology and GPRS network. The key characteristics of the meteorological station are as follows: reliability, precise measurement capability, operation under any environmental conditions, protected against lightning, theft and vandalism, long-term operability, remote operability without maintenance, using batteries and solar panel, low power consumption.

2.2.13 References

[1] World Meteorological Organization , Wheather observation
http://www.wmo.int

2.3 Flame Detection Techniques

2.3.1 Introduction

Flames and smoke produced during a wildfire behaves in a chaotic manner. For this reason, a typical wildfire does not have a specific identifiable shape that could be recognized using classical pattern recognition techniques.

A feature that is most identifiable by a video flame detection method is its colour. The colour of the flame is not a reflection of the natural light, but it is generated by it as a result of the burning materials. In some cases, the colour can even be white, blue, gold or even green depending on the materials that are burned and the temperature values. However, in the cases of organic materials such as trees and brush, the fire has the well-known red-yellow colour.

Many natural objects have similar colours as those of the fire (including the sun, various artificial lights or reflections of them on various surfaces) can often be mistakenly detected as flames, when the decision takes into account only the colour criterion. Examples can be seen in the following images shown in Figure 2.3-1,Figure 2.3-2, Figure 2.3-3, Figure 2.3-4.

Figure 2.3-1: Sunset in a forest road. The sun, the clouds and the reflections on the road surface have typical colours of fire.

Figure 2.3-2: Fire fighting airplane with typical colors of fire.

Figure 2.3-3: Autumn forest scene, with leaves having typical colors of fire.

Figure 2.3-4: Photo of street with lights having typical colors of fire.

For this reason, additional criteria have to be used to discriminate between such false alarm situations and real fire. Many researchers use motion characteristics of the flame as well as the special distribution of fire colors in the scene. The use of spatio-temporal criteria in the flame detection algorithm may significantly increase the computational complexity, since multidimensional image processing is needed. Four dimensions due to position, pixel luminance information and time (x,y,Y,t) exist in the case of grayscale images or 6 dimensions (x,y,r,g,b,t) exist in the case of colour images having red, green and blue components. Therefore, to keep the complexity low, most works in the literature use either a) purely spatial or b) purely temporal criteria or c) a two-step approach combining results obtained using purely spatial or purely temporal criteria [1]-[27]which are summarized in Table 2-2.

Due to the chaotic nature of wildfires, flame modeling in video is often difficult. As a result, detection can be problematic in some cases. The methods presented in the literature can be categorized as follows:

- **Change (including Motion) Detection:** In most flame detection algorithms there exist a pre-processing step focusing on regions of interest where there is a temporal change in the scene. This can significantly reduce the computational burden for the subsequent processing by reducing the video processing only in moving regions. Some of the techniques used for this task include a) simple temporal differencing, b) background estimation and subtraction, and c) optical flow based motion detection techniques.

- **Colour Detection:** Colour is a very important criterion of the fire which is used in most of the currently available methods. Usually, chromatic analysis of the images to search for regions with fire colors uses one or more decision rules in a colour space. Usually, the RGB colour space is used but other colour spaces as HIS or YUV have also been used in the literature. In some cases look-up tables and/or neural networks are also used for this task. Look-up tables can reduce the complexity but have high memory requirements.

- **Shape/Geometry/Contour Cues:** Specific features of the candidate regions of interest in video such as its shape, geometry and/or contour are examined and an effort is made to identify particular characteristics, patterns or models that are consistent with the presence of flames (e.g. random contour shape etc).

- **Temporal Analysis:** Temporal cues due to flame flickering process leading to strong high frequency content in video are identified in image frames forming the video. This is a good indication of the presence of a wildfire. The Fast Fourier Transform (FFT), wavelet analysis or simpler mathematical rules can be used for the task of identifying rapidly changing regions in video.

- **Spatial Analysis:** Flame colours may follow certain models or spatial distribution patterns which can be identified, e.g. fractal models, wavelet models in multiple spatial resolutions. Such models are used to discriminate flames from other natural or man-made moving objects in video.

Table 2-2: List of flame detection methods in the literature and the methods that they use.

Reference	Change Detection	Color Detection	Shape/Geometry/Contour cues	Temporal Analysis (flame flickering)	Spatial Analysis (flame colour patterns)
[1]		√		√	
[2]	√	√			
[3]	√	√	√	√	√
[4]	√	√	√	√	√
[5]	√	√	√	√	√
[6]	√	√	√	√	√
[7]		√		√	
[8]	√	√			
[9]	√	√			
[10]	√	√			
[11]	√	√	√		
[12]	√	√	√		
[13]	√	√		√	√
[14]	√	√	√	√	√
[15]	√	√			
[16]	√	√	√	√	
[17]	√	√			
[18]	√	√			√
[19]	√	√			
[20]	√	√			
[21]	√	√	√	√	
[22]	√	√		√	
[23]		√			
[24]	√	√			
[25]	√	√		√	
[27]	√	√	√	√	√

Flood Detection

Most detection systems use optical/electronic sensors (instead of video cameras) to monitor for floods, which lead to a significant increase of cost and complexity if the area to be monitored is large. No explicit and effective way to detect flood via video processing techniques exist, with the exception of [19], which is presented below. Also, some previous partially-related research works are [28], [29].

In this project, we will not develop flood detection algorithms using cameras. It is possible to monitor the soil and rain using cameras and provide estimates but we believe that weather stations will provide more reliable estimation results for flood detection.

2.3.2 State of the Art

In this section, we briefly review the currently available methods in the literature one by one and we categorize the techniques used.

2.3.2.1 Detection using color and motion cues

In [1], a Gaussian-smoothed histogram is used as a color model. A fire color probability is estimated by using several values of a fixed pixel over time. Considering temporal variation of fire and non-fire pixels with fire color probability a heuristic analysis is done. Effort is made to solve the reflection problem and a region growing algorithm is implemented.

An Early Fire-Detection Method Based on Image Processing is presented in [2]. After moving pixels are segmented, chromatic features are used for determining fire and smoke regions. Dynamics analysis of flames is done. According to this analysis, dynamic features of fire and smoke regions are used to determine whether it is a real flame or a flame-alias.

HSI color model based segmentation algorithm is used in [8] to find fire coloured region. Image differencing, which is taking absolute value of 2 consecutive frame's pixels difference, and same segmentation process are used to separate fire coloured objects from flames. A method for estimating degree of fire flames is proposed.

Highlighted regions in grayscale images are found by using thresholding in [9]. Improved version of image differencing is suggested and used for separating fire-coloured fast moving objects such as lamps of motorcycles from flames and circularity is taken account for final decision.

Static (colour) and dynamic (motion) features are used to provide fire alarms from videos in [15]. A two-stage approach is followed: first fire regions are extracted using three simple decision rules, similar to [2] using the RGB Color model. In the second stage, additional decision rules examining a) the growing trend of the fire, b) the invariability of the centroid of the fire region. The method seems to be computationally efficient and should operate in real time.

Fire flame features are first extracted from the HSI colour model and are used to separate fire-like regions from an image in [17]. Then, the image difference method and the invented color masking technique are used to remove spurious regions. Finally, an alarm is provided, along with the burning degree of fire flames. The method seems to be computationally efficient and the results are promising.

A rule-based color model in the YCbCr color space for flame pixel classification is proposed in [23]. The method is seen provide improved results when compared to two other approaches ([2] and a previous approach by the same authors). The method is also seen to have low computational complexity.

Video based wildfire detection is particularly important at night, when smoke is not visible. This method described in [25] uses four sub-algorithms to achieve this goal: a) slow moving video object detection, b) bright region detection, c) detection of objects exhibiting periodic motion and d) interpretation of the motion of moving regions. The decisions of individual algorithms are combined using a least-mean-square (LMS) based fusion approach that is trained by an active learning method.

Yamagishi and Yamaguchi [12] presented a flame detection algorithm based on the spatio-temporal fluctuation data of the flame contour and used color information to segment flame regions.

2.3.2.2 Techniques based on Wavelet-based / Markov / other Flame models

In [3], moving and fire colored pixels are found according to background estimation algorithm [4] and Gaussian mixture models. Quasi-periodic behavior in flame boundaries and color variations are detected by using temporal and spatial wavelet analysis. Irregularity of the boundary of the fire-colored region is taken into consideration at the decision step.

Background estimation algorithm [4] and chrominance model [2] are used in [5] to detect both moving and fire colored pixels. Two Markov models are proposed to separate flame flicker motion from flame colored ordinary object motion. Same Markov model is used to evaluate spatial color variance.

An adaptive flame detector is implemented and trained by in [6] using weighted majority based online training. Outputs of Markov models representing the flame and flame colored ordinary moving objects and spatial wavelet analysis of boundaries of flames are used as weak classifiers for training.

Background estimation, temporal and spatial wavelet analysis and a variant of m-out-of-n voting scheme are used to detect flames in [13]. Performing temporal wavelet analysis only for moving pixels instead of every pixel is proposed since this is more advantages in terms of efficiency.

In [10], Linear discriminant flame model and logistic regression flame model are implemented and latter one is used for segmentation since it gives better performance. Same image differencing, color masking and degree of fire flame estimation techniques are used in their early work [8].

A new probability model using the colour, edge trembling and the spectrum of the flame height is used to implement a probabilistic detector in [11].

In [14], after fire regions are extracted by using spectral, spatial and temporal properties of fire regions in video sequences. The spectral model is represented in terms of the color probability density of fire pixels. The spatial model captures the spatial structure within a fire region. Spectral characteristics of the pixels in a region, and the spatial structure defined by their spectral variation are used to specify the potential fire regions. Then, the shape of a fire region is represented in terms of the spatial frequency content of the region contour using its Fourier coefficients. The temporal changes in these coefficients are used as the temporal signatures of the fire region by feeding them into an AR model. Fourier bases shape descriptors and (optionally) AR model coefficients are used to build a feature vector that is provided into SVM classifier, which is used to detect fire.

An Early Fire Image Detection and Identification Algorithm Based on DFBIR Model is presented in [18]. More specifically, the Discrete Fractal Brownian Incremental Random Field model (DFBIR) is used fro fire image detection and identification. Initially, the high-brightness regions with colors that match the flame model are identified (YUV model). Then the differential model is used to test if the fire region expands continuously. Finally, the DFBIR fractal model is used as the ultimate test to discriminate between flame and man-made objects. This last step increases the computational complexity, but improves the detection accuracy from 95% to 99%.

Feature vectors (spatial-temporal spectra variation, color/greyscale histogram concentration, etc) analysis provided early fire and flood detection in [19]. The following features are used:

- Fire features: Flame color is different according to the fire temperature, so it is NOT used. Instead, the difference image is used and increase of R component and dominance of Cr over Cb is used to detect possible fire regions. Shape/position of flame is time-varying, so time variation is also tested. Smoke is identified in the power spectra (frequency domain) as a time-varying loss of image detail.
- Flood features: a) change of colour information and background detail (large variance in the histogram of image sequence in HSV model) b) pattern of ripple or spectral energy change due to rain movement of water. For this reason, a “fluctuation index” is defined and measured. High variance of this index also indicates possible alarm.

Two new flame feature vectors are defined in [20]: a) the flame detection context based dynamic feature row vector and b) the optimal flame feature area vector. This technique aims to improve the efficiency with respect of point by point scanning RGB color space.

A Contour Based Forest Fire Detection Using FFT and Wavelet is presented in [21]. Specifically, a three-step approach is proposed: a) Fire region is segmented b) FFT is applied on the fire contour and c) the Fourier descriptors from all frames are analyzed using temporal wavelet to detect fire flickering. Promising results for detecting early fire are demonstrated and are even shown to be better than [3] for the case of blazing fire.

A new vision sensor-based fire-detection method for early fire warning is presented in [22]. Candidate fire regions are first extracted based on color and differencing criteria. Then, a luminance feature map is made to remove non-fire pixels, which are characterized by a lower variance. Finally, a temporal fire model with wavelet coefficients is created and applied to a two-class SVM classifier with an RBF (Radial Basis Function) kernel, which is used for the final fire-pixel classification. Higher robustness to noise, e.g. smoke than other methods (e.g. [3]) is observed.

A Fire detection using a statistical color model in video sequences is described in [24]. A simple adaptive background model of the scene is initially generated using three Gaussian distributions (one per color channel). At each time instant, foreground information is extracted and verified by a statistical fire colour model to determine if the object is a fire candidate or not. The approach is seen to have low computational complexity and to result to high detection rates.

2.3.2.3 Advanced classification techniques

Detection algorithms based on probability density and fuzzy neural network are implemented in [7]. A new adaptively updating target extraction algorithm (NAUTEA) is also used for target extraction. It is realized that fuzzy neural network based algorithms behave more fine than probability density based ones and performance can be upper by using historical data fusion techniques. It is proved that evidence combination rules (Dempster-Shafer rules) cannot always get the best result.

In [16], fire (and smoke) boundaries are determined using canny edge detection and an optimized BP algorithm is used to learn the moving pixels in the training phase and to see if they match the pre-specified colors in the testing part. Finally, as an extra step, fire (and smoke) flickering is determined and used by analysis of the video in the wavelet domain. This hybrid optimized BP algorithm is seen to provide better results than two alternative approaches (namely the “Gradient-descent” and “Differential Evolutionary” algorithms).

The shortcomings of conventional fire and smoke sensors are evaluated in [28]. The advantages, achievements, research contents, and characteristics of a new fire detection technique based on video image processing are discussed in detail. Based on the findings of this review, video smoke and fire detection is recommended

A recent review of video fire detectors can be found in [29]. A review of different fire detection methods including video fire detection is first presented. Various video fire detection methods are reviewed, including methods for flame detection and smoke detection. Thoughts for the challenges in this field and promising research direction predictions are also included

2.3.3 Conclusion and Remarks

Flame detection is usually performed by combining colour and motion cues.

High-level cues like flame flickering or spatial colour distribution of flame colours can also be well identified using specific modeling and/or wavelet techniques. Many advanced techniques have also been proposed for the classification of such features to determine whether a flame exists in the video images or not. However, problems still exist in many cases, due to the chaotic nature of fire and the large variations in flame appearance in video. In spite of extensive research results listed in the literature video flame detection is still an active research area. Elegant techniques, possibly fusing the results of several sub-algorithms describing various aspects of flames in video can significantly improve the detection rates of current methods and reduce the false alarms.

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2.4 Video Smoke Detection Techniques

2.4.1 Introduction

The rapid development in computer industry in the last two decades has enabled integration of intelligent algorithms into video based surveillance systems. Most surveillance systems already have built-in simple detection modules (e.g. motion detection, event analysis). In recent years there has been significant interest in developing real-time algorithms to detect fire and smoke for standard surveillance systems [1].

Most commercially available smoke detectors are point sensor type detectors. These sensors are actuated when the smoke plume gets close to the sensor. Therefore there is always a transport delay until the smoke reaches the sensor. Video based smoke detection can be used to remedy this situation, since a single camera can monitor a large area from a distance and can detect smoke earlier than a traditional point detector if a robust detection algorithm is used. Although video based smoke detection is a promising alternative to traditional smoke detectors, it has some drawbacks that need to be resolved before a reliable system is realized. Smoke is difficult to model due to its dynamic texture and irregular motion characteristics. Unstable cameras, dynamic backgrounds, obstacles in the viewing range of the camera and lighting conditions also pose important problems for smoke detection.

2.4.2 State of the Art

There has been increasing interest in video-based smoke detection algorithms during the last few years. The earlier works in smoke detection were aimed at providing early alarms or forest surveillance systems. Smoke plume observed from a long distance and observed from up close have different spatial and temporal characteristics. Therefore, generally different algorithms are designed to detect close range and long range smoke plume. Below we describe the algorithms that are developed so far to detect smoke by exploiting various characteristics of smoke plume observed from visible range cameras.

Jerome and Philippe [7], [9] implemented a real-time automatic smoke detection system for forest surveillance stations. The main assumption for their detection method is that the energy of the velocity distribution of smoke plume is higher than other natural occurrences except for clouds which, on the other hand have lower standard deviation than smoke. They first perform temporal analysis on image sequences to segment the pixels that have important dynamical activity at low frequencies. The instantaneous dynamical information denotes the ratio of slow dynamical variations to fast variations. The cumulated dynamical data is obtained by temporally weighting the instantaneous low frequency variations. Then spatial analysis methods are used to obtain the region boundaries. In the classification stage they use fractal embedding and linked list chaining to segment smoke regions. This method was used in the forest fire detector “ARTIS FIRE”, commercialized by “T2M Automation”. The system is reported to have average detection time below 3 minutes. Despite being one of the first complete forest fire detection systems this implementation has a relatively robust detection algorithm, but the average detection time might be improved to obtain a faster response.

Another smoke detection method with an application to wildfire prevention was described in [20]. This method takes the advantages of wavelet decomposition and optical flow algorithm for fire smoke detection and monitoring. The optical flow algorithm is used for motion detection. Wavelet decomposition based method was used to solve well-known optical flow equation that is also known as aperture problem. In this paper, authors proposed a modification for this method that enables a simplification without affecting the system performance. After the smoke is detected and segmented, smoke characteristics such as speed, dispersion, apparent volume, maximum height, grey level and inclination angle of the smoke can be extracted using the video frames or image sequences. Computational cost of the smoke monitoring algorithm proposed in this work can be reduced and the smoke characteristics can be further improved used to improve safety in fire fighting strategies.

Damir et. al. [3] investigated different colour space transformations and feature classifiers that are used in a histogram-based smoke segmentation for a wildfire detection system. They provide evaluations of histograms in YCrCb, CIELab, HSI, and modified HSI colour spaces. They use look up tables and two different naive Bayes classifiers with different density estimation methods to classify the histograms. The experimental results suggest that different colour transformations do not drastically improve the classifier performance. For a specific colour transformation there is a histogram resolution where the classifier achieves its maximum performance. Each classifier shows similar performance for each colour space but maximum rates are achieved at different resolutions. The best performances are achieved with HSI and RGB colour spaces when using the Bayes classifier. The method described is not a full wildfire detection system. It is one of the algorithms used in the Intelligent Forest Fire Monitoring System (iForestFire) that is used to monitor the coastline of the Republic of Croatia.

Qinjuan et. al. [10] proposed a method for long range smoke detection to be used in a wildfire surveillance system. The method uses multi-frame temporal difference and OTSU thresholding to find the moving smoke regions. They also use colour and area growth clues to verify the existence of smoke in the viewing range of the camera. The system is deployed in a forest park for real-time tests. It is reported to achieve high detection rate and low false alarms. In the actual classification stage they only use colour information and check if the region is growing in size. This might cause problems in difficult environments with other moving objects and imperfect image acquisition devices. Therefore, as the authors also suggest, they need to incorporate additional features (texture, edge etc.) to increase the robustness of the system.

Some algorithms in the literature only use spatial characteristics of smoke to find features that can represent smoke well. Nobuyuki and Kenji [8] designed a fractal encoding method to segment smoke regions from images using the observation that smoke regions have the self-similarity property. They use fractal encoding to segment grey-scale images. Some decision rules are implemented to find which of the segmented regions contain smoke. The method has high computational cost and its performance is not thoroughly tested with a large set of smoke images.

Smoke detection algorithms usually start with motion detection and then smoke colour analysis of moving regions. The authors [21] proposed a smoke detection algorithm based on video processing for early fire-alarming system. The algorithm is based on two decision criterions; static and dynamic. The static decision is based on the greyish colour of the smoke and the dynamic decision rule is based on the spreading features of smoke such as smoke disorder and smoke growth-rate. The greyish colour is described with the intensity component of the HSI colour system. By performing a statistical analysis, the authors observed that the intensity value of the smoke pixel must be in a certain interval. Before applying the smoke decision rules, moving regions are segmented using a simple frame differencing algorithm. In smoke detection, depending only on the chrominance value is not sufficient. Greyish coloured moving objects, such as clouds or shadows may cause false alarms. Therefore, proposed method cannot be an efficient smoke detection algorithm.

In [19], another algorithm was proposed that starts with colour analysis and motion detection. The models are based on different colour models for fire and smoke detection. These colour models are obtained by statistical analysis of samples extracted from images. The authors used a smoke detection system based on the greyish colour of the smoke. The smoke detection algorithm consists of simple motion detection, thresholding between RGB colour channels and low saturation manner in HSV colour space. Since simple motion detection detects clouds as moving objects and the clouds have greyish colours, there may be too many false alarm rates. Therefore, the proposed method cannot be an efficient smoke detection algorithm.

Maruta et al. [25] proposed a smoke detection system based on texture analysis in order to use the system in outdoor applications. Before the smoke detection part, a simple moving object detector based on frame differencing algorithm is used as a pre-processing step. Also in this step, image binarization and morphological operations are performed to eliminate noises. Then an image mask is generated to obtain moving objects. After the moving object detection part, "*smoke detection measure*" (SDM) is defined in order to determine whether the moving object is smoke or not. Although the authors obtained some promising results, the proposed algorithm must be tested with a larger test set. Another weakness of the proposed system is that, the system cannot be used in real time applications.

Smoke has irregular boundaries and it is usually not necessary to use sophisticated motion detection algorithms for close range smoke detection with real-time constraints. Apart from simple frame differencing and IIR filter based methods, GMM based background subtraction methods can also be used. The irregularities around the border and inside smoke contours is usually detected using temporal flicker analysis. Ziyou et. al. [18] designed a smoke detection system that uses background subtraction, flicker analysis, contours, and features that characterize turbulent phenomena of smoke. Gaussian mixture models (GMM) are used for background subtraction. The low frequency flickering nature of the smoke is quantified using mean crossing rate. The blobs that have enough number of flickering pixels inside are used to extract the contours of the candidate regions. These regions are passed through a final classifier that uses features characterizing turbulent behaviour of the smoke. The results are promising but there are still the issue of false alarms.

Another method that uses background subtraction and flicker analysis was proposed in [28]. Xu et. al. proposed a fire smoke detection algorithm that is realized in four main steps. In the first step, moving target detection is implemented using background subtraction technique. Then the contour of the moving object is extracted. After extracting contour of the object, a feature extraction procedure is performed. The authors define several features such as growth, disorder measurement, frequent flicker feature, self-similarity feature and local wavelet energy. They combine these features in order to represent each object with a joint feature. In the recognition of fire smoke, a two layer Back-Propagation neural network classifier is implemented. Although the system is tested with sufficient number of videos, number of smoke detected frames and false alarm rates are not presented in the results.

Discrete wavelet transforms are widely used to extract both spatial and temporal characteristics of smoke. Neural networks can be used to classify extracted features. Yu Cui et. al. [15] developed a method that uses wavelet decomposition based features to classify smoke textures. They perform tree-structured wavelet transform (wavelet packets) to decompose the texture images and use gray level co-occurrence matrices (GLCM) to extract the features. Neural networks are used for the final classification stage. The method is tested with a relatively small texture database and achieved good recognition results. Despite the results it is not clear whether the method can be used in an actual smoke detection system. The method needs to be tested with a larger and more diverse dataset that have smoke textures of different sizes and high noise levels. Another issue is the real-time implementation feasibility. The feature extraction and classification steps need to be optimized for use in a real-time system.

Another method that makes use of wavelet features and neural networks is developed in [22]. The authors proposed a method based on texture analysis to detect smoke for real-time fire detection. The proposed method consists of three main steps. First, the video frames are divided into M x M blocks. Then adaptive Gaussian Mixture Model (GMM) based background subtraction algorithm is applied to the blocks in order to determine foreground pixels. If number of foreground pixels in a block is greater than a certain threshold, the block is considered as a candidate block. In the last step of the method, feature extraction using gray level co-occurrence matrices (GLCM) is performed for each of the candidate blocks. To determine the characteristic of smoke regions, the features are generated by computing the energy, contrast and homogeneity of the related candidate block. In the classification part, the extracted features are applied to a back-propagation neural network. Although the authors obtained promising results, the algorithm needs to be tested with a large test set. They used only two smoke and 2 non-smoke videos.

The proposed method in [17] also uses wavelet features but this time with SVM classifiers. The authors developed a system for fire and smoke detection using quaternionic wavelet features. Moving objects are taken as candidate smoke regions when they tend to have a velocity with a positive vertical component. Low frequency flickering of the smoke is used in the temporal analysis stage. Gray level co-occurrence matrix (GLCM) based texture descriptors are used for classification. 5 GLCM features, Entropy, Contrast, Angular Second Moment, Inverse Difference Moment and Image pixel correlation, together with the mean value of the candidate smoke regions are used to train a support vector machine (SVM) based texture model. The method is shown to have better performance than some of the previous implementations.

Support vector machines are shown to provide good results in practical classification schemes and they are largely used in smoke detection systems as well. Jayavardhana et. al. [6] proposed a method for smoke detection that uses discrete wavelet transform and a support vector machine (SVM). Wavelet features from approximate coefficients and three levels of detailed coefficients, a total of 60 features for each block, are used for characterizing the smoke. The system is implemented in visual C++ on a PC and was shown to work well using a 32x32 block segmented images. The method is also integrated into a surveillance system that have a motion detection module to reduce the processing time by only classifying the moving image regions.

In the work [26], authors proposed a smoke detection algorithm that uses Support Vector Machine (SVM) in the classification. After a simple motion detection algorithm, a feature extraction step based on the irregularity property of smoke is performed. They describe some parameters such as foreground area, number of smoke blocks, area of the smoke and perimeter of the smoke in order to generate feature vectors. The proposed method's performance can be considered as satisfactory but the false alarm rate is needed to be decreased.

Another feature to characterize the turbulent behaviour of smoke is the upward motion of smoke plume. This might work in specific environments; for example in indoors without ventilation. Yuan [16] used motion detection together with color information and the direction of the motion flow to design a video-based smoke detector. Moving regions are detected by applying frame differencing to images divided in blocks. The smoke color is determined using thresholds in RGB color space. The smoke plume is assumed to move upwards and the histogram of the accumulated orientations is used to determine the direction of the motion.

Some smoke detection algorithms are specifically designed for certain environments. Dongil and Byoungmoo [4] proposed a method for real-time detection of fire and smoke in a tunnel environment. They use motion history images to implement a background subtraction algorithm. Invariant moments are used to separate smoke from ordinary moving objects. The method is shown to work successfully in a tunnel environment.

In most video based smoke detection implementations the camera is assumed to be stationary but there are some works which try to handle camera motion as well. In [27], authors proposed a smoke detection system that is composed of three steps. First, the system makes a decision about whether the camera is moving or not. The system starts detecting moving regions by comparing the background image with current frame in order to obtain region of interest (ROI) or BLOB, unless the camera is moving. After detecting ROIs in the input video, the algorithm extracts features including area, bounding rectangle, average and standard deviation of Y value of the YUV channel. The ROI is determined as smoke, if the shape of the BLOB is changing and the Y-Values of the ROI have same statistics in consecutive k frames. The paper present some promising results but the test dataset is not sufficient. The authors only use two videos in the experiments. Moreover, the authors do not mention whether the proposed system can be used in real time applications or not.

Target tracking methods are also used to provide feedback to the smoke classifiers in some implementations. Ho et. al. [5], [31] proposed a new method for real-time video-based flame and smoke detection that can be used with a surveillance system. Motion history images are used to find the moving pixel positions whose spectral, spatial and temporal characteristics are later analyzed to find the smoke regions. Histograms are calculated in HSI colour space to represent the spectral probability density of the regions. The perimeter and area of the regions are used to represent the spatial characteristics of the smoke. The candidate regions are obtained using the spectral and spatial densities in a fuzzy decision fusion framework. To detect the flickering frequency of the candidate regions level crossing rate is used. Continuously adaptive mean shift (CAMSHIFT) is also used to provide the real-time position of the smoke regions as a feedback to the detection algorithm. The algorithm is tested under different conditions and was shown to provide reliable detection performance. Although the results presented in the paper are promising, a larger test set can be selected for a better performance evaluation.

In [29], Wei et al. proposed a target tracking based fire smoke detection algorithm. The algorithm starts with moving region segmentation using background estimation method proposed in the work [30]. Then tree structure based connected region extraction algorithm is implemented and target tracking is realized. In order to determine if the region is smoke or not, static and dynamic feature extraction are performed. In static feature analysis, brightness consistency property of smoke is used. In point of dynamic features, the authors use motion accumulation and spreading properties of smoke. Although the authors claimed that they obtained a reliable smoke detection system, the proposed system must be tested with a larger test set. Moreover, the authors must mention about false alarm rates for a better performance measure.

Toreyin et. al. from Bilkent University developed both close and long range video-based smoke detection algorithms [12][13],[14]. In [14] a method for smoke detection is developed for stationary cameras monitoring a scene from a relatively close distance (<100 meters). The moving regions in the images are found using a background subtraction algorithm with an adaptive threshold. The main assumption is that close range smoke is semi-transparent and because of that the edges of objects in the image frames lose their sharpness when smoke plume covers them. This leads to a decrease in the high frequency content of the image. To detect this behaviour, spatial discrete wavelet transforms of the background image and the current image are calculated and the decrease in the high frequency energy of the scene is monitored using these wavelet images. Edges in the image frames produce peaks in the wavelet domain and therefore the decrease in the values of those peaks is used as an indication of smoke plume in the scene. The flicker of the smoke is quantified by applying a temporal wavelet transform to moving pixels. Colour and convexity of the regions are also used in the final decision. In [13] same background subtraction and spatial wavelet domain analysis methods are used. But this time hidden Markov models (HMM) are used to characterize the temporal behaviour of the smoke. The irregular contours of the boundaries of the smoke regions are also reresented in wavelet domain to check their high frequency behaviour.

Piccinini et. al. [23] proposed a smoke detection system that combines background suppression with smoke detection. Statistical and Knowledge-Based Object tracker [24] is used as background suppression module. Smoke detection part of the algorithm consists of wavelet transform energy analysis and colour analysis. The authors observed that the wavelet energy decreases as smoke propagate in the region of interest. In the colour analysis, *blending parameter* is defined in order to identify smoke regions. The energy term and colour blending parameter is applied to Bayesian approach in order to make a decision whether the block is smoke or not.

In [1] a method is proposed to reduce the false alarms of the smoke detection systems described above. The smoke is represented as a texture using the parameters of background estimation, wavelet transform, and colour information. A class imbalanced learning algorithm is then proposed for to reduce false alarms in automatic smoke detection methods. The algorithm is trained using SVM (support vector machine) and provided promising simulation results.

Steven et. al. [11] evaluated the current fire and smoke detection algorithms and proposed a new chromaticity-based smoke detection algorithm with back-step correction. Background subtraction, energy analysis, and boundary disorder analysis are applied to sub-blocked (16x16) video frames, to make a distinction between smoke and non-smoke regions. The algorithm is shown to work in real-time with reduced false alarms compared to the other methods.

In [12] an algorithm for long range smoke detection is developed to be used in a wildfire surveillance system. The algorithm is an online learning method that updates its decision values using the supervision from an oracle (security guard at the watch tower). The main detection algorithm is composed of four sub-algorithms detecting (i) slow moving objects using adaptive background subtraction, (ii) gray regions using YUC colour space, (iii) rising regions using hidden Markov models (HMM), and (iv) shadows using RGB angle between image and the background. Each algorithm yields a fuzzy decision value as a real number in the range [-1, 1] at every image frame of a video sequence. Decisions from sub-algorithms are combined using the Least Mean Square (LMS) method in the training stage. The error function which is the difference between the overall decision of the main algorithm and the decision of an oracle is minimized using LMS to get the correct classification. It is reported that the learning duration is decreased with the proposed active learning scheme compared to some other methods. The system is reported to produce 0.25 false alarms in an hour.

2.4.3 Conclusion and Remarks

Most smoke detection algorithms start with motion detection. Different motion detection algorithms are developed for close range and long range smoke detection tasks. Motion detection reduces the area that is searched for smoke which in turn reduces the computational cost of the algorithm. Therefore the detection quality of the method directly depends on the reliability of the motion detection algorithm. Although there are many motion detection algorithms that work well in practice, new algorithms can be developed to handle dynamic backgrounds and moving cameras.

After motion detection spatial and temporal image features that characterize smoke well are calculated. The features are used in a decision mechanism or a classifier (SVMs, neural networks, Bayesian) to find the final segmentation. A thorough comparison of all the feature extraction methods described in the references can be made to find the ones that are suitable for a specific purpose.

2.4.4 References

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2.5 Infrared Fire Detection

2.5.1 Introduction

The remote Multispectral Imaging System will include 2 or 3 bands that will be selected on the base of the analyzed measurements. The cameras basic properties are the following:

Video cameras sensitive in visible spectrum will detect and recognize the smoke at the early stages during the day and flame detection and recognition during the night.

The Infrared Thermal Imaging Camera is based on the detection of the heat radiation flux from the fire.

The Multi Spectral Imaging Cameras spectral characteristic of fire and smoke gases will be measured with the help of filters. We will check if it could be used as an IR spectrometer.

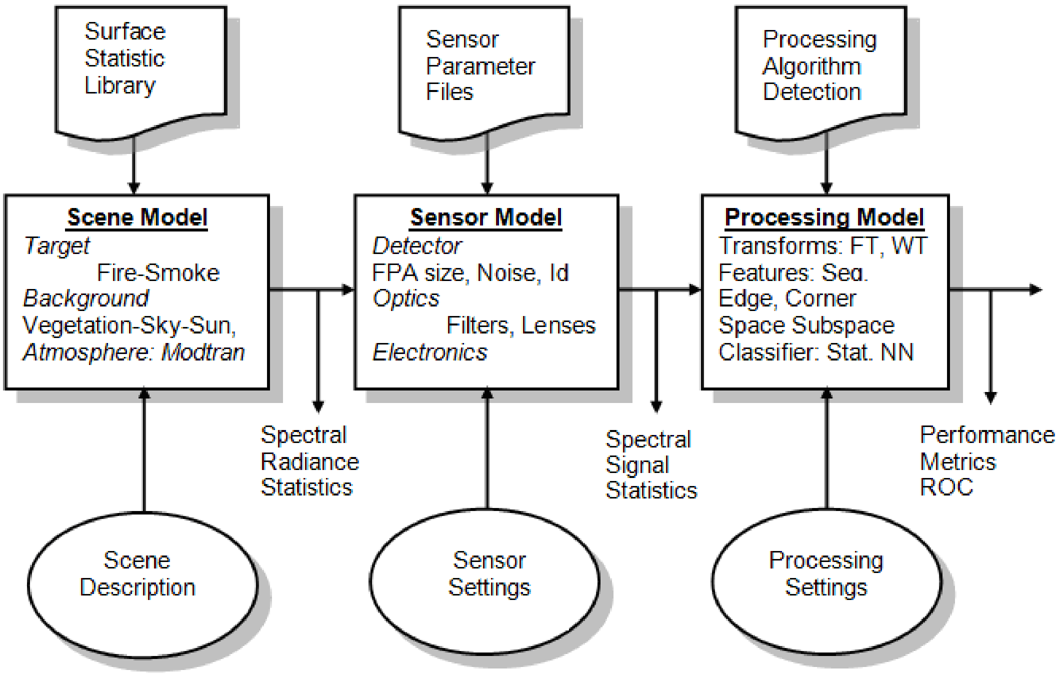


Figure 2.5-1: Block Diagram of a Multi-Spectral Imaging System

The ***scene model*** will be:

The **fire and smoke**, heat flux, the temperature or emitted thermal (Planck's radiation formula), the emissivity, the reflectance, the fire flickering, the smoke transparency or obscuration, the fire contour, the smoke contour, absorption-emission lines analysis of the atoms (e.g. potassium) and the molecules (water, carbon dioxide) are characteristics to be investigated.

The **background** emits the thermal heat, the reflectance of sunlight, the clouds (clouds shadow) the buildings and the sky polarization. The surface is wavelength dependent. These parameters depend on the wavelengths, the position of the sun, the seasons (summer) and the geographical position (latitude). The spectral radiance depends also on the view angle.

The **atmosphere** has its own gaseous content (N2, O2, CO, CO2, H2O…) with their specific absorption and emission lines. Water vapor concentration could vary consequently. Carbon dioxide is more uniformly distributed but its value is larger over industrial cities and vegetation fields than over oceans and deserts. The attenuation of the optical radiation due to atmosphere is mainly due to molecular absorption and scattering as well as aerosol absorption and scattering. Atomic absorption is due to the transition of electrons in the atom and molecular absorption is due to the transition between electronic, vibration or rotational energy of a molecule (vapor water) or a combination of these. Due to the heat and the heat of the fire, atmospheric turbulence is appearing. The atmospheric turbulence is the irregular air movement and the random refractive index fluctuation.

The ***sensor model*** will be based on the sensor description data and the user manual of the software interface for the cameras parameterizations. The sensor performance model is based mainly on three groups of parameters:

The **detector**: FPA size or resolution, bandwidth, detector pitch, QE: Quantum Efficiency or Responsivity (V/W, A/W)…

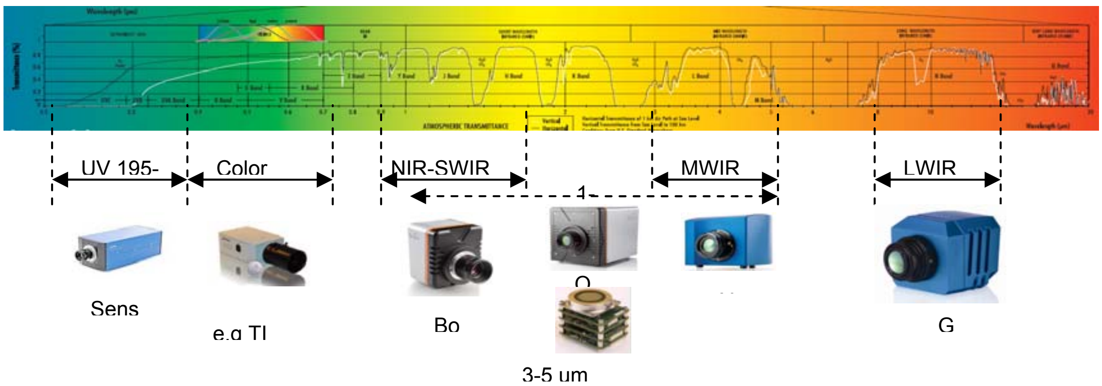


Figure 2.5-2: Cameras of XENICS

The **electronics:** FPA read out, frame rate, integration time.

The **optics**: FOV: Field Of View, IFOV: Internal FOV, Aperture size: D, F number: F/#, Fn, Effective Focal Length, Bulk transmission and bulk emissivity.

The ***processing model*** will be based on the literature and described after the measurements and data analysis.

2.5.2 State of the Art

2.5.2.1 Physical aspects of forest fire detection

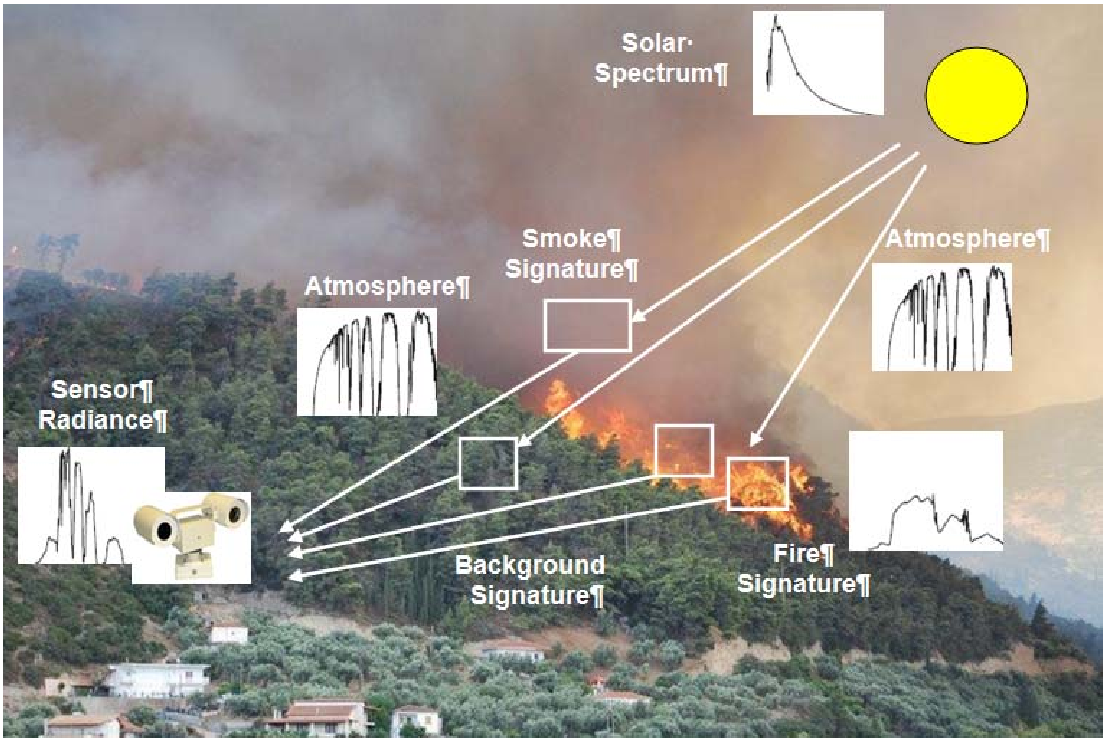


Figure 2.5-3: Spectral Radiance Information of the scene, the smoke and the fire

The figure here above describes the physical aspects related to forest fire detection. A good understanding of the physical aspects of the electro-optical surveillance of wild fires will help to increase the detection efficiency of the sensors. The atmosphere strongly influences the radiation transfer of the forest fire by absorbing and scattering radiation. The combined effect of absorption and scattering is called extinction. The extinction is the result of the interaction of radiation with air molecules and aerosols.

2.5.2.1.1 Atmospheric Influence

The atmospheric influence on solar radiation is wavelength dependent. In the Visible, NIR and SWIR wavelength band all the detected radiations are photons emitted by the sun which are scattered by objects and atmosphere towards the sensor. With the MWIR, parts of the photons are reflected during the day by the sun which are also heating the objects and part are radiated by the heat of the object itself (Planck Equation). At LWIR wavelength only the photon emitted by the object are mainly detected.

Figure 2.5-4: Images taken in haze

Figure 2.5-5: Comparison of a forest fire scene in SWIR and VISIBLE

2.5.2.1.2 Background Influence

The background influences the detection rate, the false alarms and the missed detection. The simplest form of detection is to compare two subsequent images of the same scene using an image processing system. If a difference is found between two images above a certain threshold which is defined by the noise in the images, an alarm is generated. If the time interval (ms) between the two scans is very short the changes between two sequential images will be small and are mainly the result of noise in the detector. If the time interval (seconds, minutes) between the 2 images increases the likelihood of differences other than noise becomes much higher. The appropriate time for automatic fire detection can be in an interval of one minute.

The false alarms could be generated by the following points:

- *Daily motion of the sun*

The daily solar motion causes a change of irradiation as a function of time. The apparent background will differ in the morning compared to the evening because of the gradual change in the orientation of the shadows and because of the angular reflection properties of various types of background. These changes are slow compared to the observation period. The differences in apparent sizes of shadows may introduce false alarms. Several scans could be needed. A temporal evolution of the spectral content of each pixel in the image should be analyzed. Temporal analysis could increase the reliability of the detection algorithm.

- *Moving clouds*

The variation in the solar illumination as well as the wind creates variation in the cloud cover. The wind velocity and the height of the clouds determine the change rate. The cloud pattern influences the solar illumination at every location differently. The reflected solar radiation at the vegetation and other background change proportionally to the variations of solar irradiation, and this regardless of the specific reflectivity of the background:

$$M(\lambda) = E(\lambda) * p(\lambda),$$

where $M(\lambda)$ is the reflected radiation, $E(\lambda)$ is the incident energy and $p(\lambda)$ is the surface reflectivity. The amplitude of variations depend on the type of cloud cover and the atmospheric conditions. The amplitude will be reduced at greater distances. These variations in illumination of the background due to a non uniform cloud cover could produce false alarms. We could discriminate clouds from smoke with a temporal analysis. This effect could be reduced when measuring at two different spectral bands. When the solar illumination varies, the illumination will vary proportionally in all the bands. As long as the ratio of the two bands does not vary, than no differences resulting from variations in solar illumination will be detected. But if the sun is blocked by a cloud the spectral characteristic of the illumination changes because the contribution of the yellow spectrum of the sun decreases.

- *Variation of atmospheric extinction*

The atmospheric extinction changes when the atmospheric conditions change. The varying extinction introduces changes in the apparent spectrum of the background. If the transmission of the atmosphere decreases, the contrasts will decrease and the detection probabilities will be reduced. The variation of the atmospheric extinction is slow. In this case the false alarms will be low.

- *Vegetation*

The motion in the image could be due to the vegetation (e.g. trees moving in the wind). This could cause many false alarms. The spectral characteristic of vegetation is different from smoke. This will reduce the false alarms.

- *Human activities such as cars, people, animals, ...*

False alarms could be generated by the smoke of industrial origin, of dust clouds from vehicle on sandy roads, etc. We could build a data base with areas that will be excluded from the surveillance area. We could discriminate dust from smoke with a temporal analysis. Moving object such as man, animals, cars could also generate false alarms depending on the threshold detection.

- *ROC*

The relationship between the system response and the state of nature is described in the table hereunder.

		State of Nature: Fire	
		Yes	No
System Response	Yes	Hit (Correct Detection)	False Alarm
	No	Miss (Missed Detection)	Correct Rejection

Receiver Operating Characteristics Curve (ROC) will help to evaluate and to optimize the relationship between the detection rate and the false alarm rate of the sensor.

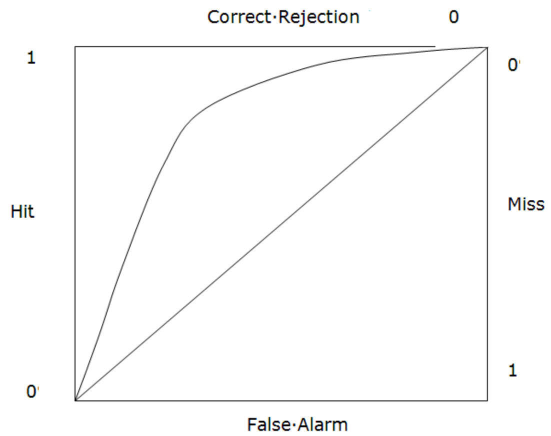


Figure 2.5-6: ROC for two independent binary variables

2.5.2.1.3 Forest fire: the flame and the smoke

2.5.2.1.3.1Flame information

NIR Atomic Spectroscopy information

Based on articles articles [4]-[19] detection of fire forest could be done with NIR sensors by taking a unique characteristic of forest fire, which is strong narrow band potassium emission lines that could be clearly distinguished in the forest fire. This unique potassium (K) emission lines occur in two narrow bands peaking at 766.5 and 769.9 nm.

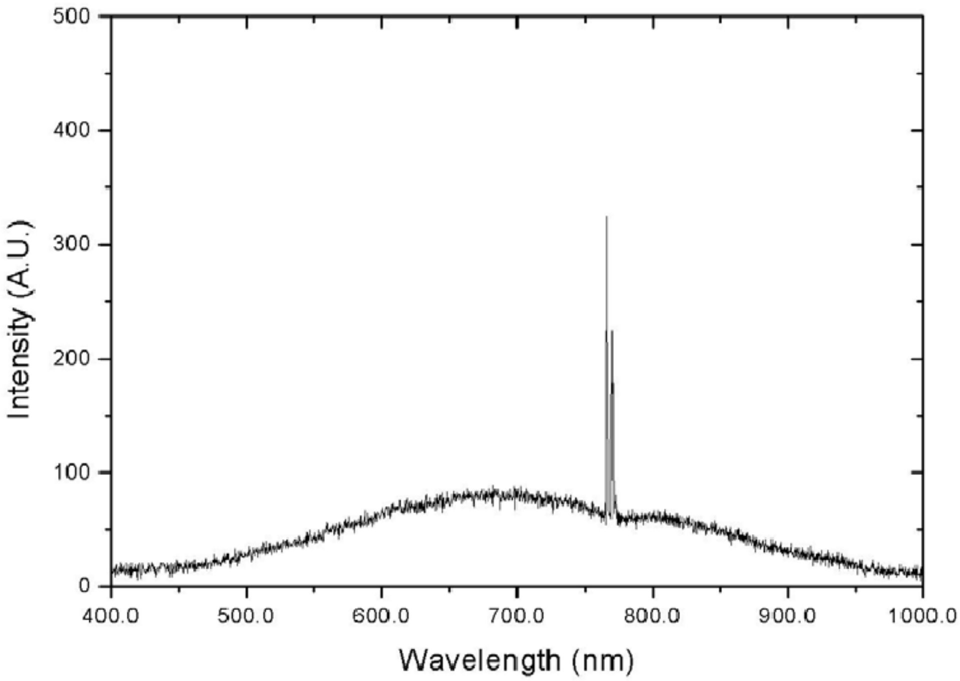


Figure 2.5-7: Potassium emission lines

This emission feature is very strong due to the relative high abundance of potassium in the plant life and the low ionization potential. We asked Bob Tremens from RIT if the Potassium emission line was in practice effective. The answer was the following:

Benedict,

This is an interesting project!

We have used the two-band method (one band in the potassium emission lines, one band outside of the emission lines) with a simple detector system, (two silicon photodiodes and amplifiers) and it has been effective in locating biomass combustion as long as there isn't much smoke. There is quite a bit of illumination from the sun, which varies of course, at different times of day, but when biomass combustion is present, the ratio of potassium to not-potassium light is large. Saying that, a standard LWIR thermopile also does a very good job of detecting fire outdoors, and doesn't require any sophisticated algorithms…and penetrates smoke very well. We aren't currently researching line emission from fires, but I would be happy to discuss the problem in depth of in you would like.

Bob Kremens

Temperature information

Temperature is estimated with an infrared camera. Segmentation algorithms such as region growing, Random Markov Field, Anisotropic Diffusion and other will be used. Temperature correction is computed in function of the chosen optics and the range. Atmospheric extinction is directly related as seen to the range, the wavelength and the bandwidth. The fire should be detected as soon as possible. The flame could have different sizes in function of the fire ranking, the optics and the distance between the fire and the sensor. Occlusion from the trees, the vegetation and the hills could be a problem to estimate correctly the temperature.

Numerical studies of a crown fire spreading toward a fuel break using a multiphase physical model could be found in [34] it simulates the propagation of the wildfire. It took into account the vegetation, the thermal decomposition of the solid fuel by drying and pyrolysis as well as the radiative and convective heat transfer between gas and vegetation.

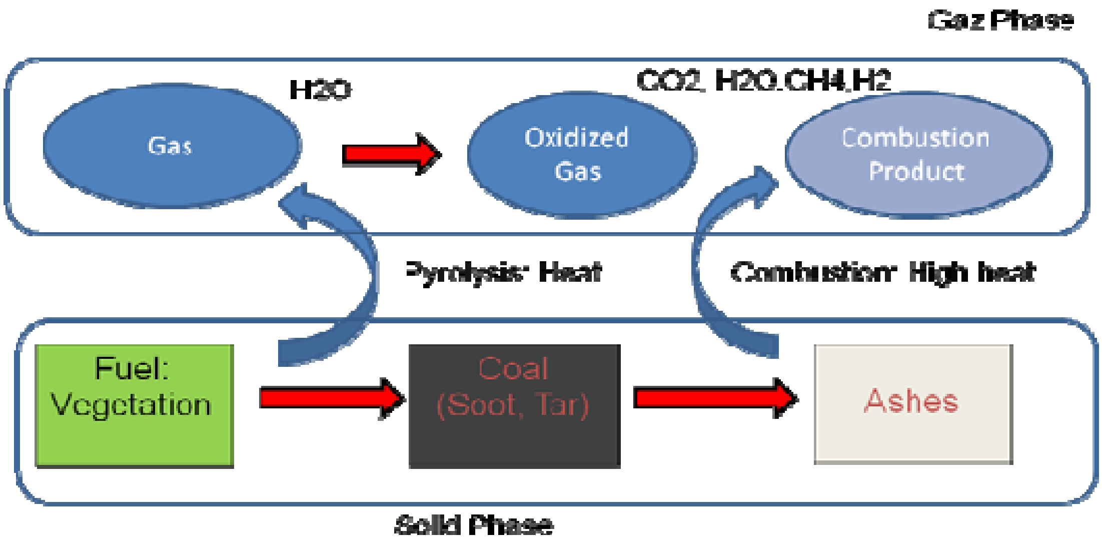


Figure 2.5-8: Solid and Gas Phase Model

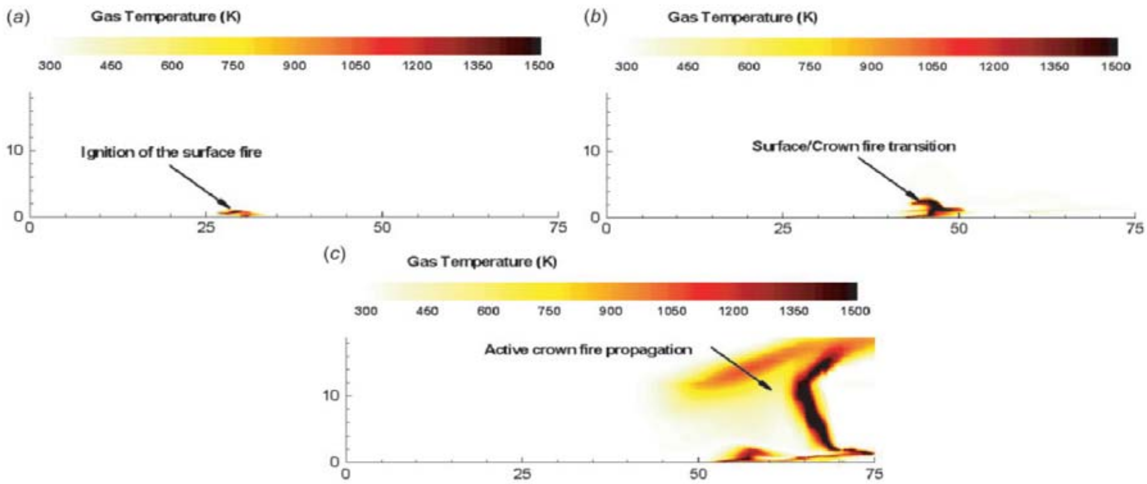


Figure 2.5-9: Fire Propagation and Gas Temperature

Incident radiant heat flux model:

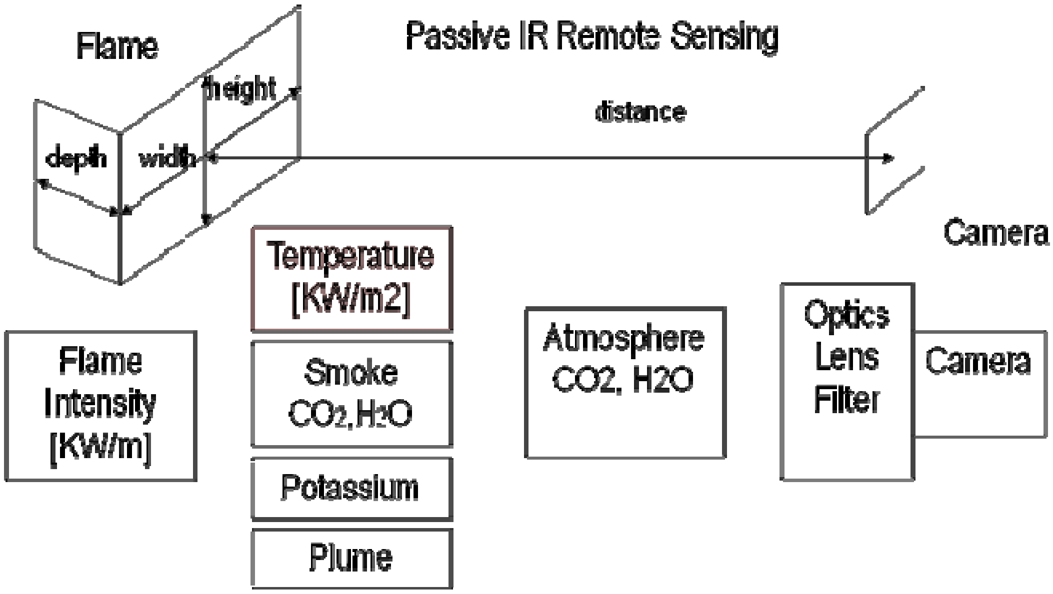


Figure 2.5-10: Incident Radiant heat model

A fire has very strong IR emission. The maximum wavelength at 1000 degrees Celsius is 4 µm. According to Planck's Law, 31 % of the radiated power is emitted in the MWIR band, 16 % in the LWIR and the percentage is even lower in the visible. The fire has 2 main contributions in the IR emission, the emitted gases (CO2, H2O) with discrete bands and hot solids (embers, hot ashes) with continuous bands. The emission of the fire is seen through the atmosphere. But the atmosphere contains water and carbon dioxide that will absorbs strongly the IR emission of those gases.

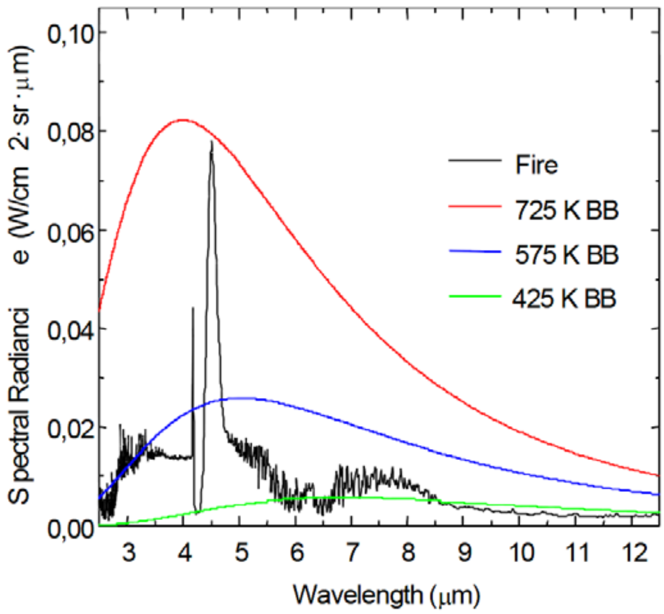


Figure 2.5-11: Spectral Radiance of the fire and of 3 different black bodies

The fire spectrum has a double peak between 4 and 5 um.

The flame region could de detected from the color the digitized image with the help of the segmentation algorithms based on different channels in visible (red, green, blue) or with other wave bands in NIR or SWIR.

Range is an important parameter. The shape of the geometric features such as the contour could change. The range should be defined in a specific range in such a way that the features remain invariant.

Spectrum variability due to the material will also vary in function of the range. The range affects the resolution, the atmospheric conditions and the location.

Several situations could occur with the spectral fire detection:

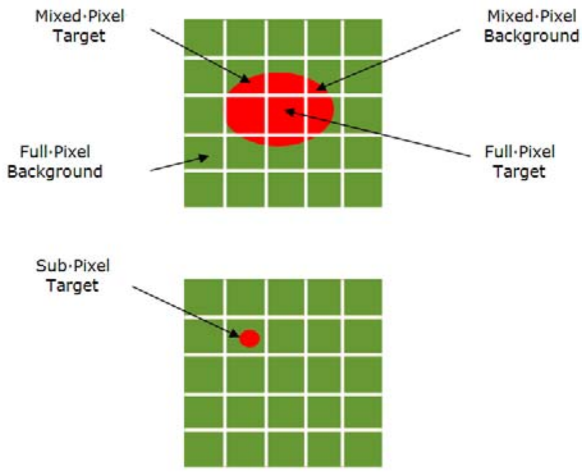


Figure 2.5-12: Full pixel, sub pixel and mixed pixel target [21]

In the full pixel target and full pixel background the material surface is homogeneous. This will allow us to build spectral libraries as idealized prototype spectral signatures associated with different materials. In this case the features could be separated. In the case of mixed pixel target and mixed pixel background, we have a linear spectral mixing model. The target fill factor will be defined as the ratio between the target/fire area with the pixel area. Three different methods (Probability Density Models, Subspace Model and Linear Spectral Mixing Models) are in general used to characterize the spectral variability of the pixels comprising a hyper spectral data cube.

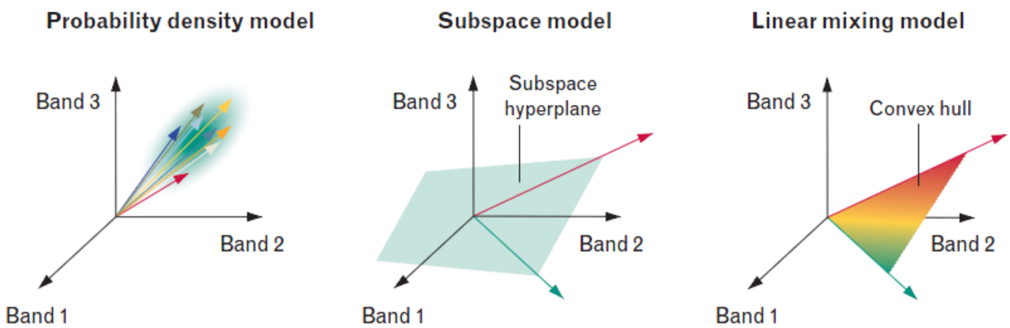


Figure 2.5-13: Model description of spectral variability from Dimitris Manolakis [21]

The wavebands will be selected after the data recordings and the data analysis. Subspace Model description example from Dimitris Manolakis [21]

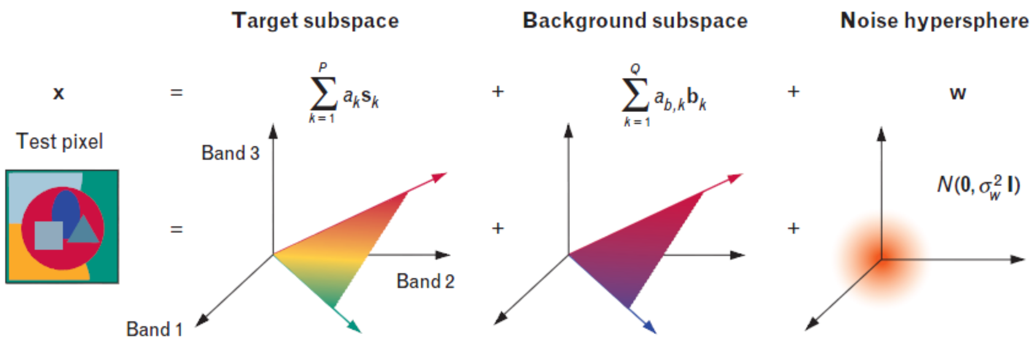


Figure 2.5-14: Full pixel, sub pixel and mixed pixel target [21]

The target detection involves the following hypothesis:

H_0: $x = Ba_{b,0} + w$ *target absent*

H_1: $x = Sa + Ba_{b,1} + w$ *target present*

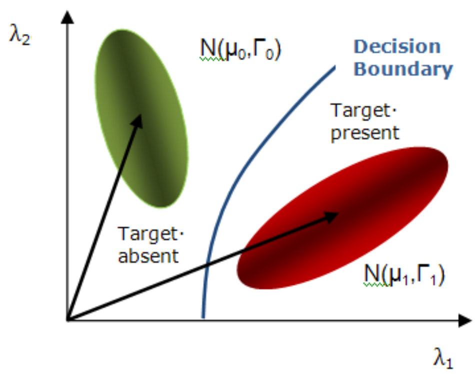


Figure 2.5-15: Decision Boundaries

Contour information and contour evolution

Contour analysis of the detected moving flame in infrared was analyzed by the Prof. Ahmet Enis Cetin and Behcet Ugur Toreyin team from Bilkent University [84] and [68]. Moving pixel could be detected by subtracting the current image from the background image. A hot-segmented region is selected and a contour line constructed from the center of mass of the segmented area. The frequency content through a set of coefficients is extracted from the wavelet transform.

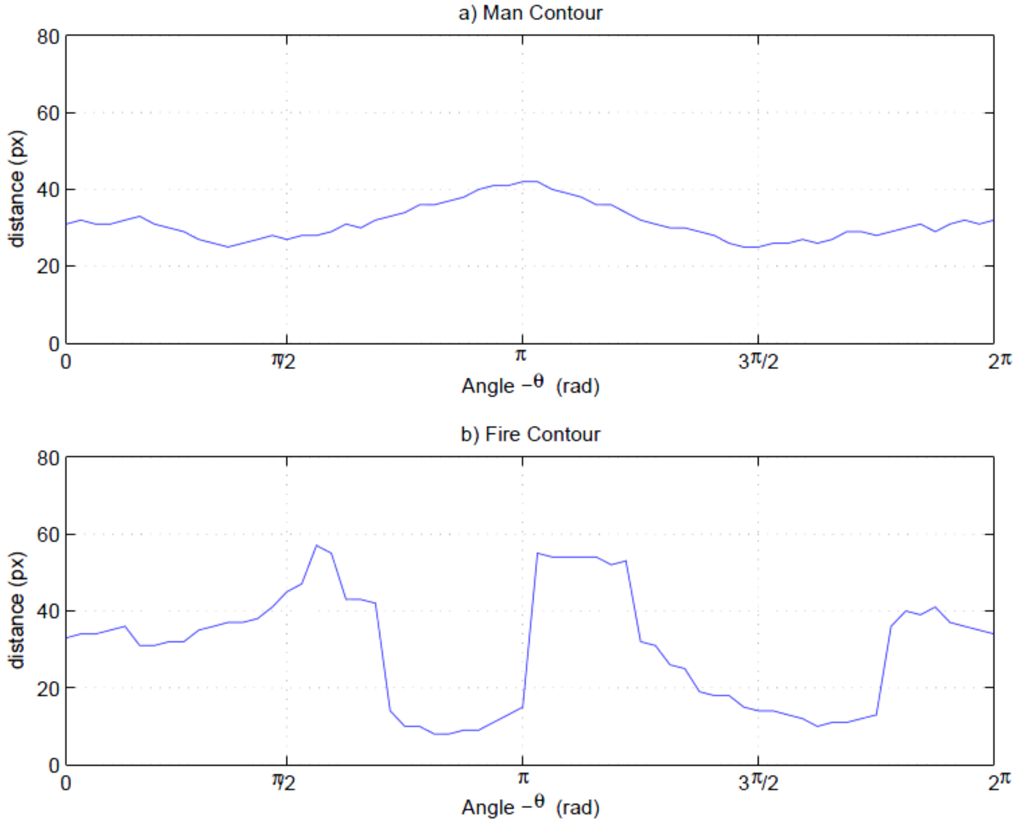


Figure 2.5-16: Space contour points of a man and a fire, page 40 from [68] and page 067204-3 from [84]

Flame flickering information in IR Wavelength

It is reported that turbulent flames flicker with a frequency of 10 Hz, see [68]. Flicker frequency distribution was analyzed by the Prof. Ahmet Enis Cetin and Behcet Ugur Toreyin team from Bilkent University [84] and [68].

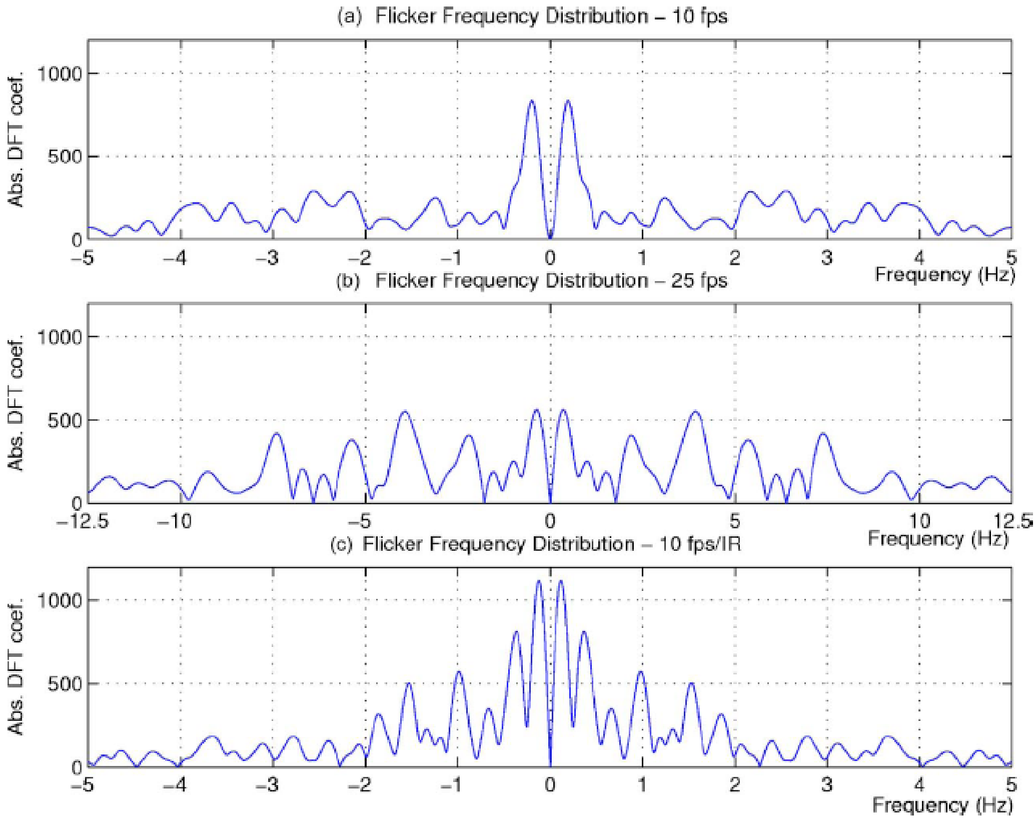


Figure 2.5-17: Flicker frequency distribution for (A) 10 FPS color video and (c) 10 FPS IR video page 067204-5 from Toreyin al. [84].

The flicker process in IR video was analyzed by the Prof. Ahmet Enis Cetin and Dr Behcet Ugur Toreyin's team from Bilkent University, see publications [84] and Thesis [68]. The flicker process was characterized by a 3 state Hidden Markov Model. As described page 45 in [68] the HMM analysis is based on the pixel near the contour boundaries of bright moving regions.

Smoke information

The content of the smoke could be white if the water content is high or grey if the water content is lower. The smoke will also contain the product of the combustion, which is water and carbon dioxide. At short ranges we could use the IR Molecular spectroscopy information. But due to the fact that the atmosphere content water and carbon dioxide at long ranges this information could vanish.

2.5.2.2 Infrared Image Processing

Some selected image processing techniques, based on the data analysis, will be applied on the SWIR, MWIR and LWIR cameras. Several methods are described in literature such as non-parametric models (Discrete Cosine Transform, Discrete Wavelets Transforms, Gabor Transforms…), parametric models, feature extraction (movement, segmentation, edge, corner, space/subspace), classification (statistical, support vector machines, neural networks, statistical signal processing) and image preprocessing (image enhancement, image co-registration, image stabilization and image fusion).

The image processing selection will varies in function of the type of fire features depending on the range (subpixel, pixel, and small group of pixel or large number of pixels.

2.5.2.2.1 Processing Methods

Spatial Processing
Information is embedded in the spatial arrangement of pixels in every spectral band (two dimensional image)
It exploits the geometrical shape information
Very high spatial resolution required
High spatial resolution requires large apertures and leads to lower SNR
Data Volume grows with the square of the spatial resolution
Success depending on the invariant features selection
Segmentation/Edge based on color, texture or energy
This information was exploited by Professor Cetin team in Bilkent University.
Time Processing
The signal could be quasi stationary and evolve in one pixel or a group of segmented pixel having to same properties (Flame flickering).
Movement analysis by image difference
Contour evolution of the Flame
Flame Flickering at the contour
Contour evolution of the Smoke
This information was exploited by Professor Cetin team in Bilkent University.
Spectral Processing
Each pixel has an associated spectrum that can be used to identify the materials in the corresponding ground resolution cell.
Processing can be done one pixel at a time
No need for high spatial resolution (one pixel on the target).
Subpixel Target (mixed pixel), Full pixel Target, Subpixel Background (mixed pixel), Full pixel Background.
Linear Spectral Mixing Models and Non Linear Pixel Mixing Models
Data volume increases linearly with the number of spectral bands

This will be investigated.
Polarimetric Processing
Stokes parameters for each pixel
Polarisation dependent on Sun position. Due to the dependence of the sun position implementation is very difficult.
Depolarization due to clouds, fog or smoke from fires
This will not be investigated

2.5.2.2.2 Image Pre-Processing Techniques

Image Fusion and Enhancement algorithms will be investigated with CWI in order to reduce the communication bandwidth, to improve the image enhancement, to increase the probability of detection and to decrease the false alarms.

The image fusion will be done for example with two cameras. The exact wavelength selection will be done after data analysis and an image fusion on the PC. Image fusion could be done without co-registration correction but the camera should be aligned perfectly, have exactly the same resolution, have no parallax and no optical distortions. Otherwise the image will be blurred. If the previous conditions are not full filled we need to do warping correction. After the warping image fusion algorithms will be applied (Discrete Wavelets Transforms, PCA …).

2.5.2.2.3 Dimension Reduction and Classification Techniques

2.5.2.2.3.1 Fire Detection in Infrared Video Using Wavelet Analysis

The method is composed of two part; spatial and temporal analysis. Fire is a moving bright region in IR video. Therefore, at the first step of the spatial analysis, boundaries of moving bright regions are estimated in the captured IR video frame. Most IR imaging sensors provide a measure of the heat distribution in the scene and each pixel has a single value. Usually, hot (cold) objects in the scene are displayed as bright (dark) regions in white-hot mode in IR cameras. Therefore, fire and flame pixels appear as local maxima in an IR image. If a relatively bright region moves in the captured video, then it should be marked as a potential region of fire in the scene monitored by the IR camera.

However, an algorithm based on only motion and brightness information will produce many false alarms because vehicles, animals, and people are warmer than the background, and they also appear as bright objects. Therefore, in addition to motion and relative brightness information, object boundaries are analyzed both spatially (intraframe) and temporally (interframe)

Moving objects in IR video are detected using the background estimation method developed by Collins, Lipton, and Kanade. After moving object detection, it is checked whether the object is hotter than the background, i.e., it is verified if some of the object pixels are higher in value than the background pixels. The next step of the proposed method is to determine the center of mass of the moving bright object. A 1-D signal $x(\theta)$ is obtained by computing the distance from the center of mass of the object to the object boundary for $0 \le \theta \le 2\pi$. The feature signal $x[l]$ is defined as $x[l] = x(l\theta_s)$, where $x[l] = x(l\theta_s)$. To determine the high frequency content of a curve, single scale wavelet transform is used. The feature signal $x[l]$ is fed to a filter bank shown in Figure 2.5-18.

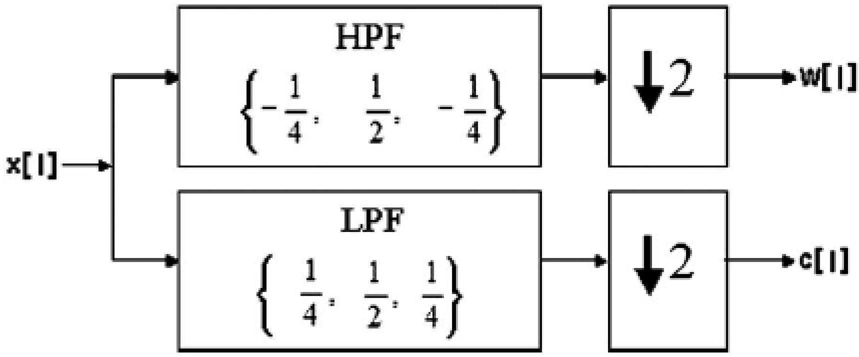


Figure 2.5-18: Wavelet filterbank structure that is used in the analysis

Using the absolute values of high-band (wavelet) $w[l]$ and low-band $c[l]$ coefficients of the fire region ρ is defined as $\rho = \frac{\sum |w[l]|}{\sum |c[l]|}$. Since regular objects have relatively smooth boundaries compared to flames, the high-frequency wavelet coefficients of flame boundary feature signals have more energy than regular objects. Therefore ρ is a good indicator of a fire region.

A threshold ρ_t for ρ was experimentally estimated offline. During real-time analysis, regions for which $\rho > \rho_t$ are first determined.

In the temporal analysis stage, three-state Markov models are trained offline for both flame and nonflame pixels to represent the temporal behavior. These models are trained using a feature signal, which is defined as follows: let $I_k(n)$ be the intensity value of the k'th pixel at frame n. The wavelet coefficients of I_k are obtained by the same structure shown in Figure 1, but filtering is implemented temporally.

Non-negative thresholds T1<T2 are introduced in the wavelet domain to define the three states of the hidden Markov models for flame and nonflame moving bright objects.

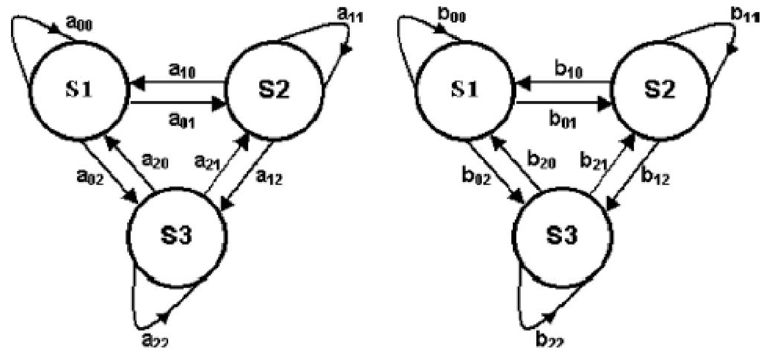


Figure 2.5-19: Three-state Markov models for (a) flame and (b) nonflame moving pixels.

The states of HMMs are defined as follows: at time n, if $|w(n)| < T_1$, the state is in S1; If $T_1 \leq |w(n)| \leq T_2$, the state is S2; else if $|w(n)| > T_2$, the state S3 is attained. For the pixels of regular hot objects like walking people, the engine of a moving car, etc., no rapid changes take place in the pixel values. Therefore, the temporal wavelet coefficients ideally should be zero, but due to thermal noise of the camera, the wavelet coefficients wiggle around zero. The lower threshold T_1 basically determines a given wavelet coefficient being close to zero. The state defined for the wavelet coefficients below T_1 is S1. The second threshold T_2 indicates that the wavelet coefficient is significantly higher than zero. The state defined for the wavelet coefficients above this second threshold T_2 is S3. The values between T_1 and T_2 define S2.The state S2 provides hysteresis and it prevents sudden transitions from S1 to S3 or vice versa. When the wavelet coefficients fluctuate between values above the higher threshold T_2 and below the lower threshold T_1 in a frequent manner, this indicates the existence of flames in the viewing range of the camera.

In flame pixels, the transition probabilities should be high and close to each other due to the random nature of uncontrolled fire. On the other hand, transition probabilities should be small in constant-temperature moving bodies, because there is no change or little change in pixel values. Hence we expect a higher probability for b_{00} than any other b value in the nonflame moving pixels model (Figure 2), which corresponds to higher probability of being in S1. The state S2 provides hysteresis and it prevents sudden transitions from S1 to S3 or vice versa.

The transition probabilities between states for a pixel are estimated during a predetermined period of time around flame boundaries. In this way, the model not only learns the way flame boundaries flicker during a period of time, but also it tailors its parameters to mimic the spatial characteristics of flame regions. The way the model is trained drastically reduces the false alarm rates.

During the recognition phase, the HMM-based analysis is carried out in pixels near the contour boundaries of bright moving regions whose ρ values exceed ρ_t. The state sequence of length of 20 image frames is determined for these candidate pixels and fed to the flame and nonflame pixel models. The model yielding higher probability is determined as the result of the analysis for each of the candidate pixels. A pixel is called as a flame or a nonflame pixel according to the result of this analysis. A fire mask composed of flame pixels is formed as the output of the method.

The probability of a Markov model producing a given sequence of wavelet coefficients is determined by the sequence of state transition probabilities. Therefore, the flame decision process is insensitive to the choice of thresholds T_1 and T_2, which basically determine if a given wavelet coefficient is close to zero or not.

The method was implemented in a personal computer with an AMD AthlonXP 2000+1.66-GHz processor. The HMMs used in the temporal analysis step were trained using outdoor IR video clips with fire and ordinary moving bright objects like people and cars. Video clips have 236,577 image frames with 160x120 pixel resolution. All of the clips are captured at 10 fps. The FLIR camera that recorded the clips has a spectral range of 8 to 12 μm. Some of the clips were obtained using an ordinary black and white camera.

The fire model was trained with fire videos and the other model was trained with ordinary moving bright objects. The remaining 48 video clips were used for test purposes.

Table 2-3: Video Clips

Video clips	Number of frames with flames	Number of frames in which flames detected by suggested method
V1	0	0
V2	0	0
V3	71	63
V4	86	85
V5	44	41
V6	79	79
V7	0	0
V8	101	101
V9	62	59
V10	725	718
V11	1456	1449
V12	993	981
V13	1434	1430
V14	999	995
V15	37	31
V16	18	13
V17	0	2

2.5.2.2.3.2 Statistical Signal Processing Classification Techniques

Some Statistical signal processing techniques will be investigated for the hyperspectral analysis in NIR and SWIR.

Table 2-4: Statistical Signal Processign Classification

Method	Target	Background	Hypothesis	Description
MF or SMF	S: Signature	$N(\mu_b,\Sigma_b)$	x = a.s+n a=0: no target a>0: target present	Matched Filter Spectral Matched Filter s : target spectral signature n : background clutter noise
QD	$N(\mu_t,\Sigma_t)$	$N(\mu_b,\Sigma_b)$	H_0: $\mathbf{x} \approx N(\boldsymbol{\mu}_b,\boldsymbol{\Sigma}_b)$ H_1: $\mathbf{x} \approx N(\boldsymbol{\mu}_t,\boldsymbol{\Sigma}_t)$	Full Pixel Target Quadratic Discriminator Spectral Matching Filter using Likelihood Ratio Test $(r-\mu_b)^T\Sigma_b^{-1}(r-\mu_b) - (r-\mu_t)^T\Sigma_t^{-1}(r-\mu_t)$ μ_b, μ_t, Σ_b, Σ_t
AD	Φ Empty	$N(\mu_b,\Sigma_b)$	H_0: x = n H_1: x = as+n	Full Pixel Target Anomaly Detection $RX(r) = (r-\mu_b)^T\Sigma_b^{-1}(r-\mu_b)$ Mahalonobis Distance Training data for μ_b,Σ_b only
MSD	$P_t=V_tV_t^T$	$P_B=V_bV_b^T$	H_0: y=Bξ+n H_1: y=Tθ+Bξ+n	Matched Sub Space Detection B : Background Subspace T : Target Subspace
OSP	S: Signature	$P_B=V_bV_b^T$	H_0: r=Bξ+n H_1: r=sμ+Bξ+n	Orthogonal Subspace Projector s : Target Spectral Signature B : Background Subspace n : noise

If the spectral information is relevant after data analysis, we will focus on the full pixel target (Matched Filter, Quadratic Discriminator and Anomaly detection in function of the a priori information of the target). These methods could be adapted with "regularization" and "kernelisation" techniques.

2.5.2.2.3.3 Neural Network Classification Techniques

There are a large variety of neural networks techniques. The Multilayer Neural Network and Convolutional Network with the Back Propagation Algorithm were methods applied in a large number of applications.

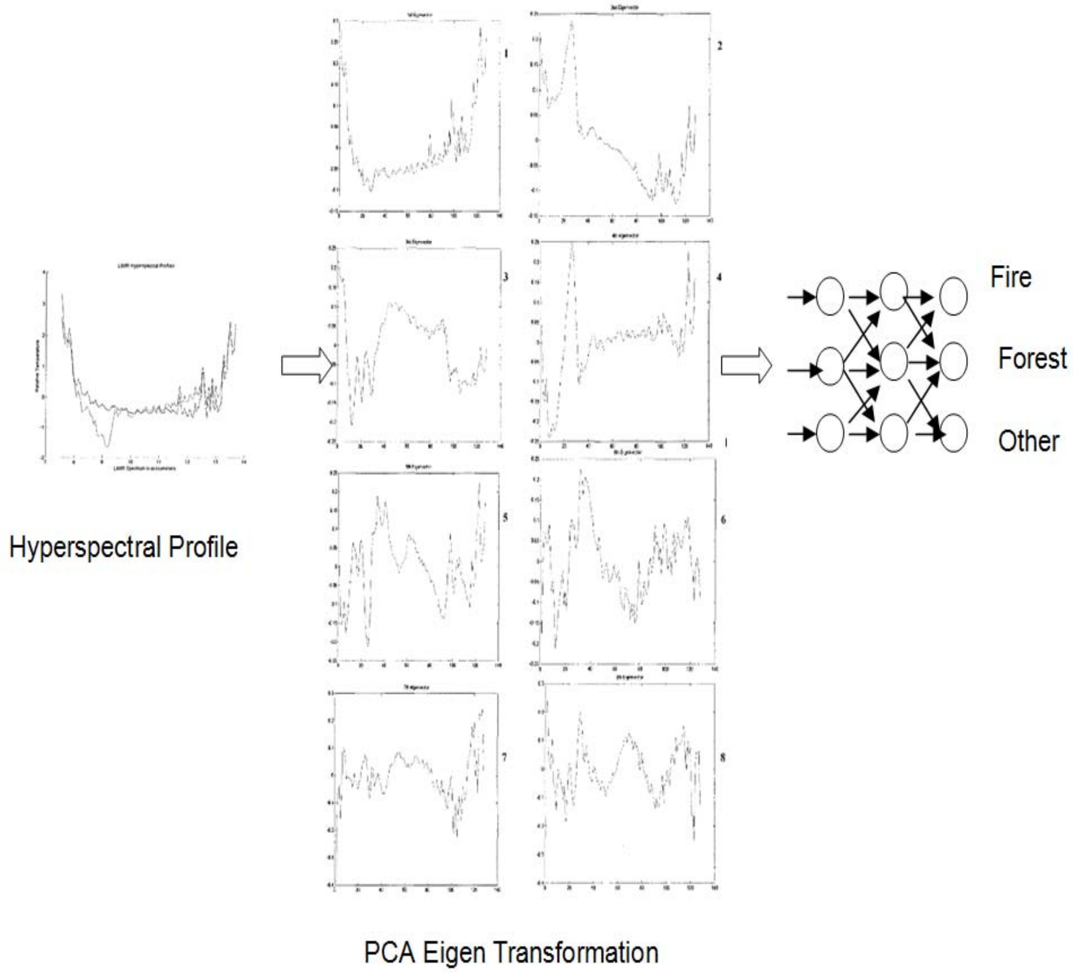
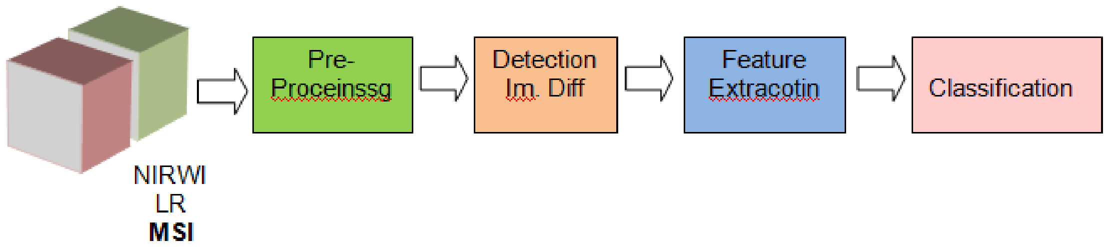


Figure 2.5-20: PCA and Neural Network Technique Applied on a Hyperspectral Profile

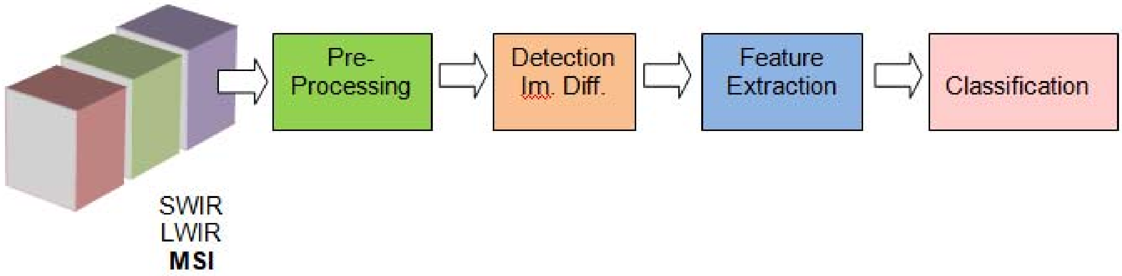
2.5.2.2.3.4 Statistical classification or statistical learning techniques

This includes in general the Maximum Likelihood and Bayesian Parameter Estimation, the non parametric estimation (Parzen Windows, k-nearest neighbour), the linear discriminant function (Support Vector Machines - SVM), the unsupervised learning and clustering (k-means clustering), component analysis (Principal Component Analysis - PCA, Non Linear Component Analysis, Independent Component Analysis - ICA) and Hidden Markov Model – HMM [14].

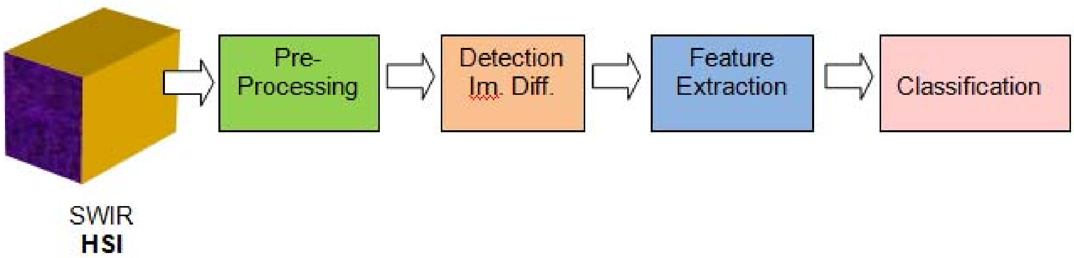
Selected Processing Scheme



This processing scheme will check if we can extract the potassium emission line with the NIR camera and the high temperature of the flame with the LWIR camera. Emissivity and range information provided from Geographic Information system could provide more precise temperature differences.



This processing scheme will check if we can extract the same or other features with the SWIR, MWIR and LWIR cameras based on the algorithms developed by the Professor A. E. Cetin team. The algorithms could be integrated in the processing scheme.



This processing scheme will allow us to check if specific features could be selected with the SWIR spectrometer.

2.5.3 Conclusion and Remarks

Long Wave Infrared (LWIR) cameras at medium resolution (384x256 or 640x512) are still used for fire detection. The advantage and the reason why uncooled LWIR were so popular is the relative low price and the valuable temperature information that could be extracted and evaluated. The other advantage to extract the temperature information is it is invariant to range. Often, features based on space geometry information require high resolution infrared cameras or heavy optics (zoom). This could only be achieved at short distances or high zoom. If the temperature difference is estimated, care should be taken from the atmospheric attenuation.

There is nearly no research in the other Infrared wave band. Investigation was done by the RIT (Rochester Institute of Technology) with the NIR cameras to analyze the presence of Potassium emission lines at high fire temperature. We will check the RIT results concerning the potassium emission lines.

Middle Wave Infrared (MWIR) cameras were mainly used in military unmanned aerial surveillance mode applications. Fire surveillance was used as a dual use technology. MWIR was not applied in automatic fire detection due to price mainly. No articles were found in automatic fire detection with Short Wave Infrared (SWIR) cameras. Hyperspectral and Multispectral Data analysis will be done with the SWIR cameras. If features could be extracted, these will be integrated in the processing scheme.

The image processing and learning techniques developed by Bilkent University Cetin team could be applied on the other wavelength infrared cameras.

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2.6 Wireless Sensor Network Technologies for Fire Detection (including temperature/humidity sensors, network and communication issues)

2.6.1 Introduction

Forest fire monitoring, requires (1) near real time response; so that the firefighters can act immediately, and (2) ease of deployment; the regions of interest being very large, the surveillance apparatus needs to be cost and power effective. Wireless Sensor Networks are cut out for this type of setup, as the sensor nodes (also called motes) are:

• Inexpensive and thus more area is observed per unit cost,

• Easily deployed over large areas (simply by throwing them out from an aircraft),

• Made of low power processors and therefore capable of operating long intervals without human intervention.

Accordingly, the sensor networks are easily installed and require low maintenance. Furthermore, the locations of the nodes can be either estimated roughly, through localization techniques, or queried exactly, if the nodes are equipped with GPS receivers. The location information, in turn, can be used to keep track in which direction the fire spreads.

2.6.2 State of the Art

The Wireless Sensor Network (WSN) for real-time forest fire detection has attracted many research efforts during the past few years. Its basic aspects and future trends concentrate around the following domains:

- structure of the sensor node
- node hardware and software: signal acquisition, data processing and transmission capabilities
- communications between the nodes: communication protocols, frequency bands, modulation
- sensor network topologies
- lifetime maximization, power consumption minimization , energy harvesting
- robustness and fault tolerance
- production cost
- node size

New electronic components or designs that can be used for the WSN are found every day. However, the FIRESENSE Project WSN will not be built for general purposes, but only for selected requirements with some important parameters. During the WSN's designing process a solution for every of the above mentioned domains have to be worked out. This process requires many simulation and measurement tests.

Current surveillance systems use a camera, an infrared sensor system and a satellite system. These systems cannot support real-time surveillance, monitoring and automatic alarm. A wireless sensor network can detect and forecast forest fire more promptly than the traditional satellite-based detection approach. WSN based fire surveillance systems can measure temperature and humidity, and detect smoke.

The main challenge is to produce small sensor nodes with low cost. With respect to these objectives, current sensor nodes are mainly prototypes. Miniaturization and low cost are very important features and as well availability of a very low power communication method.

The main components of a sensor node as seen from Figure 2.6-1 are microcontroller, transceiver, external memory, power source and a single or multiple sensors.

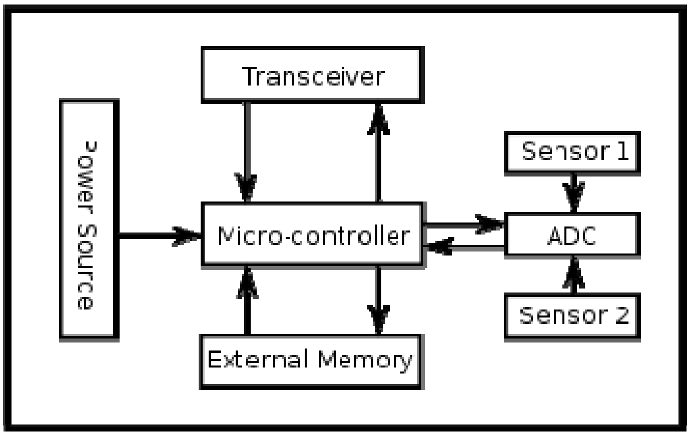


Figure 2.6-1: Sensor Node Architecture

2.6.2.1 Monitoring with Wireless Sensor Networks

There are various studies on wildfire and forest monitoring by means of WSNs. The common element in these studies is that all these works try to establish a framework on how the WSN should be constructed. Consequently, these efforts are based on different assumptions and lack unity on grounds of fire behavior. Every region of interest to be monitored comes along with different modalities in terms of coverage area or number of sensor nodes needed. At some cases, the conclusions arrived at are supported with simulations and similar experiments, but no real outdoor testbeds or fire are used, except for a minority of these works, which will be explained in detail below. In [6], the authors propose a WSN design consisting of, among other compounds, sampling nodes (collecting temperature, humidity, barometric pressure and light intensity) and routing nodes (for transporting relative readings from the sampling nodes to the base station). The sampling nodes are also equipped with barometric pressure, acceleration and GPS location sensors. Fire danger is assessed when temperature readings exceed 45°C or vary more than 5°C in short periods of time.

The system proposed in [7] can detect and forecast forest fires by making use of a neural network, which produces a weather index to calculate the likelihood of a fire event. The system consists of clusters, which construct the neural network by processing the data collectively. A similar WSN construction is suggested in [8], consisting of a sensor network for fire detection, information gathering layer, middleware, and escape support system. The sensor nodes can determine whether there is fire, according to the temperature readings they collect. The routing algorithm is protected against network partitioning by modifying the routing paths over the healthy neighbors of the damaged nodes.

As for the works including real outdoor testbeds, FireWxNet [9] shows significant differences compared to other testbeds: The deployment environment is topographically very uneven, including some regions reachable only with helicopters. The sensor node deployment is relatively sparse, covering a large topology spanning 160 Kilometers. The system consists of 5long range links and 3 sensor networks. In short, the deployment of FireWxNet costs roughly $22,000 but is useful for the fire community as it shows that a sparsely deployed wireless system can provide meaningful scientific data for fire managers.

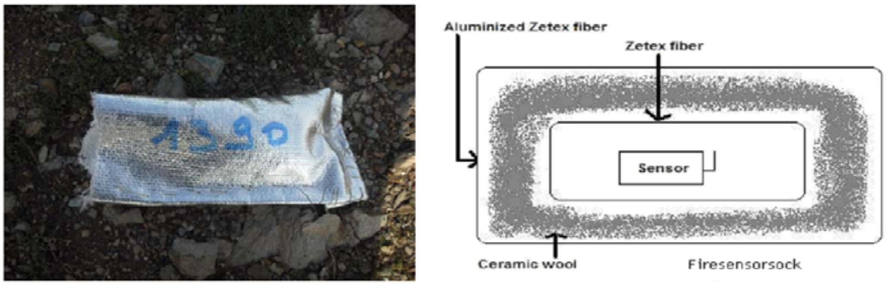


Figure 2.6-2: Firesensorsock [10]

Widely accepted testbeds are provided by FireBug [10] and Antoine-Santoni et al. [11]. In their work, Antoine-Santoni proposed a testbed similar to Firebug. However, the sensor nodes are covered with a thermal insulation (Firesensorsocks) in order to operate under fire. They studied sensing temperature data, detection of fire, and propagation of fire on the open vegetation areas. The Firesensorsocks is composed of several layers of protecting material. Furthermore, since the nodes are shielded, the maximum value of measured temperature is 40°C. The Firesensorsocks and its schematics can be seen in Figure 2.6-2, and a snapshot of an experiment is shown in Figure 2.6-3.

Figure 2.6-3: A snapshot of the Firesensorsock Experiments [6]

Further details on grounds of network and communication issues are given the following subsections.

2.6.2.2 Network and Communication Issues

2.6.2.2.1 Wireless Sensors

The most suitable choice for a sensor node is a low power microcontroller. In WSN, the wireless communication should be modest i.e., simpler, easier to process modulation and signal processing tasks. ASICs are specialized processors designed for dedicated applications. ASICs provide the functionality in the form of hardware, but microcontrollers provide it through software.

Sensor nodes use the ISM band, which covers three ranges between about 433 MHz and 2.4 GHz. Radios used in transceivers operate in four different modes: Transmit, Receive, Idle, and Sleep. When in Idle mode, radios consume almost equal to the power consumed in Receive mode. Thus it is better to completely shutdown the radio when it is not Transmitting or Receiving. And also significant amount of power is consumed when switching from Sleep mode to Transmit mode to transmit a packet.

Currently the preferred solution is low power mixed signal microcontrollers that have all basic application required units as built-in peripherals. These System-On-Chip solutions require minimum number of external components, such as crystals and capacitors.

The most relevant kinds of memories are on-chip memory of a microcontroller and Flash memory. Flash memories are used due to low cost and storage capacity reasons, as

- User memory for storing application related or personal data.
- Program memory used for programming the device.

Table 2-5: ZigBee enabled System-On-Chip solutions – Part 1 [4]

Manufacturer	Part Number	Supply Voltage (V)	MCU RAM Size (kB)	Flash Size (kB)	GPIO	Sleep Current (uA)	Tx Current (mA)	Rx Current (mA)
Atmel	ATMEGA128RFA1	1.8-3.6	16	128	38	<0.25	14.5 @ 3dbm	12.5
Freescale	MC13211/2/3	2.0-3.4	1.2, 4	16,32,60	32	.02 - .675 (MCU) 1 (RF)	.8 - 6.5 (MCU) 30 @ 0dBm (RF)	.8 - 6.5 (MCU) 37 (RF)
	MC13224	2.0-3.6	96	128	64	< 5 uA	29	24
Texas Instruments	CC2430	2.0-3.6	8	32,64,128	21	0.5	27 @ 0dBm	27
	CC2431	2.0-3.6	8	128	21	0.5	27 @ 0dBm	27
	CC2530/1		8	32-256	21	0.4	33.5 @ 4.5 dbm	24
Ember	EM250/260	2.1-3.6	5	128	17	1	33 @ 5dBm	29
	EM351/7	2.1-3.7	12	128/192		24	30 @ 3dbm	25
ST	SN260	2.1-3.6	5	128	17	1	33 @ 5dBm	29
	STM32W	2.1-3.6	8	128	24	0.8	31 @ 3dbm	27
Jennic	JN5121	2.2-3.6	96	0	21	5	45 @ 0dBm	50
	JN513x	2.2-3.6	96	0	21	0.4	39 @ 3dBm	39
	JN5148	2.0-3.6	128	0	21	0,1	15 @ 2.5dbm*	17.5
Radiopulse	MG2400	2.7-3.6	4	64	16	9 (VREG OFF) 42 (VREG ON)	31 @ 4dBm	26
	MG2450/5	1.9-3.6	8	96	24	<1	42 @ 8 dbm	32

Table 2-6: ZigBee enabled System-On-Chip solutions – Part 2

Manufacturer	Part Number	Tx Power (dBm	Rx Sensitivity (dBm)	Security	Package	Size (mm)	Comments
Atmel	ATMEGA128RFA1	3.5	-100	AES	64 QFN	9x9	Tx/Rx curr not incl MCU.Rand generator, 2Mbit/s mode, hw ant diversity, Tx/Rx ctrl, AVR, 16 MHz @ 1.8V (nice), 32-bit MAC symb ctr.
Freescale	MC13211/2/3	4	-92	None	71 pin LGA	9x9	Multi-chip modules using the HCS08 + MC1319x, sleep current depends on supply voltage and stop mode, active current depends on supply voltage and clock freq.
	MC13224	5	-100	AES	145 pin LGA	9.5x9.5	Serial flash mirrored in RAM. includes ROM with full 802.15.4 MAC.ARM7 MCU.
Texas Instruments	CC2430	0	-92	AES	48 QFN	7x7	IEEE 802.15.4 timer, random number generator, onboard temp sensor, 8051.
	CC2431	0	-92	AES	48 QFN	7x7	Same as CC2430, Includes Location Engine, 8051
	CC2530/1	4.5	-97	AES	40 QFN	6x6	802.15.4 timer, rand generator, batt mon, temp sensor. cc2531 has USB, 8051
Ember	EM250/260	5 (Boost Mode)	-98	AES	48 QFN	7x7	Boost Mode increases tx 2 dBm and Rx, EM260 same as EM250 but running in Zigbee coprocessor mode
	EM351/7	8	-102	AES	48 QFN	7x7	-102 Rx sens = boost mode, ARM CORTEX M3
ST	SN260	5 (Boost Mode)	-98	AES	48 QFN	7x7	This looks like an EM260
	STM32W	7	-100	AES	48 QFN	7x7	Looks like an EM351. ARM CORTEX M3
Jennic	JN5121	0	-90	AES	56 QFN	8x8	Jennic Stack is in ROM. Requires external serial flash for apps.
	JN513x	3	-97	AES	56 QFN	8x8	See above
	JN5148	2.5	-95	AES	56 QFN	8x8	Tx current not incl MCU, serial flash req for user app, 500 & 667 kbit/s mode
Radiopulse	MG2400	3 (TYP), 5 (MAX)	-98 (TYP)	AES	48 QFN	7x7	Non-standard bit rates of 500 kbps and 1 Mbps supported as well.
	MG2450/5	8	-98	AES	48 QFN 72 BGA	7x7 5x5	8051 MCU, voice codec, high output power, MG2450 = BGA, MG2455 = QFN

Sensors are hardware devices that produce measurable responses in case of a change in a physical condition e.g. temperature and humidity in our case. The analog signal sensed by the sensors is digitized by an Analog-to-digital converter (ADC) and processed further by the microcontroller. Each sensor node has a certain area of coverage for which it can reliably and accurately report the particular quantity that it is observing.

Power consumption in the sensor node is for the measurement, processing, and communication. Data communication requires more energy than measurement and processing. The energy cost of transmitting 1 Kb to a distance of 100 m is approximately the same as that for the executing 3 million instructions by 100 million instructions per second/W processor.

Power is stored either in Batteries or Capacitors. Batteries are classified as chargeable and non-rechargeable. They are also classified according to electrochemical synthesis as NiCd (nickel-cadmium), NiZn (nickel-zinc), NiMH (nickel metal hydride), and Lithium-Ion.

Current sensors are able to harvest ambient energy from solar, temperature, or vibration. For power saving Dynamic Power Management (DPM), which shuts shuts down the inactive or not used parts of the sensor node, is used.

2.6.2.2.2 Physical Communication Layer

WSNs have been implemented according to one of the following standards: IEEE 802.11 (WLAN), IEEE 802.15.x (ZigBee, Bluetooth, 6LoWPAN, ISA100, and WirelessHART). Both standards may coexist in the same RF band (ISM at 2.4 GHz).

Several other standards and proprietary specifications are currently either ratified or under development for wireless sensor networks.

1. **IEEE 1451**

Also relevant to sensor networks is the emerging IEEE 1451 which attempts to create standards for the smart sensor market. The main point of smart sensors is to move the processing intelligence closer to the sensing device.

2. **ISA100**

ISA100 is a new standard under development that makes use of 6LoWPAN and provides additional agreements for industrial control applications.

3. **IEC 62591 - WirelessHART**

The Wireless HART standard is specifically designed for Industrial applications like Process Monitoring and Control. The International Electrotechnical Commission (IEC) approved the WirelessHART specification as a full international standard (IEC 62591Ed. 1.0) in April 2010.

4. **IEEE 802.11 (IEEE Std 802.11 (ISO/IEC 8802-11: 1999))**

IEEE 802.11 standards focus on the physical and link layer of the ISO model. LAN applications run on an 802.11-compliant WLAN as they run over Ethernet. The high power consumption makes this standard unsuitable for low power sensor nodes.

5. **IEEE802.15.4 - ZIGBEE**

ZigBee specifies a set of high level communication protocols using small, low-power digital radios based on the IEEE 802.15.4 standard for wireless personal area networks (WPANs). ZigBee is promoted by a large consortium of industry players. It operates in the industrial, scientific and medical (ISM) radio bands; 868 MHz in

Europe, 915 MHz in the USA and 2.4 GHz in most jurisdictions worldwide. The technology is intended to be simpler and cheaper than other WPANs such as Bluetooth. The most capable ZigBee node type is said to require only about 10% of the software of a typical Bluetooth or Wireless Internet node, while the simplest nodes are about 2%. However, actual code sizes are much higher, closer to 50% of Bluetooth code size.

ZigBee protocols are intended for use in embedded applications requiring low data rates and low power consumption.

There are three different types of ZigBee device:

- **ZigBee coordinator (ZC)**: the most capable device, the coordinator forms the root of the network tree and might bridge to other networks. There is exactly one ZigBee coordinator in each network. It is able to store information about the network, including acting as the repository for security keys;
- **ZigBee Router (ZR)**: routers can act as an intermediate router, passing data from other devices;
- **ZigBee End Device (ZED)**: contains just enough functionality to talk to its parent node (either the coordinator or a router) and cannot relay data from other devices.

The current profiles derived from the ZigBee protocols support beacon and non-beacon enabled networks. The standard specifies the physical layer (PHY), and the medium access control (MAC) portion of the data link layer (DLL).

It uses the unlicensed 2.4 GHz, 915 MHz and 868 MHz ISM bands. In the 2.4 GHz band there are 16 ZigBee channels, with each channel requiring 5 MHz of bandwidth. The radios use direct-sequence spread spectrum coding, which is managed by the digital stream into the modulator.

Table 2-7 ZigBee modulation scheme

Frequency	Modulation	Bitrate
868 MHz	BPSK	20 Kbits/s
915 MHz	BPSK	40 Kbits/s
2.4 GHz	QPSK	250 Kbits/s

Transmission range is between 10 and 75 meters heavily dependent on the particular environment. The maximum output power of the radios is generally 0 dBm (1 mW).

The software is designed to be easy to develop on small, cheap microprocessors. The radio design used by ZigBee has been carefully optimized for low cost in large scale production.

6. IEEE 802.15.1 - BLUETOOTH

Bluetooth is a short-range wireless communications technology intended to interconnect portable and/or fixed devices while maintaining high levels of security. Bluetooth enabled electronic devices connect through short-range, ad hoc networks known as piconets. Each device can simultaneously communicate with up to seven other devices within a single piconet. Each device can also belong to several piconets simultaneously. Piconets are established dynamically and automatically as Bluetooth enabled devices enter and leave radio proximity.

Bluetooth simultaneously handles both data and voice transmissions (e.g. hands-free headset for voice calls, and synchronizing PDA, laptop, and mobile phone applications). It operates in the ISM band at 2.4 to 2.485 GHz, using frequency hopping spread spectrum, full-duplex signal at a nominal rate of 1600 hops/sec.

The range of Bluetooth devices depends on the class. Table 2-8 summarizes the situation.

Table 2-8 Bluetooth range

Class	Maximum Permitted Power (mW/dBm)	Range (approximate)
Class 1	100 mW (20 dBm)	~100 meters
Class 2	2.5 mW (4 dBm)	~10 meters
Class 3	1 mW (0 dBm)	~1 meter

7. **IEEE802.15.4 – 6LoWPAN (IPv6 over Low power Wireless Personal Area Networks)**

6LoWPAN is IPv6 for IEEE802.15.4 based personal area networks (PANs). IEEE802.15.4 with 6LoWPAN provides wireless internet connectivity at lower data rates for devices with very limited form factor (e.g. automation and entertainment applications in home, office and factory environments).

2.6.2.2.3 MAC Protocols with Sleep Scheduling and Clustering Mechanisms

Wireless sensors are battery operated low cost devices with limited processing and communication capabilities. A wireless sensor mainly consists of four components: sensing unit, processing unit, power unit, and transceiver. They differ from traditional sensors since they can process the sensed data and communicate through wireless channel. The phenomenon to be sensed can be ambient temperature, humidity, motion, seismic activity, etc. Large numbers of these nodes are deployed to form a WSN (Wireless Sensor Network). In a WSN, sensor nodes sense the environment for some sort of activity and report the collected data to a sink node. Sink nodes have more processing power than an ordinary sensor and are usually assumed to have unlimited power. A WSN should have at least one sink.

A WSAN (Wireless Sensor and Actuator network) is a WSN that contains actuator nodes besides sensor nodes and sink. Actuator nodes have more processing power and more power than an ordinary sensor. Moreover, they can communicate to much longer distances than regular sensor nodes. An actuator node costs less than a sink and may be used for coordination in WSNs that are deployed for monitoring a large area in a cost effective way.

A WSN can operate in different ways depending on the context it is used for. An application may require constant monitoring in which nodes should report collected data to the sink periodically. Some WSNs operate in a query-based fashion where sink propagates a query into the network and some relevant sensors report back to the sink.

Another type of WSN operation is for event detection. In this type, collected data is usually irrelevant to the sink unless some sort of event occurs. Most of proposed protocols for WSNs assume that communication unit of nodes are always on. However, it is known that idle listening (listening the channel for possible communication) consumes nearly the same energy as reception. Therefore, in order to obtain a network with a longer lifetime, sensors' transceiver units should be turned off to save energy. The trade-off for this action is increased packet latency. Even if transceiver unit is shut down, sensing and processing units still consume power. To have a long-lived network, one should also shut down those units whenever possible, putting nodes into sleep mode in which they consume negligibly small amount of energy.

A WSN is composed of a large number of connected sensor nodes with sensing, processing, and communication capabilities [12]. Nodes are battery operated, tiny, and inexpensive devices with limited communication range. A node may be specialized in just sensing a single phenomenon or it may sense a couple of different aspects of the environment including but not limited to temperature, humidity, seismic activity, intrusion, etc. A WSN is deployed in an ad-hoc manner and sensors are usually placed randomly in ROI (Region of Interest). A WSN does not require a fixed communication infrastructure so it can easily be deployed.

In addition, ROI is usually a remote and/or hostile area so after initial deployment nodes should organize themselves as a network. After deployment, nodes monitor the data and report back to sink. Since ROI may be huge, there can be thousands of sensors. To ease up communication and coordination, actuator nodes with more processing capability and power may also be deployed.

WSNs are used in both civil and military applications. For civil applications, the usage may range from monitoring a patient's health to monitoring a habitat. On the other hand, for military applications, the aim may be border surveillance or target tracking. As sensors have limited power supply, their lifetime is also limited. Since they are deployed in a remote area, accessing the ROI after deployment may not be an easy task. Moreover, since a WSN consists of a large number of sensors, recharging or replacing the battery of each sensor is not a feasible solution. When designing a protocol, these inherent disadvantages should always be considered and the protocol should try to maximize network lifetime.

In a sensor unit, transceiver circuitry expends most of the energy compared to other units. Some sources of energy wastage due to communication can be listed as:

- idle listening where a node listens the channel for possible communication,
- packet overhearing where a node hears a packet while it is not the intended receiver,
- protocol overhead due to message exchanges required by the protocol employed,
- packet collisions when two transmitters transmit a packet at the same time without knowing each other's transmission and a receiver that hears both of them.

First two cases can be avoided by putting radio to sleep mode whenever possible. For the third case, protocol must be designed carefully in order not to induce too much overhead. Finally, for the last case, some clever medium access schemes should be employed to avoid collisions.

Sensors have a limited communication range; they may not be able to reach to the sink directly. Even if they could, transmitting a packet to a long distance costs more energy than transmitting it in hops. To increase network lifetime, one should use multihop communication whenever possible to reduce the energy expenditure. Another aspect of multihop communication is that it causes a couple of nodes to expend less energy rather than just one node to use too much battery power, providing a little degree of evenness in consumed energy.

Another difficulty of WSN comes from the fact that nodes have limited processing power and memory. There is no overall coordination of the network and global knowledge of the network at any given time cannot be obtained without incurring a huge communication cost. Even if this is tolerable, the state of the network may change until all the information is collected at the sink due to delay. That is to say, a protocol designed for WSNs should be distributed and each node should take its own actions depending on its current state, its neighbors, and environment to be monitored. Moreover, due to large number of nodes, the protocol should be scalable.

When the purpose of WSN is event detection, nodes do not need to report periodically to sink unless the event of interest has occurred. It is obvious that the traffic load is very low in this case. However, when the event occurs, especially the nodes close the event need to report periodically. The type of event is very important in the design of a protocol. Depending on the event, protocol may need to satisfy some strict requirements. For instance, if radioactive material leakage is to be detected from a reactor, even seconds may be important. On the other hand, if the event to be detected is forest fire where the response time is rather long, delay requirements may not be that strict.

Duty cycling is a commonly used term in WSNs to refer to the case when nodes switch between *on* and *off* states to save energy. A DC (Duty Cycle) with a value 0.01 means that a node is in the *on* state for one unit of time and in the *off* state for 99 units of time. In the *on* state, all units of a node are on whereas, depending on the protocol, the *off* state may refer to the case where just the transceiver circuitry is off or all units are off. A low DC leads to a longer lifetime for the network but it may also cause unacceptable delays. Therefore, depending on the context both of these metrics should be balanced carefully.

2.6.2.2.3.1 MAC Protocols with Sleep Scheduling in WSNs

Sleep scheduling in WSNs can be defined as putting nodes into sleep mode whenever possible to save energy in an organized manner such that some latency requirements are met.

A new channel is introduced for pipelined tone wakeup in [13]. Wakeup radio is on for *Tdtone* and off for *Tsleep* where *Tdtone* + *Tsleep* = *T*. When a node has a packet to send, it sends a tone to wakeup channel that lasts for *Tp*. Wakeup tone does not contain the identity of the receiver so any node with active wakeup channel and within transmission range switches to data channel. *Tp* is set to *T* + *Tdtone* so that all neighbors become awake. Transmitter first notifies the receiver so other neighbors go back to sleep whereas receiver begins to wake up its neighbors to minimize delay. Similar wakeup radio schemes are also used in [14], [15] and [16]. The problem with these schemes is that a sensor with an extra wakeup channel is not feasible to manufacture both industrially and cost wise. In addition, since wakeup radio is assumed to be low power, its transmission range would be shorter than the data channel so a transmitter may not be able to reach all its neighbors on the wakeup channel.

A sleep-scheduling scheme for high density cluster-based WSNs is proposed in [17][16]. It is assumed that clusters are already formed, nodes have variable transmission ranges, and each member node knows its distance from its CH (Cluster Head). Three different sleeping mechanisms are discussed, which are randomized scheduling, distance-based scheduling, and balanced energy scheduling.

A delay efficient sleep-scheduling scheme is discussed in [18]. They assumed perfect node synchronization and low traffic load such that no interference or collisions occur. The number of slots is fixed and slot length is defined as the time required to successfully receive a packet. They tried to minimize DD (Delay Diameter) that is defined as the maximum delay among the shortest path for all pairs. Exponentially distributed node sleep times and per hop delays are assumed in [19][18]. Each transmitting node appends a timestamp to its packet that shows how long it has been waiting. Per hop delay constraint $\{t, P_r\}$ is met when per hop delay is less than t with probability P*r*. After waking up nodes estimate the ongoing activity based on the timestamps of waiting packets and update their DC accordingly.

Another distributed algorithm is proposed in [20]. Slot length is again the time required for successful reception of a packet and all nodes are synchronized. Another assumption is that a node can only receive in its active time whereas it can transmit at any time. A stochastic distributed algorithm where each node only knows the schedules of its neighbors is used.

A protocol for Heterogeneous WSNs is introduced in [21] and [22]. Geographic routing with FCSs (Forwarding Candidate Sets) is used. A node's FCS is the set of neighbors that are closer to sink than itself. A random asynchronous wakeup scheme is discussed in [22] where each node in FCS wakes up one in every slot; stay awake for a predetermined period of time, and go to sleep again. On the other hand, active time is a function of node's energy in [21]. Nodes exchange their energy levels by using beacons and each node knows the energy levels of its neighbors.

A pipelined mechanism is offered in [23]. A static sleep schedule is used when there is no query. If sink broadcasts a query nodes adapt to dynamic schedule. Static sleep schedule forms a pipeline based on the node's hop count from sink. But whenever sink broadcasts a query the sleep schedule becomes dynamic. This approach brings energy savings and with its pipeline mechanism latency is at minimum. However; it cannot be used for other usage cases.

A sleep-scheduling scheme for rare event detection is proposed in [24]. Network is assumed to be consisting of two layers, primary nodes and secondary nodes. Primary nodes are selected in such a way that they maintain sensing coverage with minimum number of nodes. They are rotated periodically. On the other hand, secondary nodes have a very small DC. The proposed algorithm assumes synchronized nodes and concentrates only on how to rotate the primary nodes.

A sleeping discipline for data gathering is offered in [25]. The network is assumed to be like a tree where sink is at the root. Nodes start to send to their neighbors at the upper level when they wake up. DC of a node consists of time for reception, time for transmission, and time for sleep. Nodes transmit their messages just at the time when their parents wakeup for reception. S-MAC protocol is introduced in [26]. Nodes exchange schedules and sleep and listen at the same time. A node receiving multiple different schedules adapt to both of them. This scheme provides virtual clustering among nodes. Slot length is fixed.

IEEE 802.11 DCF (Distributed Coordination Function) is used and nodes overhearing RTS (Ready to Send) or CTS (Clear to Send) packets go to sleep mode during data packet transmission. Message passing, where long messages are fragmented into small fragments and transmitted in bursts, is used. RTS and CTS messages are exchanged just for the first fragment, but all fragments require ACK (Acknowledgment) messages.

Each fragment and ACK have duration field to prevent hidden terminal problem. The problem with S-MAC is that since nodes form virtual clusters, a node receiving a packet has to wait until the next slot to transmit it to its neighbor. At each hop, a latency equal to slot length is incurred.

T-MAC also uses IEEE 802.11 DCF for communication and schedule exchange mechanism for virtual clustering [27]. Unlike S-MAC active period of a node is adaptive.

Active period of a node ends when no activation event occurs for a time period of *TA*. Activation events can be listed as: firing of a periodic timer, data reception, sensing of communication (collision), ending of a packet transmission, overhearing a data exchange by a neighbor.

Schedule based access schemes are proposed in [29] and [30]. TRAMA (TrafficAdaptive Medium Access) protocol assumes time slotted channel and offers a distributed election mechanism based on schedules [29]. It consists of a neighborhood protocol, a schedule exchange protocol, and an adaptive election algorithm. FLAMA (Flow Aware Medium Access) is very similar to TRAMA but this time instead of traffic, flows are used to select the transmitter for a particular slot [30]. FLAMA is designed for query based WSNs whereas TRAMA is designed for a general case.

2.6.2.2.3.2 Clustering Protocols for WSNs

Clustering protocols group nodes into clusters and select one of them as the cluster head. Member nodes usually just communicate with CH (cluster head). CH is responsible for aggregating gathered data and sending it to the sink. With clustering hierarchy, some benefits for WSNs can be obtained that can be listed as follows:

TDMA scheme is used for member nodes to access the CH. With its inherent duty cycling, TDMA provides energy savings. CHs are responsible for coordination and management of member nodes, which reduces the burden of the sink and also the burden of the network as a whole. It is assumed that different clusters use different codes for communication and TDMA scheme is used within a cluster. Hence, interference is reduced.

Besides these advantages of clustering, the main disadvantage is that CHs consume more energy than member nodes since they are active all the time. To prevent CHs to die quickly, they need to rotated periodically, which induces significant protocol overhead.

LEACH (Low Energy Adaptive Clustering Hierarchy) is introduced in [31]. In LEACH, single hop architecture is assumed, where CHs can reach the sink in one hop. All non-CH nodes transmit their data to CH, which aggregates the data and transmits it to sink. Operation of LEACH is divided into rounds. Each round begins with a setup phase in which, the clusters are organized, followed by a steady-state phase where data is transferred from member nodes to CH and from there to sink.

A refined version of LEACH is presented in [32]. The aim of refinement is to achieve better evenness of energy load distribution over the whole network. To accomplish this goal, remaining energy levels of candidates and their cost for transmission is considered. The main idea of the algorithm is to avoid selecting nodes with lower residual energy and higher energy dissipation as cluster heads.

Another modification of LEACH is introduced in [33]. The main difference is that cluster sizes are more predictable than LEACH since in this protocol each elected CH broadcast the advertisement message within a predefined range. This predefined range may be calculated by some theoretical analysis for dense networks.

An energy-efficient version of LEACH for event-driven applications is presented in [34]. This time member nodes use E-TDMA (Energy-Efficient TDMA) to communicate with the CH. This time when a member node wakes up, it does not send any data to CH, if it has no significant data to send. This scheme provides major energy savings and thus, an increased lifetime. Shortcomings of LEACH are discussed and an ACW (Adaptive Contention Window) based algorithm is proposed in [35]. In the proposed algorithm, each node selects a random back off value from the contention window (between 0 and CW) and the one with the minimum back off value becomes the CH in its region.

An iterative clustering protocol, HEED is proposed in [36]. Before the first iteration, each node sets a probability of becoming a CH that is given by:

$$CH_{prob} = C_{prob} \cdot \frac{E_{residual}}{E_{\max}},$$

where C_{prob} is the desired percentage of CHs among all nodes $E_{residual}$ is the remaining energy of the node, and $E_{\max}$ is the energy of a fully charged battery. During any iteration $i, i < N_{iter}$, where N_{iter} is the maximum number of iterations (predefined), every non-CH node elects to become a CH with probability CH_{prob}. After step i, the set of tentative CHs -S_{ch}- is set to {CHs after step i – 1 $\cup$ new heads selected at step i}. A node, s_i, selects its CH to be the node with the lowest cost in S_{ch} (S_{ch} may include s_i). Every node than doubles its CH_{prob} and goes to the next step.

If a node elects to become a CH, it broadcasts an announcement message containing its ID and status. In this message status is set to tentative CH if its CH_{prob} is less than 1, or final CH if its CH_{prob} has reached 1. A node is said to be covered if it hears an announcement message, otherwise it is uncovered. An uncovered node, announces itself as a CH with state as final CH. A tentative CH can become a regular node at a later iteration if it finds a lower cost CH.

A sink-coordinated algorithm is presented in [37]. It is assumed that sink knows location of all nodes in the network. During each setup phase, sink gathers information from all sensors about their current energy. Then, sink computes the average node energy of the network and chooses a subset -S- of nodes whose energy values are above average as tentative CHs. The algorithm is applied recursively until the desired number of clusters is obtained.

A clustering protocol for HWSNs is offered in [38]. The algorithm uses the initial and residual energy of the nodes to select CHs. To avoid global knowledge of the network by each node, the algorithm estimates the average energy of the network by using the initial energy of the network and energy spent for each round.

An unequal clustering mechanism for multihop communication is presented in [41][38]. The logic behind the idea is that nodes closer to the sink become hot spots and die quickly. Each node has a competition range for becoming a CH that decreases as a node's distance to the sink decreases. The result is clusters closer to the sink have smaller cluster sizes.

A similar unequal clustering mechanism for single hop WSNs, where each CH reaches sink directly, is discussed in [39]. This time clusters far from the sink should have smaller sizes, since they consume more energy reaching to sink, than clusters nearby the sink. The algorithm is similar to the one in [39], but this time after CHs are selected, each node decides its cluster based on a cost function that is a weighted sum of the distance of CH to the sink and distance of node to the CH.

Clustering problem has also attracted interest for mobile ad hoc networks and metaheuristics are used for the problem. A simulated-annealing based technique is proposed in [41]. A weighted metric that uses the weighted

- sum of a node's sum of distances of members of the cluster,
- average speed of the nodes in the cluster,
- accumulative time of that node being the cluster head,

- degree (number of neighbours) difference.

After introducing the metric, simulated annealing is applied to find a solution to the problem. The same metric is also used in [42] where genetic algorithm is used for optimization.

Two budget based algorithms, where nodes have local growth budgets to allocate for neighbours, are offered in [43]. The first algorithm is called Rapid and produces of clusters of bounded size whereas the other one called Persistent always tries to produce a cluster with specified size.

Balancing the energy consumption throughout the network, which also leads to increasing coverage time of the network, is also an important criterion. It does not necessarily mean minimizing consumed total energy. To tackle this problem, a signomial optimization problem is formulated and solved using generalized geometric programming for two different approaches in [44]. The first approach is routing-aware optimal cluster planning, and the second one is clustering aware optimal random delay.

Another method for balancing the energy consumption is considered as balancing the size of the clusters [45]. In the initial phase of the protocol, nodes adjust their power in such a way that its number of neighbouring nodes is about a predefined threshold. That is to say, nodes that have more neighbours than threshold shrink their transmission power with certain power level in each step until the desired number of neighbours is achieved. The procedure operates the opposite way around for nodes that have fewer neighbours than the threshold. The aim of this setup phase is to balance the energy expenditure of each node.

Cluster radius configuration is also studied in [46]. In this work, CHs are assumed superior to ordinary sensors with high energy capacity and more processing capability. Moreover, it is also assumed that sink knows the position of all CHs. The protocol is able to regulate the cluster radius for energy savings.

Some design guidelines for cluster based WSNs are proposed in [47]. In general, the analysis focuses on communication within a cluster to decide when single hop communication should be used to reach to CH and when multiple-hop should be used for the same purpose. A hybrid approach is also proposed; in which nodes alternate between single hop and multi hop communication. The problem with single hop is that nodes far from CH consume more energy. On the other hand, with multi-hop communication, nodes nearby the CH become hot spots and die quickly.

All of these works about clustering assume constant monitoring over the ROI. An event-based clustering mechanism for Heterogeneous WSNs is discussed in [48]. Actuator nodes provide communication between CH and sink. In this work, a sensor can be in one of the four states, which are given in Table 2.1. Transceiver state T, R means node can both transmit and receive, whereas R means it can only receive incoming packets.

Table 2-9: Sensor states for the event-driven clustering scheme [48]

State	Processor	Memory	Sensor, ADC	Transceiver
S_0	Active	Active	On	T, R
S_1	Active	Active	On	R
S_2	Active	Active	On	Off
S_3	Active	Sleeping	On	Off

In the initialization phase, every node is in S1 state. Sink broadcasts a control packet that includes a threshold value (such as critical temperature) leading to the state change of sensors. A sensor receiving the value stores it and goes to S3 state. If an event occurs, all sensors that sense the event and whose data exceeds the threshold go to state S_0.

Once an event occurs, each sensor node near the event broadcasts its energy to a close gateway node. Gateway nodes exchange sensor energy information with each other. One of them sorts the values, selects k nodes with highest energy as CHs, and broadcasts the information.

2.6.2.2.4 QoS Aware MAC Layer Protocols

Popularity of wireless sensor networks combined with the multimedia requirements of new applications have enabled Wireless Multimedia Sensor Networks. WMSNs are composed of embedded cameras and microphones besides traditional scalar sensors and generally carry heterogeneous, quality of service (QoS)-constrained traffic such as video and audio streams, still images and scalar data [49]. Since WMSNs are used in more bandwidth-hungry applications with respect to WSNs, operating under severe resource constraints becomes more challenging. Moreover, in order to create a better global view of the observed phenomena or support latency-intolerant real-time applications, QoS support mechanisms become necessary for WMSNs.

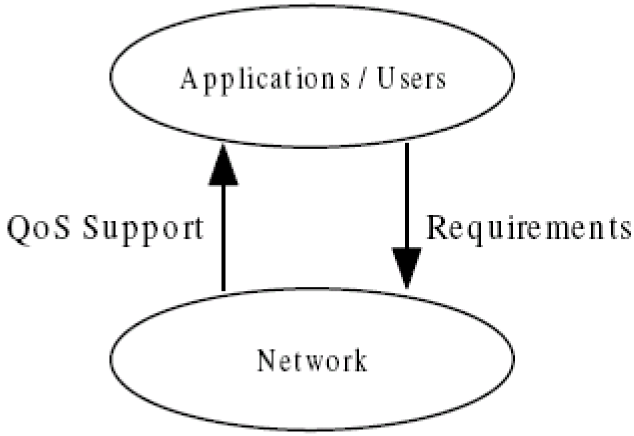


Figure 2.6-4: A Simple QoS model [50]

Although the term QoS is widely used in the area of computer networks, there is still an uncertainty in what exactly QoS means. However, the simple model depicted in Figure 2.6-4 may be considered as a common ground. It is certain that, QoS support is provided in response to particular requirements of the customer who will be given the service. International Telecommunication Union (ITU) [51] has defined QoS as "Totality of characteristics of a telecommunications service that bear on its ability to satisfy stated and implied needs of the user of the service". Traditionally it refers to control mechanisms that orchestrate the resource reservation rather than the provided service quality itself. Simply or practically, QoS brings the ability of giving different priorities to varied users, applications, and data ows, frames or packets based on their requirements by controlling the resource sharing, hence achieving higher level of performance over others. However, the meaning of the QoS can vary based on the application-specific needs and an accurate definition might be done for each implementation according to its specific characteristics.

In case of WMSNs that deliver various types of traffic, QoS support mechanisms are required to prioritize and manage the resource sharing according to the requirements of each traffic class. In order to meet these requirements, WMSNs need novel and well-designed QoS support mechanisms in each layer of the communication protocol stack since envisioned applications are dissimilar to traditional end-to-end applications. Especially real-time multimedia and mission-critical applications brought forward new QoS requirements since they need delay-bounded and reliable delivery of the data. Moreover, additional characteristics of WMSNs such as resource constraints, dynamic topology, and interaction with the environment make the QoS support much more challenging than in others.

In the following section, existing QoS-Aware MAC protocols for WMSNs will be surveyed and their advantages and disadvantages will be pointed out.

2.6.2.2.4.1PSIFT

PSIFT [52] is a QoS-aware MAC protocol designed for event-driven applications and based on SIFT by Jamieson et al. [53]. The motivation behind SIFT is that when an event is sensed, the first R of N potential reports is the most crucial part of the messaging and has to be relayed with low latency. Relayed R reports will be sufficient for the sink node to accurately identify the event and elimination of redundancy decreases both probability of collision and latency. They proposed two methods “Explicit ACK” and “Implicit ACK” for suppressing unnecessary redundant reports based on the broadcast nature of wireless transmission.

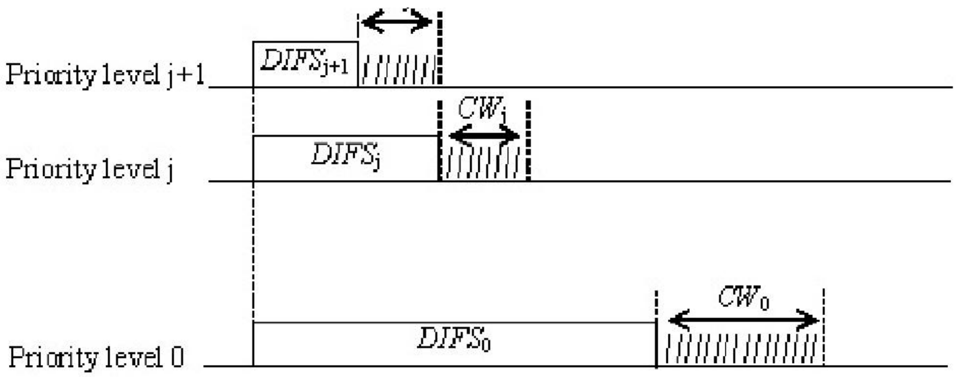


Figure 2.6-5: Service differentiation in PSIFT [52]

PSIFT is a Carrier Sense Multiple Access (CSMA)-based MAC protocol and provides traffic differentiation by varying the inter frame space (IFS) and contention window (CW) size for each traffic class as seen in Figure 2.6-5. They prioritize the traffic classes in a dynamic manner based on the traversed number of hops, i.e. the higher number of hops traversed, the higher level of priority that a packet has.

Advantages and disadvantages: Although PSIFT might be a sensible choice for event-driven applications it is nearly impossible to be used in any other type of applications. Besides, removal of the redundancy may result in unreliable data delivery since identification of reports belonging to separate events will be an issue to be solved. Report suppression mechanism decreases the traffic load in the network and leads to mostly idle sensor nodes. This advantage of the PSIFT must be utilized to decrease the energy consumption of the network by integrating a kind of sleep-listen schedule.

2.6.2.2.4.2 Q-MAC

Q-MAC [54] utilizes intra-node scheduling to select the next serviced packet from five different priority queues and inter-node scheduling to coordinate the medium access among multiple neighboring nodes as seen in Figure 2.6-4. The priority of an incoming packet is determined by two factors. Application layer perspective gives priorities based on the content of the packet and MAC layer based on traversed hop count. By this way, packets are mapped into predefined five different priority queues including one instant queue that any packet in this queue served immediately. Within the context of intra-node scheduling, MAX-MIN fairness algorithm [55] used to control the rate and packetized Generalized Processor Sharing [56] algorithm used to select the next trans- mitted packet. For inter-node scheduling, a novel protocol named Loosely Prioritized Random Access (LPRA) proposed for coordinating the medium access based on the transmission urgencies of the packets waiting to be transmitted. There are four factors determining the transmission urgency i.e. priority of the packet: packet criticality from the application point of view, traversed number of hops, remaining energy of the sensor node and queue's proportional load.

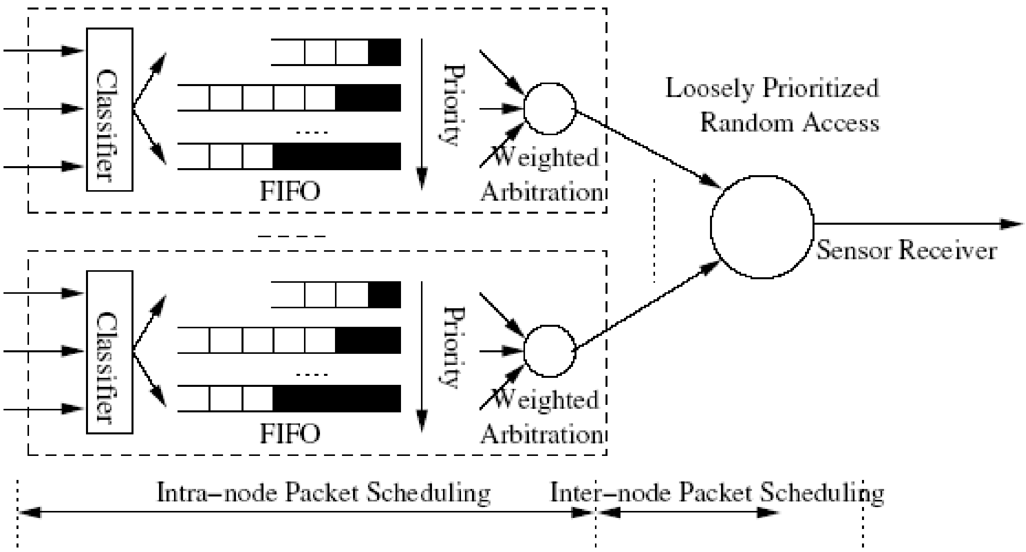


Figure 2.6-6: The multi-queue architecture of Q-MAC [54]

A Frame represents single RTS-CTS-DATA-ACK packet exchange and consists of contention period (CP) and transmission period (TP). Figure 2.6-7 depicts the CPs of different priority levels (PL) and the non-uniform probability distribution for selecting a CW slot. As congestion control mechanisms, doubling the CW size proposed for decreasing the probability of collision and decreasing the packet deadline for alleviating the traffic load. For energy efficiency, sensor nodes follow sleep-listen schedules with fixed duty cycles.

Advantages and disadvantages: Dynamic priority assignment provides robustness against changing conditions of the sensor network. However, calculation of the transmission urgency of the packet is relatively complex. Integration of the increasing geometric probability for CW selecting may decrease the collision rate but also may result in higher latencies.

2.6.2.2.4.3PQ-MAC

PQ-MAC [57] aims to use advantageous features of both contention based and schedule based approaches and proposes a hybrid scheme for medium sharing. Global clock synchronization, neighbor discovery and accordingly slot assignment are done during the setup phase and followed by the transmission phase which real data delivery takes place.

Slot assignment within the setup phase regards the two hop distance neighbor nodes and allocates different time slots based on the DRAND [58] algorithm as seen in Figure 2.6-7. Frame size of the protocol determined by the Time Frame (TF) rule of the Z-MAC [59] and similarly depends on the two-hop neighborhood of the sensor node. Owner sensor node of a specific transmission slot assigned in the setup phase has an exclusive right to send data in it. If the owner of the slot does not have any data to send or has lower priority data, non-owners of the slot can contend for the slot based on priorities of their data.

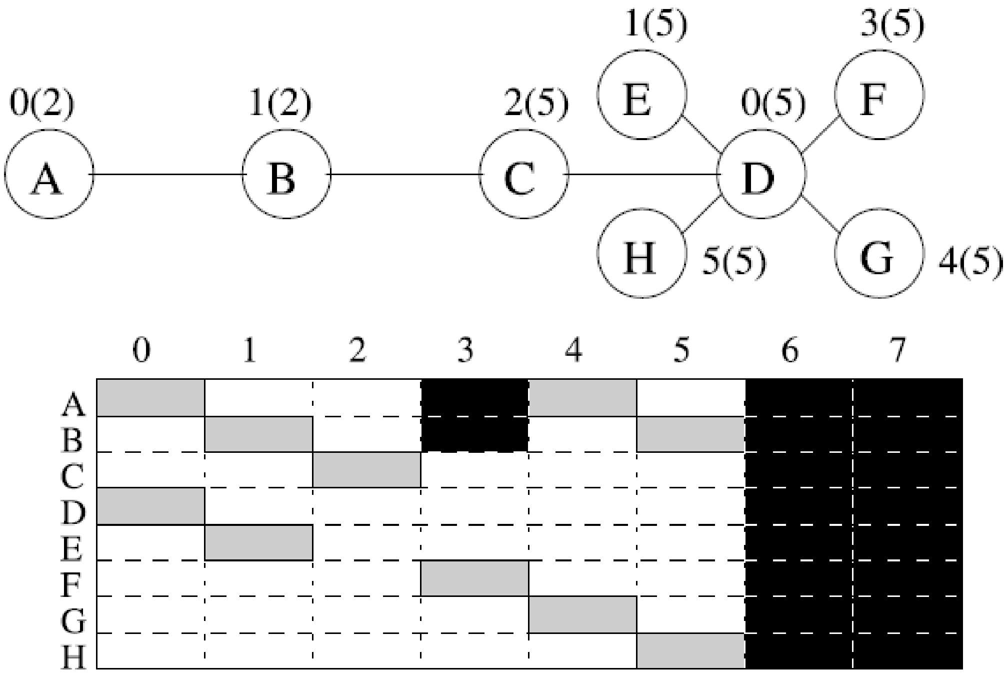


Figure 2.6-7: The slot scheduling of PQ-MAC by TF rule [57]

The super frame (SF) structure of the PQ-MAC can be seen in Figure 2.6-8 and consists of two sub frames: Data frame (DF) which is used for data delivery and Control Frame (CF) which used for sleep-listen schedule. Adaptive sleep-listen schedule used for energy efficiency and synchronization between neighboring sensor nodes provided by generating sequence of bits indicating whether it will sleep or be awake during the corresponding time slot. In Figure 2.6-9, medium access prioritization mechanism can be seen for three different traffic classes. Only the owner of the slot can access privileged contention windows T0, T2 and T4 while non-owners can contend during T1, T3 or T5 with respect to their traffic types.

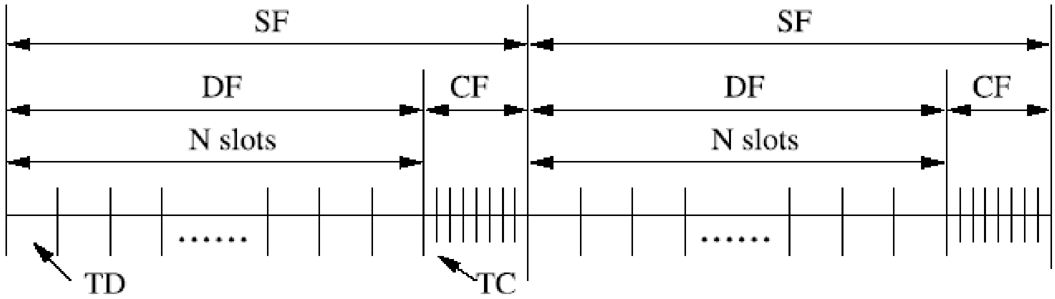


Figure 2.6-8: The super frame structure of PQ-MAC [57]

Advantages and disadvantages: Neighborhood of the sensor nodes, relay nodes or cluster heads can change frequently because of the dynamic nature of the WSNs as mentioned earlier. That's why, permanence of the slot assignment accuracy which is done once at the beginning of the setup phase severely effected. In heavy traffic conditions, PQ-MAC behave like a Time Division Multiple Access (TDMA) based protocol since almost all nodes will have a packet to send and use its own transmission slot. This improves the channel utilization and reduces the probability of collision significantly at the cost of tight clock synchronization.

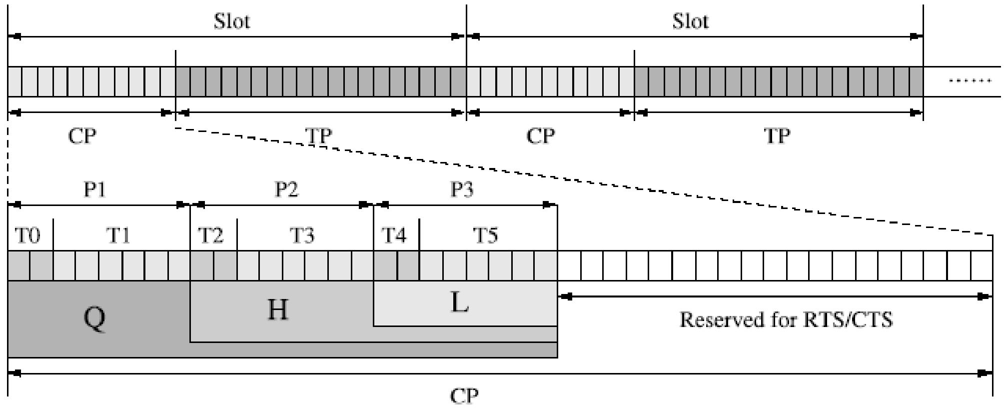


Figure 2.6-9: The slot structure of PQ-MAC [57]

2.6.2.2.4.4Saxena et al. MAC

The closest work to ours is introduced by Saxena et al. [60], [61] where they use a CSMA/CA approach and assume three types of traffic carried in the network: streaming video, non-real-time (NRT) and best effort (BE). Basically, their MAC scheme periodically monitors the dynamics of the sensor nodes and the medium, and collects relevant network statistics like transmission failures and transmitted traffic type. Accordingly, the protocol updates the CW size adaptively, based on the gathered information. CW adaptation is performed in a “stop-for-a-round” fashion and differentiation is provided by varying the up and down scale factors for different traffic classes. Consequently, CW size for higher priority traffic decreases faster than the lower priority where an increase is performed more slowly. Duty cycle is adjusted directly according to the dominating transmitted traffic from a sensor node as seen in Figure 2.6-10. Although, CW size and duty cycle adaptation are common features between our protocol and Saxena et al. MAC, we use a different approach for CW size adaptation. Saxena et al. MAC waits for other sensor nodes to adjust their CW size whereas Di_-MAC continuously adapts the CW size regardless of the neighbouring sensor nodes, hence achieves better CW sizes faster than Saxena et al. MAC. Additionally, Saxena et al. MAC uses a FIFO based queuing method to process packets from different priorities where we utilize a packetized weighted fair queuing method which brings the ability of controlling the medium access, hence relative throughput, for each traffic class. Additionally, Di_-MAC uses a \traversed number of hops based prioritization" scheme to prioritize the packets according to their generation times and to deliver them as quickly as possible to the sink node, whereas Saxena et al. MAC does not differentiate the packets from the same class and always processes the packets according to the priority of their traffic type.

Advantages and disadvantages: Since sensor nodes have to wait for others to further adjustments, stop-for-a-round adaptation of CW size may result in inaccurate adjustments or very slow convergence to target CW size. Moreover, using the same packet format for every traffic class might be a waste of limited resources because scalar data and video frames will not be at the same size probably.

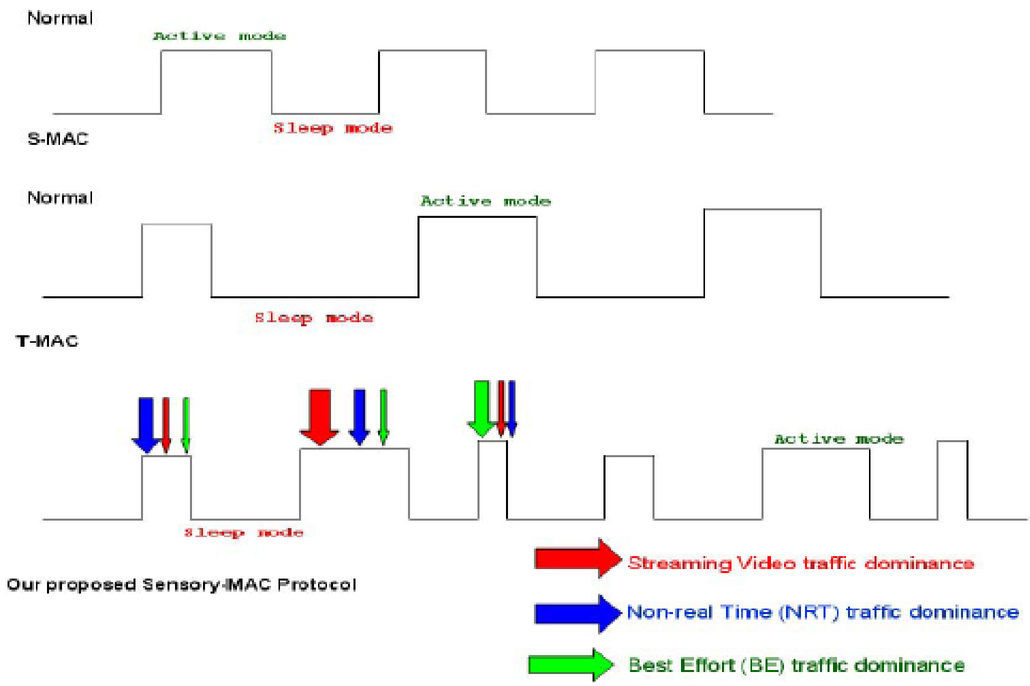


Figure 2.6-10: Duty cycling in Saxena et al. MAC [61]

2.6.2.2.4.5RL-MAC

RL-MAC [62] is a QoS-aware reinforcement learning (RL) based MAC protocol and uses a CSMA scheme. It adaptively changes the duty cycle of the sensor nodes based on not only local observations but also neighbour nodes. As a local observation, the number of successfully transmitted and received packets during the active time period is recorded to be used in the duty cycle adaptation with proportional load of the queues. For neighbour observation, a field is added to the packet header to provide information to the receiving node regarding the number of failed transmission attempts by the sender. With this field, RL-MAC tries to save energy while minimizing the number of missed packets due to early sleeping. Three traffic categories are defined and service differentiation between them is implemented by varying the CW size of each class. Although the algorithm includes various features for QoS-constrained traffic, using complex reinforcement learning algorithms might not be feasible for resource constrained sensor nodes.

Advantages and disadvantages: Relatively complex RL based algorithm adapts the network conditions very well but might not be feasible for energy and processing power constrained sensor nodes.

2.6.2.2.4.6 Properties of a Well-designed QoS-Aware MAC Protocol

The major problem in WSNs is lack of resources. Since depletion of energy makes the sensor nodes useless, energy scarcity leads the resource constraints. Therefore, designed MAC protocol must be aware of energy while providing QoS support. Also, WSNs have limited resources in terms of memory and processing capability. Hence, computationally complex and overwhelming algorithms are not feasible. Since aim of the MAC layer is coordinating the medium access and WSNs have to operate at relatively scarce bandwidths, better throughput performances need to be provided with high channel utilization.

WSNs can contain numerous sensor nodes or can be deployed to huge areas. For this reason, scalable MAC protocols are needed. Moreover, node mobility, natural disasters or node malfunctioning may result in highly dynamic network topology which makes the adaptive MAC layer requirement a must.

Priority assignment methods must be fair and accurate in order to achieve better QoS performance. Poor prioritization of the traffic leads to non-utilized network resources or waste of resources. Since WSNs are highly application-specific, the requirements need to be identified with great attention and must be used as a primary factor for design tradeoffs.

Features listed above must exist in a well-designed QoS-Aware protocol but not enough to be one. Performance of the QoS-aware MAC protocols extremely depends on the requirements of the application. For example; delay intolerant real-time applications necessitate fast delivery of the data or evenly distributed latency among sources to reduce the jitter meanwhile mission critical applications require reliable communication. As a final remark, specific requirements of the application related to QoS constraints must be determined and fulfilled with great care.

2.6.2.2.5 Reliable Data Delivery in Wireless Sensor Networks

The purpose of any WSN application is to collect data from the environment by the use of sensor nodes and transport it to a node or group of nodes called sinks, for further processing. Such a sensing data transport towards a sink may include a large number of unreliable and low bandwidth radio links among the networked set of sensor nodes possessing limited processing and power capabilities. In addition, this resource-constrained environment is also subject to frequent sensor and communication failures. Because of these intrinsic characteristics of WSNs, the problem of reliable data transport in WSNs does not have a trivial solution.

Communication over wireless links is characterized by limited bandwidth, high latencies, high bit-error rates and temporary disconnections that must be dealt with by network protocols and applications. Unlike in the wired environments, reliability cannot be provided only by the end systems and using transport protocols in WSNs. Rather, the inherent tradeoffs between reliability, quality of the provided information, and constrained energy requires cross-layer solutions. Applying TCP, for example, to achieve reliability is badly influenced by several mismatches between TCP and WSNs. Since TCP protocol adopted the conventional end-to-end retransmission-based error control and the window-based additive-increase multiplicative-decrease congestion control mechanisms, it is not feasible for the wireless sensor domain and hence may lead to waste of scarce wireless sensor resources [63],[64]. In addition to poor performance of TCP in wireless links, TCP uses IP addressing architecture and address centric routing instead of data-centric addressing and routing [65] that is preferable in sensor networks. Even with header compression, TCP protocol has a very large header overhead, particularly compared to specialized sensor network communication protocols [66]. Although TCP had been made more suitable by caching mechanisms [67], it still remains problematic to use it in WSNs to achieve reliability.

The problem of reliable data delivery in WSNs has received increasing concern lately. The research efforts can be categorized according to the dimensions of reliable transmission in WSNs [68] as:

- Single packet vs. block of packets vs. stream of packets: Reliable delivery of single packets can be important for example for highly aggregated data, reliable delivery of blocks is required for applications like disseminating new code or new queries into the network [69]. Periodic data reporting is the primary example for streams of packets.
- Guaranteed vs. stochastic delivery: Some applications require guaranteed delivery. Examples are: (i) reporting of very important events from sensors to a sink node, (ii) the distribution of new code or queries from the sink node to sensors [69], or (iii) handing over the target state in a tracking application between nodes close to the target trajectory [70]. Other situations might well tolerate a certain degree of losses. For example, when many sensors transmit strongly correlated sensor readings, occasional loss is tolerable. One way to specify the tolerable amount of losses is to prescribe a delivery probability. In general, the higher the desired delivery probability, the higher are the energy costs needed to achieve this.

Sensors-to-sink vs. sink-to-sensors vs. local sensor-to-sensor: Communication in sensor networks does not take place between arbitrary nodes, but is either from (groups of) sensors to a single or a few sink nodes, from a sink to (groups of) sensors or locally between (groups of) sensors when these run collaborative algorithms.

2.6.2.2.5.1 Single Packet Delivery

Single packet delivery is important for example when a sensor node wants to deliver aggregated data to a sink node. Most of the literature focuses on the case of stochastic guarantees and, accordingly, the most important performance measure is the packet delivery probability.

2.6.2.2.5.1.1 Approaches using a single path

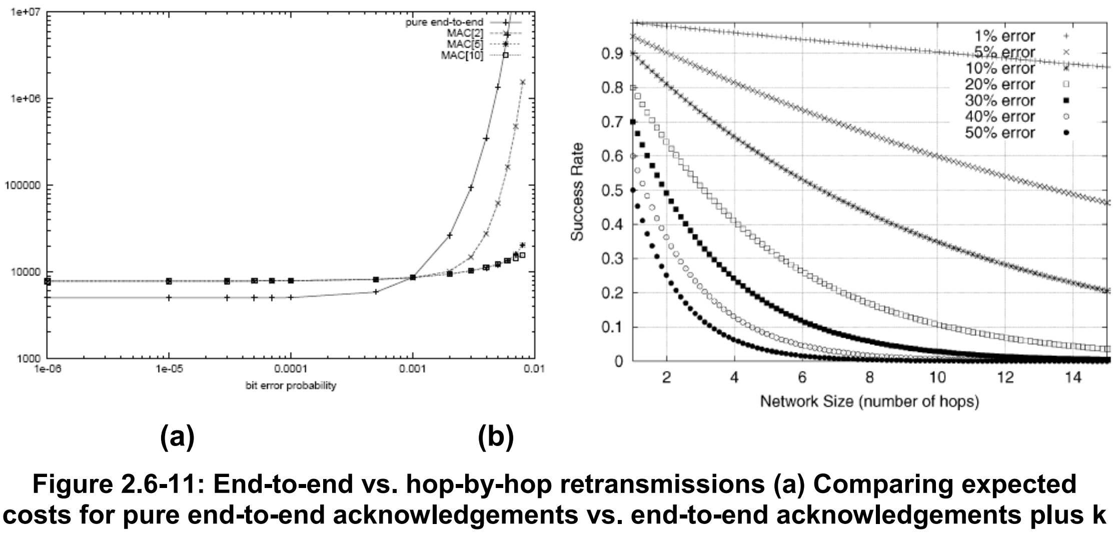
The primary mechanisms to ensure reliability are retransmissions and the usage of multiple packets. In single packet delivery the data packet can get lost and the transmitting node has to use timers and retransmissions; the receiver uses acknowledgments. There is more flexibility in case of block or stream delivery. For example, it is possible to let the receiver detect losses by checking for holes in the sequence number space and request retransmission of missing packets by using negative acknowledgement (NACK) packets. If additionally NACKs are understood as carrying implicit acknowledgements then there is no necessity to send positive acknowledgements for every packet, thus saving lots of energy.

For single hop delivery, two standard positive acknowledgment approaches are as:

MAC-layer retransmissions: when a node on the path forwards the data packet, it expects to receive a MAC-layer acknowledgment. Setting timers is easy, since only single-hop propagation delays and packet processing times have to be considered. Typically, the transmitter makes a bounded number of trials to successfully forward the packet and drops it after this number has been exhausted. However, for small data packets the acknowledgements create significant overhead

End-to-end retransmissions: the source node needs to buffer the packet until an acknowledgement from the sink node arrives. Again, the number of trials made by the source node is typically bounded. However, setting timers in this case is much harder, since reasonable guesses would need knowledge on the number of hops, the per-hop delay and the current traffic in the network. End-to-end retransmissions can be combined with MAC-layer retransmissions.

It is shown in [68] that for very good channels it is best to do without MAC-layer acknowledgements. Beyond a certain point, however, the pure end-to-end scheme is overly wasteful. For small numbers of hops it is better to not use MAC-layer acknowledgements, but beyond a threshold they are indispensable. To make optimal usage of energy resources, the actually chosen scheme should be decided dynamically. In addition, in [69] it is shown that for larger networks it is almost impossible to deliver a single message using an end-to-end approach in a lossy link environment when the error rate is larger than 10%, with the assumption that the success rate across *n* hops is $1-p^n$ if the packet error rate of a wireless channel is *p*. Figure 2.6-11.a and Figure 2.6-11.b are the illustrations of these results, respectively.



(a) (b)

Figure 2.6-11: End-to-end vs. hop-by-hop retransmissions (a) Comparing expected costs for pure end-to-end acknowledgements vs. end-to-end acknowledgements plus k trials at the MAC layer for varying bit error rate p and n = 10 hops model across a multihop network [68] , (b) Probability of successful delivery of a message using an end-to-end retransmission scheme [69]

The HHR approach (Hop-by-Hop Reliability) described in [71] relies on sending multiple copies of the same packet; unicast by each node back to back to the next upstream node. The required number of copies is determined from a locally estimated packet error rate, the desired packet delivery probability and the hop-distance to the sink. Alternatively, packets are repeated until a local acknowledgment has been received (HHRA). In comparison, there is a threshold bit error rate below which HHR is better than HHRA and beyond which the reverse behavior can be observed. Both schemes work well for channels with independent errors, on typical wireless channels with bursty errors (for example caused by multipath fading), however, they are sub-optimal. Specifically, for HHR the multiple copies are simply wasted when all copies are transmitted within the same channel deep fade and during good channel periods, a single or a few packets would likely suffice.

Other approaches in this category are [72], [73], [74], [75].

2.6.2.2.5.1.2 Approaches using multiple paths

A first approach to utilize multiple paths is to set them up in advance (either node-disjoint ones or braided paths) and declare one of them the default route. Once problems occur, another route is used [76] or the route is repaired locally by a rerouting scheme [77]. However, in either case, extra route maintenance is required which does not necessarily pay off in single packet delivery applications.

Other approaches send not only a single packet over one of the paths but transmit multiple packets over multiple paths in parallel. In the ReInForM scheme [78], multiple copies of the same packet are transmitted over randomly chosen routes. Specifically, it is assumed that a packet is destined to a sink node and that each node knows its hop distance to the sink as well as the hop distances of all its immediate neighbors. Packet duplication can occur at every intermediate node, not only at the source node. An intermediate node has to decide two things: the number of copies to create and the upstream nodes to which the packet is actually forwarded. With respect to the latter choice, ReInForM prefers nodes which are really closer to the sink but otherwise the choice is random. This distributes the load over many nodes and avoids quick depletion of nodes along a “good” route. The number of duplicates is determined from the locally estimated error rate, the hop distance to the sink and the target delivery probability.

Another possibility using multiple copies extends the HHR and HHRA protocols by exploiting the broadcast property of wireless media [71]. Unlike the point-to-point based HHR, in Hop-by-Hop Broadcast (HHB) a broadcast packet is considered successful if any of the sender’s neighbors towards the destination forwards the packet further. To avoid degenerating into flooding, a neighbor forwards the packet only with probability p; p is chosen by the sender, using the number of its neighbors such that on average only a single copy is forwarded. The HHBA scheme (Hop-by-Hop Broadcast with Acknowledgements) uses the same idea, however, similar to the HHRA scheme there is a gap between the packet copies. Any upstream node receiving the packet sends an acknowledgement (slightly randomized to avoid collisions) and the forwarding node x stops transmission of further copies as soon as such an acknowledgement is received.

In a further scheme [79], the source node adds a number of redundancy bits to the original data. The resulting increased data block is fragmented and each fragment is transmitted on another path. The coding is chosen such that a subset of these fragments is sufficient to reconstruct the original data.

There are many other approaches which uses multipath to achieve reliable data delivery [80], [81], [82], [83], [84], [85], [86], [87], [88].

2.6.2.2.5.1.3 The case of multiple receivers

The problem of delivering a single packet to a set of receivers is much harder. One particular problem is that positive acknowledgements would lead to the *ACK* implosion problem known from multicast protocols [89]. One option is reliable MAC-layer broadcast [90], another one is the WFP approach (Wait for First Packet) taken in the GARUDA project [91] for reliably delivering the first packet of a block of packets from the sink to all sensors. This approach rests on the transceivers ability to generate short pulses of high energy at the transmitting side and the ability to distinguish these pulses from normal data transmissions based on their energy profile on the receiving side. The sink sends these pulses periodically. The neighboring nodes start generating pulses by themselves once they hear the sinks pulses. Repeating this, after some time the whole network will be pulsing and the sink transmits the data packet. A sinks neighbor receiving the data packet stops pulsing and also transmits the data packet. This process continues and the data packet propagates through the network. Any node (including the sink) having the data packet and still hearing a pulsing neighbor retransmits the packet. This way, continuing pulses functions as an implicit *NACK*. The pulsing interval has to be carefully adjusted to avoid too frequent collisions with data packets.

Other research efforts in this category of reliable data delivery in WSNs are [92], [93], [94].

2.6.2.2.5.2 Packet Block Delivery

Block transfers occur when large amounts of data (e.g., code updates) have to be transported. One important feature of such a block transfer is that NACKs can be used. This potentially reduces the number of acknowledgement packets. A NACK can be regarded as a retransmission request issued by the receiver. When an intermediate node caches the segments, it can serve such a request as well as the original source node could but with the benefit that the NACK and the following retransmitted segment do not need to travel the whole distance between source and sink nodes. Such a node is also called a recovery server [91][95]. In an extreme case, all nodes in the network spend some buffer for caching.

In [68], the PSFQ (Pump Slowly, Fetch Quickly) mechanism is proposed for reliable retasking / reprogramming in the wireless sensor networks. PSFQ is based on slowly injecting packets into the network, but performing aggressive hop-by-hop recovery in case of packet loss. The protocol consists of three basic primitives: a *pump* operation, a *fetch* operation and a *report* operation. The *pump* operation in PSFQ simply performs controlled flooding and requires each intermediate node to create and maintain a data cache to be used for local loss recovery and in-sequence data delivery. The *fetch* operation corresponds to a NACK or a retransmission request and is triggered by missing sequence number. If the upstream neighbors do not possess the missing segments, they forward the NACK further, until it eventually reaches a node having the missing segments. The NACK packets themselves are broadcasted and *any* upstream neighbor having some of the missing segments is invited to respond. To avoid collisions among them, they introduce random delays before sending their answer. The *report* operation is requested from the sink node. The most distant nodes (as indicated by a TTL field in the packet) issue report packets indicating their own address and the received/missing segments. This way the sink can judge the progress of the code block dissemination.

Although PSFQ is an important solution for the wireless sensor networks, it does not address packet loss due to congestion.

Another framework called GARUDA for providing sink-to-sensors reliability in WSN is introduced in [91]. The GARUDA sink-to-sensors reliability framework incorporates an efficient pulsing based solution, which informs the sensor nodes about an impending reliable short-message delivery by transmitting a specific series of pulses at a certain amplitude and period. A virtual infrastructure called the core that approximates a near optimal assignment of local designated servers is instantaneously constructed during the course of a single packet flood. In case of a packet loss detected by a core node via an out-of-sequence packet reception, a core node initiates a two-stage negative-acknowledgment (NACK) based packet recovery process that performs out-of-sequence forwarding to assure the reliable delivery of the original message. GARUDA also supports other reliability semantics that might be required for sink-to-sensors communication such as (i) reliable delivery to all nodes within a sub-region of the sensor network; (ii) reliable delivery to minimal number of sensors required to cover entire sensing area; and (iii) reliable delivery to a probabilistic subset of the sensor nodes in the network.

The RMST scheme [96] adds reliable data transfer to directed diffusion [97]. RMST is designed for delivering larger blocks of data in multiple segments from a source node to a sink node. This is for example required when time series data has to be transmitted. RMST combines several mechanisms to enforce reliability:

- MAC-layer retransmissions.
- In RMST's *cached mode* the sink node and all intermediate nodes on an enforced path cache segments and check the cache periodically for missing segments. When a node detects missing segments, it generates a NACK message which travels back to the source along the reinforced path. The first node *A* having missing segments in its cache forwards them again towards the sink (and thus towards the requesting node). If *A* can retrieve all requested segments from its cache, then *A* drops the NACK packet, otherwise it is forwarded further upstream. Both the segments and the NACK packets are represented in terms of attributes, to be compatible with directed diffusion. In the *noncached mode* of RMST only the sink node has such a cache but not the intermediate nodes; therefore, NACK's travel back to the source node (which clearly also needs to cache the segments).
- on the application layer redundancy is used: the source sends out the whole data block periodically until the sink explicitly unsubscribes.
- by frequently repeating interest propagation, dissemination of exploratory events and subsequent establishment of (new) reinforced routes some resilience against node failures is achieved. By investigating different combinations of the above mechanisms for their total number of bytes (data plus overhead) needed to transmit 50 segments of 100 bytes size, it showed up that MAC-layer retransmissions are helpful in case of higher packet loss rates, but interestingly using the cached mode *without* MAC-layer retransmissions (and thus without MAC layer overhead like acknowledgements or RTS/CTS handshakes) is the cheapest approach (given that *all* intermediate nodes cache segments).

In summary, the discussed schemes reveal that for the case of block transfer the usage of NACK packets and of caching data within the network are beneficial in terms of energy. RMST has shown that the utility of additional MAC layer delays is disputable, at least when *all* intermediate nodes in the network have sufficient memory to cache all segments. It is suspected that MAC layer acknowledgements can bring real benefits when only a fraction of intermediate nodes can cache segments and NACK packets and retransmissions have to travel longer ways.

Other approaches that can be counted in this category are [98], [99], [100], [101].

2.6.2.2.5.3 Packet Stream Delivery

Some sensor network applications require the sensor nodes to generate and report their data periodically. One important reliability target in such a setup is to ensure that the sink receives a sufficient number of packets per unit time, for example to achieve desired information accuracy. Since many environmental processes vary only slowly, repeated sensor readings of the same or neighbored sensors are often correlated and accordingly some lost packets are acceptable. Therefore, the key mechanism to ensure delivery of the desired number of packets at the sink node are not retransmissions, but instead to control either the packet generation rate of the sensor nodes or alternatively the number of nodes generating packets at a fixed rate.

Controlling the packet transmission rate is intimately related to congestion control issues [102][103][104]. The adverse effects of congestion on the overall energy consumption and information accuracy have been shown in [102]: dropping packets is a waste of energy and can lead to throughput reduction, i.e. to a reduction of the number of packets delivered at sink nodes. In [103] the CODA congestion control framework is presented which is composed out of: (i) a localized congestion detection mechanism based on nodes observing their buffer occupancy and the load on the channel, (ii) a local back-pressure mechanism for short-term congestion handling, and (iii) a rate-regulation mechanism by which the sinks control the source nodes on a longer-term basis.

The ESRT protocol works by adjusting the reporting sensors packet generation rate such that it stays in a region where sufficient numbers of packets arrive at the sink without producing congestion [104]. It is assumed that the sink requires this minimum number of packets to achieve a desired information quality.

The situation considered by the algorithm is that of a single sink node to which all sensor nodes direct their readings. The sink node is not energy-constrained and can transmit with sufficient power to reach all the sensors. It uses this ability to control the rate by which sensors generate data packets. The control strategy is based on a certain relationship between the generation rates on the one hand and the observed sink quality given as the rate of delivered packets per unit time and congestion state on the other hand. Specifically, the following regimes can be distinguished:

- for very low generation rates there is no congestion and insufficient quality.
- ωhen increasing the generation rates, the desired quality is reached to within some fraction without causing congestion. Stated differently: the network is not congested and the sink receives just the right number of packets to achieve the desired quality, not much more or less. This is the *target region*.
- when increasing the generation rates further more packets than needed are delivered without causing congestion.
- another increase in generation rate starts to decrease the number of delivered packets, because congestion starts to build up and packets are dropped. There is one region with congestion but still delivering sufficient quality, but the quality drops below the required level when the rates are increased further.

The sink node collects congestion signs and observes the rate of incoming packets for a certain time. Based on this information it determines the current regime, computes a new desired generation rate for the next round (which can be larger, smaller or equal to the current generation rate) and broadcasts this to all sensor nodes. The control strategy strives to reach the target region. The congestion state is detected by sensors from their local buffer occupancy, taking the current occupancy and the growth trend of buffer occupancy with respect to previous rounds into account. Upon congestion detection the sensor node sets a congestion notification bit in outgoing packets. The sink infers a congestion state when any incoming packet has this bit set.

Under the assumption that in the non-congested regime there is a linear relationship between the reporting rate and the number of packets received at the sink per unit time, it can be shown that the protocol always converges to the target region. The protocol does not require the sink or the sensor nodes to have global knowledge like for example the current number of available sensor nodes. A disadvantage is that *all* sensor nodes are controlled at once, treating interesting regions (where faster rates are appropriate) or regions with higher node density in the same way as uninteresting regions or regions with low node density.

Other approaches that can be cited in this category of research are [105], [106], [107], [108].

2.6.2.2.6 Fair Resource Management for Event Based Fairness

Tiny wireless sensor devices, which are able to communicate in the wireless medium, sense and process the data, build up the Wireless Sensor Networks (WSNs) [109]. Sensor networks are capable of gathering sensor readings such as temperature, humidity, light, acceleration, pressure, and magnetic field. Beside the sensing task, sensor devices are desired to be self-organizing. With random deployment, they are required to sense the environment, discover their neighbors and relay the information gathered from the field to the decision centers called sinks. Each sensor can individually process and perform preliminary filters on the data, however hardware constraints such as processors at 13-416 MHz, 32 MB available memory, lack of permanent energy supply [110], force them to operate collaboratively in large numbers. Additional to individual sensing, they are expected to cooperatively sense the area and aggregate the data according to the application specific requirements such as a temperature reading demanded for a region of the deployment area.

Since the energy is the scarcest resource and directly related to the network lifetime, novel energy saving techniques are required in order to prolong the network lifetime. For instance, sensors send their readings to the sinks employing a multihop communication pattern since multi-hopping saves energy in quadratic orders of the distance. Also sensor nodes are designed to dynamically power up and down the equipments to save energy. Especially the antenna part of the devices changes its power state in cycles called duty cycles (DC). Sensor nodes are expected to agree upon the duty cycle strategy and keep on networking without huge amounts of information losses.

In recent years, with the advances in CMOS cameras, availability of low-cost hardware and novel protocols, a new research field Wireless Multimedia Sensor Networks (WMSNs) [111] has emerged in WSNs. Basically, WMSNs are developed by upgrading the capacities of WSNs with low resolution cameras [112][113] and microphones. Beside the scalar sensor readings in traditional sensor networks, WMSNs can relay high bandwidth data such as video and audio streams, still images and use the same wireless architecture as WSNs. While the data sizes in WSNs are nearly 8 bytes (Double), WMSNs have to carry 10000 bytes every second. Therefore, the same problems in WSNs also exist in WMSNs and due to high bandwidth requirements additional constraints make the design of the network even more difficult.

A type of WMSNs is Video Sensor Networks (VSNs) which are multimedia sensors equipped with cameras. VSNs have the ability to generate and relay video streams. They introduce video to the sensor networks which emerge the need for application specific Quality of Service (QoS) requirements. Like in all other networks carrying multimedia content, in VSNs also expected latency, video quality and jitter are key performance metrics that need attention. Some foremost peculiarities are [111]:

- *Resource constraints:* As mentioned above, sensor nodes have limited capacity of processing, caching and bandwidth, which are mandatory for video stream processing and relaying.
- *Variable channel capacity:* Differently from wired networks, in wireless networks, the channel capacity depends on the signal to interference ratio (SIR). In VSNs, the channel capacity varies among the nodes and regions on the network. For instance, if two video streams coincide on the network due to interleaving paths, they have to share the bandwidth. Even if there exists intelligent routing techniques that organize the paths, appearance of dead nodes makes interleaving paths inevitable.
- *Cross-layer coupling of functionalities:* In order to optimize the network performance, cross-layer protocols preferred in WSNs. When we try to obtain certain level of QoS for the streams, the interdependence between the network layers should be considered also.
- *Multimedia in-network processing:* In the literature considering multimedia processing, in general, as we have high processing power in the source that encodes and compresses the video and less processing power is needed in the destination that decodes the stream. However, in sensor networks, the situation is vice-versa, we have low processing capabilities in the source and high processing power in the destination. Therefore, collaborative encoding and compressing algorithms on the network are required to handle the huge data streams.

Sensor networks are planned to be deployed in military [114], [115], habitat monitoring [116], [117], high quality and efficient agriculture [118], [119], [120], health [121], [122], [123] commercial [124], [125] and disaster monitoring [126], [127] applications. VSNs increase the reliability and precision in these applications and also create new applications. Among them, Video Surveillance Sensor Networks (VSSNs) are composed of video and acoustic sensors and aimed to be deployed in crime inspection, public event monitoring, border security and early warning systems for disasters [111], [128], [129]. The video capability in the surveillance networks enhances the traditional WSNs by [111]:

- *Enlarging the view:* Besides deploying less number of high resolution cameras, deploying many low resolution cameras increases the available view choices. Many tiny cameras means many images captured from the field compared to few detailed images captured by high resolution capable cameras.
- *Enhancing the view:* With dense deployments, cameras can view the same event from multiple perspectives. Though it can be considered as needless information or burden to the network, it increases the reliability of the applications.

Enabling multi-resolution views: VSNs enables the idea of heterogeneous multilevel camera architectures. When tiny cameras detect an event, high end cameras can zoom to the specific points and leverage the performance of the detection.

2.6.2.2.6.1 Addressed Problems

VSSNs are mostly configured to operate in event-triggered mode where nodes start pumping video frames as soon as they detect an event and continue to do so as long as the target is within the sensing radius and the Field of View (FoV). The number of frames triggered by an event is variable and as shown in Figure 2.6-12, it is a function of the duration of the event and the camera frame rate. Event duration is actually the target residence time inside the coverage area, which in turn depends on the target speed, V , and the path length, D_{AB}, covered inside the FoV.

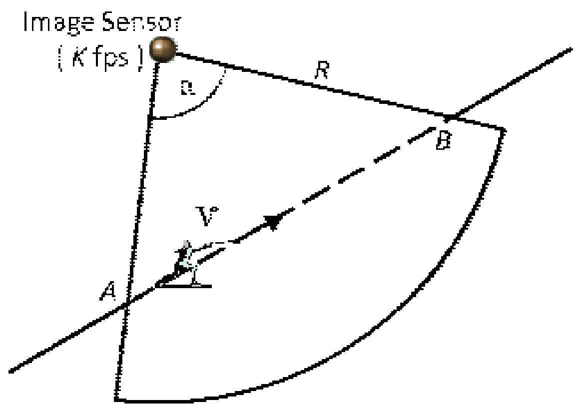


Figure 2.6-12. Number of frames F produced by a single sensor node upon detection is F = KxDAB / V where K, V and DAB stands for the camera frame rate, target speed and path length respectively. The path length DAB, in turn, depends on the sensing radius R and the FoV, alpha.

An event-flow is identified as the sequence of image frames produced by the same source node triggered by the detection of a target. As opposed to the time-triggered (periodic) traffic pattern, for event-triggered traffic, the number of events created per unit time may easily reach high values depending on the number and mobility of the target(s). When combined with the large video frame sizes, this leads to instantaneous traffic volumes that exceed the capacity of the network, which in turn results in packet drops due to buffer overflow.

As a result of lost traffic and congestion, the bandwidth assigned to the events can vary. Some events capture larger bandwidth and experience reduced delays compared to other events. In order to satisfy the fairness among the events, novel techniques which consider the variability in event size and constraints of the sensor nodes, need to be proposed and tested.

2.6.2.2.6.1.1 Motivation

When we focus on the contents of an event-flow, we observe that there is spatio-temporal redundancy among consecutive frames. This is mainly because the camera module of the sensor node takes continuous snapshots of the scene with a certain frame rate. It is not possible to generically define the number of frames to be received at the sink for healthy reception of the event. This depends on the type of the detection method running on the back end. This could range from simple event detection in which only the existence of the event is notified to the classification or the identification of the target. Also the frames received could be an input to an image recognition engine or to an human operator. Another factor is the specific positioning and movement of the target within the visual sensing range. A target closer to the camera module takes a bigger portion of the picture, however assuming that the target is mobile, proximity to the sensor also implies shorter residence time inside the sensing range, hence a shorter event-flow. Therefore, we can crudely conclude that event-flows as they become longer, they contain more frames of the scene and likely to have more redundancy among frames. The information contribution of the individual frames of a generic event-flow is depicted in Figure 2.6-13.

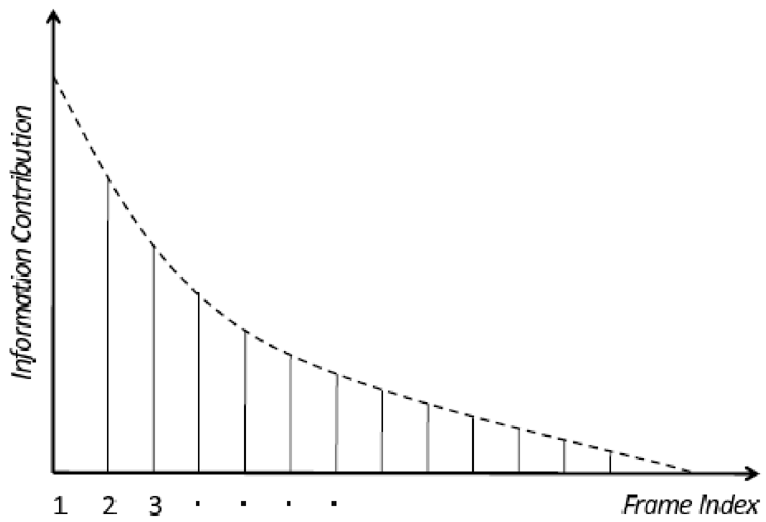


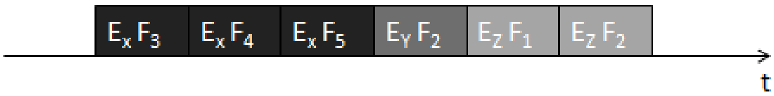
Figure 2.6-13: Information contribution of individual frames of a surveillance video event-flow.

With this observation in mind, we propose that irrespective of the duration of the events, initial frames of an event deserve special care. That is because they contain much of the visual information and also the delay experienced by them directly affects the reporting delay. In this work, we give priority to the initial frames via an application level fair queue management scheme, namely *Event Based Fairness*.

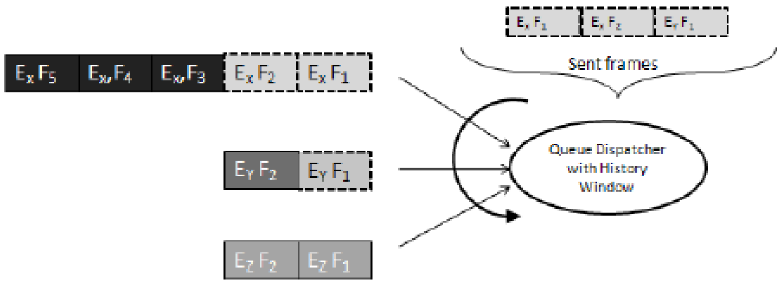
In order to achieve Event Based Fairness, two network parameters are determined to be tunable. Firstly, the packet queue is arranged to maintain fairness among the frames of the events. Least Attained Service (LAS) with two different variants are proposed for scheduling in the queue. One is designed for single-path routing called History-based LAS (HLAS) and the latter is designed for multi-path routing called Distributed LAS (DLAS). As a second resource, the contention window is altered according to the priority of the event frames. Thus, inter-node fairness among the neighbors is preserved.

2.6.2.2.6.1.2 History based Least Attained Service

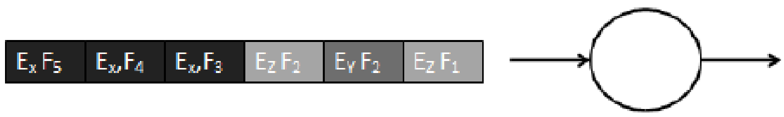
The main idea behind History based LAS (HLAS) is that an event is a sequence of frames flowing in the network and at a specific time instance, only a portion of it may be contained in the buffer of a VSSN node. This is due to the buffer size limitations and earlier frame drops that an event may experience. In this respect, a way to provide better fairness among events is to consider not only the current buffer composition but also to take into account the frames of an event that has been relayed previously. HLAS, forms logical queues of frames per event and service one frame from each queue in an epoch in a round robin fashion. However, HLAS also keeps track of the sent frames and inserts a virtual frame to the event queues as placeholders for each frame of an event that is relayed. Therefore, a logical queue for an event contains both real frames that are waiting to be send and virtual frames that are already sent. In every logical event queue, virtual frames are placed in the front of the queue; therefore, when deciding on the next frame to get relayed, HLAS gives explicit priority to the events that have fewer frames sent. Figure 2.6-14 shows a sample sequence of incoming frames and how they are enqueued both by the FCFS and the HLAS implementations.



(a) Arriving sequence of the frames of the events and queue state in FCFS case (E_iF_j stands for j^{th} frame of i^{th} event)



(b) The history window and logical queues formed by HLAS



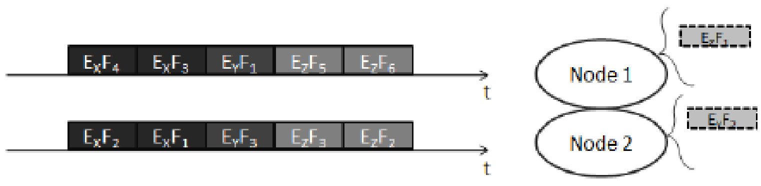
(c) The resulting queue obtained with HLAS and DLAS

Figure 2.6-14: The comparison of the FCFS with the HLAS and DLAS implementation.

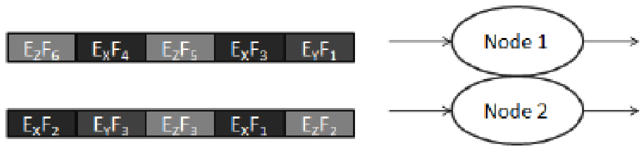
2.6.2.2.6.1.3 Distributed LAS Implementation on Multi-path Routing Schemes

Since multi-path routing algorithms are expected to be employed in VSNs, we need to modify the HLAS [130] scheduling scheme which is designed for single path routing. When the routing scheme allows only single paths, each frame follows the same route and the nodes can set the priority of the frames according to the history of the events. However, in multi-path schemes, the frames of the events are relayed from different paths therefore, the history of the events in the individual nodes does not denote the state of the whole network.

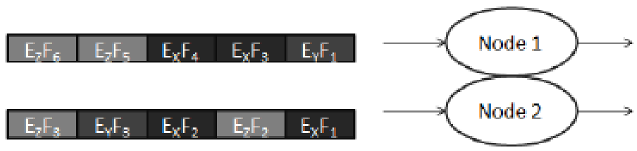
In order to overcome the problem described above, a unique sequence number is assigned to each frame of the event where priority of the event is reversely proportional with its sequence number. The frames of different events with the same sequence numbers are served in the first come first served order. In single path routing as presented in Figure 2.6-14 (c), both DLAS and HLAS creates the queue with the same order when there is no lost packet.



(a) Arriving sequence of the frames of the events to different nodes (E_iF_j stands for j^{th} frame of i^{th} event)



(b) The queues formed by HLAS in different nodes



(c) The queues formed by DLAS in different nodes

Figure 2.6-15: The comparison of the DLAS with HLAS implementation.

However, as shown in Figure 2.6-15 with a multi-path routing algorithm, the resulting queues differ where DLAS seems to give precedence to initial frames in both nodes.

In the case of frame losses in the network, DLAS cannot be able to denote the exact amount of service given to each frame. The lost frames are also counted as relayed. However, DLAS is a simple method that does not waste the network resources in the form of additional control packets or memory requirements.

2.6.2.2.6.1.4 Variable Contention Window for Increased Fairness

When we deploy DLAS scheduling on the nodes, we achieve fairness among the events. The frames of the events are ordered in the queue according to the event they belong to. By ordering the frames, we specify which events should get the precedence in order to capture the medium. Although the events are served in each node based on DLAS, when the nodes try to capture the medium in order to relay the frames, each event has equal chance. In CSMA based systems, since the slots are mostly chosen according to a uniform distribution, there is no prioritization among the flows from each node. Therefore, the fairness among the events from different nodes could not be achieved. In order to achieve fairness between the flows of different events, variable contention window sizes can be used for each event. According to the priority of the event, we can adjust the size of the contention window and give explicit priority to the events, which has been served less.

In order to observe the effect of variable contention sizes on the fairness of the events, we apply a simple mechanism, which divides the contention window into three non-overlapping equal sized partitions. The normalized contention window (CW_{NORM}) is computed as a function of the frame sequence numbers (f_{seq}). As depicted in Equation 1, the first partition is dedicated to the frames of events with sequence numbers one, two and three, the second partition is dedicated to fourth, fifth and the sixth frames of the events, lastly the rest of the frames reside in the third partition. This new scheduling method is called as DC-DLAS (DLAS with Differentiated Contention windows).

Equation 1: Variable contention window sizes

$$CW_{NORM} = \begin{cases} [0, CW/3), & f_{seq} \leq 3 \\ [CW/3, 2CW/3), & 3 < f_{seq} \leq 6 \\ [2CW/3, CW], & 6 < f_{seq} \end{cases}$$

2.6.2.2.6.2 Comparative evaluation of HLAS, DLAS, DC-DLAS and FCFS

2.6.2.2.6.2.1 Experiment Setup

We examine the effect of event based fairness mechanisms using the OPNET simulation environment [131] in a surveillance application. A new event is created when a camera detects activity and the frames which are labeled with the event id, are created according to the camera frame rate. In the experiments, we compare the performance of FCFS, HLAS, DLAS and DLAS with Differentiated Contention (DC-DLAS) feature.

2.6.2.2.6.2.2 Results

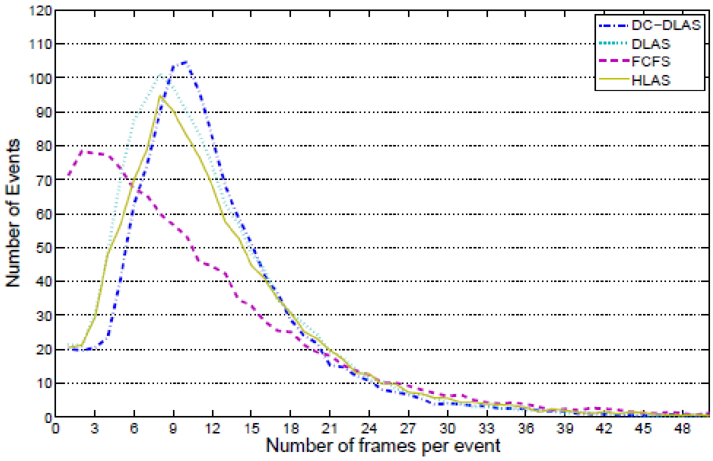


Figure 2.6-16: Histogram of number of frames reached to sink for each event

2.6.2.2.6.2.2.1 Results for Event Reporting Fairness:

A histogram summarizing the events according to the number of successfully received frames at the sink is presented in Figure 2.6-16. For instance, for the FCFS case, around 80 events are reported only with two frames whereas around 55 events are reported with 9 frames. As indicated by the histogram, by enabling DLAS, HLAS or DC-DLAS scheduling, we can improve the video quality and fairness for the events. While most of the events are reported with few frames in FCFS scheduling, we observe that the number of events which are reported with higher number of frames increases in other scheduling mechanisms. In Figure 2.6-16, the effect of differentiated contention is also observed. The precedence devoted to the initial frames by arranging the contention windows decreases the less reported events more than the others. Since with DC initial frames are promoted more than they are in DLAS, the DLAS graph seems to be shifted to right. Although intelligent scheduling schemes seem to increase the number of frames received at the sink, in fact they are decreasing the number of over reported events, and share the available bandwidth among the less reported events.

2.6.2.2.6.2.2.2 Results for Event Reporting Latency:

As stated previously, we have two goals for employing such scheduling schemes. One is offering a fairer network which is observed in Figure 2.6-16, the other goal is reducing the event reporting latency. We define the event reporting time as the time of the first arriving frame since the arrival of the first frame indicates the existence of an event. In Figure 2.6-17, the latencies of the frames of the events are depicted. The latencies of the initial frames are shown to be reduced with DLAS, HLAS and DC-DLAS in Figure 2.6-17 and also it is observed that DLAS and HLAS have better results with respect to FCFS for all the frames. However, in the DC-DLAS scheduling, while the initial frames have lower latencies, the latency of the frames that have less priority encounter higher delays which results in higher jitter values for the videos. The reason of high jitter is that the back of the contention window is reserved for frames with higher sequence numbers. Hence, there is a tradeoff between the initial reporting delay and the jitter. The priority mechanism implemented in the form of variable contention windows, therefore should be fine tuned according to the requirements of the application.

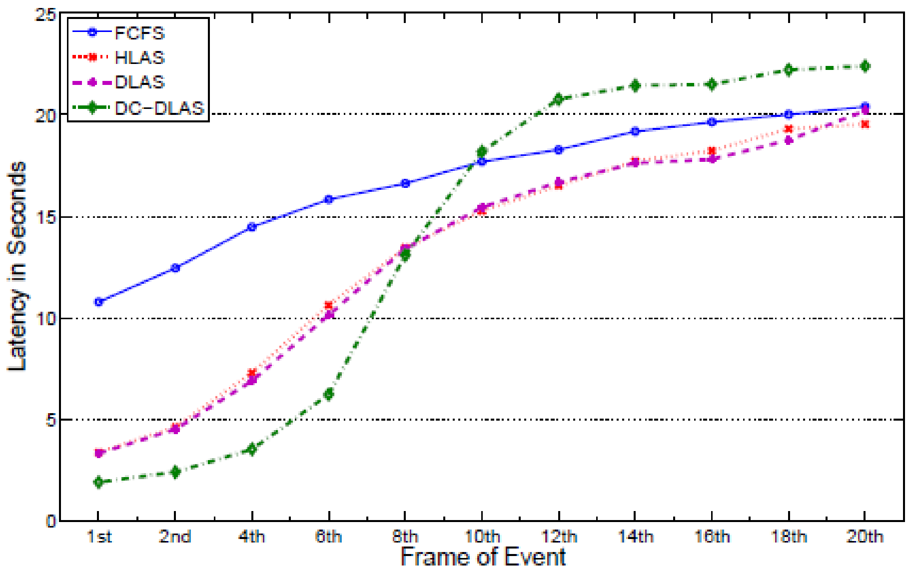


Figure 2.6-17: Latencies of the frames of the events

2.6.2.2.7 Sensor and Sink Deployment

Due to their distributed operation ability, requirement of little maintenance during operation, scalable coverage range and the ability to operate on difficult deployment sites, wireless sensor networks (WSN) are very suitable for sensing different phenomenon over large areas. Composed of many battery powered sensing/communication units, sensors, and mostly one data gathering unit called a sink, those networks are dispersed over the area to perform a given task for as long as possible. Sensors have a goal of monitoring the environment for different types of events like forest fires, border intrusions, chemical gas leakages.

The key steps of the whole life line of a sensor network can be listed as:

1. Deployment of the sensors over the area.
2. Initial discovery and communication between nodes, network formation.
3. Start of environment sensing.
4. In case of an event detection related data is sent to the sink.
5. Routing information update (if needed).
6. Network announced dead when sensing or communication quality falls below a certain threshold.

Commonly adapted algorithms for routing, communication, location planning are not suitable for WSNs because of the architecture of the sensors, mainly due to lack of high range communication and high energy capacities [132]. Yet, the distributed and automated nature of a WSN makes it tolerant against partial losses of sensing units.

Nonuniform network formation is generally unavoidable for a sensor network. Initial deployment characteristics can result in such a formation. Many–to–one routing from the sensors to the sink can bring nonuniformity. Intermediate nodes that relay the information will spend their batteries earlier than others and die out. Loss of intermediate nodes will also lead to nonuniformity in the network. External effects such as intentional destruction of nodes, jamming, field obstructions may have similar effects. The most important outcome of nonuniform formations is the decreased lifetime. For a WSN there are different types of lifetime criteria such as the death of first node or last nodes, death of a certain percentage of nodes, inability to cover a percentage of the deployment region, the fall of the sensing quality below a threshold. All are based on the lifetime of the individual nodes. If all the nodes use their batteries for similar time periods, network will have the optimal lifetime, however nonuniformity causes some nodes to die earlier.

Deployment and operation of a sensor network is a costly process and requires high amount of initial effort. The autonomous operation ability and longer lifetime of the network is expected to offset the network design effort and cost, shorter lifetime must be avoided by all means.

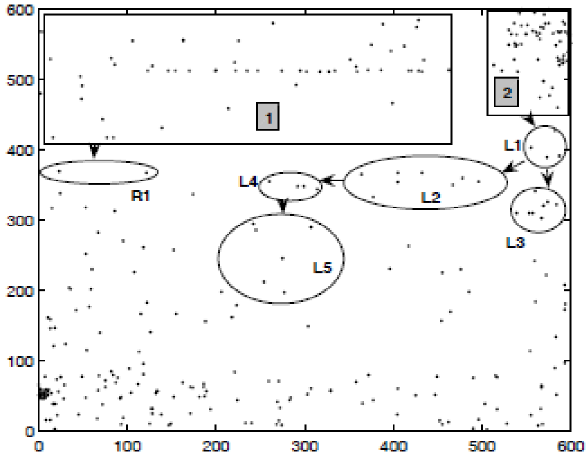
It is possible increase the lifetime of network by optimizing different parameters of the network and mitigating the hole occurrences inside the network. This thesis proposes methods that are based on the optimized placement of sink and redeployment the sensor nodes to increase the lifetime.

The distance to sink node from a sensor directly affects the energy expenditure of the initiator node and the relaying nodes. Given an already deployed network, changing the node locations is infeasible and impossible at times. However, the location of the sink can be chosen based on some parameters. In this thesis, a method is proposed to find the sink location that provides longer lifetime values and is in a relatively safe location. Compared to two different heuristics the lifetime gains are presented.

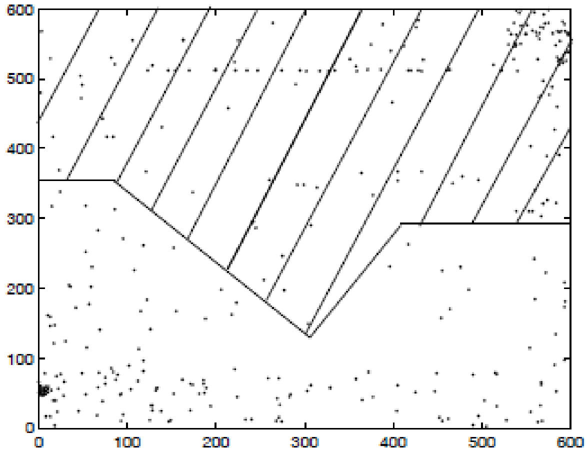
As previously stated, node deaths limit the network lifetime; although there may be still operational nodes in the network. Due to the inherent redundancy, not all of the dying nodes have direct effect on the network lifetime. Nodes, which will disconnect a part of the network when dead, are of more importance from this point of view. Such nodes are critical nodes, since their loss can limit the overall network lifetime. For most scenarios, when the area covered by the network falls below a certain ratio of the initially covered area, the lifetime of the network may be said to have ended. For such lifetime calculations, death of critical nodes result in loss of coverage for the network, which is certainly not desirable under the initially given coverage requirements. Discovery of those nodes in the earlier stages of the network formation will make it possible to prolong the network lifetime without too much overhead and with smaller costs.

Figure 2.6-18 shows examples of bottleneck nodes. Simulations on the network have shown that the routing traffic is concentrated on some particular nodes as seen in Figure 2.6-18.a. Region marked as 1 passes all the sensing traffic onto the nodes in the ellipse marked as “R1”. For this part of the network, the bottleneck nodes are those within the “R1” region. For region marked as 2, the traffic passes through either “L1, L2, L4, L5” or “L1, L3” paths. For this part of the network, sensors inside the “L1”, “L5” and “L3” regions are the bottleneck nodes. Figure 2.6-18.b shows the network status when the simulation terminates, where the shaded area shows the sensors that cannot communicate with the sink. The criterion for the termination is that the area covered by the sensors, which can communicate with the sink fall below a certain threshold value. Results have shown that most of the nodes inside the unreachable region still have high battery levels. However, the death of sensors within the presumed bottleneck regions lead to the death of the network since regions one and two are not able to communicate with the sink anymore.

The load imbalance comes from the fact that some nodes provide the best routing choice and are chosen as the next hop by nearly all of the relaying nodes. Those nodes die out soon to leave the network disconnected and crippled in terms of coverage. Such nodes are found mostly at the perimeter of some local clusters and do not have nearby alternative nodes. We see that those nodes are located near some uncovered regions that form the border areas between clusters.



(a) Bottleneck sensors and networks relying on them.



(b) Network connection status at the end of simulation.

Figure 2.6-18: Example figure for bottleneck scenario

2.6.2.2.7.1 Sink Placement

For WSNs, the routing process increases the energy burden on the intermediate nodes, because the message receiving and submitting operations are very energy consuming and for every operation there is unavoidable energy loss which cannot be lowered without changing the electronic architecture of the nodes. The energy terms for a node are a total of the energy to sense, to receive and to transmit. The transmission energy term depends on the distance and the medium, whereas other terms are fixed costs. Transmission cost depends on the path loss value, a physical property of the medium and is proportional to the path loss exponent and distance. Very long communication distances cause high-energy consumptions, yet increasing the hop count and decreasing the distance will increase the receiving costs in the network. For three-dimensional terrains, obstructions can also cause communication and sensing disruptions.

Given those facts, it is very crucial to optimize the network parameters as much as possible to increase the sensing quality and the network lifetime. Many approaches have been proposed to optimize the information routing from sensors to the sink, optimize the radio communication between sensors, decrease the battery expenditure by sleep schedules. One other approach is to adjust the coordinates of the sink nodes such that the overall energy loss due to the routing is minimal. Such a problem is called the “Sink Location Problem”. It can be defined shortly as: “Given a group of sensors, whose locations, sensing and communication ranges and capacities are known, finding the coordinates of the sink that maximize the lifetime of the network during which a certain lifetime criteria is always met.”

This problem is somewhat similar to the “Facility Location Problem”, given a group of demand nodes, a place for the source node is found such that the overall communication (or transportation) cost is minimized [133], [133]. Facility location problem specifies that the demand nodes can directly communicate with the source node (e.g., a customer can go directly to a supermarket). Because of this fact, sink location problem differs significantly from the facility location problem. In sensor networks, intermediate nodes lose energy due to data routing operations. This requirement adds one more level of complexity to the problem. Also, sink location should be chosen as safe as possible to decrease the risks associated with the nature of surveillance tasks Literature includes various sink location strategies. Stann and Heidemann proposed to place the sinks by hand or only random choice [135]. Their optimization depends on the routing itself, rather than the sink placement, hence the sink coordinates are chosen by hand. Das and Dutta have chosen to place the sink on coordinates that are outcome of a uniform random distribution, which is similar to their choice of their sensor coordinate distribution [136]. Similar choice for the sink placement is made by Intanagonwiwat *et al.* They choose random locations for the sinks and try to optimize the number of sinks [137]. Random placement is well studied in the literature, as seen in the articles by Handsizki *et al.* and by Simon and Farrugia,[138], [139].

Sink placement on the edges of the deployment region is another possible choice. Gnawali *et al.* have used the corner locations as sink places for their simulations and experiments to find high quality data transmission paths [140]. The same choice of placement is also used by Yu *et al.* and Zhou and Krishnamachari,[141] [142]. Li and Cassandras and Xing *et al.* have also chosen the edges, however they use the midpoint of the sides of the deployment region to place the sinks [143], [144]. In [145], authors place the sink at the edges of the network, with the main aim to decrease the energy expenditure. Their nodes make use of ambient energy harvesting schemes.

Choosing the center of the deployment region is another popular choice, which has been employed by Cristescu *et al.*, Ganesan *et al.* and Maleki and Pedram [146],[147], [148]. A somewhat similar choice is to partition the deployment region into clusters and place the sinks at the center of those clusters instead of the whole region, which increases the topology awareness of the network, such a scheme is employed by Oyman and Ersoy, Perillo and Heinzelman [149], [150]. Solis and Obraczka have tested a variety of sink placement strategies, placing the sink at corner, random and center coordinates. Then they evaluate the performance of different in–network aggregation algorithms in terms of the trade-offs between energy efficiency, data accuracy and freshness [151]. A different and interesting approach for the sink placement is by Akkaya and Younis [152]. They choose to make the sink mobile, which differs significantly from the other approaches. Their aim is to obtain an efficient routing using a mobile sink. Mobility of sinks is also exploited by Ye *et al.* to increase the efficiency of the flooding based communication scheme [153]. Kim *et al.*

use mobile sinks to receive the information from the nodes directly [154]. The nodes do not route the information, instead opt to wait for the sink to get inside the communication range and directly communicate. Mobility of the sink is also proposed [155], [156]. Yet it should be noted that mobility comes with the price of the energy loss caused by frequent network-wide broadcasting. Such broadcasting operations occur since the network will need continuous the position notification to the nodes and corresponding routing updates [157].

Yang and Lin try to decrease the load on the sink by adapting the high energy nodes around the sink as base stations and distribute the load between the proposed base stations [158]. Poe and Schmitt try to place the sink nodes using genetic algorithms; however their objective is based on the delay between the sink and the nodes with no energy optimization assumptions [159][158]. Integer programming methods are also used to optimize the sink location [160]. However as the problem size gets bigger, such methods become infeasible as the time they take to complete grows very fast too.

It should also be noted that the underlying physical terrain causes line of sight blockages between the elements of the network. Many approaches in the literature assume that the deployment field is flat and thus nodes are not blocked by the obstructions caused by the undulations of the terrain. For 2D regions, the communication between two sensors and the sensing of a point over the region by a sensor is directly related with the Euclidean distance over (*x; y*) coordinates. Same operations over 3D regions face another problem, the line-of-sight between two points. The elevation of points in the visual access path between the sensor locations can obstruct the actual communication or sensing path, as shown in Figure 2.6-19. The differing elevation characteristics of the terrain will heavily alter the sensing and communication coverage of WSN. A realistic sink placement approach should take blockages and obstructions into account and aim to minimize the loss caused. Such a modification will increase the complexity of the calculations, yet the results will become much more realistic compared to scenarios with 2D assumptions. Figure 2.6-20 shows a sample terrain generated synthetically, with a total elevation difference of 50 meters.

Figure 2.6-19: Surveillance line of sight blockage due to terrain obstructions

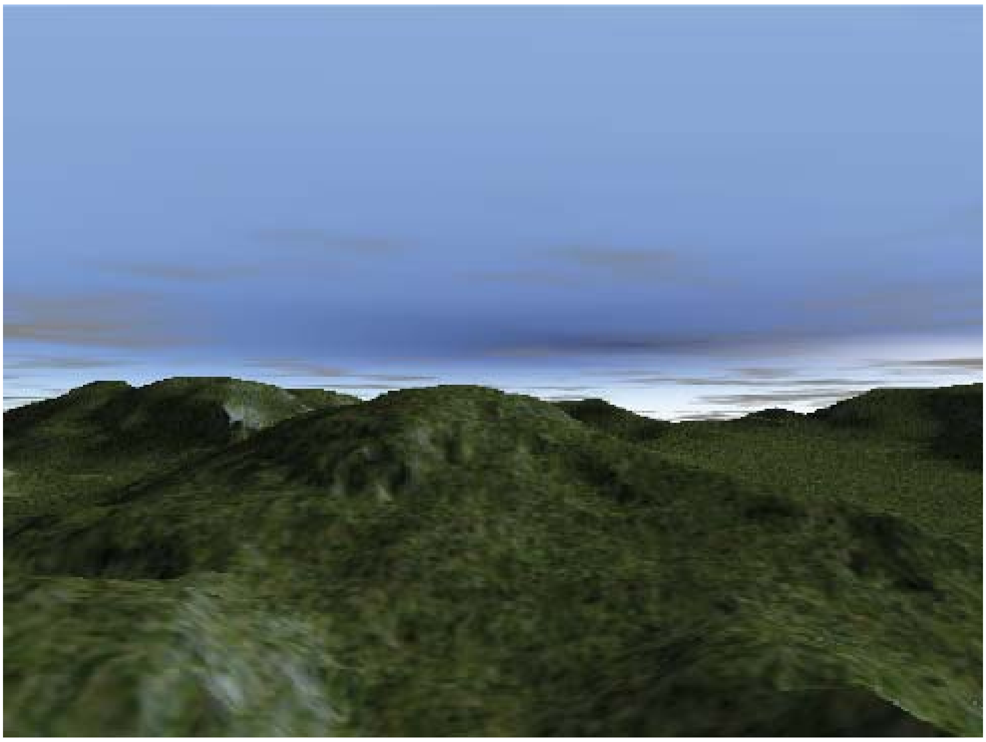


Figure 2.6-20: A synthetically generated terrain sample

2.6.2.2.7.2 Sensor Deployment and Hole Problem

A highly important problem faced in border surveillance applications and more broadly in many-to-one WSNs is the uneven energy consumption[161]. The large number of sensors reporting to a single sink exposes the sensors around the sink to higher traffic loads. Larger radio communication on those nodes causes rapid consumption of energy, as their battery capacities are limited [162]. Consequently, the nodes around the sink begin to die, rendering sink as unreachable to other sensors in the network. Moreover, as explained in the previous chapter some nodes in the network become bottlenecks whose early deaths cause unreachable areas. In surveillance cases, some regions of the network can be blocked out due to intentional destructions sensor or jamming of the region. The resulting phenomenon is named as the energy hole problem in wireless sensor networks [163][164]. Mitigation of the energy holes is crucial to extend the network lifetime in surveillance applications of WSNs.

There are two dominant approaches for energy conservation in a given WSN. The first method aims to reduce communication costs by keeping the transceiver of a node off as long as possible without affecting the network functionality which is called as duty cycling. The second one tries to reduce communication costs by transmitting only useful data to the destination which is also called as data reduction or in-network processing. There exist various proposed algorithms [165] and protocols for each of the approaches most of which are based on some common and not always correct assumptions such as the unit disk model and the at world model as described in [166].

Most of the approaches minimize only the energy consumption without considering network performance or sensing quality.

Energy holes cause nonuniform coverage and decrease the sensing quality of the network. They can be avoided by balancing energy consumption in the network or maintaining uniform coverage. In Kosar et al., a sensor redeployment method is proposed that can be used to mitigate sensing holes [167]. Initially only a portion of the available sensors is deployed and the rest is spared. Later on, sensors are redeployed over poorly covered regions in order to maximize the deployment quality of the network. Networks using the proposed redeployment technique achieve better sensing quality than networks using the same total number of sensors at once. However, the effects of redeployment on the network lifetime are not considered. In some cases, hole information may be the result of intentional node destruction. Arifler propose an information theoretic approach for detecting systematic node destructions [168]. A self-deployment technique for mobile sensors based on potential fields to achieve uniform coverage through the network is also proposed [169]. This approach has been shown to provide good coverage and can be used to maintain sensing quality above critical values but is not applicable in the case of static sensors. Chen et al. propose a virtual force algorithm based sensor deployment [170]. A distributed algorithm based on the Voronoi diagrams for sensor deployment that produces better coverage is proposed by Wang et al. [171]. However, both approaches assume mobility of sensors which may be impractical for majority of the applications. Kim et al. propose a fuzzy system based method for deciding sensor redeployment [172]. Their method requires special cluster head sensor nodes for deciding on the deployment site and number of sensors. This method may be useful for energy depleting nodes, yet initial sensing holes due to external factors cannot be covered by this method. Binary integer programming approach is also proposed for effective sensor placement when there exist various sensor types with different sensing quality and cost [173]. Authors also suggest the usage of a probabilistic approach in cases when calculation of effective positions is not feasible. Chiang and Byrd propose an algorithm for density control in which sensors decide whether to participate in the network by using the incoming packet information [174]. Olariu and Stojmenovic analyze the uneven energy consumption observed in many-to-one sensor networks [175]. They show that for energy consumption models having path loss value of two, there is no routing strategy that can avoid the energy hole creation around the sink.

When hole formation cannot be avoided, routing protocols try to forward packets along hole boundaries causing hole diffusion. A geometric modelling for the hole problem which prevents packets from travelling along hole boundaries is presented by Yu and friends [176]. Instead of bypassing encountered holes, Jia et al. propose avoiding holes in advance by using neighbour feedback [177]. Fang et al. find the hole boundaries using a distributed algorithm to enable formation of new routes [178]. This method, albeit useful for route formation, does not offer a solution for mitigating the hole problem. The holes defined by the authors are not actual ensign/communication voids but rather the nodes that does not offer routing improvements. An algorithm that makes use of specific beacon nodes to detect communication holes is also proposed by Funke [179]. However, the algorithm proposed does not present a solution for locating sensing holes. A hole detection method based on the largest empty circle problem is proposed [180]. Their approach finds local holes as circles for sensor deployment. However, to mitigate the holes, multiple iterations are required and the number of iterations is not known a priori and depends on the performance of the intermediate steps.

For sensor redeployment, there are different approaches employed. Yang and Cardei divide the deployment region into circles with the sink at the center and performing the redeployment such that the sensor density increases with the decreasing distance to the sink [181]. A similar redeployment method where sensors are deployed iteratively by either uniform distribution or with a specific distribution that enables more sensor deployment on the regions around the sink is proposed by Chatzigiannakis et al [182]. Wu *et al.* propose a somewhat similar method [183]. To mitigate the hole problem, sensors are deployed to circular strips, called coronas, around the sink. Each strip has different node densities that lead to a different type of nonuniformly deployed sensor network. However, this approach is ideally suited to sensor deployment regions that are square or circular. For different type of regions like rectangular narrow strips, meandering regions like river beds sink centered deployment approaches will not be able to avoid hole formations.

2.6.3 Conclusion and Remarks

The hardware platform will be designed and developed in FIRESENSE Project using a System–On Chip or an of the shelf module. Also, some standard software elements for low rate wireless sensor network (IEEE 802.15.4), e.g. physical and MAC sub layers, will be applied. Special attention will be given to the following issues, which are very important for FIRESENSE Project.

Automatic early detection of outdoor fire and an efficient environmental protection are issues that involve a substantial amount of various sensorial information and data. The reliability of the automatic very early detection system is a significant issue in this domain. FIRESENSE Project WSN can monitor real-time related parameters, e.g. temperature and relative humidity, and immediately send the data to the monitoring center. Open architecture for implementation of the other quantities sensors, e.g. intrusion sensor for some cases, is used in order to enhance environmental protection.

The project's key features are to achieve low power operation and very low message complexity. Moreover, the choice of the antenna and the efficient antenna design are extremely important for the system operation. Another very important issue is the monitoring quality that the network can provide. This quality is usually measured by how well deployed sensors cover the target of the early fire detection (deployment guidelines). Finally, a factor that is of high importance is to minimize the size of the node and its housing.

2.6.4 References

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2.7 Data Fusion Techniques

2.7.1 Introduction

Sensor fusion is defined as combining sensory data or data derived from sensory data from disparate sources such that the resulting information is in some sense *better* than would be possible when these sources were used individually. The interpretation of the term *better* is problem-dependent but usually means: *more accurate, more informative* or *more complete*. The different inputs may originate from different sensors, often monitoring different modalities (e.g. audio and video), but could also refer to single sensor sampled at different times, or even a single sensor at a given moment, but equipped with different types of pre-processing.
Fusion processes are often categorized as *low, intermediate* or *high level* fusion depending on the processing stage at which fusion takes place.

- **Low level fusion**, also called **data fusion**, combines several sources of raw data to produce new raw data that is expected to be more informative and synthetic than the inputs. For instance, in image processing, images presenting several spectral bands of the same scene are fused to produce a new image that ideally contains in a single channel all (or at least, most) of the information available in the various spectral bands. An operator (or an image processing algorithm) could then use this single image instead of the original images. This is particularly important when the number of available spectral bands becomes so large that it is impossible to look at the images separately. This kind of image data fusion requires a precise (pixel-level!) registration of the available images. This registration is intrinsic when the various bands come from the same sensor but it is a lot more complicated when several different sensors are used. The latter is highly relevant for FIRESENSE where we will need to fuse images from optical and various IR cameras.
- **Intermediate level fusion**, also called feature level fusion, combines various features extracted from the raw data. These features may originate from several sources (several sensors, different moments, etc.) or from a single data source. In the latter case, the objective is to select relevant features amongst available features that might come from several feature extraction methods. The objective is to obtain a limited number of relevant features. Methods of feature fusion include linear methodologies such as Principal Component Analysis (PCA), as well as highly non-linear approaches such as diabolo-shaped Multi-Layer Perceptrons (MLP). Typically, in image processing, feature maps are computed as pre-processing for segmentation or detection. Features such as edges, corners, lines, texture parameters etc., are computed and combined in a fused feature map that may then be used for segmentation or detection.
- **High level,** also called **decision fusion** combines decisions coming from several (human or computational) experts. By extension, the term *decision fusion* is also used when the experts return a confidence score rather than a binary decision. Methods of decision fusion include voting methods, statistical methods, fuzzy logic based methods, etc.

Within the FIRESENSE project it is envisaged that the most important sensor data fusion applications will be in the area of:

- **Image fusion**: e.g. fusing IR and optical images, or fusing different IR-bands. These are examples of *low level data fusion*. Recall that low level image fusion requires accurate image registration. When the different image streams can be collected from the same camera (e.g. using different lenses), registration is usually fairly straightforward. However, when different cameras are involved and/or the observed spectra are very different, registration might be quite challenging.
- **Intermediate or high level fusion of sensor data**: e.g. integrating temperature and humidity data captured from wireless in situ sensors with information obtained from IR cameras. In these applications we first have to extract features (or even decisions) from the individual sensors, after which they are fused.

The problem with intermediate- and high-level data fusion is that the type of fusion and its efficacy are highly problem dependent. There is no general theory that provides generic solution strategies for these types of problems: everything depends on the specifics of the sensors involved. We therefore need to defer further discussion until it has been decided what sensor modalities will be incorporated.

2.7.2 State of the Art for Image Fusion

Low level image fusion algorithms assume correspondence between pixels in the input images. In fact, the quality of image fusion depends crucially on the accuracy of the preceding image registration step. Under certain conditions, it is possible to capture registered images. For instance, if the camera intrinsic and extrinsic parameters are not changed and only environmental parameters change, acquired images will be spatially registered. Some sensors are even capable of capturing registered multimodality images, e.g. by splitting the incoming light bundle and guiding it through different filter systems. Again, in this set-up registration is not an issue. However, when the images are captured with cameras where extrinsic and/or intrinsic parameters are different, the need for accurate registration arises. For that reason we include some considerations on the latter problem in our overview.

2.7.2.1 Image registration

Roughly speaking, *image registration* (a.k.a. *spatial normalization*) is the process of estimating an optimal transformation between two images [1]. Depending on the problem, the optimal transformation will be taken to have appropriate geometrical properties: rigid, affine, projective, elastic, etc.

Typically, registration is required in remote sensing (multispectral classification, environmental monitoring, change detection, image mosaicing, weather forecasting, creating super-resolution images, integrating information into geographic information systems (GIS)), in medicine (combining computer tomography (CT) and NMR data to obtain more complete information about the patient, monitoring tumour growth, treatment verification, comparison of the patient's data with anatomical atlases), in cartography (map updating), and in computer vision (target localization, automatic quality control), to name just a few.

Although it is impossible to design a universal method applicable to all registration problems, the following four steps tend to re-appear when registering a sensed image with a reference image [2]:

- **Feature detection**. Salient and distinctive objects in both images (closed-boundary regions, edges, contours, line intersections, corners, etc.) are manually or, preferably, automatically detected. For further processing, these features can be represented by their point representatives (centers of gravity, line endings, distinctive points), which are then called *control points* (CPs).

- **Feature matching**. In this step, the correspondence between the features detected in the two images is established. Various feature descriptors and similarity measures along with spatial relationships among the features are used for that purpose.
- **Transformation model estimation**. The type and parameters of the so-called mapping functions, aligning the sensed image with the reference image, are estimated. The parameters of the mapping functions are computed by means of the established feature correspondence.
- **Image resampling and transformation**. The sensed image is transformed by means of the mapping functions. Image values in non-integer coordinates are computed by the appropriate interpolation technique.

Since the methodologies involved in steps two through four are fairly well established we will focus on the initial step of **feature detection**.

Features are salient structures such as regions, lines or points that are fixed and distinct, spread all over the image and efficiently detectable. Features tend to represent information at a level that is higher than mere image intensity, and are therefore better suited for situations in which the illumination changes or when different spectral bands are used.

***Regions**:* Region features are detected by segmentation methods. Tuytelaers et.al [3] introduced affinely invariant neighbourhoods anchored at corners identified by Harris corner detector and edges (curved or straight) going through detected corners. Matas et.al. [4] used *maximally stable extremal regions* (MSER) based on homogeneity of image intensities to identify salient regions. In the same vein, Ranguelova et.al [5] introduced morphology-based stable salient regions (MSSR).

Interestingly, Goshtasby et al. [6] proposed a refinement of the segmentation process in which segmentation was done iteratively together with the registration; in every iteration, the rough estimation of the object correspondence was used to tune the segmentation parameters to achieve subpixel accuracy of the registration. A similar integrated approach within the context of medical image registration can be found in [7] and [8].

***Lines**:* Standard edge detection methods in combination with the Hough transform [9] or RANSAC [9],[10] can be used for the detection of line- or contour-like features. The extraction of contour-like structures has been given a new impetus by the introduction of the curvelet transform. Curvelets were introduced in 1999 by Candes and Donoho [12] as a generalization of the wavelet transform to address the edge representation problem. Curved singularities (e.g. intensity contours) can be well approximated with very few coefficients and in a non-adaptive manner - hence the name "curvelets." Furthermore, they developed fast computational algorithms [13] that inspired a host of related developments. For instance, BeamLab [14] is a collection of MATLAB routines implemented by D. Donoho et.al. that implement computational algorithms related to beamlets, curvelets, and ridgelet analysis.

***Points**:* The *scale-invariant feature transform* (SIFT) [15] is one of the most successful and widely used techniques in the detection of *image keypoints* and description of their features. SIFT inspired the development of related algorithms such as PCA-SIFT [16] in which the feature vector is obtained by applying PCA to a 3042-dimensional vector of gradient information at a 39x39 grid centerd at each of the keypoints. Gradient location-orientation histograms (GLOH) method uses a log-polar histogram to determine the locations of the sampled gradient information [17].

SURF (Speeded Up Robust Features) [18],[19] uses integral images for image convolutions to reduce computation time, builds on the strengths of the leading existing detectors and descriptors (using a fast Hessian matrix-based measure for the detector and a distribution-based descriptor). SIFT has also been generalized to handle colour images [20]. An in depth comparison of local descriptors can be found in [17].

2.7.2.2 Image Fusion

As explained above, image fusion algorithms can be categorized into low (pixel), intermediate (feature), and high (symbolic/decision) levels.

Pixel-level algorithms work either in the *spatial* domain or in the *transform* domain. Although pixel-level fusion is a local operation, transform domain algorithms create the fused image globally. By changing a single coefficient in the transformed fused image, all (or a whole neighbourhood of) image values in the spatial domain will change. As a result, in the process of enhancing properties in some image areas, undesirable artefacts may be created in other image areas. Algorithms that work in the spatial domain have the ability to focus on desired image areas, limiting change in other areas. Well-established methods in the spatial domain include averaging, Brovey's method, principal or independent component analysis (PCA or ICA) and IHS based methods fall under spatial domain approaches [21]. Another important spatial domain fusion method is the high pass filtering based technique. Here the high frequency details are injected into upsampled version of the multispectral images.

In the *transform domain*, multi-resolution analysis is a popular fusion method at the pixel level. The basic idea is to apply filters with increasing spatial extent to generate a sequence of images (pyramid) from each image, separating information observed at different resolutions. Then at each position in the transform image, the value in the pyramid showing the highest saliency is selected. An inverse transform of the composite image is then used to create the fused image. Petrovic and Xydeas [22] used intensity gradients as a saliency measure. De Zeeuw [23] used multigrid methods developed for numerical PDE-solvers. In a similar manner, various wavelet transforms can be used to fuse images. The discrete wavelet transform (DWT) has been used in many applications to fuse images. Mallat [24] put all the methods of wavelet construction into the framework of functional analysis and described the fast wavelet transform algorithm and general method of constructing wavelet orthonormal basis. On the basis, wavelet transform can be readily applied to image decomposition and reconstruction. In particular, the dual-tree complex wavelet transform (DT-CWT), first proposed by Kingsbury [25] was shown by Lewis et al. [26] to outperform most other grey-scale image fusion methods..

In general, as a typical feature level fusion method, wavelet-based fusion could evidently perform better than conventional methods in terms of minimizing color distortion and denoising effects. It has been one of the most popular fusion methods in remote sensing in recent years, and has been standard module in many commercial image processing software packages, such as ENVI, PCI, ERDAS. Problems and limitations associated with wavelet include: (1) Its computational complexity compared to the standard methods; (2) Spectral content of small objects often lost in the fused images; (3) It often requires the user to determine appropriate values for certain parameters (such as thresholds). The development of more sophisticated wavelet-based fusion algorithm (such as ridgelet, curvelet, and contourlet transformation) could improve the performance results, but these new schemes may cause greater complexity in the computation and setting of parameters. [27]

Feature-based algorithms typically segment the images into regions and fuse the regions using their various properties. Feature-based algorithms are usually less sensitive to signal-level noise. Toet [28] first decomposed each input image into a set of perceptually relevant patterns. The patterns were then combined to create a composite image containing all relevant patterns. Nikolov et al. [29] developed a technique that fuses images based on their multi-scale edge representations, using the wavelet transform proposed by Mallat and Zhong [30]. Fusion of edge maps is discussed in [31]. Another mid-level fusion algorithm was developed by Piella [32] where the images are first segmented and the obtained regions are then used to guide the multiresolution analysis.

High-level fusion algorithms combine image descriptions, for instance, in the form of relational graphs [33], [34].

2.7.3 Conclusion and Remarks

In the scenarios most relevant for FIRESENSE we envisage that image fusion will play a crucial role when it comes to combining or superimposing images from optical cameras and IR cameras. Although the near-IR spectrum can be sensed with cameras that can also capture the visible spectrum, the medium- to far-IR spectrum (conveying the all important heat information) require separate specialized cameras. As a consequence, fusing images in these modalities necessitates accurate registration. This problem is further compounded by the fact that the same scene will look very different when sampled in different parts of the spectrum, thus rendering automatic registration highly non-trivial.

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2.8 Fire Propagation Estimation and Visualization Techniques

2.8.1 Introduction

Early detection of wildfires at cultural heritage sites or nearby forestal areas is just one step of the prevention. To encounter wildfires in places like this is unavoidable. In such cases one major step in order to minimize the damage from wildfires is early intervention by predicting the propagation direction and the rate of spread (ROS) of fire.

Governments of countries such as Canada, USA and Australia pioneered in this research area and developed several fire propagation estimation models. This research effort not only led to the development of empirical models but also some theoretical models relying on physical behavior of the fuel. If the model of the fuel (e.g. vegetation in forest fires) and some other parameters like the wind speed, humidity slope and aspect of the terrain etc., are known, the propagation of fire can be estimated [1], [2].

Pioneered by [1], [2], several fire propagation models and software are described in the literature. However, most of these systems supply very limited visualization capabilities. The visualization of the propagation of fire is a very important issue since it helps the fireman in the deployment process. Geographical Information Systems (GIS) are widely used for this purpose. By using a propagation simulator with GIS support, a real-time decision support system can be developed [3]. Thus, the effectiveness of the fire fighting strategies is enhanced.

In this section we will give a brief survey about the fire propagation models and libraries in the literature. The variables effecting the propagation and needs will be discussed. Moreover, a brief survey of the tools of Geographical Visualization System (GIS) will be given.

2.8.2 State of the Art

Wildfire is one of the most encountered natural disasters in the world. Avoiding wildfires altogether may not always be possible; therefore early detection and intervention are the other options to control the fire before it becomes a catastrophic event. One of the most efficient ways in fire fighting is predicting fire propagation and getting rid of the fire's fuel by means of counter fires. This can only be achieved if the propagation of the wildfire can be estimated beforehand. Therefore fire propagation research has been an active topic since 1910's.

USA, Canada and Australian governments are the pioneering organizations in this research area. During the last century these countries developed different fire models for their wildlands. Spain, South Africa, Russia, Portugal and France can also be named as other countries that have shown significant effort in the development of new techniques. Especially during the summer season, wilfires become a huge problem in the Mediterranean and Aegean countries of Europe. Hence, since 1990s European Union (EU) has also been investing funds on this research area [4], [5], [6].

Fire propagation is a physical phenomenon. However, in order to simulate this *physical* phenomenon using all its variables (wind, heat transfer, moisture, terrain etc…) is at this point too complex computationally. Hence, people developed *empirical* approaches to the problem. Researchers used the statistics of formerly recorded fires or controlled fires to build a correlation between fire characteristics and fire variables.

Some researchers also carried out controlled burn experiments to understand the effect of different environmental conditions and fuel types on the behaviour of fire.

The obtained results are then extended to larger problems like wildfires. The empirical data collected during these controlled experiments are sometimes correlated to physical phenomena, too. The models developed in this manner are called *semi-empirical* models.

Due to this, the algorithms are categorised into three main groups in the fire propagation literature: empirical, semi-empirical, and physical [7]. We organize this survey as follows: First we give brief information about the variables that affect the fire propagation. In separate subsections we give information about these three different groups of models. Then the visualization techniques in the literature are dealt with. Conclusions and remarks are given in the last subsection.

2.8.2.1 Factors Effecting the Fire Propagation

2.8.2.1.1 Topology

Slope and aspect are two topological factors that affect the propagation properties of wildfires. Digital terrain models (DTM) are frequently used in the representation of topology of a terrain. However the slope and the aspect values of the terrain are not given directly in DTM. Only the height and the coordinate information of the terrain points are specified in this representation. A method to extract the slope and aspect of a specific coordinate is defined in [12]. First a 3x3 kernel on the terrain is defined as in Table 2-10. $\mathrm{h_{ij}}(\mathrm{i}, \mathrm{j} \in \{1,2,3\})$ is the height value of a specific cell in the kernel of the interest.

Table 2-10: Heights of the 3x3 Kernel on the terrain.

h_{11}	h_{12}	h_{13}
h_{21}	h_{22}	h_{23}
h_{31}	h_{32}	h_{33}

Using the height values, north/south and east/west gradients are calculated as;

$$\frac{dEW}{dz} = \frac{[(\mathrm{h}_{13} + 2.\mathrm{h}_{23} + \mathrm{h}_{33}) - (\mathrm{h}_{31} + 2.\mathrm{h}_{21} + \mathrm{h}_{11})]}{8.\mathrm{dx}}$$

$$\frac{dNS}{dz} = \frac{[(\mathrm{h}_{11} + 2.\mathrm{h}_{12} + \mathrm{h}_{13}) - (\mathrm{h}_{31} + 2.\mathrm{h}_{32} + \mathrm{h}_{33})]}{8.\mathrm{dy}}$$

x is the east-to-west cell width and y is north-to-south cell height. Then, the slope and the aspect at the center point are calculated as:

$$Slope = \arctan[(\frac{dEW}{dz})^2.(\frac{dNS}{dz})^2]^{0.5}$$

$$Aspect = \arctan(\frac{dEW}{dNS})$$

Thus, the aspect and the slope information can be calculated from the height information. Therefore, they do not need to be stored separately.

In [13] the effect of the slope on rate of spread (ROS) is defined empirically. For the experiments a square platform with 1.6m side length was used. The platform can be inclined by α (0°< α < 40°) degrees with 5° intervals. The platform can also be rotated, therefore an arbitrary edge can make an angle β (0°< β <180°) with the incline. The author made various tests with different α and β values. In most cases, β can also be interpreted as the angle between the direction of spread and the direction perpendicular to slope.

Figure 2.8-1 gives empirical results from [13], when the propagation of the fire front direction is perpendicular to the slope. From this result it can be observed that:

i) As the slope increases, the ROS also increases non-linearly.

ii) As the slope decreases (for α<0), ROS decreases but the decrease is minor. Negative slope means the direction of propagation is in the opposite direction of the slope.

From the empirical results of [13] given in Figure 2.8-2, a very important property of fire propagation can be concluded. In case of a burning area with homogeneous fuel distribution under no wind and no slope, it is expected that the shape of the burnt area will be a circle. It can be observed from Figure 2.8-2 that the direction of propagation of fire front is always aligning itself with the perpendicular angle to the slope. This aligning procedure becomes much faster as the β gets larger until it reaches ~60° then it slows down.

This concept of fire rotation can be used for explaining the elliptical shaped evolution of the fire. The head of the fire propagate with a faster speed compared to the back of the fire. Therefore the fire front will take an elliptical shape form. An example expansion of fire on 30° sloped terrain is given in Figure 2.8-3

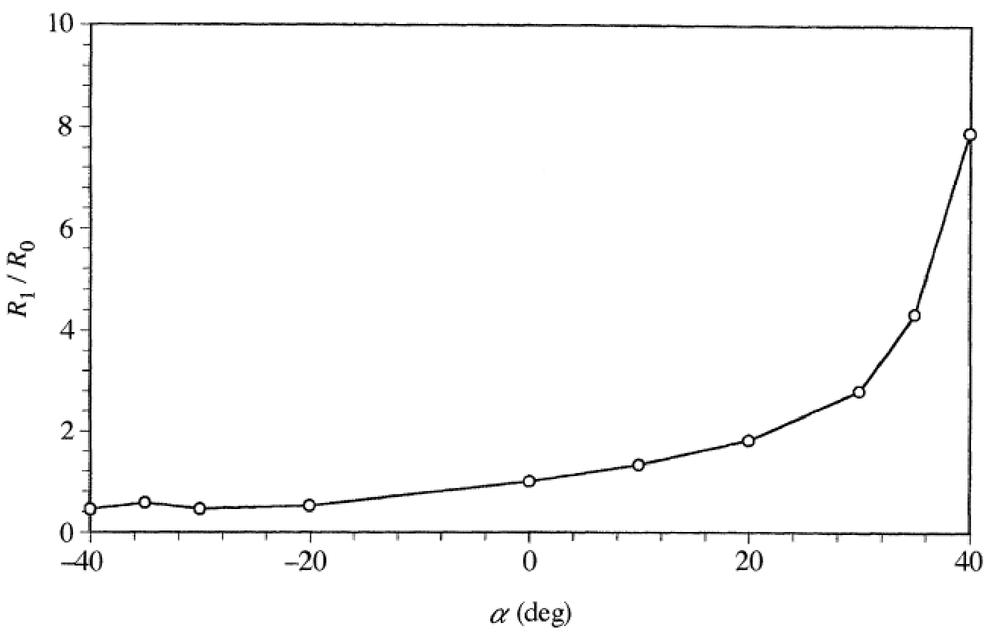

Figure 2.8-1: Rate of change in ROS for different slopes. (The figure is taken from [13])

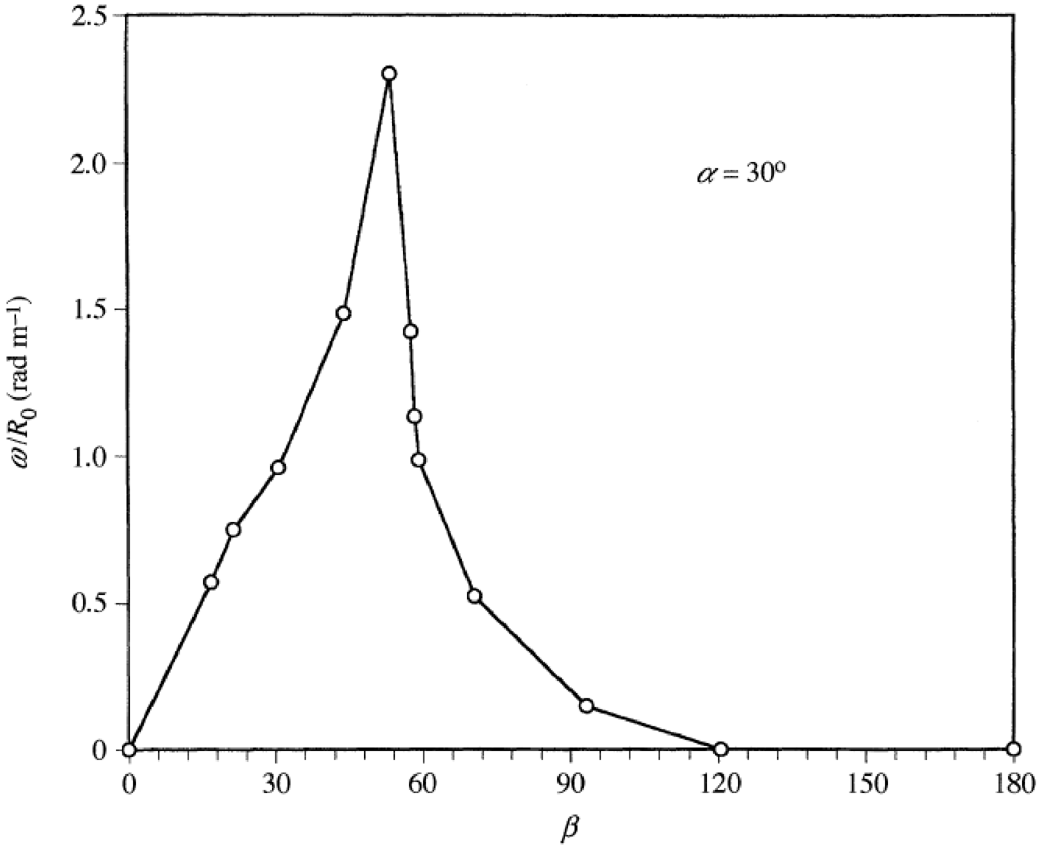

Figure 2.8-2: Rate of change in direction of ROS, as β changes. (The figure is taken from [13])

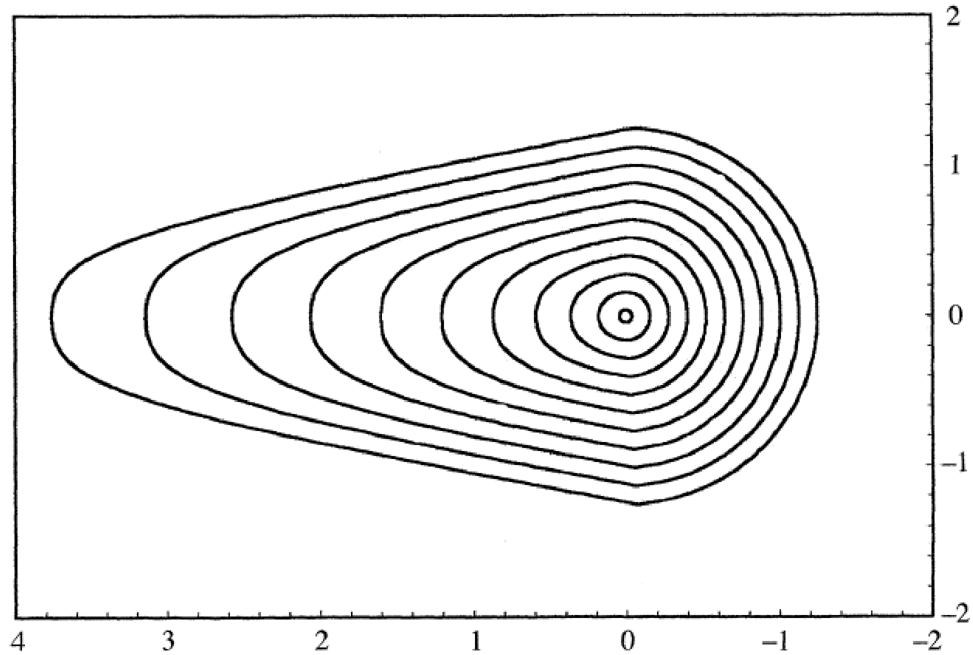

Figure 2.8-3: An example illustration evolution of the fire on 30° sloped terrain. (The fuel on the terrain is assumed to be of the same type and homogeneous) (The figure is taken from [13])

In [1], [14], [15] similar results with [13] for different types of fuel beds are also presented.

Aspect determines the wind-terrain interaction. If the slope is facing the wind direction, the effect of the wind on the fire increases. More details on the change in ROS with respect to wind is given in the next section.

2.8.2.1.2 Meteorology

The meteorological conditions are considered to be the most influential factor on the fire spread. Wind, temperature, humidity, precipitation can be counted as the most influential ones among all meteorological factors. Especially wind is the main factor that determines the direction and rate of the wildfire spread. In most of the empirical models the effect of wind is defined as non-linear, e.g. as the speed of the wind increases, the increase in ROS will be according to a power-law. However above a limit speed, the wind may have an extinguishing effect on the fire [1].

It should be kept in mind that the effect of the wind is different for different fuel types. Especially in porous fuel beds, wind is more effective because it can penetrate into the fuel more easily. In [13], the author also validated the results of [1] by wind tunnel experiments. Experiments with dead needles of *Pinus Pinaster* are conducted in this research. As seen in Figure 2.8-5 the effect of wind speed on the rate of spread is nonlinear. In Figure 2.8-5, R_0 is the ROS of fire under no wind conditions. R_1 is the ROS under wind with wall shear effect of τ_w. Figure 2.8-5 also gives results for negative wind speed values, which means wind against the direction of propagation. If the wind is not aligned with the direction of the propagation, a similar effect as in the case of the negative inclined terrain occurs. The direction of the propagation will start to align itself with the direction of the wind.

Environmental temperature is another factor affecting the fire spread. As the temperature of the environment increases, the likelihood of an unburned area to ignite also increases. Actually the effect of environmental temperature is more significant for the first ignition to occur. As the fuel starts to burn, the effect of the heat carried by radiation and convection becomes more dominant than the heat from the environmental temperature.

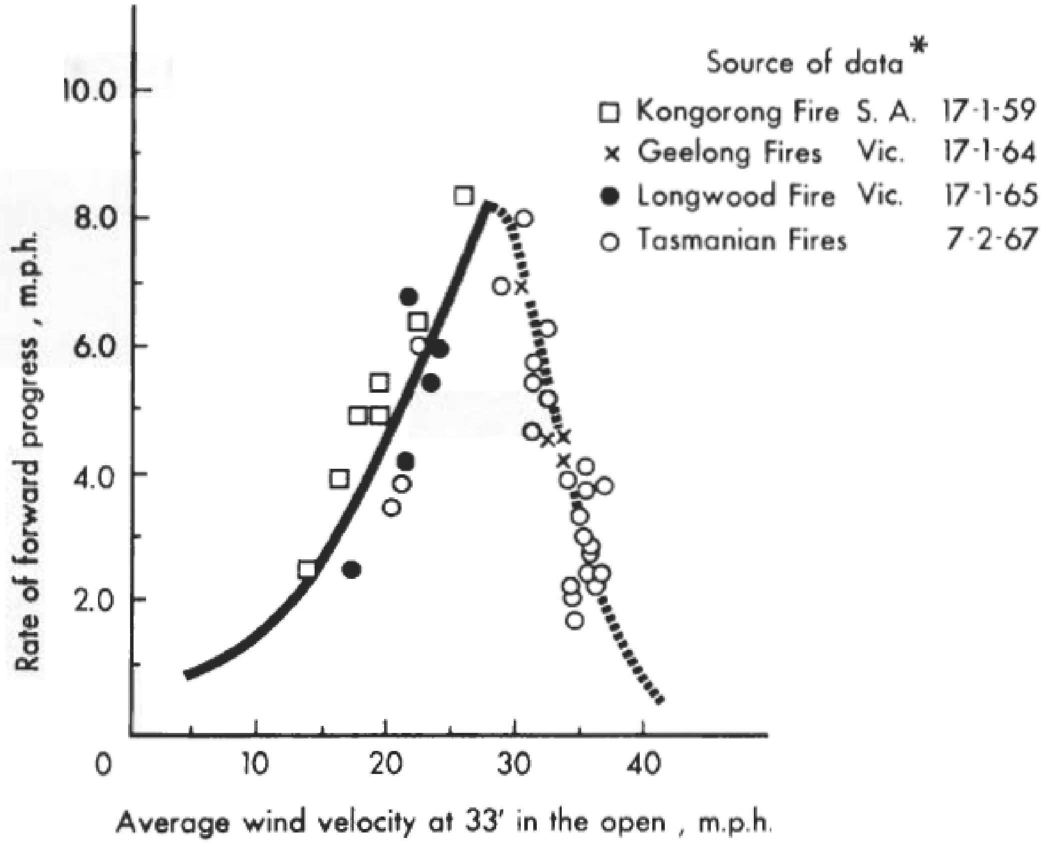

Figure 2.8-4: Reproduction of [11] rate of spread data for grass (The figure is taken from [1])

Other factors that affect the fire propagation are humidity and precipitation. Increasing humidity of the environment has a direct effect on the fire spread: It will be harder for the unburned area to ignite. On the other hand, if there is no precipitation at the moment of the fire, the effect of precipitation is indirect. Due to past rainfall or snow, the fuel may have become wet and the moisture level of the fuel may have increased. Therefore, keeping record of the rain/snow fall during the last few days preceding the fire would give an idea about the moisture level of the fuel. The effect of the moisture on the fuel is described in the fuel subsection.

The empirical results presented in [13] are also verified by the information from past wind-driven fires given in [16], [17], [18], [19]

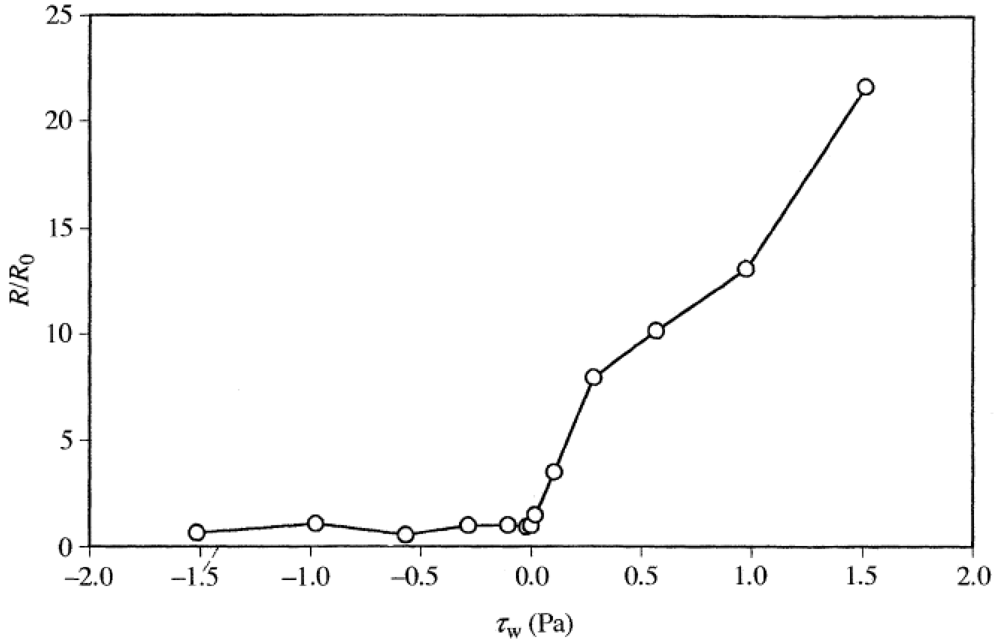

Figure 2.8-5: Increase in the rate of spread with respect to the wall shear stress created by the wind. The graph is obtained from combustion tunnel experiment with dead needles of the pinus pinaster. (The figure is taken from [13])

2.8.2.1.3 Fuel

In order for the propagation model to be efficient, forest fuels must be described in a particular way, in which the fuel characteristics are represented by certain average values. The set of these representative values is called a fuel model. The main drawback of the general fire propagation models is that they are mostly specific to fuel types. Therefore, a model developed in a country can not be directly used in another country with different vegetation. For example, the *firelib* library has 13 default fuel models, which are specific to the forest of USA [20]. For creating a new fuel model, some properties of the vegetation and the environment, such as depth of the fuel bed, dead fuel extinction moisture content, fuel particle load, surface area-to-volume ratio of the particle, etc. should be investigated. Some systems e.g. *firelib* give users the opportunity to define their own fuel models by entering the above mentioned properties of the fuel in the system. An empirical way of defining the vegetation models is just using the spread statistics of the past-fires to estimate the properties of the fuel.

The part of the vegetation that participates most in the propagation of the forest fire is called the fine particles [13]. Fine particles are the particles that are typically smaller than 6mm in their larger dimension (thickness or diameter). The larger particles are either burnt after the fire is propagated to the neighboring area (after the fire front passed) or at very intense fires. Therefore, fine particles are the most important particles for the calculation of the ROS.

The fuel particles can be grouped into three layers: ground, surface and canopy. The ground layer is the layer just above the soil and it consists of organic residues, decomposing litter etc.. The surface layer is over the ground layer and it consists of litter, fallen leaves or needles from the trees, shrubs, short trees, etc... The canopy layer is composed of the foliage of trees. In [1] each of these layers are characterized by their physical properties such as height, thickness, fuel load etc… In [21] it is claimed that the chemical composition of the particles varies with the vegetation type and moisture level of the particles. However, it is said that the heat released from the unit mass is not affected by these factors. The moisture content of the particles just affects the ignition of the fuel, therefore, only ROS is influenced.

The moisture content of the fuels depends greatly on the weather in the fire region. Both the past and the current weather conditions determine the moisture content of the fuel. Therefore, long-term meteorological data is strongly correlated with the moisture content of the fuel.

As the moisture content of the fuel increases, ROS decreases. Moreover, there exists a threshold, called moisture of extinction [1], after which the ignition is impossible. In [13] experimental results from tests with Pinus Pinaster needles are given. The results of the tests are given in Figure 2.8-6. Similar results are also reported in [1].

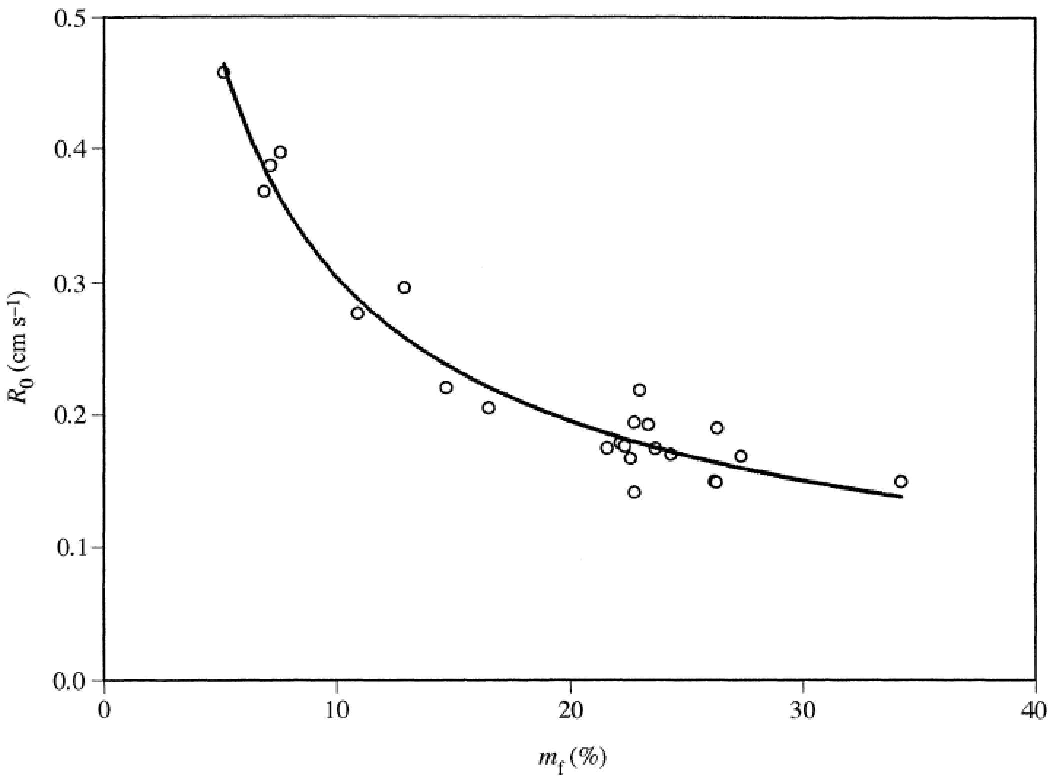

Figure 2.8-6: Effect of the moisture content on ROS. Results of the experiments with pinus pinaster needles. (The figure is taken from [13])

2.8.2.2 Empirical models

An empirical model tries to explain the wildfire propagation phenomena using the statistical information collected from past wildfires or controlled wildfire experiments. The statistics collected in this way are correlated with the behaviour of fire and its environment [7]. Parts of a possible approach are given in [5]. For each part a series of experiments are conducted and the effects of the variables are measured.

Characteristics and quantification of the fuel and the terrain properties are the first variables to be tested. Some of the characteristics of the fuel include the type of the vegetation, moisture, thickness of the vegetation layer, etc... The second part is the experiments with meteorological -or so-called atmospheric- variables. These experiments are used for measuring the properties of the fire such as ROS, flame length, flame shape etc... In the last part the correlation between the above collected statistical information and the factors affecting fire is investigated. In

Table 2-11, a summary of the empirical models developed since 1990 is given. In

Table 2-12 some of the simulation parameters of the empirical models are given.

2.8.2.3 Semi-empirical Models

Semi-Empirical models are just a combination of the physical and empirical information from the fire. The statistical data collected from experiments is analysed, and the factors affecting the fire propagation are correlated to the spread model in a physical framework. Basically, the semi-empirical models are based on the principle of the conservation of the energy. The energy released from the burnt fuel particles is transferred to its neighbours as heat. This heat will cause the ignition of the neighbouring fuel cells therefore the fire will spread. The extent of this physical framework varies; however, the models are mostly based upon the empirical information [5].

In

Table 2-13 and Table 2-14 a summary of the semi-empirical models developed since 1990 and simulation parameters of the semi-empirical models are given respectively.

Table 2-11: Summary of the empirical models (during 1990) (The Table is taken from [5])

Model	Author	Year	Country	Field/Lab	Fuel Type	No. Fires	Size (WxL)	Reference
CFS-accel	Mc Alpine	1991	Canada	Lab	Needles/Excel	29	0.915x6.15	[29]
CALM-Spinifex	Burrows	1991	Australia	Field	Spinifex	41	200x200	[30]
CFBP	FCFDG	1992	Canada	Field	Forest	493	10-100x10-100	[31][32]
Button	Marsden-Smedley	1995	Australia	Field	Buttograss	64	501100x50-100	[33]
Calm Mallee	McCaw	1997	Australia	Field	Mallee/Heath	18	200x200	[34]
CSIRO Grass	Cheney	1998	Australia	Field	Grass	121	100-200x100-200	[35]
Heath	Catchpole	1998	Australia	Field	Heath/Shrub	133	100x100	[36]
Port Shrub	Fernandes	2001	Portugal	Field	Heath/Shrub	29	10x10	[37][38]
CALM Jarrah I	Burrows	1999	Australia	Lab	Litter	144	2x4	[39][40]
CALM Jarrah II	Burrows	1999	Australia	Field	Forest	56	100x100	[39][41]
Port Pinas	Fenandes	2002	Portugal	Field	Forest	94	10x15	[42]
Gorse	Baeza	2002	Spain	Field	Gorse	9	33x33	[43]
Maquis	Bilgili	2003	Turkey	Field	Maquis	25	20x20	[44]
CSIRO Forest	Gould	2006	Australia	Field	Forest	99	200x200	-

Table 2-12: Summary of simulation properties of the empirical models (The Table is taken from [5])

Model	FMC Func.	FMC Range (%)	Wind Func.	Wind Range (m/sec)	ROS Range (m/sec)
CFS-accel	-	-	-	0-2.22	?
CALM-Spinifex	-82.08M	12-31	U^2	1.1-10	0-1.5
CFBP	$e-^{0.1386M}(1 + M^{5.31})$	?	$e^{0.05039U}$	?	?
Button	$e^{-0.0243M}$	8.2-96	$U^{1.312}$	0.2-10	?
Calm Mallee	$e^{-0.11M\_id}$	4-32	$U^{1.05}$	1.5-6.9	0.13-6.8
CSIRO Grass	$e^{-0.108M}$	2.7-12.1	$U^{0.844}$	2.9-7.1	0.29-2.07
Heath	NA	NA	$U^{1.21}$	0.11-10.1	0.01-1
Port Shrub	$e^{-0.067M}$	10-40	U	0.28-7.5	0.01-0.33
CALM Jarrah I	$(0.003+0.000922M)^{-1}$	3-14	$U^{2.22}$	0-2.1	0.002-0.075
CALM Jarrah II	$23.192M^{-1.495}$	3-18.6	$U^{2.674}$	0.72-3.33	0.003-0.28
Port Pinas	$e^{-0.035M}$	8-56	$U^{0.868}$	0.3-6.4	0.004-0.231
Gorse	-0.0004M	22-85	NA	<1.4	0.004-0.039
Maquis	NA	15.3-27.7	0.495U	0.02-0.25	0.001-0.15

* Fuel moisture content (M) = FMC
* Wind (U)

Table 2-13: Summary of the semi-empirical models (during 1990) (The Table is taken from [5])

Model	Author	Year	Country	Field/Lab	Fuel Type	No. Fires	Size (WxL)	Reference
TRW	Woff	1991	USA	Lab	Match splints	?	1.1x7	[45]
NBRU	Beer	1993	Australia	Lab	Match splints	18	0.4x0.16 (2D)	[46][47]
USFS	Catchpole	1998	USA	Lab	Pond./Excel	357	1x8	[48]
Coimbra	Viegas	2002	Spain	Lab	Pond. Needles	23	3x3	[49]
Nelson	Nelson	2002	USA	Lab	Birch sticks	65	?	[50]

Table 2-14: Summary of simulation properties of the semi-empirical models (The Table is taken from [5])

Model	FMC Func.	FMC Range (%)	Wind Func.	Wind Range (m/sec)	ROS Range (m/sec)
TRW	NA	NA	$U^{0.5}$	0.4.7	0-0.007
NBRU	NA	NA	U^{3}	0-9	0.004-0.38
USFS	$e^{-4.05M}*(700+2260M)^{-1}$	2-33	$U^{0.91}$	0-3.1	0-0.23
Coimbra	NA	10-15	-	?	?
Nelson	NA	NA	$U^{1.51}$	0.-3.66	<0.271

2.8.2.4 Physical Models

Physical models take one or more energy transfer issues into account. The energy released in the burning area heats its unburned neighbours and thus the fire spreads. Therefore, the spread of fire is just a balance of heat transfer equations. On the fire front, where the unburned areas meet with burning areas, there is a balance of heat transfer. As the temperature of the particles at the unburned areas reach the ignition temperature, they start to burn.

Most of the models consider just the top of the fuel bed as the interaction surface, and others like [22] consider the whole fuel bed. In [8] and [9] the author calculated the energy balance in 2 dimensions and used an interaction space around a point located at a specific coordinate inside the fuel bed.

Different from the semi-empirical models, the spread is modelled without the statistical data, but only with equations from physics. In the most sophisticated versions the energy transfer from the burning area to the unburned area is caused by:

- Radiation from the embers
- Radiation from the flame [8], [9]
- Radiation from the unburned particles themselves [8], [9]
- Convective type thermal exchange between the fuel particles and the gas [10]

All the above mentioned phenomena are modelled with physical equations and ROS is calculated using these equations. These physical models can take atmospheric and topological constrains into account [23], [24], [25], [26]. In [27], [28] atmospheric airflow is also considered.

In Table 2-15 and Table 2-16 some properties of the physical and semi-physical models developed since 1990 are reviewed briefly.

Some simulation parameters of the physical and semi-physical models are given in Table 2-17

Table 2-15: Summary of physical models (1990-present) (Table is taken from [4])

Model	Author	Year	Country	Dimensions	Plane	Reference
Weber	Weber	1991	Australia	2	XY	[30]
AIOLOS-F	Croba et al	1994	Greece	3	-	[52]
FIRETEC	Linn	1997	USA	3	-	[53]
Forbes	Forbes	1997	Australia	1	X	[54]
Grishin	Grishin et al.	1997	Russia	2	XZ	[55][56][57][58]
IUSTI	Larini et al.	1998	France	2	XZ	[59][60][61][62]
PIF97	Dupuy et al.	1999	France	2	XZ	[63][64]
LEMTA	Sero-Guillaume et al.	2002	France	2(3)	XY	[65]
UoS	Asensio et al.	2002	Spain	2	XY	[66]
WFDS	Mell et al.	2006	USA	3	-	[67]

Table 2-16: Summary of semi-physical models (1990-present) (Table is taken from [4])

Model	Author	Year	Country	Dimensions	Plane	Reference
ADFA I	de Mestre	1989	Australia	1	X	[68]
TRW	Carrier	1991	USA	2	XY	[69]
Albini	Albini	1996	USA	2	XZ	[70][71][72]
UC	Santoni	1998	France	2	XY	[73][74][75]
ADFA II	Catchpole	1998	Australia/ USA	2	XZ	[76]
Coimbra	Vaz	2004	Portugal	2	XY	[77]

Table 2-17: Summary of all simulation parameters of the models (Table is taken from [4])

Model	Domain size	Resolution (m)				CPU No& Type	Simulation Time	Computation Time
		∂x	∂y	∂z	∂t			
Weber	?	?	?	?	?	?	?	?
AIOLOS-F	10x10x? km	?	?	?	?	?	?	?
FIRETEC	320x160x 615 m	2	2	2	0.002s	128	?	?
Forbes	?	?	?	-	?	?	?	?
Grishin	50x-x12m	?	-	?	?	?	?	?
IUSTI	2.2x-x0.9m	0.02	-	0.09	?	?	?	?
PIF97	200x-x50m	0.25	-	0.25	1s	P4 2GHz	200s	48h
LEMTA	?	?	?	-	?	PC	?	?
UoS	?	1.875	1.875	-	0.25 μs	?	?	?
WFDS	1.5x1.5x0.2 km	1.5	1.5	1.4	-	11	100s	25h
ADFA I	?	?	-	-	?	?	?	?
TRW	?	?	?	-	?	?	?	?
Albini	?	?	-	?	?	?	?	?
UC	1x1x-m	0.01	0.01	0.01	0.01s	Sun Ultra II	144s	114s
ADFA II	?	?	-	?	?	?	?	?
Coimbra	?	?	?	?	?	?	?	?

2.8.2.5 Visualization Techniques

2.8.2.5.1 GIS systems

A geographic information system (GIS) can be defined as “a computer based information system, which attempts to capture, store, manipulate, analyze and display spatially referenced and associated tabular attribute data for solving complex, research, planning and management problems” [78]. Therefore, GIS systems are widely used in many areas such as cartography, remote sensing, land surveying, photogrammetry, geography, urban planning, emergency management, navigation, and localized search engines.

In recent years, GIS technology is used by forest fire spread simulations as it can provide a user friendly environment for representing all types of information and data needed for planning requirements. GIS stores spatial information in a digital mapping environment that allows fire managers to quickly select and view data that can influence fire behaviour. Factors such as vegetation types, slopes, aspects, natural or man-made barriers, and historical weather patterns can be overlaid to determine fire hazards based on modelling potential fire behaviour [79]. Regarding the visualization of data, there are two main methods: raster and vector. Raster data type consists of rows and columns of cells, with each cell storing a value. Geographical features can be expressed by different types of geometry (i.e. vectors) such as points, lines or polylines and polygons. Finally, a new hybrid method of storing data is point clouds, which combine three-dimensional points with RGB information at each point, returning a 3D color image.

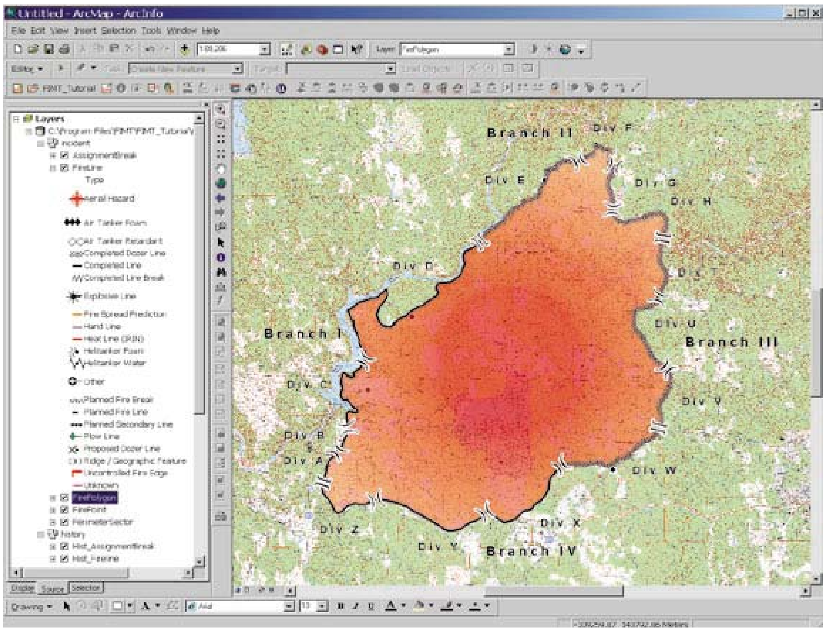

Figure 2.8-7: The Fire Incident Mapping Tool extension for ArcGIS is used to manage and support wildfire incidents [79].

GIS systems can be classified into different categories. Below we classify GIS applications as open source and commercial software [80].

Table 2-18*: Open Source GIS software*

Open Source GIS	
GIS Software	***Description***
GRASS GIS (Geographic Resources Analysis Support System)	It can be used on multiple platforms, including Mac OS X, Microsoft Windows (natively or with optional Cygwin tools) and Linux.
Capaware	It was developed in C++ programming language and at present works only on Microsoft Windows. Capaware is a 3D general purpose virtual worlds viewer that allows interaction with 3D virtual terrain maps.
SAGA GIS – System for Automated Geoscientific Analyses	SAGA has a unique Application Programming Interface (API) and a fast growing set of geoscientifc methods, bundled in exchangeable Module Libraries
Quantum GIS	Quantum GIS is written in C++, and its GUI uses the Qt library [81]. Quantum GIS allows integration of plugins developed using either C++ or Python. Quantum GIS is a multi-platform application and runs on different operating systems including Mac OS X, Linux, UNIX, and Microsoft Windows.
MapWindow GIS	MapWindow GIS is distributed as an open source application under the Mozilla Public License distribution license, MapWindow GIS can be reprogrammed to perform different or more specialized tasks. There are also plug-ins available to expand compatibility and functionality. The application is built upon Microsoft .NET technology.
TerraView	TerraView is an GIS application built on the TerraLib GIS library. TerraView handles vector data (polygons, lines, points) and raster data (grids and images), both of them stored in a relational or geo-relational database, including ACCESS, PostgreSQL, MySQL and Oracle Spatial.
gvSIG	gvSIG has been developed using Java, and being available for Linux, Windows and Mac OS X platforms
Mapnik	Mapnik is used for both desktop- and server-based map rendering.
MapGuide Open Source	MapGuide Open Source is a web-based map-making platform that enables users to quickly develop and deploy web mapping applications and geospatial web services. The MapGuide platform can be deployed on Linux or Microsoft Windows, supports Apache and IIS web servers, and offers extensive PHP, .NET, Java, and JavaScript APIs for application development.

MapServer	MapServer is an open source development environment for building spatially-enabled internet applications. It can run as a CGI (Common Gateway Interface) program or via Mapscript which supports several programming languages.

Table 2-19: ***Commercial GIS software***

Commercial GIS	
GIS Software	***Company***
ArcView, ArcGIS, ArcSDE, ArcIMS, ArcWeb services and ArcGIS Server.	ESRI
Map 3D, Topobase, MapGuide	Autodesk
GeoMedia, GeoMedia Professional, GeoMedia WebMap	Intergraph
MapInfo Professional and MapXtreme	MapInfo
spatialSUITE: spatialWEB, spatialOFFLINE, BILLINGsync, ADDRESSmanager, MAPupdater, and spatialWEBSERVICES	SPATIALinfo
Bentley Map, Bentley PowerMap	Bentley Systems

There are different approaches of coupling GIS with models. The first approach is the coupling of GIS with a stand-alone modelling package by exchanging files. In this case, GIS is used mainly for pre-processing (data preparation) and post-processing (display/visualization). This is the easiest approach and the only requirement is an exchange format that is understood by both the GIS and the modeling package. The second approach requires the integration of GIS with a modelling package using standards such as Microsoft's COM and .NET that allow a single script to invoke commands from both packages. This is now a common approach (e.g., ArcObjects with COM-compliant programming languages). Finally, in the third approach, the entire model is executed by calling functions of the GIS using a single script i.e. the model is embedded in the GIS [82], [83].

As far as the fire simulations are concerned, there are three main semi-empirical models that are applied to fire-modelling programs in GIS:

1. Rothermel Model: Applied to programs such as ***BEHAVE*** and ***FARSITE***.
2. Huygens Model
3. Cellular Automata

BehavePlus (the predecessor of BEHAVE) is a commonly used program that is a collection of models that describe fire behavior, fire effects, and the fire environment. It is a flexible system that produces tables, graphs, and simple diagrams and can be used for a multitude of fire management applications. However, the most popular program is FARSITE and its companion program ***FlamMap***. FARSITE is a fire behavior and growth simulator for use on Windows computers, which automatically computes wildfire growth and behavior for long time periods under heterogeneous conditions of terrain, fuels, and weather. It is a deterministic model, meaning that you can relate simulation results directly to your inputs [84]. FlamMap is an add on to the FARSITE program allowing the display of raster data over an entire FARSITE landscape, removing the need for an external GIS program for the plotting of spatial data. It is however a less functional program than ArcGIS [85]. Using FlamMap is different from most Windows applications. In addition to utilizing menus, commands, and toolbar buttons, FlamMap uses an expanding tree structure and context menus in the left hand pane of the project window to guide you through your work. The right hand pane of the "Project" window displays the active theme selected in the left hand pane. This display can be zoomed, colors changed, legends displayed, etc [84].

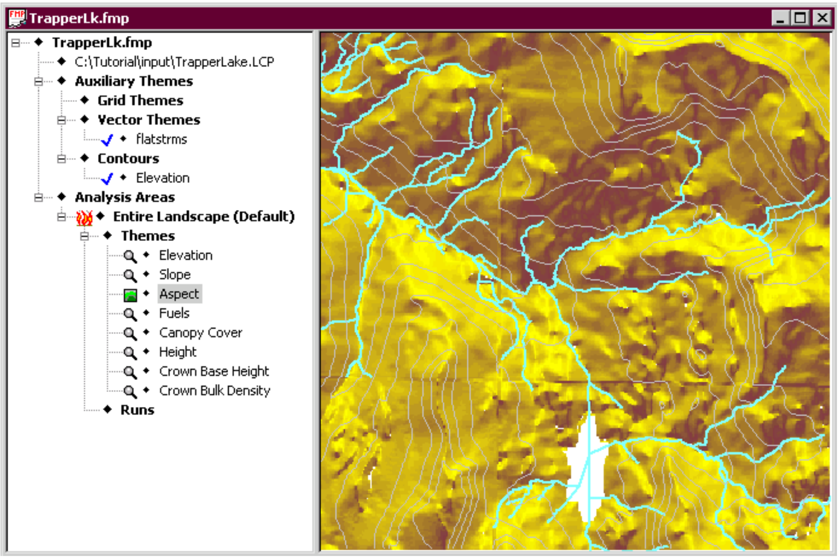

Figure 2.8-8: FlamMap Display [84]

Apart from the use of semi-empirical models in fire simulations, recently, there are efforts of using physical-based models. VESTA - Large Scale Fire Simulator has been developed by the MTDA team (France) as part of the ***European FP6 Fire Paradox programme***, to simulate fire spread by means of drawing successive map-based contours, based on the current knowledge of physics at a landscape scale. The key-objective of this fire simulator is to replace the existing tools based on empirical or semi-empirical models by a new type based on physical fire modelling, which are more accurate and reliable. Another feature of VESTA simulation is the 3D visualization of data as shown in next figure [86].

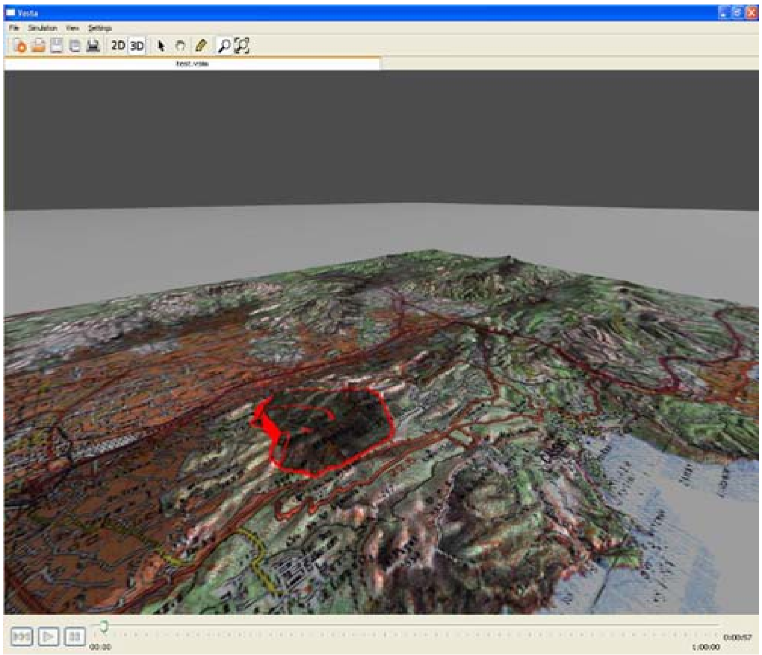

Figure 2.8-9: VESTA Large Scale Simulation supports 3D data visualization.

In general, there is a trend of using 3D graphics for visualizing geographical information. 3D GIS have now become a reality due to pipelined 3D graphics and efficient terrain visualisation algorithms. Several GIS systems have the capability of creating three dimensional perspective images using elevation data for geographic areas with GIS variables (such as population distribution or land use) overlaid [87]. In [88] and [87] approaches, which provide realistic representation of the third dimension, free movement of the user within the three dimensional representation and normal GIS functions, are presented.

Most GIS software is capable of handling topographic data, usually as a **digital elevation model** (DEM), and of generating isometric views and contour maps. DEM data is a regular grid of terrain elevation values that is placed on a grid specified by the geographical location of the elevation value. It is also widely known as a **digital terrain model** (**DTM**). Each elevation point in the DEM is interpolated from a spot height measurement or contour data [89]. There are two ways to construct DEM information: 1) using TIN (Triangulated Irregular Network) [90], and 2) employing direct processing of all points as a regular grid [91]. The quality of a DEM is a measure of how accurate elevation is at each pixel (absolute accuracy) and how accurately the morphology is presented (relative accuracy).

During 2006-2008, BILKENT and CERTH were partners in a bilateral project on the detection of forest fires. Within this framework, a simulation tool was developed, which can visualize the fire propagation on a 3D-GIS environment like GoogleEarth™. The visualization is done in 3D so that a more realistic view of the fire propagation can be obtained. Using GoogleEarth™, visualization techniques for the fire propagation simulation was obtained. New features of GoogleEarth™ enable the visualization of any geographical and logistical information on the 3D-GIS environment. Using this information, fire fighters can plan their movements and actions in order to confront the fire. Besides the GIS functionality of GoogleEarth™, an innovative visualization was used, by rendering above mentioned outputs in a

Sharp Actius™ autostereoscopic notebook. By the help of Tridef™ Visualizer plug-in, it is now possible to view GoogleEarth™ scenes in real-time 3D.

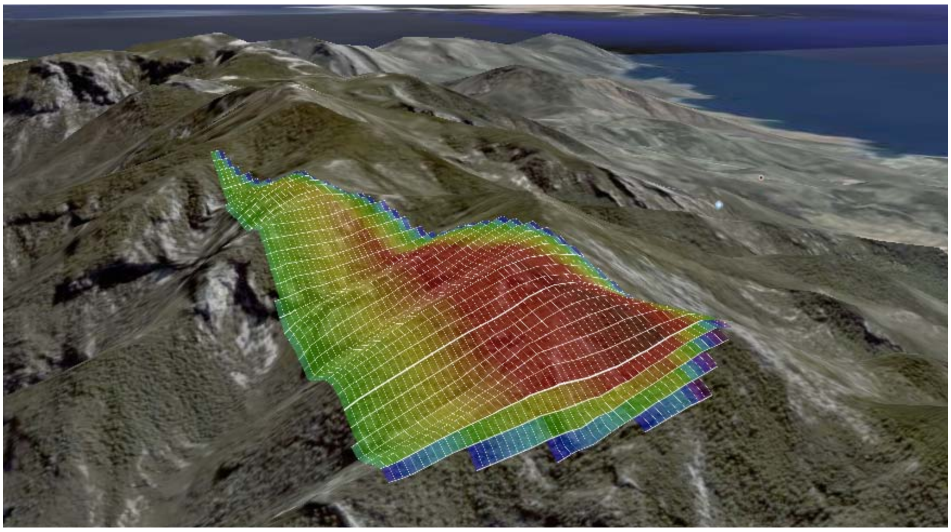

Figure 2.8-10: 3D visualization of fire propagation using Google Earth™ (CERTH-BILKENT)

1.1.2 Virtual Environments

Recently, multimedia and virtual reality technologies have also been applied, aiming to assist fire-fighters in wildfire management. The main objective of such systems is to provide a realistic and intuitive 3D visualization of the area of interest that should serve as an aid to local wildfires analysis and management of the situation when a wildfire occurs.

In [92] a 3D virtual environment is present based on Capaware [93], which is a cross-platform software that has been developed in C++ using the graphics toolkit Open Scene Graph and the wxWidgets library. With its plug-in system capability, any software developer is empowered to increase both functionalities and capabilities. The software has the usual GIS software features and it allows the integration of geographical layers and 3D objects over the virtual terrain. The system makes use of FARSITE, which uses spatial information on topography and fuels along with weather and wind files. The visual representation of wildfires in a virtual environment is a complex task since they may affect a large stretch of land and the amount of information to manage is usually very large. After a simulation, FARSITE provides information about the fire perimeters, the intensity of flames in each perimeter, the time arrival of the fire to a point, the velocity of the front, etc. The fire visualization is based on two particle systems to model the flame and the smoke.

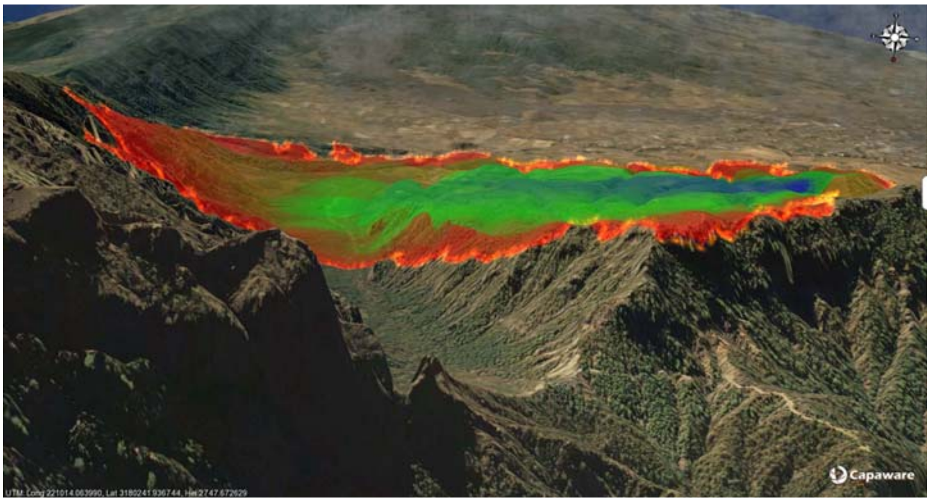

Figure 2.8-11: Wildfire visualization over the 3D landscape.

Another forest fire simulation, which combines GIS and virtual reality is presented in [94]. Specifically, a software application was developed in collaboration with French firemen to help them in their awareness campaigns. This application combines a simulation of fire propagation with a Geographic Information System (GIS) and a real-time three-dimensional visualization. This application has been designed such that, it can be used by people without much experience in fire fighting or simulation software. Thanks to very intuitive tools, the user has the possibility to simulate brush clearing or the planting of new tree species on 3D representation of real landscapes. A forest fire can then be simulated anywhere on this landscape and visualized in 3D from any viewpoint. The interactive 3D visualization permits a good understanding of the process and reinforces the desired pedagogical impact by its realism. The simulation uses the empirical model BEHAVE and Digital Elevation Models form French Institut Geographique National, with a sampling rate of one point every 50m. The application supports a 3D display that enables a realistic visualization of the landscape and forest fire. The display has been optimized to allow real time interaction by the user who can observe the 3D scene from any viewpoint.

Figure 2.8-12: Computer generated flames and smoke.

In [95], a visual simulation system that supports GIS-based realistic modelling and real-time rendering of forest scenes is presented. Geometric models of trees are automatically generated according to inventory database and pre-designed template models. A combined image and geometry representation method for a 3D tree model is used along with a specific level of detail (LOD) algorithm for ensuring real-time frame rates. The simulation uses Huygen's principle of wave propagation as the fire growth model. Finally, in [96] an immersive visualization application for wildfire spread analysis is presented. The application is called VRFire and is a virtual reality tool for visualizing wildfire scenarios. VRFire is intended to allow users to visualize wildfires from different perspectives to facilitate analysis and the experience of wildfires. Wildfire scenarios are constructed from remote sensing data combined with a computational simulation of fire spread and simulated atmospheric conditions. The immersive visualization facility hardware includes both a four-screen CAVETM-like Fakespace FLEXTM display, and a single-screen Visbox-P1TM and it is based on the open-source FreeVR and OpenSceneGraph (OSG) libraries.

2.8.3 Conclusion and Remarks

Fire propagation estimation is crucial for forest fire management. Although there have been a lot of attempts from many researchers in the last decades to model the behaviour of fire, its propagation estimation is still an open research issue. A challenging aspect for all this kind of applications is the accurate definition of all the parameters affecting the behaviour of fire e.g. topography of land, meteorological conditions and fuel characteristics. Existing models used for fire modelling can be classified into three basic categories: empirical, semi-empirical and physical models. Empirical models are based primary on statistics collected by observation of experimental or historical fires and their application is only feasible to the areas for which the models have been created. On the other hand, physical models are based on fluid dynamics and laws of conservation of energy and mass. Physical models provide more accurate results; however, their use is limited, since they require high computational power and accurate input data. For these reasons semi-empirical models are considered as the most appropriate for fire simulation applications. Semi-empirical models combine the analytical formulation of physical phenomena with statistical information measurements. The most known semi-empirical models are: Rothermel model, Huygens model and Cellular Automata. The Rothermel model is the most popular model. It is the base of the widely used BEHAVE and FARSITE simulation programs. For the visualization of the predicted fire, Geographic Information Systems (GIS) are used, as they can provide a user-friendly environment for representing all types of information and data needed for wildfire planning requirements. Recently, 3D graphics and virtual reality technologies have also been applied to provide a realistic and intuitive 3D visualization of the area of interest.

2.8.4 References

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2.9 Commercial Fire Detection and Management Systems

2.9.1 Indoor (Industrial/Residential) fire alarming systems

2.10.1.1 Introduction

One of the first and most important systems of buildings and industrial structures to protect against fire are fire detection systems. Fire detection systems allow quick response and increase the security of life and property. Field personnel receive alarms and notifications from such systems at the earliest level. Fire Detection Systems consist of three main elements that form the system and work together to provide fire detection and notification:

I. Sensors
II. Control Server
III. Warning Elements

I- SENSORS:

1. Smoke detectors

Typically, two kinds of smoke detectors are widely used in indoor applications at smaller facilities (offices, businesses, houses, hotel rooms, hospital rooms, general-purpose warehouses, etc): ionization sensors or photoelectric sensors [1]. However, such sensors can still report false alarms, so many researchers tried to solve this problem by fusing input from different sensors to solve this problem. A more complete classification of smoke detection technologies is as follows:

a. Ionization Smoke Detectors

This type of detector has a structure which contains radioactive material. The air in the detector's chamber ionizes by reduction of radioactive substances. High-energy open-flame fires which extract small smoke particles are quickly detected by ionizing smoke detectors.

b. Photo-Electric Smoke Detectors

Photo-electric smoke detectors are based on the principle of distribution of light or its absorption by smoke. Optical smoke detectors are successful in finding fires extracting large and low-energy particles of smoke. The Filtrex™ smoke detector is a specially enclosed photo-electric smoke detector that pulls smoke and dust to photoelectric sensing chamber and simultaneously eliminates dust through a small air fan and with high-density air filters. It can provide accurate detection will reduced false alarms in the most severely polluted and dusty environments. It also reduces the need for frequent maintenance for smoke detectors caused by pollution and can be integrated fire alarm system. Applications areas include textile factories, paper factories, furniture factories, grain stores, flour factories, cement factories, coal plants, etc.

c. Beam Type Smoke (Beam) Detectors

Beam detector set consists of a transmitter and a receiver. Light is emitted from the transmitter unit and the receiver unit receives the signal. An alarm is activated when the detector sensitivity falls below a threshold value.

Beam detectors are suitable for larger venues, such as warehouses, atriums, factories, cinemas, sports venues such as the large and high ceilings, where the use of point-type smoke detectors is not recommended.

d. Duct Type Smoke Detectors

This type of detectors is used in places where ventilation is present, such as central air conditioners. They perceive faster than point-type detectors and are suitable in places/situations where air velocity is high.

e. Laser Smoke Detectors

These detectors are based on laser smoke sensing and respond quickly and accurately to smoky fires and intense flame. They are 100 times more sensitive than Spot-type smoke detectors. They are used at places where require sensitive detection such as museums, historic buildings, etc.

2. Heat / Temperature Sensors

These detectors report the alarm information to the control center by monitoring the effect of the heat generated during the fire and temperature rises at certain situations. The response time is higher than smoke detectors but false alarm conditions are less visible and more secure. They are typically used at placed where smoke detectors cannot be used, e.g. dusty and smoky places or situations where there is constant high humidity and heat which disrupt the operation of smoke detectors. Examples include dusty and smoky production halls, kitchens, garages, laundries, etc.

a. Standard Heat Detector

An element exists whose resistance changes when temperature rises (fixed temperature heat detector). This resistance is sensitive to heat and warming will decrease its value. Shows a high value when it is cold. This detector is activated when the temperature is between 58^{o} C and 78^{o} C.

b. Growth Rate Heat Detector

These detectors will give the alarm signal perceiving of up to 8 - 10oC ² sudden increases in temperature, regardless of the ambient temperature. These types of detectors return to old state when the ambient temperature decreases. They are much faster than standard heat detectors.

c. Line Type Heat Detector

They are heat detectors in the form of the cable and detect early overheating of devices and cables. They are placed where cables and ventilation ducts, board rooms and generators are available. A pair of these detectors basically consists of conductive and heat resistant cable. These cables normally are separated by a protective layer that is melting heat. When ambient temperature reaches the value specified protective coating melts and creates a short circuit by touching the wires, thus triggering the alarm system.

3. Combined Optical/Heat Detector

Consist of two independent sensing technologies. Combined optical and heat detectors are used in places where products of first combustion is smoke or heat such as IT and server room etc.

4. Flame Detectors

Flame detectors detect the infrared or ultraviolet radiation occurred during a fire and gives out alarm and can provide rapid detection. UV - IR - UV / IR flame detectors can be selected according to the site to be protected. They are used in indoor environments containing very flammable material such as fuel, paints, solvents, explosive liquids or gases etc, warehouses or aircraft hangars.

5. Gas Detectors and Extinguishers

The principle of gas fire extinguisher is remove flammable material from the environment. For this purpose, fire alarm detectors are used to prevent potential explosion by giving alarm if it is determined that limits are exceeded for natural gas, methane, propane, hydrogen, acetone, etc. flammable and explosive gases.

Explosion limit for each gas is different. Therefore, Gas Detectors, for each gas are produced in different properties. A semiconductor gas sensor unit is structured in them.

6. Humans pressing Fire Alarm Buttons

People are very advanced fire detectors. Fire Alarm buttons, found in various types, can be used to report a fire perceived by people.

II- Control Server

This server can be considered as the brain of system, evaluating information from sensors and producing alarms and notices when needed.

III-Warning Elements

Sound and/or light alarm modules that are used to warn about the presence of fire determined from a fire alarm system.

2.10.1.2 Standards for fire and smoke detection in indoor environments

Three important standards for fire and smoke detection already exist:

- **the European EN 54 standard** [2] specifies requirements for all component parts of a fire alarm system and consists of a number of parts each related to specific sensor technologies, power supply, etc.
- **the Dutch NEN 2575 standard** specifying requirements and standards related to evacuation alarm systems that are meant for emergency situations such as fire
- **the UK BS5839 suite of standards** relate to specific areas of application for fire detection and alarm equipment. BS5839-1, refers to public premises and is a comprehensive code of practice for fire detection and alarm systems, the requirements relate to both life and property protection and the standard includes much advice and comment with is very useful in informing the providing background information to the building owner or system specifier. The standard has been developed through input from the whole fire detection industry over a period of 30 years and is the distillation of expert opinion and practical advice.

2.10.1.3 Research systems for fire and smoke detection in indoor environments

Neural networks and expert systems have been used to reduce false alarms when using multiple (and different) smoke sensors [3], [4].

An optical smoke detector along with a temperature sensor are used in [5], where a fuzzy expert system is used to issue alarms where needed. Optical smoke detectors were seen to be more robust compared to ionization smoke detectors.

In [6] rising rate of CO concentration was seen to appropriately indicate nonflaming fires while rising rate of CO2 concentration was seen to properly indicate flaming fires.

A new flame detector sensor along with a fuzzy-wavelet or multi resolution fuzzy system technique is used to distinguish between fires and possible interferences in [7].

In this new patented detector, the light emitted by a flame is analyzed with 3 sensors working each at a different wavelength. The algorithms in the detector combine the information obtained in the spectral domain with the results of a time-frequency analysis (Fuzzy-wavelet) to recognize the fingerprint of a flame and exclude possible false alarms due, for instance, to the flickering of the sun reflected on a water surface.

Gottuk et al [8] studied a number of sensor combinations for different fire and noise scenarios. They finally concluded that ION(ization) and CO sensors are the best sensor combination and a threshold approach based on (ION ×CO) ≥10 condition is an optimal algorithm to separate fire sources from noise. Their conclusions can be summarized as:

- Ionization detectors are advantageous for flaming fire detection,
- Photoelectric detectors are beneficial for non-flaming fire detection,
- Combining CO and Ionization sensors can more accurately detect fire.

Chen et al. [9] used combination of three sensors i.e., smoke, temperature and CO, as well as a fuzzy system technique to fuse the sensory data.

Cestari et al. [10] investigated different sensor combinations with some multi-criterion functions and after several experiments they concluded that:

- Ionization detector is more beneficial for detecting flaming fires,
- Photoelectric detector is more beneficial for detecting nonflaming fires,
- Ionization and photoelectric sensors are noise sensitive,
- Rising rates are more helpful for flaming fires,
- CO and temperature's rising-rate improve noise immunity,
- Combination of temperature's rising-rate together with CO and ionization can lead to an accurate, yet noisy immune, classification.

Although temperature sensors are probably the simplest and the most obvious sensors for fire detection, most researchers agree on the fact that they alone cannot be used to reliably detect fire and avoid false alarms.

2.10.1.3 Commercial systems for fire and smoke detection in indoor environments

Most large suppliers of fire and smoke detection systems for indoor use participate in the NFPA (National Fire Protection Association) conferences and Expo organized every year in US. Just to name a few:

- Product – Company – Country – Web site - Description
- Air Intelligence - Air Intelligence/UTC Fire & Security – US - http://www.air-intelligence.com/ - Advanced smoke detectors
- Apollo Fire Solutions - Apollo Fire Detectors Ltd – UK - www.apollo-fire.com - Fire alarm and detection system
- Asbuilt IP-Based Life Safety Systems – US - http://www.asbuiltes.com/ - Smoke detectors
- FireRay – Fire Fighting Enterprises Limited - UK/US - http://www.ffeuk.com/ - Optical beam smoke detectors
- EST, Vigilant, FireworX – General Electric - US - http://www.gesecurity.com/portal/site/GESecurity - Integrated Fire and Life Safety Solutions
- AlarmEye – Innosys – Taiwan - http://www.innosys-ind.com/ - VISFD Distributed Intelligent Video Image Smoke and Flame Detecting System is a dependable fire detecting system for use in large spaces (such as exhibition hall, stadium, aircraft hanger, shopping mall, huge warehouse, and big factory, etc) and unusual structures (such as tunnel, petroleum and petrochemical production site, explosion hazard storage area, museum, subway, train station, and hospital).

- ORION XT HSSD®, Conventional and Intelligent Smoke Detectors and Linear Heat Detection – Kidde Fire Systems/UTC Fire & Security – US - http://www.kiddefiresystems.com/ - Ionization/Photoelectric/Thermal/High Sensitivity Smoke Detectors using Laser technology
- - King-Fisher Company, inc. – US - http://www.kfci.com/ - Systems and Modules for fire detection
- - Loss Prevention Certification Board - UK http://www.redbooklive.com/ - Provide certification for Fire detection and security systems
- Micro pack FDS-301 Visual Flame Detector and Surveillance Camera - MICROPACK (Engineering) Ltd – UK - http://www.micropack.co.uk/productdetails.htm - Imaging based flame detection and video surveillance using an explosion proof CCTV Camera.
- SDI Smoke Saber – SDI – US - www.smokesabre.com – Smoke detection tester (Pressurised aerosol)
- IFP-2000 – Silent Knight/Honeywell – US - http://www.farenhyt.com/ - Scalable/Networkable Intelligent Fire Alarm System for large infrastructures (mainly based on smoke detectors)
- Fire Detection and Alarm Products – SimplexGrinnel – US - http://www.simplexgrinnell.com/Solutions/FireDetectionAndAlarm/Products/Pages/default.aspx – Components for SimplexGrinnel Integrated Fire Detection and Alarm System
- Xtralis VESDA VFT-15 – Xtralis – US - http://xtralis.com/product_view.cfm?product_id=19 - High sensitivity smoke detector.

2.10.1.4 Indoor Fire alarm systems supplied by TITAN (Simplex Fire & Integrated Solutions/AlarmEye by SimplexGrinnell)

Integrated ULV (Ultra Low Voltage) systems are used to make many buildings to be more efficient, safe, secure and comfortable. Titan has been a “single source supplier” for many commercial and industrial ULV applications. Titan made many fire alarm systems of many hospitals, shopping malls, schools, airports, military regions and many others. Titan gives service to its customers by qualified staff of professionals and has many references about Fire Alarm Systems:

- Samsun Airport, Turkey
- Adana Airport, Turkey
- Istanbul Ataturk Airport
- Istanbul Sabiha Gökcen Airport
- Antalya Terminal-II, Turkey
- Buhara-Urgenc-Semerkant Airports, Uzbekistan
- Novosibirks Airport, Russia
- Baku Airport, Azerbaijan
- Naxçivan Airport, Azerbaijan
- Astana Airport, Kazakhstan
- Tashkent Airport, Turkmenistan
- Enfidha Airport, Tunisia

Titan is the distributor of **Simplex Fire & Integrated Solutions** in Turkey. Simplex Fire & Integrated Solutions have been used by Titan in all references mentioned in the above. Besides, it is also known that Titan has been using Simplex Fire & Integrated Solutions in many shopping malls and hotels projects in Turkey.

Simplex Fire & Integrated Solutions provides a wide range of Fire Detection and Alarm packages for both new build and upgrades to existing premises. Their solutions vary from a basic **"**Stand Alone**"** compact fire detection & alarm system for smaller applications through to a fully integrated analogue addressable networked to a large Building Management System.

Simplex capabilities for commercial facilities encompass the full Simplex portfolio: fire alarm, emergency communications, integrated security, and special hazards systems and services. They provide everything from small, standalone systems to networked, enterprise-wide solutions. For those networked solutions, they can provide advanced life-safety information management systems that monitor and control multiple panels and buildings from a single location.

Simplex Fire & Integrated Solutions fully endorses the National Fire Brigade CFOA RMFAS Policy on the reduction of unwanted false alarms. Their LPS 1014 approval ensures that every aspect of their work is independently audited and that their products and services meet the most stringent requirements.

All Simplex addressable panels rely on one of the most stable lines of detection devices in the industry: the patented **TrueAlarm**® line of detectors.

Simplex addressable initiating peripherals communicate with the control panel using **IDNet**™ communications. Devices include our patented TrueAlarm® line of sensors, one of the most stable lines of detection devices in the industry, as well as addressable modules that provide addressability to conventional devices such as flow switches.

Addressable Modules typically provide addressability to conventional devices such as flow switches. Simplex has a wide range of innovative addressable modules, including multi-point modules, modules which permit individual reporting from flow and tamper switches on the same circuit, and isolator modules which protect power wiring from short circuits and ground faults.

Simplex addressable stations can be either single or double action. The Simplex addressable station combines the familiar Simplex housing with a compact communication module. Its integral individual addressable module (IAM) constantly monitors status and communicates changes to the connected control panel via IDNet or MAPNET II communications wiring.

SimplexGrinnell offers specialized detection devices to complement our standard line of area and duct detectors.

Beam Detectors are single units that house both an infrared transmitter and receiver. The transmitter signal is reflected by a matching prism back to the receiver where the internal microprocessor analyzes it for the presence of smoke.

SimplexGrinnell is offering the **AlarmEye® Video Smoke and Flame Detection System** (http://www.simplexgrinnell.com/SiteCollectionDocuments/Fire%20Detection%20and%20Alarm/AlarmEye%20Distributed%20Intelligent%20VISFD%20Introduction%20brochure%20Simplex.pdf). The first and only UL-listed Video Image Smoke and

Flame Detection System (VISFD), the AlarmEye camera can detect flame and smoke in real-time video. It is well suited for large open spaces such as warehouses, exhibition centers, stadiums and industrial plants.

- Sensitive enough to detect smoke particles before visual detection by the naked eye
- Daytime and night time round-the-clock operation equipped with IR night vision technique

2.9.2 Commercial and Research systems for forest fire detection

Early detection of any fire always leads to its easier suppression and minimization of its consequences.

Early detection of fire is traditionally based on human surveillance. This can either be done using direct human observation by observers located on monitoring spots (e.g. lookout tower located in a high point) [11] or by distant human observation based on video surveillance systems.

Relying solely on human detection of forest fires is not the most efficient method. A more advanced approach is automatic surveillance and automatic early forest fire detection (either using a) airborne b) space borne (satellite) systems or c) terrestrial-based systems).

2.9.2.1 Satellite systems

Two of the most crucial problems for this task in forest areas are minimum detection delay and the resolution in the localization of the alarm [12]. Both of these constraints render satellite detection almost useless for early detection of forest fires, while further problems can be created by the possible presence of clouds in some areas.

Satellites orbit the Earth in a predictable way, following fixed predefined orbit.

Although polar orbits allow (almost) global coverage (e.g. SPOT VEGETATION (http://www.spot-vegetation.com/ produces a daily coverage of the entire earth at a spatial resolution of 1km), there is no way to avoid clouds over some regions, or make any alteration in this orbit. Therefore, some efforts to use earth-monitoring systems, such as the Advanced Very High Resolution Radiometer (AVHRR) and the Moderate

Resolution Imaging Spectroradiometer (MRIS), for forest fire surveillance have failed. Although the resolution of some satellites has been significantly improved (up to 0.6m at best for Quickbird and 1m for IKONOS), they cannot compete still the resolution of airborne and terrestrial systems. The main problem is the high altitude and speed of the satellites, which also creates problems with geo-referencing the obtained images [13]. Still, they can be very useful for visualizing the consequences of large scale events, such as big forest fires or tsunamis. Furthermore, the meteorological data offered by them (e.g. temperature, wind, rain, relative humidity) are successfully used to create fire danger rating maps (such as the FWI, Fire Weather Index).

2.9.2.2 Airborne systems

Airborne systems refer to systems mounted on helicopters (elevation < 1km) or airplanes (up to 2 to 10 km above sea level). They offer great flexibility, short response times and are able to generate very high resolution data (typically few cm).

Also, geo-referencing is easier and much more accurate than the satellites.

A drawback is the increased flight costs, flight limitations by air traffic control or bad weather conditions and limited coverage. Turbulences, vibrations and possible deviations of the airplane from a pre-planned trajectory due to weather conditions are additional problems. However, recently a large number of early fire detection projects use Unmanned Aerial Vehicles (UAVs) which can alleviate some of the problems of the airborne systems: they are cheaper and are allowed to fly in worse weather conditions. An interesting example in the US is the Wildfire Research and Applications Partnership (WRAP, http://geo.arc.nasa.gov/sge/WRAP/) of NASA, the US Forest Service and the National Interagency Fire Centre focusing on research and development using piloted and UAV aircraft, advanced sensors, and data distribution technologies to improve information gathering over wildfire disaster events and for reduction of detection delays. In another collaboration between NASA and US Forest Service, AIRDAS (http://geo.arc.nasa.gov/sge/brass/Brass.AIRDAS.html), a new advanced sensor that can accurately measure fire temperatures, was mounted on UAVs for FiRE (First Response Experiment) experiment (http://geo.arc.nasa.gov/sge/UAVFiRE/completeddemos.html) and was successfully used for fast information acquisition and processing for disaster management.

2.9.2.3 Terrestrial systems

The terrestrial systems based on CCD video cameras sensitive in visible and near IR spectra are today the best and the most effective solution for realizing automatic surveillance and automatic forest fire detection systems. In most countries, which encounter high risk of forest fires one or more such systems was developed and proposed.

Some commercial video-based fire and smoke detection systems are described below. In all those systems automatic forest fire detection is based on smoke recognition during the day and flame recognition during the night.

- **INPAS - Integral Forest Fire Monitoring System.** Croatia have used a system called Integral Forest Fire Monitoring System (in Croatian IPNAS) [14] developed at the Faculty of Electrical Engineering, Mechanical Engineering and Naval Architecture University of Split. The system is based on remotely controlled video cameras on monitoring spots, so that the human observer is not located on the monitoring spot anymore. The observation station is the monitoring center equipped with adequate video presentation and video storing devices connected with wires or wireless to distant video cameras located on monitoring spots. Thus, the human observer is capable of monitoring a wider area covered by few video monitoring field units, while power zoom and video storing capabilities are also available.

- **NLNT - National Lookout Towers Network [15].** In Portugal the National Lookout Towers Network (NLTN) is the principal organized fire detection system, working together with some ground and aerial mobile units. NLNT is an organized fire detection system, having a total of 236 observation posts. These posts have been placed gradually over the last decades, resulting in a under optimized network. is an important element in fire detection in some Portuguese regions, while in others it only detects a very low percentage of total wildfires

The NLNT has proved to be an important element in fire detection in some specific Portuguese regions, while in others it only detects a very low percentage of total wildfires. In general and proportionally it seems that NLNT is more efficient during the day than other detection systems, but less efficient at night. Geographic Information Systems (GIS) are now researched to improve fire detection effectiveness.

- **ForestWatch (**http://www.evsolutions.biz/Forestwatch-index.php **)** is a smoke detection system used for early detection of forest fires from the South African company Envirovision Solutions. It operates in the visual and near infra-red spectrums and can therefore operate throughout the hours of darkness to detect smoke and the source of forest fires. It is a software programme that uses algorithms of movement detection. The system uses a network of video cameras placed in various towers in the forest. A video software program transmits the data that connects the towers with a central monitoring center. However, the system is semi-automatic: a watchperson observes the video transmissions and records any presence of smoke. ForestWatch can operate 24 hours a day, 7 days a week, and is precise even at night with each camera being able to record up to a distance of 40 km.

- **ForestAngel (http://www.forestangel.com/)** is a forest fire detection system that can be used to protect special interest areas or complete forests. The system is based on one or more autonomous remote look out stations, a centralised processing server and the overview console. The forest fire detection software used is based on an advanced, proprietary, multiple-input algorithm. Using a highly effective detection software the user can easily and effectively detect forest fires as soon as they develop.

The system supports input from Live meteorological feed, uses a user-friendly interface, displays the location of fire source in a geographical map. It can also employ autonomous remote stations powered by photovoltaic panels.

- **FireHawk** (http://www.firehawk.co.za/) is another video-based early forest fire detection system from South Africa (Digital Imaging Systems company). FireHawk is a computer aided forest risk management system that is controlled by a human operator.

- **Firebug and ForestVu** (http://www.dtec-fire.com/fire_products_page.htm) are advanced Video Smoke Detections platform from Detector Technologies in England.

They detect presence of smoke from available analogue camera inputs (PAL or NTSC). Operators are alerted either remotely over the system's network or local to the unit via relay outputs. FireVu is a Video Smoke Detection system while ForestVu is able to identify smoke and flame generation at the source.

- **Urafire (http://www.uratek.com/applications.php?5)** is a software for fire forest early detection by the French Uratech company. A fast algorithm adapted to the extraction of complex motions in small spatial envelopes is used. The principle of the method is to extract local motions from cluster analysis of points in a multidimensional temporal embedding space. More specifically, four successive steps are used: temporal embedding of gray-levels, fractal indexing of points, chaining points into a linked list, and motion extraction from point sequences of the linked list.

- **FireWatch (http://www.fire-watch.de/cms/)** is a digital, remote forest fire surveillance system from the German company DLR (Deutches Zentrum for Luft and Rauhmfahrt), however this product is now marketed by their industrial partner *IQ-Wireless* . The system is capable of observing larger wooded regions, and to analyse, evaluate, link and store the collective data. FireWatch is able to evaluate and classify the incoming data in multiple ways, connected to a central station. In the event of a recognized source of fire, it automatically sends out an alarm. FireWatch has been successfully installed in several regions in Germany and can protect efficiently entire ecosystems and cultural landscapes.

- **ADELIE** (http://www.paratronic.info/feux/) is an early warning video smoke detector system. Installed on high points or existing watchtowers, a set of video continuously monitors the sensitive area of 360° with a range up to 25km. The information locally developed is transmitted in real-time to an operations center. A visual and audible warning indicate to the operator the existence of a detected smoke, while corresponding images to confirm the alert are also provided.

- **Forest Fire Detector System (**http://www.sensiblesolutions.se/index.php?option=com_content&task=view&id=24&Itemid=35 **)** Sensible Solutions Sweden has in its design laboratory a family of small, low-cost, non-serviceable radio communicating fire sensors to work with a early forest fire detection system. Lightweight sensor units carrying electronic identity numbers are to be placed in the trees (from the air or from the ground). When subjected to high temperatures the (fire) sensor for few seconds transmits radio signal with unique identity code. Fire position is identified on detecting the alarm transmission, when sensor ID is linked to deployment location through the database. This strategy significantly increases fire detection speed and reliability, especially in cases when few sensors transmit together. Alarm signals are retransmitted through Gateways, placed about 5-10 Gateways per square km depending on the type of terrain and provides data linking through GSM-text/data, 3G, WiMAX or other medium. Developed sensors are environmentally friendly and do not contain dangerous materials or do not produce them when incinerated.

- **SigniFire™ Video Smoke Detection System** (http://www.axonx.com/products.htm) is the main Fire and Smoke Detection module in a suite of AxonX (American company) for Video Fire Smoke and Intrusion detection. The products pare easily configurable to address the needs of any particular customer. Guards and administrators monitor and configure systems over a local area network or remotely using the Internet. FSM-IP NVR's (Network Video Recorders) with each capable of handling as many as 32 cameras can be used to allow continuous recording and on-demand playback of any video.

- **V-MOTE (Bioinspired VLSI implementation of concurrent image sensing/processing at the nodes of a wireless sensor network** http://www2.imse-cnm.csic.es/vmote/english_version/proyecto.php**)** The main effort in this project is focused on designing a vision chip intended to segment and detect dynamic textures by means of bioinspired energy-efficient focal-plane processing. The vision system-on-a-chip will be able also to realize complex algorithms with a more conventional processor. Finally, as a direct application of such a chip, we have developed a new approach for very early detection of forest fires by means of visual smoke detection.

2.9.2.3.1 Comparative evaluation of commercial smoke detection systems for forest fires

An interesting comparative study of commercial smoke detection systems was made at 2004 by The Forest Engineering Research Institute of Canada (FERIC), which evaluated three systems in terms of smoke detection capability and suitability to Alberta's and Saskatchewan's fire management programs [16],[17]. Specifically, one manual system by Norsat Communications and two semi-automated systems, namely ForestWatch by Envirovision Solutions of South Africa, and Fire Watch™ by IQ-Wireless GmbH of Germany, were evaluated. The two semi automated systems were found to be more reliable than the manually controlled system because the potential for oversight, likely to happen due to operator fatigue, is removed. The two semi-automated systems were similar in their capability to detect smoke, but differed in user features and hardware configuration. Integration with GIS data, allowing the operator to quickly identify smoke location is another advantage of the semi-automated systems over the manual system. These evaluations can be used by FIRESENSE as a useful resource of desired advantages and undesired disadvantages that will have to be taken into account when designing the FIRESENSE system.

2.9.2.4 Wireless sensor networks

Many systems for early fire detection using Wireless sensor networks have been proposed in the literature [18],[19]. In a recent interesting work, information from FWI is exploited for early fire detection. In [20],[21], where Wireless Sensor Networks are efficiently deployed for early fire detection at small forests or particular sensitive infrastructures. The only available commercial and practical WSN system consists of Waspmotes provided by Libelium [22]. This project is noteworthy in that a forest area of 210 hectars in Spain has been monitored with 90 Waspmotes measuring relative humidity, CO and CO_2 every 5 minutes. The motes can be equipped, among many others, with boards such as Methane (CH_4), Isobutane (C_4H_{10}) and atmospheric pressure as well. Each sensor board's power can be adjusted separately and in real time, in order to conserve energy for data collection of relatively higher importance.

2.9.3 References

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2.10 Related EU Projects

In the following tables many related EU projects are briefly described. The projects were classified into the following categories:

Fire and Flood Detection – focus on Sensors and Early detection

Fire and Flood Management and Risk Analysis – focus on Management and Risk analysis

Protection of Cutural Heritage from Fire and Flood – projects protecting Cultural Heritage from Fire and Flood

Smart sensor networks/architectures – focus on WSN and smart sensor architectures (most for Risk management applications)

Communication-focused sensor networks – Communication aspects of WSNs

Some older EU Projects (1996-2001) related to the development of new technologies for early fire detection, fire danger prediction, or post-fire rehabilitation and management include MEGAFIRES(1996–1998), AFFIRM(1996–1998) (Video surveillance for fire for small forests [1]), EFAISTOS(1996–1998), FUEGO2(1998–2001) and RISCOFF(2000–2001).

EU Projects – Fire and Flood Detection		
Acronym, Title	***Programme type, Duration***	***Description***
EU-FIRE (http://www.eufire.org/about-eufire.htm)	*FP5 IST, 2006-2009*	Integration and the experimentation of innovative optoelectronic and acoustics technologies to design a really modern and efficient fire monitoring system and to develop a prototype in order to demonstrate the feasibility of a large scale forest fires long term monitoring.
DYVINE (Dynamic Visual Networks, http://www.dyvine.org/)	*FP6 IST, 2006-2008*	(a) Integration of thousands of video sensors, fixed or mobile, in situ or airborne, and the development of exploitation applications for area monitoring to support the Risk Management cycle (b) the associated resilient communication solutions to support the system. Testing will be performed in urban environment with the integration of the city camera networks through Rescue scenarios. Test Scenarios: Flood in Valencia / Truck accident with fire/smoke at Milan / Earthquake at Miraflores.
SCIER: Sensor & Computing Infrastructure for Environmental Risks, http://www.scier.eu/)	*FP6 ICT, 2006-2008*	integrated system that will assist the citizens to profit from a better safety against natural or man made hazards, and to respond in time in order to reduce the potential damage to their property. Various sensors have been considered for Fire (Temperature, Relative humidity / precipitation, Illumination, Wind speed/direction, Atmospheric pressure, Smoke, Vision) and Floods (Water Level, Rain, Vision).
DEDICS, Distributed Environmental Disaster Information and Control System, [2], [3]	DG XIII, Telematics Applications Programme	DEDICS is a telematics tool designed to facilitate environmental fighting. A system for early detection of forest fire using several sources of information (thermal

	(Environment Sector), EN 1003, *FP4*	images, video images, metheorological data, GIS data) was designed and integrated in a Telematic system with real time decision support tools to assist the operators in the forest fire fighting. The system used Artificial Intelligent Techniques for false alarm reduction.
100 Flood-related projects funded by EU between 1984 and 2006 (FP1-FP6)	*FP1-FP6,* *1984-2006*	Flood-related EU Projects, See [4] for details.

EU Projects – Fire and Flood Management and Risk Analysis		
Acronym, Title	***Programme type,*** ***Duration***	***Description***
AUTO-HAZARD PRO, Automated fire and flood hazard protection system	*EESD,FP5, 2002-2004*	*Integrates real-time and on-line fire and flood hazard management schemes into a GIS-type platform. It was developed in EU Member-State Disasters Management and Civil Protection Agencies. Collection, input, storage, management and analysis of the information will depend on advanced and automated methodologies using Remote Sensing, GPS, Digital Mapping and GIS. Proactive development of such infrastructure will assist in fast and realistic prevention and pre-suppression planning, real-time fire suppression operations, and rehabilitation of burned areas. Developed products include: wildfire danger rating indices; Flood danger index; Weather forecasting modeling; Autonomous fire detection system; On-line operational decision support system; Training of personnel; Dissemination of information and technology transfer.*

FOMFIS, Forest Fire Management and Fire Prevention System	*ENV 2C,* *1997-1998*	Aimed to provide a preventive tool for use by public and private organisations responsible for the management of forests for planning strategies to prevent fires and for distributing fire fighting resources. FOMFIS aimed to integrate a number of existing technologies in a unique and original way by concentrating on the practical aspects of forest management. The technologies that were applied are: fire prevention planning probabilistic techniques, expert and knowledge based systems, remote sensing, geographic information systems, forest fire behaviour models and fire risk analysis techniques. Each of these technologies has significant potential which can be used to create an operationally useful system.
Definition and creation of a common knowledge base for forest fire	*ENV 2C, FP4,1998-1999*	Formation of a thematic network for the organisation of existing knowledge on the topic of forest fires, through the creation of a knowledge base. This knowledge base will be collectively created by the partners, who all have established expertise in the area of forest fires, covering different aspects of the matter. Three thematic groups will be formed covering the subjects of: - forest fire risk assessment and fuel modelling - forest fire bahaviour modelling and - forest fire suppression and post fire effects.
FIREGUARD, *Monitoring forests at the management unit level for fire prevention and control*	*LIFE QUALITY, FP5, 2002-2005*	Addresses fire prevention and control in the Mediterranean region. The main focus of this project will be on long-terming fire prevention. Fire prevention,

		pre-suppression, and suppression all require information on fuelcharacteristrics (e.g. composition, structure, spatial distribution), infrastructure, and terrain (topography). This information is required in a timely and accurate manner, and in a format that is easy to handle and use for integrating into strategic plans for fire suppression management. The information will be designed for the district and sector forest unit level, but be capable of being integrated to higher levels, as necessary. The aim of this proposal will be to create an Internet application to assist forest managers in long-term fire prevention management.
FIRESMART, Forest and land management options to prevent unwanted forest fires	*FP7-Environment,* *2010-2012*	*The project will make a contribution to the prevention of unwanted forest fires. To this purpose the Consortium will retrieve, from institutions operating at several scales, the fire prevention theories and practices currently in use in the Mediterranean Europe. This information will be analysed meticulously in order to evaluate the strengths and weaknesses involved in fire prevention taking into account socio-economic, institutional and legislative aspects. The analysis will lead to the assessment of the existing different options to overcome the actual difficulties and to the subsequent elaboration recommendations and practical guidelines for stakeholders involved in the entire sustainable management chain of silviculture. Finally, using findings obtained in along the project, the Consortium will*

		elaborate the strategic roadmap that will point the path to follow in the future.
CLIFF, Cluster Initiative for Flood and Fire emergencies	IST, FP5, 2000-2002	Improves on -going disaster management (DM) applications as well as simplify the development of new systems by increasing and optimising the contribution of earth observation (EO) data. CLIFF will support this objective by paving the way towards the standardization of the various components making a typical EO enhanced emergency system. Standardization will help closing the gap between the different actors such as end-users (e.g. Civil Protection) and specialists (EO data providers, modellers) that could eventually share a common technical language. It will also stimulate the development of an operational European service market supported by the sharing of procedures, interfaces and resources (e.g. cross-projects telecommunication links).
FORFAIT, Forest Fire Risk Hazard Assessment: A Holistic Approach	FP5 IST, 1999-10649	The project sets out to develop a Decision Support System (DSS) in order to assist planners, regulators and industries in optimising the forest fire risks management. This system consists of three different kinds of applications: • planning of fire prevention actions; • coordination of personnel training activities; • simulation of critical stages. FORFAIT is based on the integration of various information sources, such as

		satellite downlink, meteorological data, state-of-the-art predictive models, or involved professionals expertise and knowledge. Any decision process will be aided by a support system based on fuzzy logic to suggest the most appropriate course of action; also a probabilistic framework, which will take account of uncertainty in the parameters, will help.
EUFIRELAB, Euro-mediterranean wildland fire laboratory, a "wall-less" laboratory for wildland fire sciences and technologies in the euro-mediterranean region, http://www.eufirelab.org/	*EESD, FP5,* *2002-2006*	Euro-Mediterranean Wildland Fire Laboratory (EVR1-CT-2002-40028) . EUFIRELAB will enable large exchange of knowledge, know-how, data, results and analysis for improving the level of the wildland fire sciences and technologies in the Euro-Mediterranean area. Specifically, a large database on existing publications and references and manin actors in the forest fire research community is freely available in several languages.
FIRE PARADOX, An innovative approach of Integrated Wildland Fire Management regulating the wildfire problem by the wise use of fire: solving the FIRE PARADOX, www.fireparadox.org/	FP6-SUSTDEV, *2006-2010*	Wildfires are a major problem for many European societies threatening human lives and property with disastrous impacts particularly at the wildland-urban interface. On the other hand humans always used fire as a tool to regulate nature and traditional use of fire is known in many regions of Europe. The understanding of this paradox, is thus essential for finding solutions for integrated wildland fire management.This concept requires considering the various aspects of fire, from its use as a planned management practice (prescribed fire) to the initiation and propagation of unplanned fires (wildfires) and to the use of fire in fighting wildfires

		(suppression fire). Prescribed or suppression fires will therefore set the limits for wildfires by controlling their spatial extent, intensity and impacts.This is the main approach adopted aiming at the creation of the scientific and technological bases for new practices and policies under integrated wildland fire management and in the development of strategies for its implementation in Europe. Three major domains of related activities were considered: research, development and dissemination. In research, the project will focus on understanding the mechanisms and modelling the processes associated with fire, from physics to biology and social sciences. Experimental and sampling methods will be used , while documentation and demonstration platforms will also be extensively used for dissemination.
FUME, Forest fires under climate, social and economic changes in Europe, the Mediterranean and other fire-affected areas of the world	*FP7 ENV, 2010-2014*	FUME IP will study the interactions between land-use and land-cover changes, socioeconomic changes and climate change. The objectives will be, first, to understand how these factors interacted in the past to produce forest fires and, second, to model future changes in all these components to produce the best available projections on how forest fires might change in the coming decades. Special attention will be given to the projected increases in climate and weather extremes (drought, heat waves) since under such conditions fires become more devastating. FUME will produce, among other things, the most complete cartography

		of forest fires in Europe, and will identify the factors that were behind fires, particularly, large forest fires. Maps with future risk will also be produced as well as an evaluation of the vulnerability of the vegetation to the new conditions. Threats for regenerating ecosystems under climate extremes, particularly drought, will also be investigated. FUME will revise current protocols to deal with extreme fire situations, in order to anticipate the changes in preparedness that will be needed. Additionally, restoration strategies in the light of the new conditions will also be developed. Training activities and close relationships with users are foreseen to keep research aligned to the actual needs, and procedures for quick transfer of knowledge to application by managers are also a main objective of this project
OASIS, Open Advanced System for dISaster and emergency Management, http://www.oasis-fp6.org/	*FP6 ICT IP,* *2004-2008*	Development and Testing of New IT Tools for Disaster and Emergency Management (including fire fighting).
ORCHESTRA, Open Architecture and Spatial Data Infrastructure for Risk Management, www.**eu-orchestra**.org/	*FP6 ICT IP,* *2004-2008*	Design and implementation of the specifications for a service oriented spatial data infrastructure for improved interoperability among risk management authorities in Europe, based on a novel open architecture that is based on standards
FIREMENTOR, http://www.firementor.gr/images/docen.pdf	*Greek project.* *2004-2006*	A Greek research project, co-funded by the Greek government, focusing on the provision of services for decisions and operational support in forest fire suppression. Self organizing fire

		sensor networks were used for various applications like creating fire suppression scenarios, solving operational logistics problems and/or simulating and getting prepared for extreme operational situations. The system locates the ignition points and sends information about the propagation of fire to the server to facilitate fire management and suppression.

EU Projects – Protection of Cutural Heritage from Fire and Flood		
Acronym, Title	***Programme type, Duration***	***Description***
FIRE-TECH, Fire risk evaluation to european cultural heritage: quantification of priorities and optimisation of fire protection strategies	*EESD, FP5, 2002-2005*	*Damage by fire is one of the most important threats to cultural heritage. The financial resources available for the fire protection are limited and priorities need to set by authorities and owners of cultural heritage. Actually no scientific tool is available to assist in the decision process. A quantitative decision method will be developed, able to prioritise between series of projects. on the basis of parameters such as value of cultural heritage, fire risk, the protection methods available - their cost and efficiency. As input to this decision method, a valuation method and risk analysis method based on statistical data on fire damage in cultural heritage will be developed. Fire protection methods will be examined on their efficiency, cost and applicability on cultural heritage.*
PROOHF, PROtect Our Heritage from Fire [*http://www.proohf.net/*](http://www.proohf.net/)	*INTERREG III ARCHIMED* *2006-2008*	Cultural Heritage Monuments (Monasteries, Museums, etc) in European Countries have a large number of invaluable treasures but often monuments are located in isolated areas, sometimes inside forests, being in great fire risk with little means to respond. The over-all objective of PROOHF project is to cope with fire risks in cultural heritage monuments, and their impact on local economies and societies. Some sub-

		objectives are: (1) Collect, catalogue, document, discuss and optimize all aspects of already existing emergency plans and procedures for coping with fire risks in heritage monuments. (2)Record and present fire status of the heritage monuments. (3)Search for possible causes which initiated fires in the past and creating a full record of all relevant conditions. (4)Develop training programs for educating people working /living there, train volunteers, foresters and civil protection personnel, as well as other operational people in coping with fires in monuments & taking measures minimizing the economic and social impact. (5)Develop post-fire-rehabilitation plans (6) Develop three pilot fire risks analysis decision support systems (one per participating country).
CLIMATE FOR CULTURE, *http://www.climateforculture.eu/*	*FP7 ENV, Climage change* *2010-*	Climate change, coupled with the increasing demand our society makes on energy and resources, has forced sustainable development to the top of the European political agenda. Scientific research shows that the preservation of the cultural heritage of Europe is particularly vulnerable to these factors. The CLIMATE FOR CULTURE project will assess the damage potential of climate change on our cultural heritage, its socio-economic impact and possible mitigation strategies. Collections in historic buildings in different parts of Europe will be included for in situ investigation of present problems and for the prediction of future issues. For this purpose and for the first time ever, high resolution climate evolution scenarios will be coupled with whole building simulation models to identify the most urgent risks for specific regions with the aim of developing mitigation strategies. The thus identified risks, and the economic consequences, for European cultural heritage will be communicated to policy makers together with possible mitigation strategies to be

		included in future IPCC Reports.

EU Projects – Smart sensor networks/architectures		
Acronym, Title, webpage	***Programme type, Duration***	***Description***
OSIRIS (Open architecture for Smart and Interoperable networks in Risk management based on In-situ Sensors, http://www.osiris-fp6.eu)	*IST, FP6, 2006-2009*	*- Service oriented architecture addressing the smart deployment, use and reconfiguration of in-situ sensor systems – Related test scenarios: a) Forest Fire (France) scenario, where an advanced fire-fighting strategy is required, b) Industrial Risk Management scenario: Indoor industrial fire threats (Germany), where the early detection of fires and reduction of false alarms combined with information management and response action support is necessary.*
WINSOC (Wireless Sensor Networks with Self-Organization Capabilities for Critical and Emergency Applications, http://www.winsoc.org/)	*IST, FP6, 2006-2009*	Advanced self-organizing networks: innovative design methodology, mimicking biological systems, where the high accuracy and reliability of the whole sensor network is achieved through a proper interaction among nearby, low cost, sensors
SANY (SANY Sensors Anywhere, http://www.sany-ip.eu/)	*IST, FP6, 2006-2009*	General architecture SensorWeb. This IP has produced CHARON general framework for Service Access Control (SAC) in Service Oriented Architectures (SOA): http://www.enviromatics.net/charon/ Risk management applications include Fire and Flood scenarios

EU Projects – Communication-focused sensor networks		
Acronym, Title, webpage	***Programme type, Duration***	***Description***
WIDENS (Wireless Deployable Network System, http://www.comlab.hut.fi/projects/WIDENS/)	*IST, FP6, 2004-2006*	Wireless ad-hoc communication system for future public safety, emergency and disaster applications.

U2010 (Ubiquitous IP Centric Government & Enterprise Next Generation Networks, Vision 2010, http://www.u-2010.net/)	*IST, FP6, 2006-2009*	Provide communication and access to information in case of accident, incident, catastrophe or crisis. Test scenario: Heavy accident with fire in the tunnel
WISECOM (Wireless Infrastructure over Satellite for Emergency COMmunications, www.wisecom-fp6.eu/)	*IST, FP6, 2006-2008*	rapidly deployable lightweight communications infrastructures for emergency conditions - GSM, UMTS and TETRA over satellite
EUROPCOM (Emergency Ultrawideband RadiO for Positioning and COMmunications)	*IST, FP6, 2004-2008*	UWB radio technology to improve reliability of communications – measuring and reporting the location and status of personnel at emergency situations.
WISEBED (Wireless Sensor Network Testbeds, www.wisebed.eu):	*IST, FP7, 2008-2011*	Aims to provide a multi-level infrastructure of interconnected test beds of large scale wireless sensor networks for research purposes, pursuing an interdisciplinary approach that integrates the aspects of hardware, software, algorithms, and data. This will demonstrate how heterogeneous small-scale devices and testbeds can be brought together to form well-organized, large-scale structures, rather than just some large network; it will allow research not only at a much larger scale, but also in different quality, due to heterogeneous structure and the ability to deal with dynamic scenarios, both in membership and location.
CHORIST (Integrating Communications for enhanced envirOnmental RISk management and citizens safeTy– www.chorist.eu)	*IST, FP6, 2006-2009*	Environmental Risk Management in relation to natural hazards and industrial accidents. It proposes solutions to increase rapidity and effectiveness of interventions following a major natural and/or industrial disaster in order to enhance citizens' safety and communications between rescue

		actors.

2.10.1 References

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[2] Begoña C. Arrue Aníbal Ollero and J. Ramiro Martinez De Dios, "Distributed Intelligent Automatic Forest-Fire Detection System", Proc. INNOCAP'99, Grenoble, France.
[3] A. Ollero, J.R. Martinez-De Dios And B.C. Arrue, Integrated Systems For Early Forest-Fire Detection,, III International Confer. on Forest Fire Research 14th Conference on Fire and Forest Meteorology, VOL II, pp 1977-1988, Luso, 16/20 November 1998
[4] Victoria Ashton, Habibul Aziz, Sarah Keith, Tim Smith, "Review of EU Flood R&D Projects", 2003, Technical Report, Univ. of Birmingham, http://www.actif-ec.net/library/review_EU_flood_projects.pdf

3 User requirements group and user questionnaires

FIRESENSE aims to develop an automatic early warning system to remotely monitor areas of archaeological and cultural interest from the risk of fire and extreme weather conditions. To achieve its objective, FIRESENSE combines several state-of-the-art technologies: multiple sensors for surveillance (optical and infrared cameras), novel image processing techniques for fire & smoke detection, wireless sensor networks that monitor different modalities (e.g. temperature, humidity, etc), local weather stations, advanced sensor data fusion techniques, estimation and 3D visualization of fire propagation.

To efficiently develop such a system it is essential to actively involve potential users in its design. This can be achieved by establishing an international group of users that will help identify user requirements and guide system design. In this section we present the FIRESENSE user requirements group and analyze the outcome of their contribution. User feedback was received in terms of carefully designed questionnaires addressing not only system design and system performance issues but also issues regarding the current status of similar systems in cultural heritage sites located in different countries.

3.1 User requirements group

As already stated the objective of FIRESENSE is the development of an integrated early warning platform to remotely monitor cultural heritage areas from the risk of fire and extreme weather conditions. The design of such a system requires close cooperation and continuous feedback from stakeholders involved in preservation of cultural heritage sites as well as organizations involved in civil protection, fire prevention and fire fighting, forest protection and environmental protection. To this end an international group of users was established by the FIRESENSE consortium. More than 100 representatives from public and private sector organizations involved in cultural heritage and civil protection were contacted by FIRESENSE partners and were invited to join the FIRESENSE user requirement group in order to share their valuable experience, express their needs and concerns and propose their ideas.

Our survey was focused on pilot sites thus the user requirement group consists of organizations coming from Greece, Turkey, Tunisia and Italy. Potential users/buyers of the FIRESENSE system in theses countries were identified and contacted by corresponding partners. CERTH and MARAC were responsible for Greece, BILKENT and BOGAZICI for Turkey, SUPCOM for Tunisia and CNR for Italy.

The FIRESENSE user requirements group consists of 48 organizations: 31 from Greece, 8 from Turkey, 3 from Tunisia and 6 from Italy. User group members can be categorized as following regarding their expertise:

1. **Cultural heritage preservation/protection** (12 organizations)
2. **Civil protection** (8 organizations)
3. **Fire fighting** (10 organizations)
4. **Forest protection** (16 organizations)
5. **Environmental protection** (1 organization)
6. **Volunteers** (1 organization).

The FIRESENSE user requirements group members are listed in Table 3-1.

Table 3-1: FIRESENSE user requirements group members

Greece
Cultural heritage organizations
9th Ephorate of Byzantine Antiquities - Thessaloniki, Ministry of Culture & Turism
15th Ephorate of Byzantine Antiquities - Evros/Rodopi/Xanthi
23rd Ephorate of Byzantine Antiquities - Evia/Boeotia
9th Ephorate of Prehistoric and Classical Antiquities - Boeotia
16th Ephorate of Prehistoric and Classical Antiquities - Thessaloniki/Chalkidiki/Kilkis
31st Ephorate of Prehistoric and Classical Antiquities - Xanthi
Holy Monastery of Simonos Petra, Mount Athos (Agion Oros)
Civil protection organizations
Region of Thessaly, Civil Protection Directorate, Department of Planning and Prevention
Region of Epirus, Civil Protection Directorate, Department of Planning and Prevention
Region of Ionian Islands, Civil Protection Directorate, Department of Planning and Prevention
Region of Western Macedonia, Civil Protection Directorate, Department of Planning and Prevention
Region of North Aegean, Prefecture of Lesvos, Civil Protection Department
Fire fighting organizations
Fire Department Administration of Eastern Macedonia & Thrace
Fire Department Administration of Chalkidiki - Fire Department of Polygyros
Fire Department of Edessa
Fire Department of Agion Oros
Fire Department of Volos
Fire Department of Thiva
Fire Department of Lechaina
Omicron LTD - Environment and Public Works Design, Study and Management, Forest fire management Dpt
Forest protection organizations
Prefecture of Pella, Directorate of Forestry
Prefecture of Florina, Directorate of Forestry
Prefecture of Argolida, Directorate of Forestry
Prefecture of Korinthia, Directorate of Forestry
Local Forest Service Office of Aridaia
Local Forest Service Office of Agrinio
Local Forest Service Office of Thiva

Local Forest Service Office of Limni Evias
Local Forest Service Office of Amaliada
Local Forest Service Office of Olympia
National Agricultural Research Foundation, Institute of Mediterranean Forest Ecosystems and Forest Products Technology
Turkey
Cultural heritage organizations
Akdeniz University, Department of Archaeology
KOÇ University, Department of Archaeology and History of Art
Bilkent University, Department of Archaeology
Bogazici University, Gymnasium & Sports Center
Forest protection organizations
General Directorate of Forestry Department, Forest Protection and Fire Fighting Department
Istanbul Regional Directorate of Forestry Department
Antalya Regional Directorate of Forestry Department, Press and Public Relations
Adana Regional Directorate of Forestry Department
Tunisia
Cultural heritage organizations
National Heritage Institute
Forest protection organizations
Regional Directorate of Forest, Zaghouan
Environmental organizations
Association of Development and Environmental Protection (NGO)
Italy
Civil protection organizations
Municipality of Perugia, Umbria Region, Environmental and Civil Protection Operative Unit
Puglia Region, Civil Protection Authority
Municipality of Prato, Toscana Region
Fire fighting organizations
Toscana Region
Centro di Scienze Naturali (CSN) , Galceti, Toscana Region
Volunteers
Associazione Protezione Civile Gruppo Lucano (Viggiano-Potenza-Regione Basilicata - Italy)

Among the sites participating in our survey is Mount Athos (Agion Oros, i.e. Holy Mountain in Greek), which is characterized by UNESCO as a World Cultural and Natural Heritage site. World Heritage sites belong to all the people of the world, irrespective of the territory on which they are located [1]. To be included on the World Heritage List, sites must be of outstanding universal value and meet at least one out of ten selection criteria. These criteria are explained in the Operational Guidelines for the Implementation of the World Heritage Convention, which is the main working tool on World Heritage [1]. Mount Athos located in the peninsula of Chalkidiki in Northern Greece is an Orthodox spiritual center since 1054 and has enjoyed an autonomous statute since Byzantine times. The 'Holy Mountain', which is forbidden to women and children, is also a recognized artistic site. The layout of the monasteries (about 20 of which are presently inhabited by some 1,400 monks) had an influence as far afield as Russia, and its school of painting influenced the history of Orthodox art [2]. Mount Athos meets 6 out of the 10 selection criteria and was thus included in the World Heritage List of UNECSO in 1988. These criteria are listed below:

i. To represent a masterpiece of human creative genius;

ii. To exhibit an important interchange of human values, over a span of time or within a cultural area of the world, on developments in architecture or technology, monumental arts, town-planning or landscape design;

iv. To be an outstanding example of a type of building, architectural or technological ensemble or landscape which illustrates (a) significant stage(s) in human history;

v. To be an outstanding example of a traditional human settlement, land-use, or sea-use which is representative of a culture (or cultures), or human interaction with the environment especially when it has become vulnerable under the impact of irreversible change;

vi. To be directly or tangibly associated with events or living traditions, with ideas, or with beliefs, with artistic and literary works of outstanding universal significance;

vii. To contain superlative natural phenomena or areas of exceptional natural beauty and aesthetic importance;

Some photographs from Agion Oros can be seen in Figure 3.1-1 and Figure 3.1-2.

Figure 3.1-1: Holy Monasteries of Agion Oros (images taken from http://www.mountathos.gr)

Figure 3.1-2: Valuable icons, wall paintings, woodcraft temples, books, manuscripts, etc can be found in the Holy Monasteries of Agion Oros (images taken from http://www.mountathos.gr, http://en.wikipedia.org/wiki/Mount_Athos and http://whc.unesco.org/en/list/454/gallery/)

3.2 User questionnaires

The potential users of the FIRESENSE system may be roughly categorized in two groups: a) organizations involved in cultural heritage preservation/protection (e.g. (archaeologists, curators, ephorates, local authorities, etc.) and b) organizations involved in fire fighting and civil protection. The latter group includes fire fighters and volunteers as well as organizations related to forest and environmental protection. These two groups of users may share a common interest in deploying the FIRESENSE system however their expertise and technical background is essentially different. As expected, people related to cultural heritage sites are not focusing so much on system architecture or performance of individual system components. Their focus is more on the performance of the integrated system (false alarms, etc), user interfaces and installation issues. On the other hand, users related to civil protection and fire fighting, due to their background and experience with similar systems, may contribute more decisively in identifying technical system requirements (e.g. technical characteristics of subsystems, system constraints, compliance with international standards and regulations, etc).

To exploit in the best possible way the expertise of both user categories, two questionnaires were prepared by the FIRESENSE consortium: the first concerns people related to cultural heritage sites and the second people involved in fire fighting and civil protection (also forest and environmental protection). These questionnaires can be found in the Appendix at the end of this document. As can be seen, the design of the two questionnaires reflects the difference in the point of view of the two user categories. The cultural heritage questionnaire focuses mainly on installation issues of the FIRESENSE system in sites of archaeological or cultural interest as well as on the experience of the corresponding stakeholders in protecting such sites against fire and extreme weather conditions. The second questionnaire mainly addresses technical issues related to system design and performance. Both questionnaires include questions regarding experience of users with similar systems (or simpler protection measures against fire/ extreme weather) and their opinion/ideas/suggestions/improvements for FIRESENSE.

In total **63 questionnaires from 48 organizations** from Greece, Turkey, Italy and Tunisia were collected (see in Table 3-1). 11 organizations are related to cultural heritage preservation/protection and 36 to fire-fighting/civil protection/forest protection. 15 questionnaires were filled in by the first group of users and 48 questionnaires by the second group of users. Table 3-2 summarizes the statistics of these questionnaires.

Table 3-2: Statistics of questionnaires filled in by members of the FIRESENSE user requirements group (number of questionnaires shown).

	Users related to cultural heritage	Users involved in fire-fighting and environmental protection					Total
		Civil protection	Fire fighting	Forest protection	Environmental	Volunteers	
Greece	7	5	8	11	0	0	31
Turkey	7	0	0	16	0	0	23
Italy	0	3	2	0	0	1	6
Tunisia	1	0	0	1	1	0	3
Total	15	8	10	28	1	1	63
		48					

3.2.1 Cultural heritage

In this section, we analyze the questionnaires filled in by users related to cultural heritage sites (see Appendix A). In total 15 questionnaires from 12 organizations were collected. These organizations include antiquities ephorates responsible for many sites of archaeological/cultural interest within their supervision area, university departments of archaeology responsible for the excavation of different sites as well as communities living inside areas/monuments of cultural interest (e.g. monasteries). The sites these organizations are responsible for include both buildings (churches, monasteries, museums, galleries, libraries, old buildings, etc.) and open-air archaeological sites (prehistoric, classical, roman, byzantine, and modern). The items exhibited and preserved in these areas or buildings cover a wide range: ruins, walls, sculptures, paintings, frescos, mosaics, woodcraft items, fabrics, jewellery, books, manuscripts, religious items and more. Moreover, a high percentage of cultural heritage sites are surrounded by valuable vegetation, which is an integral part of their history or current status (e.g. the Holy Monasteries of Mount Athos (Agion Oros) and Ancient Olympia in Greece are surrounded by forests and wild vegetation of extreme natural beauty and importance). We thus believe that the information provided by these organizations accurately represents the current status and user needs/concerns regarding cultural heritage site protection against fire and extreme weather conditions.

3.2.1.1 Questionnaires analysis

The questions included in this questionnaire are divided in three groups based on the type of information requested:

- **Previous incidents**: This section includes questions regarding previous incidents of fire/ extreme weather conditions in the sites supervised by each organization.
- **Potential actions**: This section requests information about actions/measures taken by each organization in order to protect their monuments against fire and extreme weather conditions.
- **FIRESENSE system and your involvement**: The aim of this section is to record user opinions/ concerns/ suggestions /ideas about the FIRESENSE system. It also requests information on installation issues.

In the following, we provide a detailed analysis of the answers given to each question of the questionnaire.

Question 1: In a Scale 1 (least significant) – 5 (highest priority), how do you evaluate the risk of Fire and Extreme Weather Conditions for the cultural heritage site you are related to?

In Figure 3.2-1, we present the answers provided by users. As can be seen, the risk of fire is considered quite significant by all participants. This is especially true for open air sites located near forests or surrounded by dense vegetation.

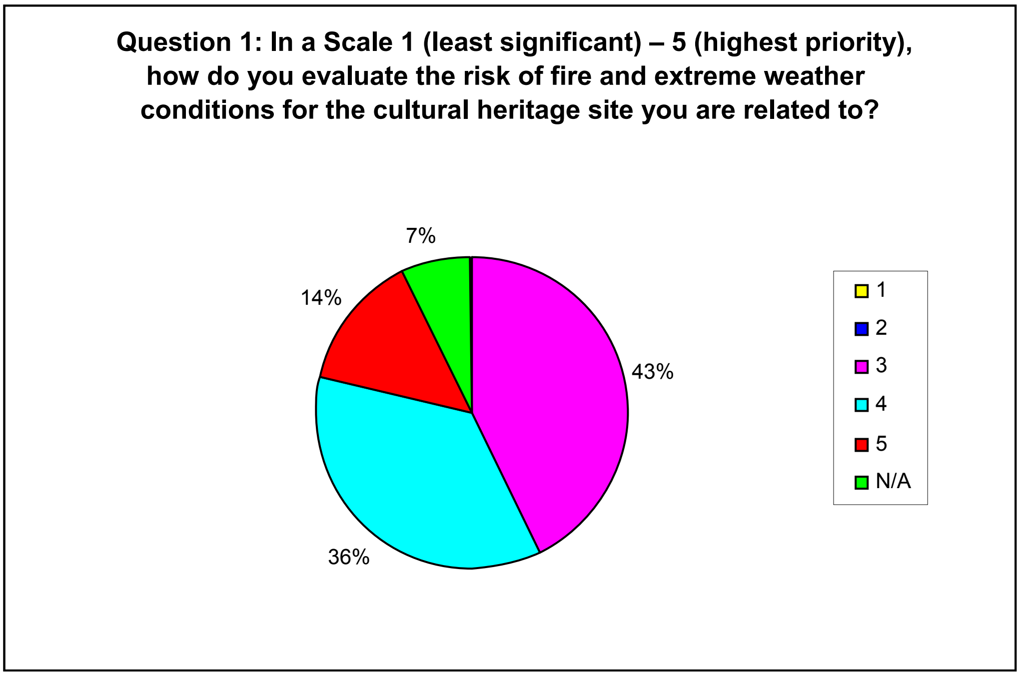


Figure 3.2-1: Analysis of answers given to Question 1

Question 2: Has your site been affected by fire in the past? Yes/No/Don't know

64% of users answered that their sites were affected by fire at least once in the past (see Figure 3.2-2). People whose sites were not affected by fire were mainly archeologists responsible for excavating a site. In the latter case, it may not be wrong to assume that these sites were not exposed to such a danger because they were only recently discovered by archaeologists (last few years).

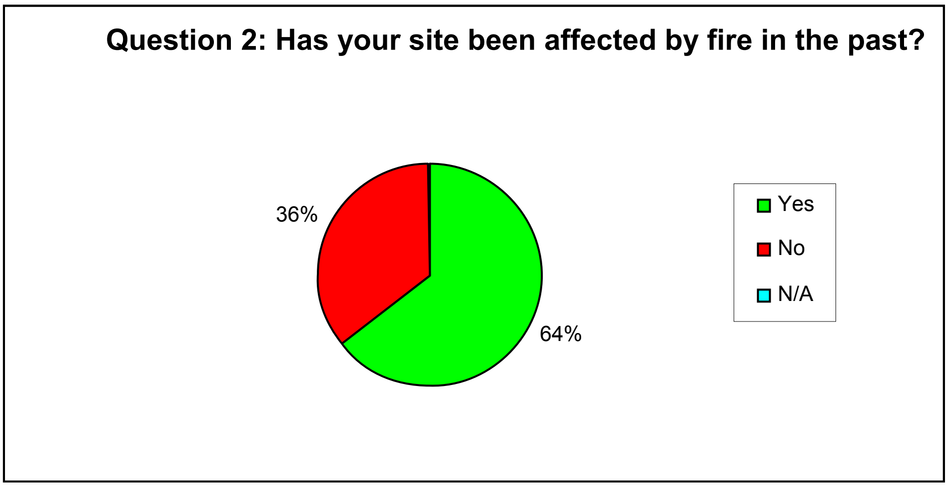


Figure 3.2-2: Analysis of answers given to Question 2

Question 3: If you answered "Yes" in the previous question, please describe: a) what and when happened, b) how much damage occurred and c) how often do such incidents occur?

From an analysis of the answers provided by users the following conclusions may be drawn:

- Fires occur during summer time and especially during periods of increased heat.
- Fires occur very often in places were no guard or other personnel is present.
- Fires usually start at a nearby area and then spread in sites of cultural interest. This is especially true for open air sites neighboring with or surrounded by forests and rich vegetation.
- Damages to sites range from few burned walls or burned surroundings to total destruction. There were many cases of buildings that were totally destroyed and rebuilt (e.g. Monasteries in Mount Athos, churches in different places around Greece). Even in cases where nothing is burned, smoke may cause significant damages to buildings and art items (e.g. paintings, mosaics, manuscripts).
- In most cases, there were big damages in places/buildings that a) were surrounded by forests (e.g. Mount Athos, Olympia), b) had no equipment/installations for fire suppression, c) was difficult for fire suppression teams and vehicles to access them, d) were not guarded.

Question 4: According to your opinion, what kind of extreme weather conditions have significant impact to a cultural heritage site?

As can be seen in Figure 3.2-3, most users believe that heavy rain can create significant problems in cultural heritage sites and monuments. Heavy rain and especially floods are the major cause of erosion in open air sites but can also create problems inside buildings (e.g. intense rainfall can damage antiquities or art items in case a roof collapses, while flood can damage items treasured at or below the ground level). Rain can also cause a sliding, which may damage sites lying in the foothill of mountains or in the hillside (e.g. in Agion Oros some Monasteries practically hang from cliffs more than 200m over the sea).

Wind can also cause erosion problems. Moreover, it can impede fire suppression and make a fire become uncontrollable in just a few minutes time. Lightnings are also identified as possible threats since they can be the cause of a fire outbreak especially in cases where the site is surrounded by dry vegetation.

Hail and snow may also cause damages especially in open-air sites (e.g. archaeological ruins such as marble columns may erode or break). Freeze and extensive heat may also damage some monuments or items.

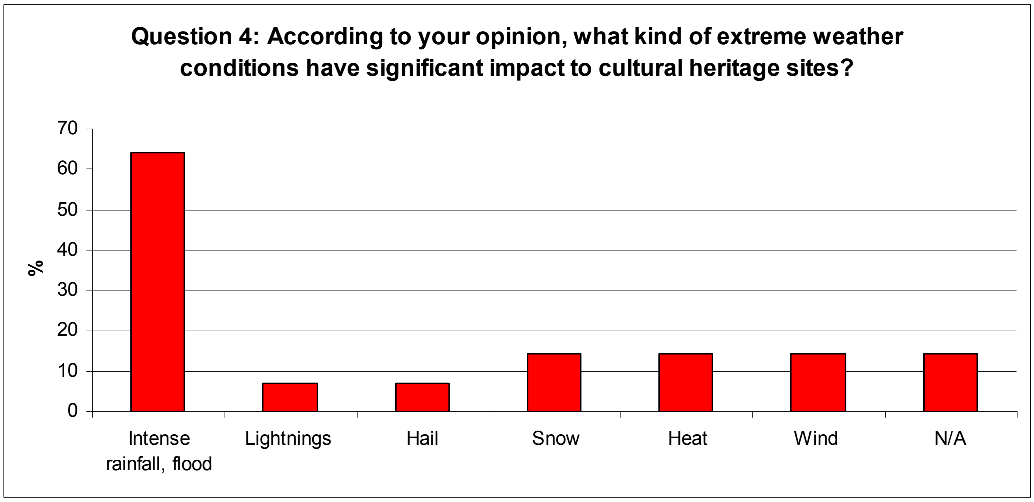


Figure 3.2-3: Analysis of answers given to Question 4

Question 5: Has your site been affected by extreme weather conditions in the past? Yes/No/Don't know

64% of users answered that their sites were affected by extreme weather conditions at least once in the past (see Figure 3.2-4). As will be seen below, the main problem is floods caused by heavy rainfall.

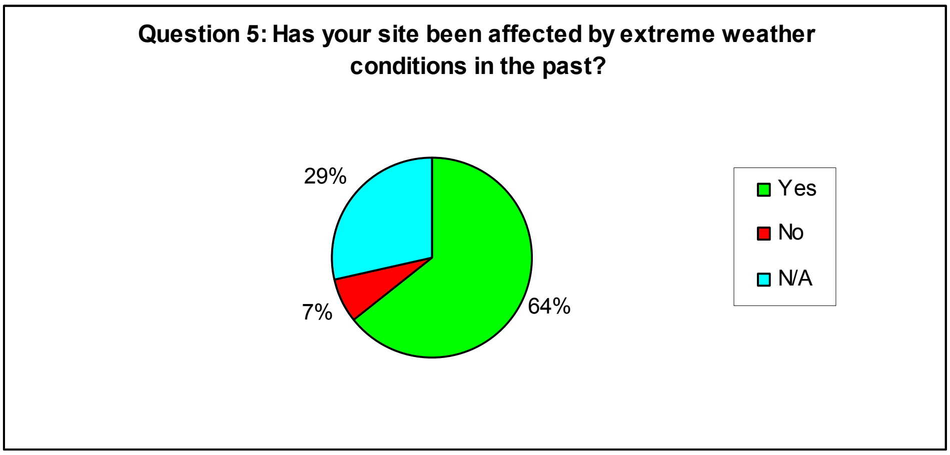


Figure 3.2-4: Analysis of answers given to Question 5

Question 6: If you answered "Yes" in the previous question, please describe: a) what and when happened and b) how much damage occurred?

From the analysis of the answers provided by users it is clear that heavy rain and flood are the major causes of damage. Almost 90% of the users have experienced damages in their sites due to heavy rain and have reported walls collapsing, erosion & damp problems, as wells as changes in the site scenery. Heavy snow also causes erosion problems. Finally, a user reported small fires caused by lightnings hitting trees.

Question 7: What kind of system(s) do you use (or intend to use in the near future) for the protection of cultural sites from the risk of fire and extreme weather conditions: a) early warning systems, b) fire extinguishing mechanisms, c) other.

From the analysis of the answers provided by users the following conclusions were drawn regarding the current status of cultural site protection against fire and extreme weather conditions:

- Early warning systems are only used inside buildings, e.g. museums, galleries, libraries, churches or monasteries. These systems are usually smoke or heat detectors that produce an audio (or visual) alarm signal. Camera-based systems are installed in big museums or monuments for surveillance purposes. Open air sites (e.g. archeological sites) are not equipped with early warning or surveillance systems. These sites are usually protected by guards or volunteers. In some cases (e.g. in archeological sites in Greece with a small number of visitors per year), the sites are not guarded the whole day: a guard visits the sites periodically (e.g. once or twice a week) to check their status. Only in one case (Agion Oros), the use of advanced electronic equipment including smoke detectors, surveillance cameras and GIS database was reported.

  Users from Greece reported that the Greek Ministry of Culture and Tourism operates a Control Center for Collection and Processing of Alarm Signals (KELESS) which is responsible for the coordinated management of security systems installed in more than 500 museums, showrooms and antiquities storehouses throughout the Greek territory [6]. KELESS is connected with all security system units via a telecommunications network and receives signals indicating attempted theft or fire. It also monitors the proper operation of security systems and directly notifies the security staff in museums, ephorates, etc.

- Fire extinguishing mechanisms are used in almost all cultural heritage sites. More specifically: All buildings (museums, churches, libraries, storage houses, etc) are equipped with portable fire extinguishers. In many buildings, automatic spraying systems are installed, which are directly connected with early warning systems using smoke or heat detectors. Open air sites may be also equipped with fire extinguishers; however it is more effective to use fire hoses, fire hydrants or water tanks. The latter can also be found outside buildings. Some open air sites are also equipped with external water spaying systems. The Monasteries in Agion Oros also have water wagons and fire trucks.

  In only one case, namely Ancient Olympia, the existence of an automatic fire protection support system was reported. This system was installed in the forest around the Ancient Olympia site in 2004 and was extended in 2010. It supports remote monitoring of an extensive hydraulic network of pipelines, pumps and water-storage tanks build in the vicinity of the site. It also provides means for remote operation of numerous revolving water-jets installed on top of 35 heavy-duty tree-high metal towers, spread at key-locations inside the surrounding forest. All system telemetry data and command signals are transmitted through a single underground wire link requiring no external electric power at sensor/actuator locations inside the forest. Special user interfaces allow immediate system deployment [5]. Until now the system is activated only manually since no outdoor fire detection system exists. According to the 7th Ephorate of Prehistoric and Classical Antiquities (responsible for Ancient Olympia), the system had problems coping with the disastrous 2007 wildfires due to the fact that that there was a power failure and the electric generators failed to be activated immediately.

- Although more than 50% of the users reported flood problems in the past, measures against floods are taken in only three of the sites. Protection against floods usually includes: a) draining canals, ditches or reservoirs to prevent flooding, b) water pumps to remove the water when the site/building is flooded. In many cases, special shelters are placed above remaining walls/ruins (also above mosaics, tombs, etc) in open air sites to protect them against rain.

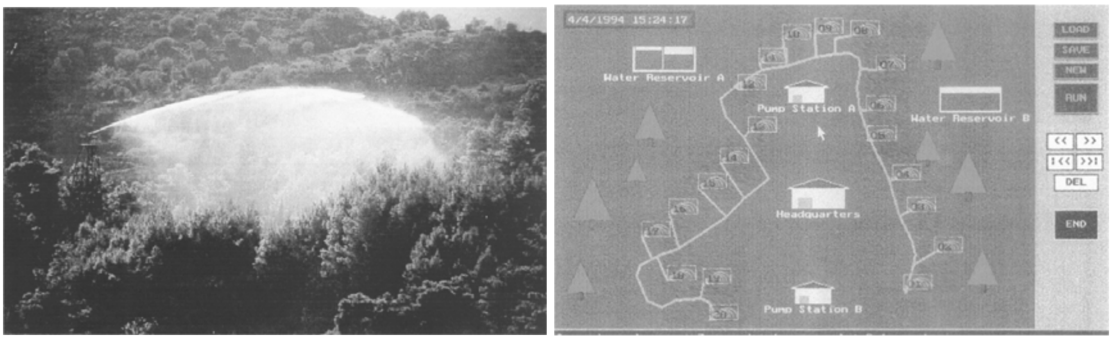


Figure 3.2-5: Fire protection support system installed in Ancient Olympia, Greece: a) operation of a tower water-jet in the forest of Ancient Olympia and b) topology of the forest fire protection system (images were taken from [5]).

Question 8: What kind of actions do you apply (or intend to apply in the near future) for protection from the risk of fire and extreme weather conditions at your site: a) cleaning the site from wild vegetation, b) maintenance of fire detection mechanisms, c) maintenance of fire extinguishing mechanisms, d) use security personnel/volunteers, e) other.

As can be seen in Figure 3.2-6, some basic measures to protect cultural heritage sites from the risk of fire are taken in almost all cases. Cleaning the site (or gardens/forests near the site) from dry vegetation is the main precaution taken. Dry vegetation is removed periodically. In open-air sites this is done once per year at the beginning of the summer season, usually with the help of local forestry departments, local authorities and volunteers. Fire detection/fire extinguishing mechanisms are maintained or replaced, as often as needed wherever they exist. Security personnel guard the sites. Guards are often supported by volunteers (especially during summer time in open air sites neighbouring with forests).

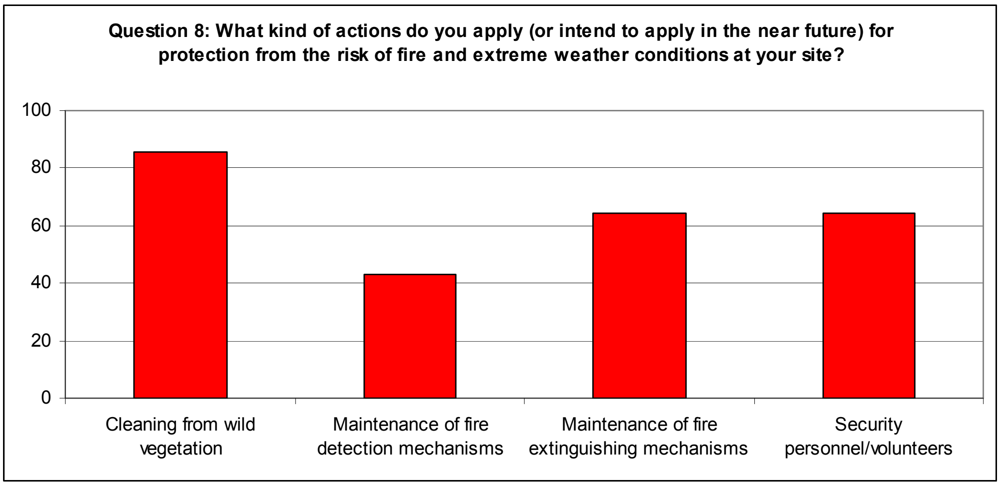


Figure 3.2-6: Analysis of answers given to Question 8

Question 9: Can you provide an estimation of the annual cost for the protection of your site from the risk of fire and extreme weather conditions?

The majority of users were not able to estimate this cost. Answers given vary depending on the area of the site, the monuments it includes, the systems used. A summary of answers provided are shown in Figure 3.2-7.

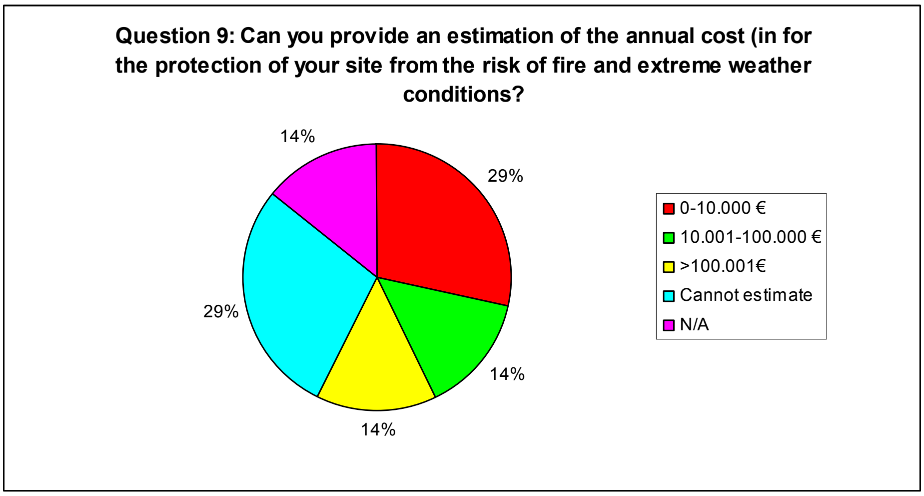


Figure 3.2-7: Analysis of answers given to Question 9

Question 10: If you gave up the use of an early warning system for fire and extreme weather conditions in the past, this was due to (please enter yes, if applicable): a) demonstration, b) market research, c) price, d) feedback from experts, e) other.

Almost 80% of the users replied that they have never used or never had to give up an early warning system in the past. The remaining 20% had to give up the use of such a system because of its high price. In case of antiquities ephorates, it was reported that the decision for buying or installing such systems is taken by the central administration and not the Head of the ephorate or the archaeologists responsible for each site.

Question 11: If you are already using an early warning system for fire and extreme weather conditions, how much did this and its maintenance cost?

Almost 90% of the users do not use an early warning system or do not answer this question. Users related to sites that use such equipment reported a purchase cost of 5.000-50.000€ and an annual maintenance cost of 3.000-10.000€.

Question 12: Are there any specific local regulations concerning the confidentiality of the information?

43% of the users answered that there are no local regulations concerning the information recorded and used by the FIRESENSE system, while the remaining 57% were not able to answer this question.

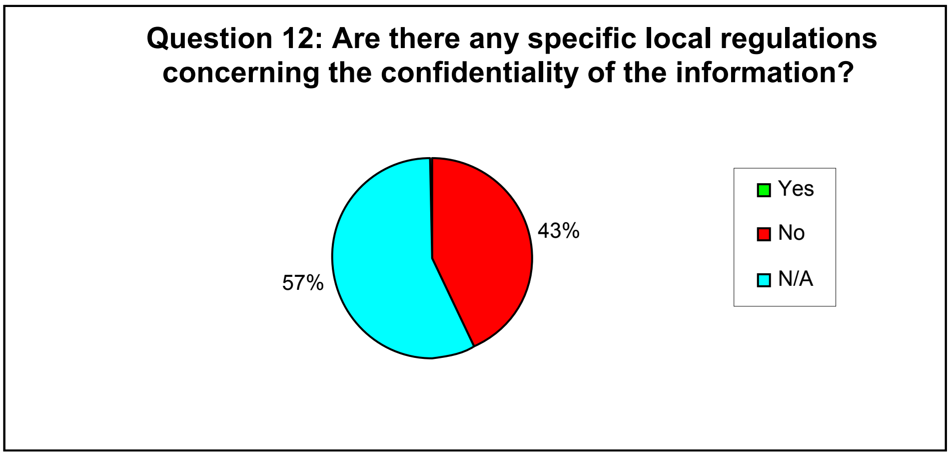


Figure 3.2-8: Analysis of answers given to Question 12

Question 13: Are there any environmental constraints to use the FIRESENSE system?

Again 50% of the users were not able to answer this question. From the remaining 50%, 36% believes that there are no environmental constraints for using the FIRESENSE system in their site, while 14% believes there are constraints mainly having to do with a) installing cameras, sensors and other equipment inside cultural sites or forestal areas (aesthetic problems, danger of damaging monuments/cultural heritage assets) and b) the unique geographical characteristics of each site (e.g. slope differences).

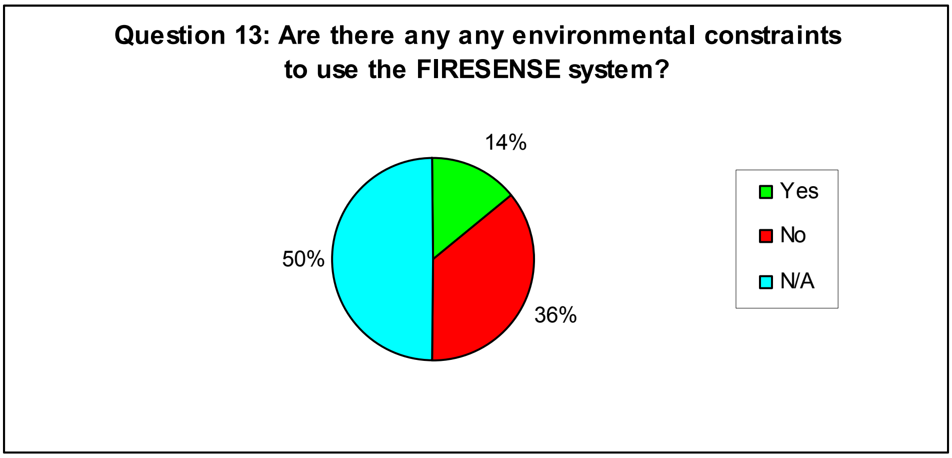


Figure 3.2-9: Analysis of answers given to Question 13

Question 14: Are there technical local supports available to regularly maintain, test and verify the FIRESENSE system?

Again 50% of the users cannot answer whether there exists technical staff that could maintain or test a system like FIRESENSE. 29% believes that the existing personnel can easily maintain and support the FIRESENSE systems. These users are related to sites that already use an automatic fire detection or surveillance system and thus have some kind of experience. The remaining 21% claim that current staff has neither the experience nor the education required for this work and that extra budget/ expenditures would be needed for this purpose.

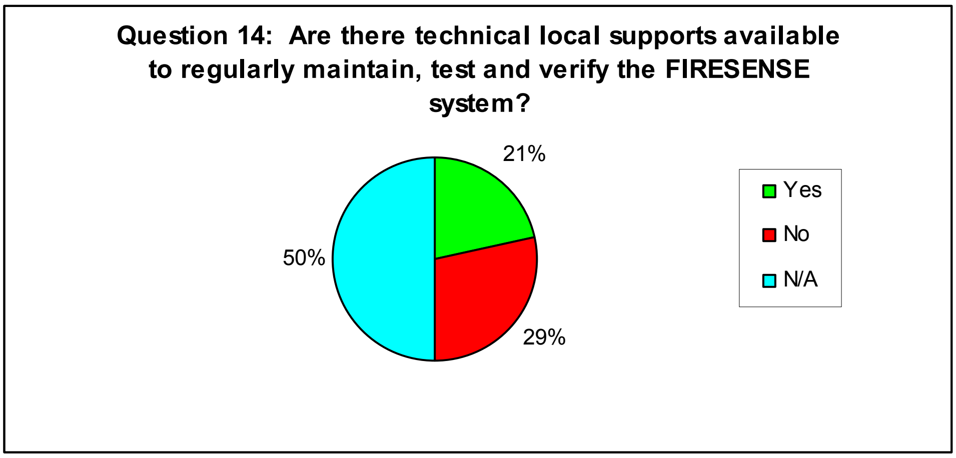


Figure 3.2-10: Analysis of answers given to Question 14

Question 15: Please estimate the cost you consider acceptable for a system like FIRESENSE

Almost 80% of the users cannot estimate the cost of a system like FIRESENSE and only 20% gives an estimation of what they consider acceptable. Users that have provided an answer gave an estimate based on the specific characteristics of their sites: area size (directly related to number of sensors), type of monuments/cultural heritage assets, existing infrastructure, etc.

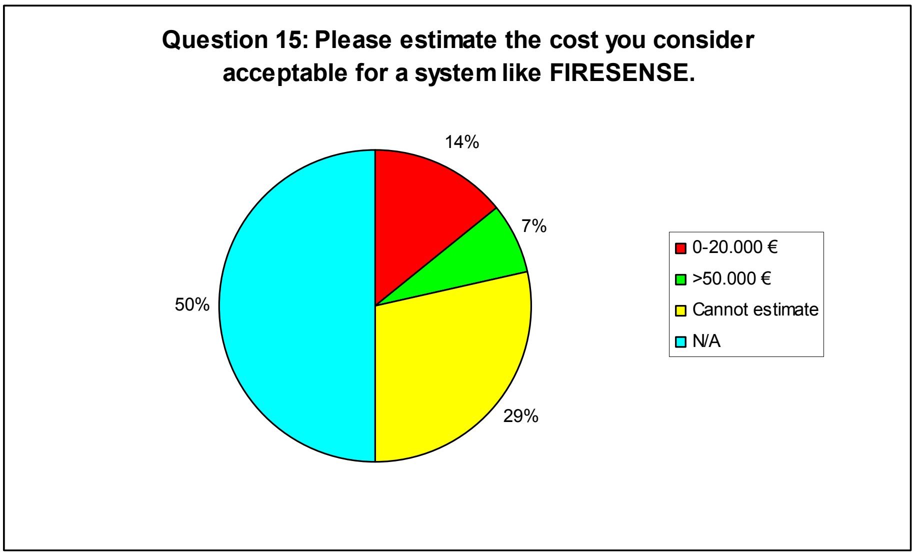


Figure 3.2-11: Analysis of answers given to Question 15

Question 16: You want to be involved in FIRESENSE to a) know about new tools, b) reinforce existing expertise and capabilities in your organization, c) participate in the development of new applications, d) other.

80% of the users want to be actively involved in FIRESENSE. All of them see their involvement in FIRESENSE as an opportunity to reinforce existing expertise and capabilities in their organization. 82% of them want to learn about new tools and technologies while 73% wants to actively participate in the development of novel applications. We should point out that in general users related to cultural heritage sites were very positive about participating in FIRESENSE and being kept informed about its progress and pilot applications. The reason is that they believe that it may successfully deal with risks (fires and floods) that have proven to be extremely disastrous in the past and for which no actual precaution measurements are taken in many sites.

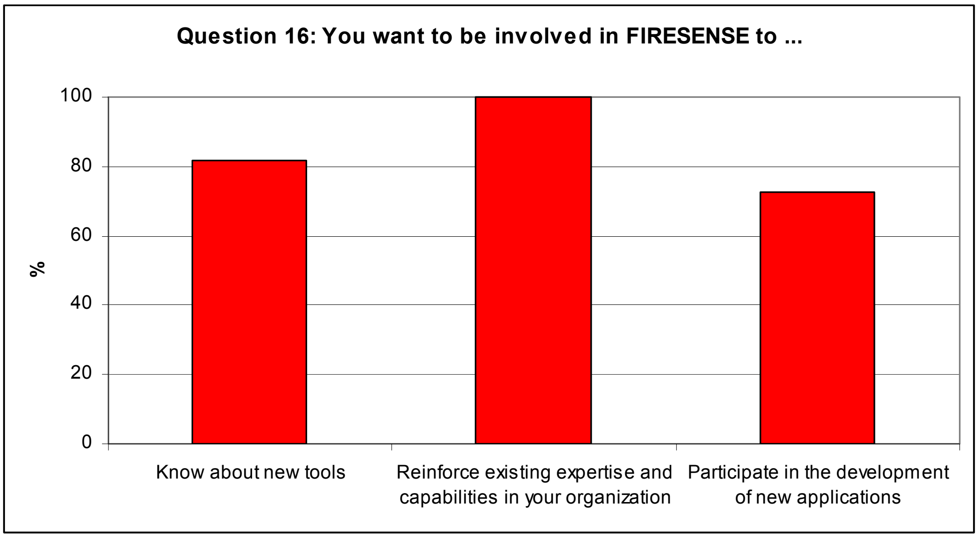


Figure 3.2-12: Analysis of answers given to Question 16

Question 17: Do you have any suggestions to improve FIRESENSE?

The majority of users (80%) did not have any suggestions. The remaining 20% pointed out that they would like to see the system actually running in a pilot application or test the system in their own site in order to be able to make useful suggestions for its improvement.

Question 18: What do you think could hamper the implementation and adoption of the FIRESENSE solution?

As can been seen in Figure 3.2-13, users related to cultural heritage sites are mainly concerned about the cost of a system like FIRESENSE (also cost of maintenance) and the ability of their staff to use it and maintain it. Issues related to the centralized administration structure of cultural heritage authorities in some countries (e.g. Greece) were also mentioned. In this case, it may be difficult for local authorities to follow an independent policy and decide to buy such a system, since financial and other planning is performed centrally. Moreover, budget is usually limited and other needs are more pressing.

Another concern is installation of cameras, sensors and weather stations inside cultural heritage sites. Users related to such sites are concerned that installing this equipment may affect the monuments and disturb the scenery or visitors. Problems related to the particular characteristics of each test site were also mentioned. For example, there are isolated open air sites that do not have electricity or internet connection.

Finally, a problem that we often encounter when proposing novel technological solutions is user unawareness. Users, especially those with limited technological background, may be sceptical about adopting solutions they are not familiar with or they find difficult to use and maintain, unless they are convinced about their effectiveness and long-term benefits.

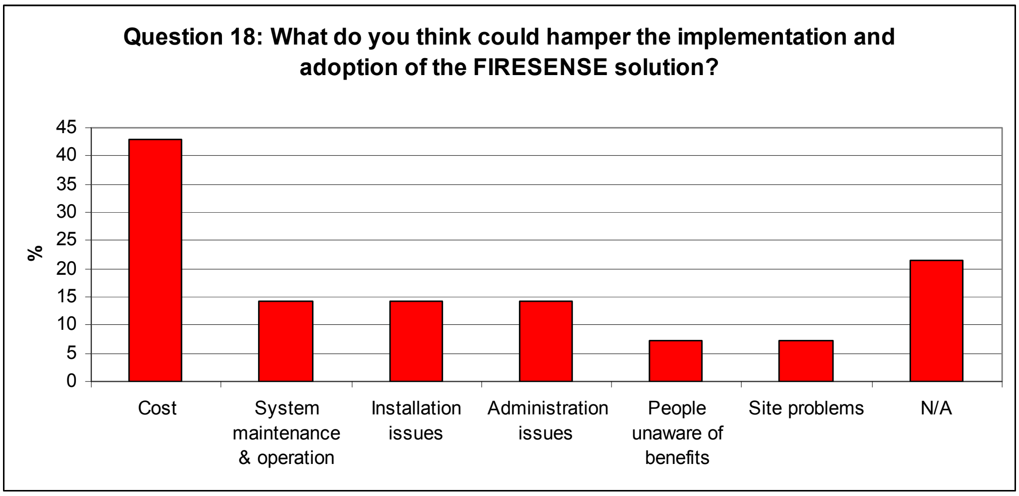


Figure 3.2-13: Analysis of answers given to Question 18

Question 19: What type of equipment can be installed at your site without causing problems to exhibits, personnel, visitors and the site itself?

As can be seen by the statistics presented in Figure 3.2-14, potential users have no major objections about installing equipment inside or near cultural heritage sites. However, many users (e.g. almost all users from Greece) explained that in order to install equipment such as cameras or temperature sensors inside a cultural heritage site it is necessary to conduct a technical and/or feasibility study, submit it to the Central Archaeological Council and ask for its approval. In general, users prefer that equipment is installed outside or near a cultural heritage site and not inside it, since in the later case they are worried about damages of cultural heritage assets or aesthetic distortion of the scenery. For monuments like churches or monasteries, the use of indoor cameras is often rejected; however the solution of camouflaged temperature or smoke sensors can be easily adopted. Regarding weather stations, the users do not object to their installation as long as they are installed at a reasonable distance from the site and do not affect the surrounding environment, which is often an integral part of the site.

To summarize the above, installation of equipment in cultural heritage sites is not a big problem as long as it does not affect damage or distort monuments, items and/or the environment they belong to. Careful technical planning, installation of equipment in well chosen places and use of camouflage materials wherever possible are the steps to be followed when using a system like FIRESENSE in cultural heritage sites.

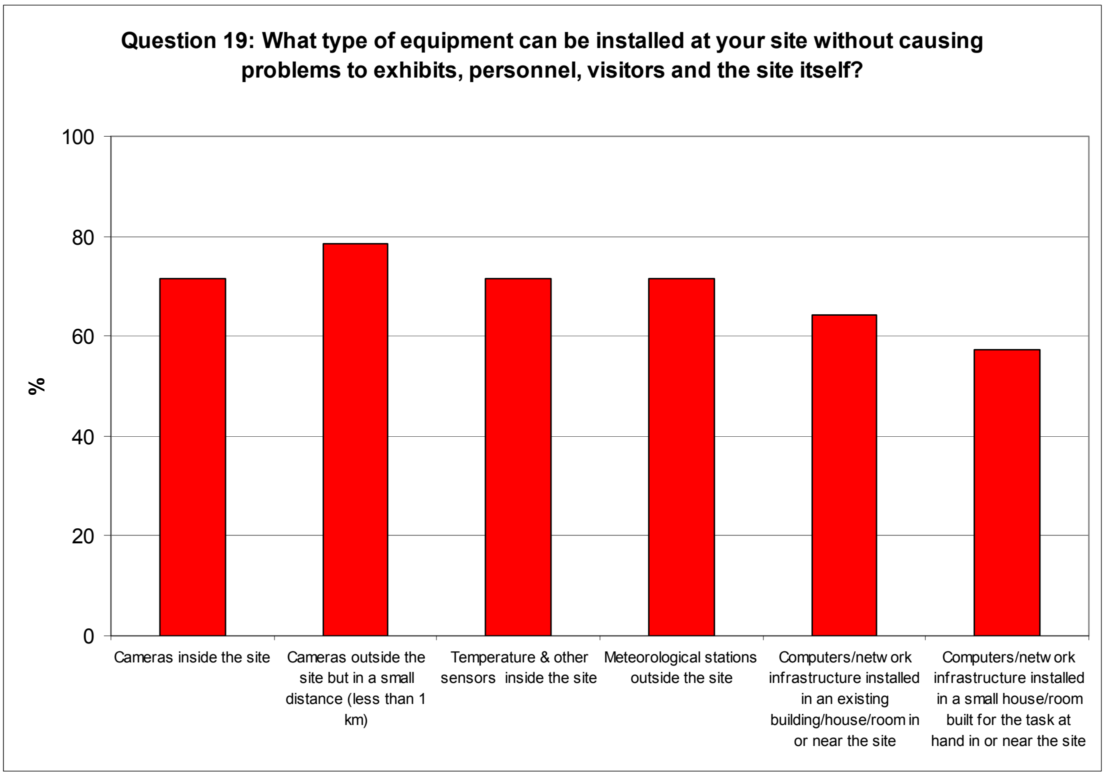


Figure 3.2-14: Analysis of answers given to Question 19

Question 20: Which types of cultural heritage assets are exposed to most significant danger in case of fire or extreme weather conditions at your site?

Users are related to different types of cultural heritage sites (and usually have more than one site under their supervision) thus a variety of answers were given as can be seen in Figure 3.2-15. These are listed below:

- Archaeological remains in open air sites: These include architectural remains (walls, pillars, floors, mosaics, etc) of houses, temples, theatres, stadiums and other buildings as well as sculptures, fountains, tombs, remains of roads, pottery, etc. Such sites can be found all over the Mediterranean region and especially in Greece, Italy and Turkey.
- Museum collections: Museums are important sites of cultural heritage. Their collections vary and cover a large range of art/ every day items: sculptures, paintings, vessels, jewellery, manuscripts, wood craft items, fabrics, costumes, and many more.
- Libraries with valuable books and manuscripts.
- Churches-monasteries: Churches and monasteries constitute a unique category of religious-related cultural heritage monuments of great importance. Not only the buildings themselves are often unique examples of architecture, but in addition the decoration and items inside them are pieces of art and invaluable items of cultural heritage. The latter include frescos, wall paintings, mosaics, icons, sculptures, woodcraft temples, furniture, stained glass windows, jewellery, fabrics, books, manuscripts, religious symbols, etc.

- Old buildings characterized as cultural heritage monuments because of their unique architecture or history.

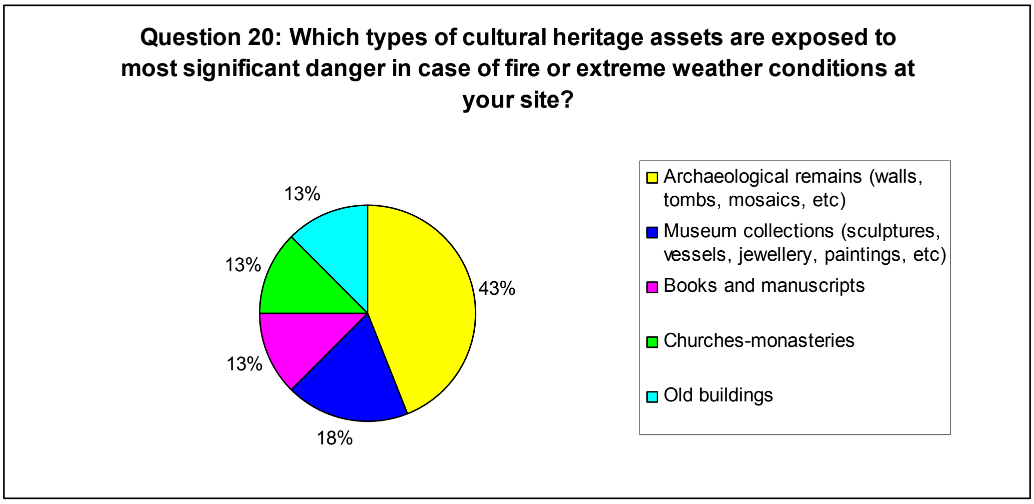


Figure 3.2-15: Analysis of answers given to Question 20

Question 21: In a Scale 1 (no) – 5 (definitely yes), would you consider using the FIRESENSE system at your site?

As can be seen in Figure 3.2-16, the majority of users would consider installing the FIRESENSE system in their sites. Users who are negative or sceptical are related to sites that have a low risk of fire and can be efficiently protected by adopting simpler solutions (e.g. smoke detectors and fire extinguishers).

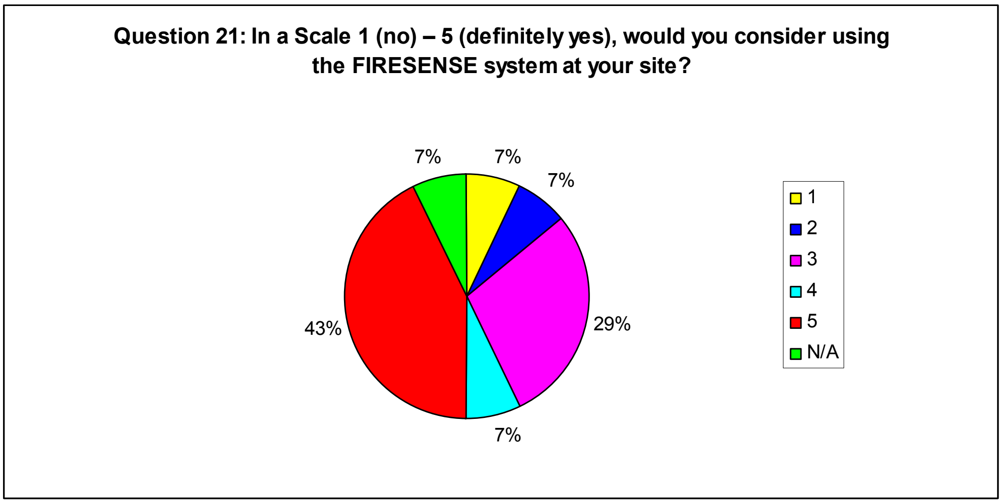


Figure 3.2-16: Analysis of answers given to Question 21

Question 22: Does FIRESENSE provide benefits for the protection of Cultural Heritage Areas? If yes, FIRESENSE improves the protection of Cultural Heritage Areas by: a) fire early warning, b) early extreme weather warning, c) disaster management, d) prevention of arsons, e) security, f) other.

93% of the users replied that they believe that FIRESENSE provides significant benefits for the protection of cultural heritage sites. The remaining 14% did not provide any answer. The answers of users replying positively are analyzed in Figure 3.2-17. As can be seen, all users agree that FIRESENSE improves the protection of cultural heritage sites by early warning for fire and extreme weather conditions. They also believe that it improves the site security as it can be used as a surveillance system. 80% of the users believe that installation of FIRESENSE may prevent arsons. Finally, more than 50% of users say that it could make fire management more effective. In Figure 3.2-18, more detailed statistics are shown.

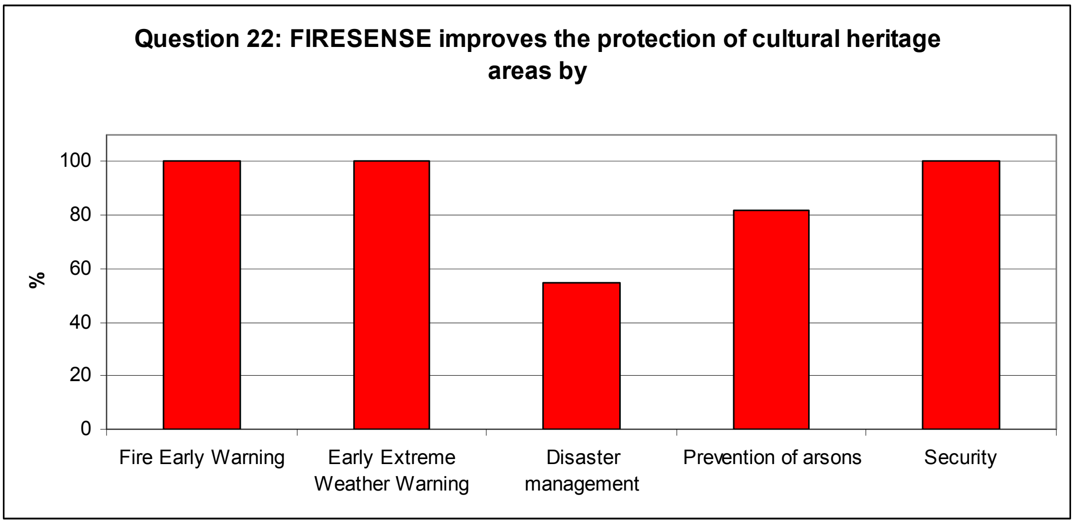


Figure 3.2-17: Analysis of answers given to Question 22

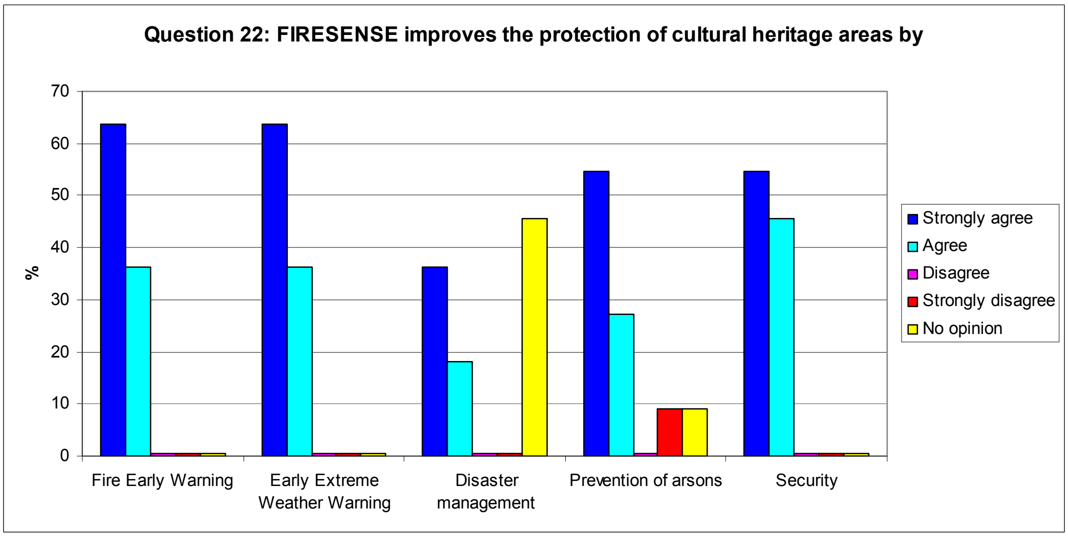


Figure 3.2-18: Analysis of answers given to Question 22

Question 23: Which of the following indirect benefits could be provided by FIRESENSE: a) cultural heritage protection, b) safer evacuation of cultural heritage sites, c) better fire-fighting capabilities, d) cost effectiveness, e) increase of security of cultural heritage sites, f) other.

From an analysis of the answers provided by users, it is clear they believe that the FIRESENSE system provides significant benefits in terms of cultural heritage protection, improved fire-fighting capabilities (providing early fire warning and reliable fire propagation and 3D visualization) and increased site security (since it can also be used as a surveillance system). They also believe that provision of early warnings may decisively help to safely evacuate cultural heritage sites and save human lives.

Finally, we observe that they are not convinced about the cost effectiveness of the FIRESENSE solution. This is directly related to the answers provided in Question 18 about things that could possibly hamper the adoption of FIRESENSE and may be attributed to the following reasons:

- The proposed system seems complex (many different sensors & modules) to users with limited technical background and this is intuitively associated with high cost and advanced technical skills required for system operation and maintenance.
- Often people that reject a solution/system due to its cost fail to evaluate its long term benefits. In our case, the cost of cultural heritage sites being destroyed or damaged because of fire or extreme weather conditions is immeasurable. Cost effectiveness should always be evaluated in terms of benefits/advantages offered in the long term.

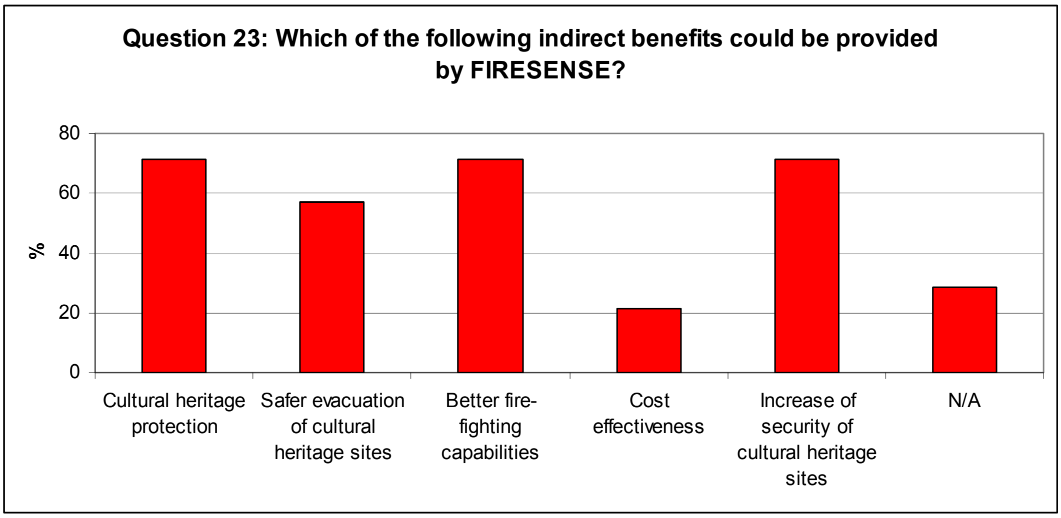


Figure 3.2-19: Analysis of answers given to Question 23

Question 24: What do you think are the strengths of FIRESENSE in general?

As can be seen in Figure 3.2-20, early warning for fire and extreme weather conditions is considered to be the most significant strength/ benefit of the FIRESENSE system (80%). A high percentage of users (65%) consider the surveillance capabilities offered by FIRESENSE an additional feature that contributes significantly in increasing the overall site security. Finally, 29% of users believe that FIRESENSE can protect cultural heritage sites & staff/visitors in many ways: protection against fire/extreme weather conditions, protection against theft/damage/arson, better fire management, safer evacuation, etc.

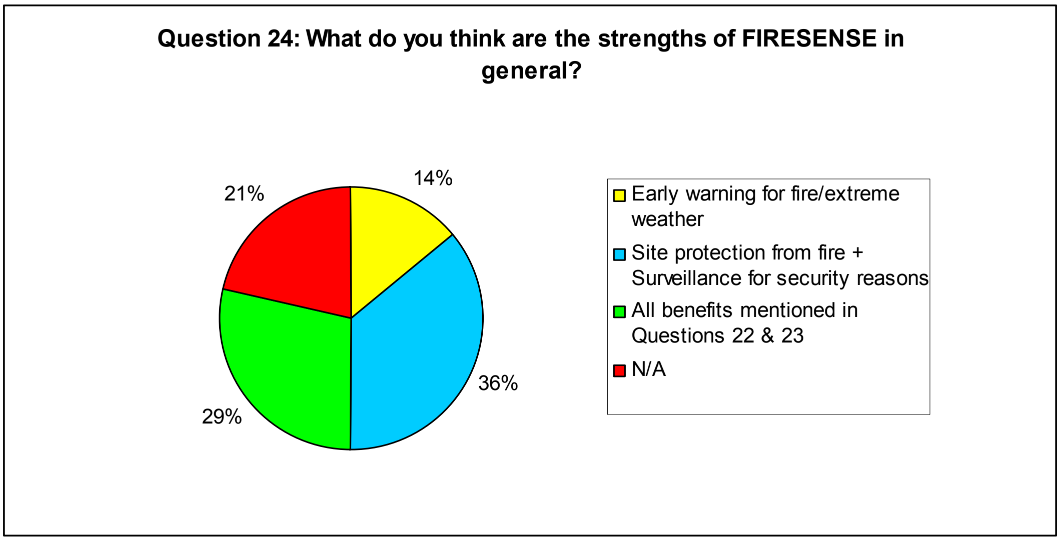


Figure 3.2-20: Analysis of answers given to Question 24

Question 25: What do you think are the weaknesses of FIRESENSE?

28% of users did not answer this question. Answers given by the remaining 72% are shown in Figure 3.2-21. As can be seen, the cost of the system is the major source of concern for potential users/buyers. This finding is in accordance with the answers given in Questions 18 and 23. Users expect that a system such as FIRESENSE using many sensors and offering many different capabilities will have a high cost. Moreover, a lot of people believe that such a system will have increased maintenance demands (and cost) and will require personnel with special training and skills for its operation and maintenance. Other potential problems include failure to deliver sensor data in real-time or detect fire incidents at an early stage, as well operational problems resulting from power outage. Finally, some users are concerned with sensitive equipment being installed outdoors, since extreme or varying weather conditions may cause significant damages.

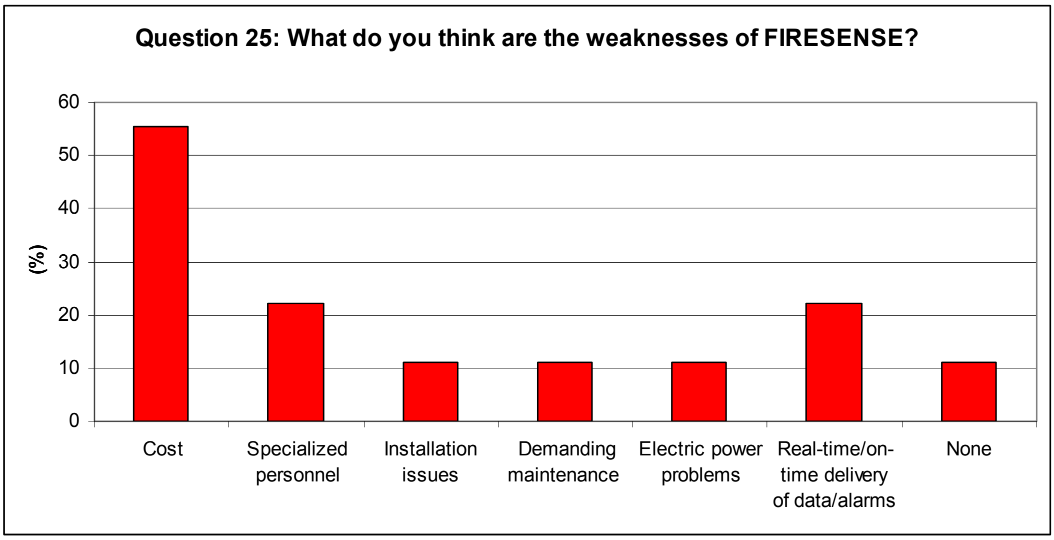


Figure 3.2-21: Analysis of answers given to Question 25

3.2.2 Fire fighting

In this section, we analyze the questionnaires filled in by users related to fire fighting and environmental protection (see Appendix B). In total, 48 questionnaires from 36 different organizations were collected. These include civil protection authorities, fire fighting departments, forest protection authorities, local authorities and environmental organizations that are responsible for municipalities, prefectures or regions including numerous sites of cultural or natural heritage interest.

These organizations are actively involved in fire & extreme weather conditions prevention & fighting, have long experience and significant technical background & expertise in FIRESENSE related matters and are the potential users of the FIRESENSE system. Therefore, they can contribute significantly in identifying user problems, needs, concerns and requirements.

3.2.2.1 Questionnaires analysis

The questions included in this questionnaire are again divided in three groups based on the type of information requested (see 3.2.1.1):

- **Previous incidents**: This section includes questions regarding previous incidents of fire/ extreme weather conditions in the sites supervised by each organization.
- **Potential actions**: This section requests information about actions/ measures taken by each organization in order to protect the sites under their supervision from the risk of fire and extreme weather conditions.
- **FIRESENSE system and your involvement**: The aim of this section is to request information about technical system requirements and collect user opinions/ concerns/ suggestions /ideas about it.

In the following, we provide a detailed analysis of the answers given to each question.

Question 1: Do you know of any fire incidents in the recent years at cultural heritage sites within the area that you are responsible for? Yes/No/Don't know

As can be seen in Figure 3.2-22, 40% of users said that sites in their area were affected by fire in the past, 33% said that no fire incidents took place in areas under their supervision, while 27% did not know. It is interesting to note that in many cases authorities related to fire prevention & fighting are not properly informed about the cultural heritage sites inside the areas they are responsible for, especially in cases that the latter are small in size or not widely known.

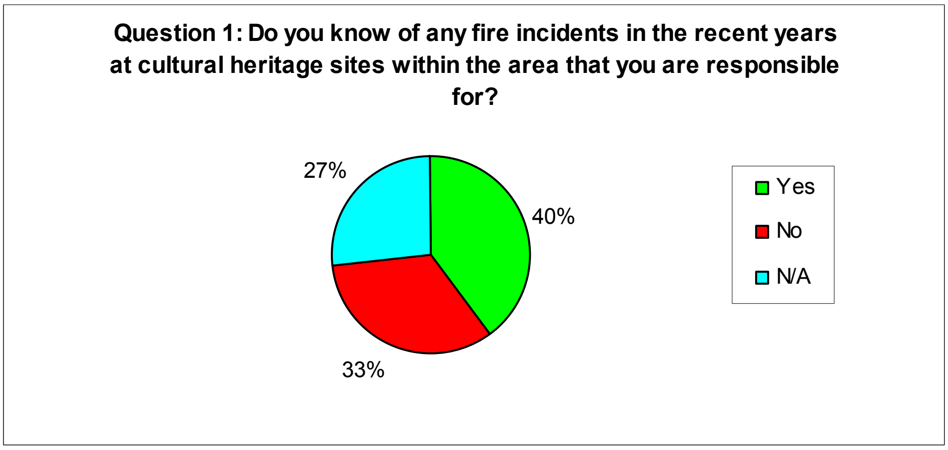


Figure 3.2-22: Analysis of answers given to Question 1

Question 2: If you answered "Yes" in the previous question, please describe: a) what and when happened, b) how much damage occurred and c) How often do such incidents occur?

Conclusions drawn from the answers provided by users are similar to those presented in Section 3.2.1.1-Question 3. More specifically, fires usually break out during the summer period in forests, fields with dry vegetation or waste dumps (landfills) neighboring with cultural heritage sites and soon become uncontrollable due to increased heat and strong wind. Many sites have been damaged or destroyed, especially sites that were isolated and had no fire suppression equipment installed. Extended catastrophes were reported in Mount Athos (monasteries inside forests) and Peloponnesus, Greece (Ancient Olympia, 2007). Smaller fires causing small damages are reported almost daily during the summer period.

Question 3: According to your opinion, what kind of extreme weather conditions have significant impact to a cultural heritage site?

Similarly to what was reported for Question 4 in Section 3.2.1.1, most users believe that heavy rain and floods can cause significant damages in cultural heritage sites and monuments. Strong winds and heat waves are also considered as possible threats.

Unlike users directly related to cultural heritage sites, a high percentage (45%) of users related to fire suppression were not able to provide an answer.

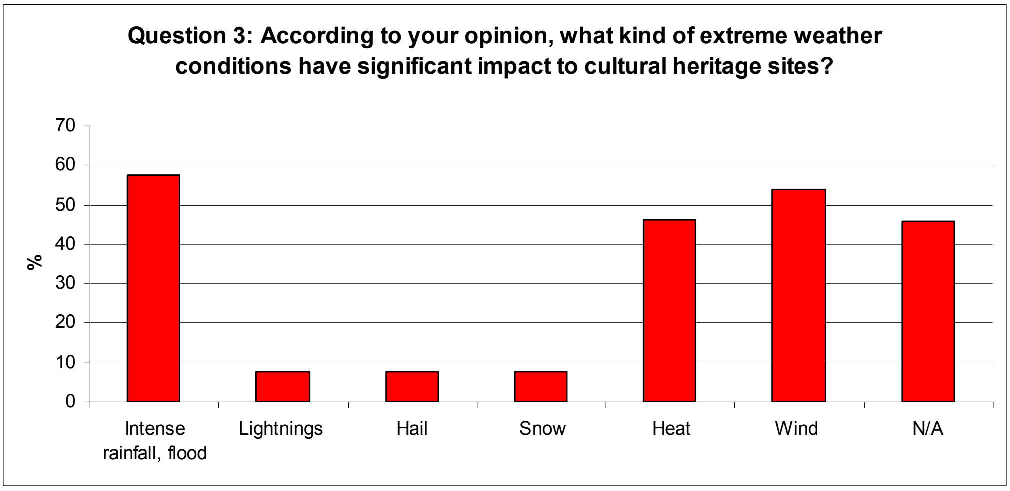


Figure 3.2-23: Analysis of answers given to Question 3

Question 4: Do you know of any incidents caused by extreme weather conditions in the recent years at cultural heritage sites within the area that you are responsible for? Yes/No/Don't know

45% of users asked answered that there were damages caused by extreme weather conditions in cultural heritage sites within the area that they are responsible for (see Figure 3.2-24). As will be seen below, the main problem is floods caused by heavy rainfall. 34% of users had no such incidents, while 21% could not answer this question (see also Section 3.2.1.1 - Question 5).

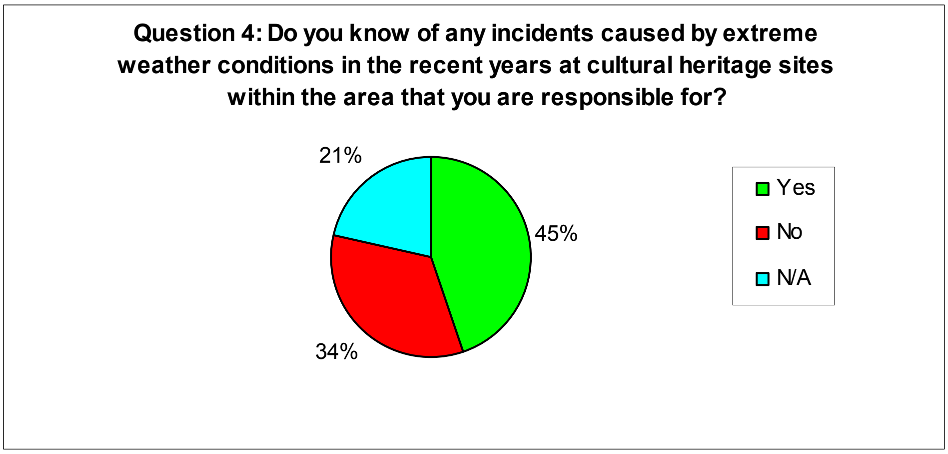


Figure 3.2-24: Analysis of answers given to Question 4

Question 5: If you answered "Yes" in the previous question, please describe: a) what and when happened and b) how much damage occurred?

From an analysis of the answers provided by users it is clear that heavy rain and floods are the major causes of damage. Strong winds and heat waves have also caused problems, since they were directly related with fire outbreaks (see also Section 3.2.1.1 - Question 6).

Question 6: What kind of system(s) do you use (or intend to use in the near future) for the protection of cultural sites from the risk of fire and extreme weather conditions: a) early warning systems, b) fire extinguishing mechanisms, c) other.

From an analysis of the answers provided by users the following conclusions were drawn regarding the current status of early warning systems and fire extinguishing mechanisms in different countries in the Mediterranean:

- **Greece**: Public authorities related to civil/forest protection do not use early warning systems based on fire/ smoke detection. Instead they use an information system managed by the General Directorate of Civil Protection, which issues forecast maps estimating the risk of fire all over the country based on local weather forecasts and Normalized Difference Vegetation Index (NDVI) maps. NDVI maps are estimated from MODIS TERRA satellite images and represent the vegetation status (dryness) using a color index (see Figure 3.2-25.a). Maps indicating the risk of fire use a 5-level scale: Level 1 corresponds to low risk, while level 5 corresponds to great danger (red alarm) (see Figure 3.2-25.b). These maps are issued on a daily basis during the summer period. Alerts for extreme weather phenomena are also issued. During the summer period there are patrols or manned fire look out posts inside forest areas and in some cases air surveillance.

  Regarding fire extinguishing mechanisms, fire suppression is usually based on fire trucks, water hydrants, airplanes, fire hoses and fire extinguishers. In just one case, users reported the existence of an automatic forest fire protection support system installed in the forest around Ancient Olympia (see Section 3.2.1.1 - Question 7).

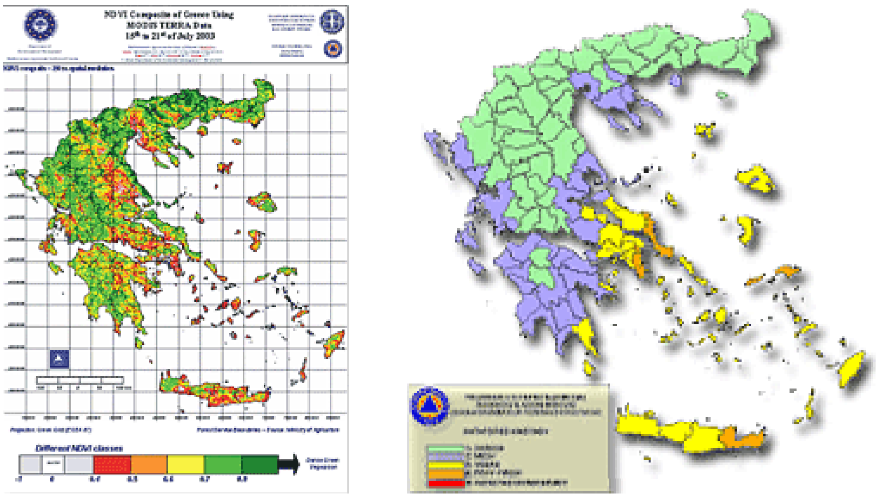


Figure 3.2-25: a) Normalized Difference Vegetation Index (NDVI) map, b) map estimating the risk of fire using 5 alarm levels (images taken from http://www.gscp.gr/ggpp/site/home/ws/promote/fisikes/pirkagies/deltio.csp#)

- **Turkey**: In Turkey, the OYEUS (Forest Fire Early Warning System) system is used for forest fire early warning [7]. The system was developed by the General Secretariat of Forestry, the Scientific and Technological Research Council of Turkey and BILKENT University (group of Prof. Enis Cetin participating in FIRESENSE). It is based on PTZ cameras installed in look-out towers and uses smoke/flame detection image processing software. The cameras rotate 360 degrees and have a range of 15-20 km depending on weather conditions. The system detects smoke or fire within 15-20 seconds and sends an alarm to the control center.

A novel forest fire management system is also installed in 27 Regional Directorates of Forestry all around Turkey [7]. Weather conditions, equipment condition, exact location of vehicles, helicopter and airplanes, direction and speed information and location of firefighters can be monitored by the system thus making decision making more effective and optimizing fire management. The system uses a web-based GIS software that makes it possible to log in using a PDA.

The aforementioned systems are used for forest fire warning and management but not for cultural heritage site protection.

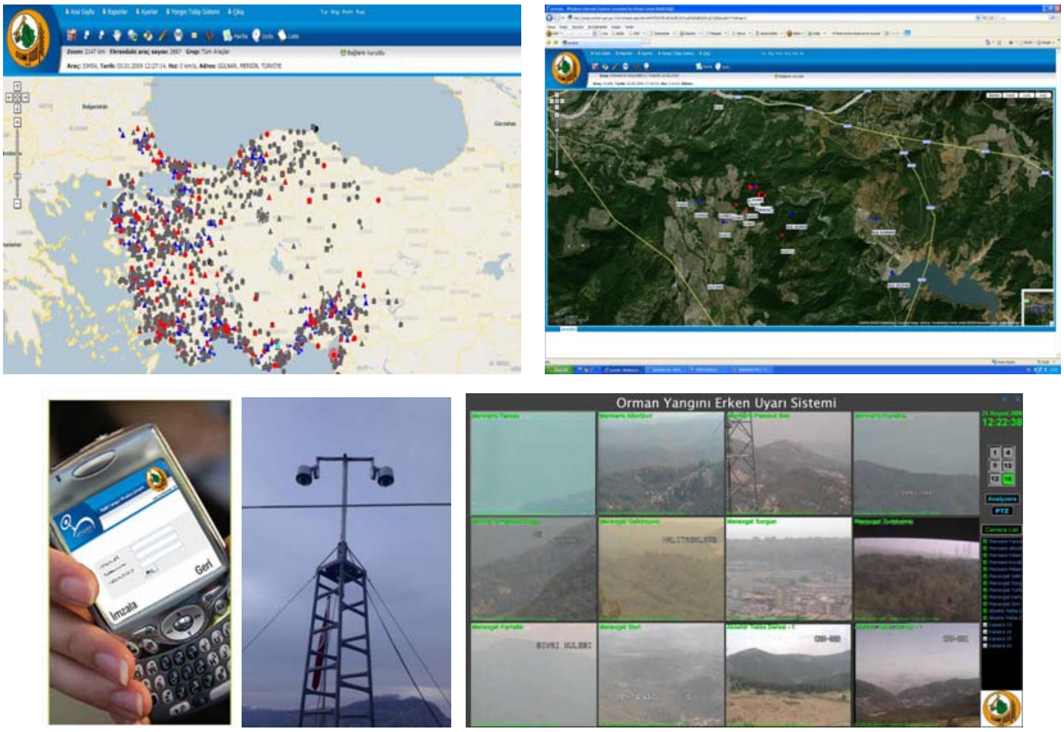


Figure 3.2-26: a-c) Forest Fire Management System and d-e) OYEUS Forest Fire Early Warning System used by the Turkish General Secretariat of Forestry (images taken from [6])

- **Tunisia**: In Tunisia, public authorities related to civil/forest protection do not use early warning systems based on automatic fire/ smoke detection. Site protection against fire is based on patrols and guards placed on look out towers. Fire fighting is based on firefighters and volunteers, fire trucks, airplanes & helicopters, water supply vehicles, sprinklers, etc.
- **Italy**: Organizations from Italy report that in some areas early warning systems based on video cameras and thermometric control are used. Camera images are transmitted to a control center, where security personnel are on standby for possible fire incidents. One of those places is the Monteferrato-Galceti Park (Figure 3.2-27).

Figure 3.2-27: View of the control centre of the CSN Volunteer Fire-Fighters at Galceti (http://www.csn.prato.it/).

Question 7: In a Scale 1 (least significant) – 5 (highest priority), how important are the following criteria for choosing a fire and extreme weather conditions early warning system for the cultural heritage site you are related to: a) cost, b) robustness, c) autonomy, d) interoperability, e) quality of data.

As can be seen in Figure 3.2-28, users consider quality of data, system autonomy and robustness to be the most important criteria in choosing a fire and extreme weather conditions early warning system. Interoperability is also quite important. Surprisingly the cost of the system is the last criterion in their list. This may be explained by the fact that the users are people with significant technical background and are thus more interested in the system performance in order to facilitate their work and less interested about its cost.

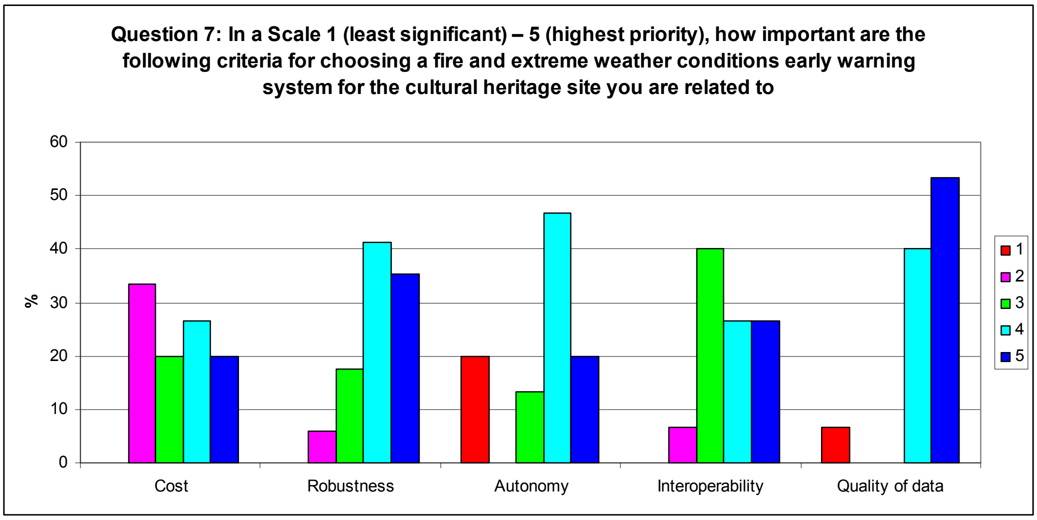


Figure 3.2-28: Analysis of answers given to Question 7

Question 8: In a Scale 1(no confidence at all) – 5 (very satisfied), how much confidence do you have in a fire and extreme weather conditions early warning system?

As can be seen in Figure 3.2-29, 68% of users have confidence in a fire and extreme weather conditions early system, while the remaining 32% is neutral.

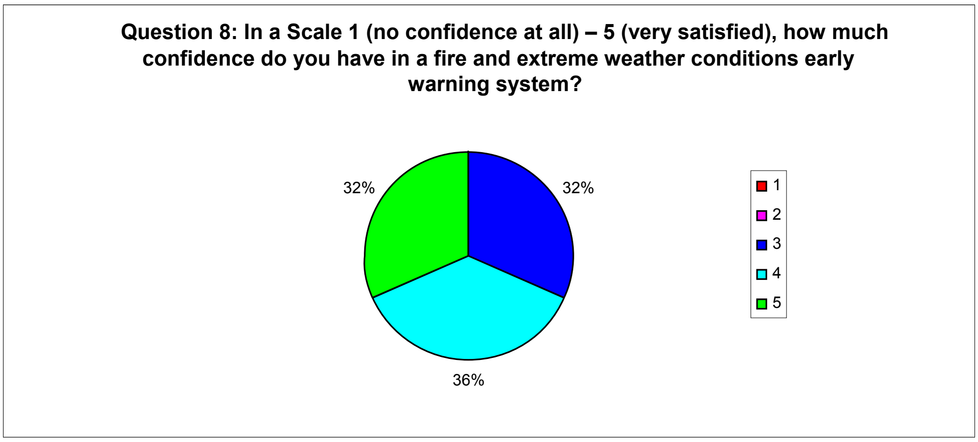


Figure 3.2-29: Analysis of answers given to Question 8

Question 9: If you gave up the use of an early warning system for fire and extreme weather conditions in the past, this was due to (please enter yes, if applicable): a) demonstration, b) market research, c) price, d) feedback from experts, e) other.

Almost 70% of the users replied that they have never used or never had to give up an early warning system in the past. From the remaining 30%, 80% had to give up the use of such a system because of its high price. Others said that they gave up the system after a demonstration, a market research or because they thought it was too difficult to for their personnel to operate it. Again, in some cases it was reported that the decision for buying or installing such systems is taken by the central administration and not the Head of each department (see also Section 3.2.1.1 - Question 10).

Question 10: If you are already using an early warning system for fire and extreme weather conditions, how much did this and its maintenance cost?

Almost 85% of the users said they do not use an early warning system or did not reply to this question. The remaining users reported a purchase cost 20.000-50.000€ and annual maintenance cost 3.000-5.000€. In one case only, a cost of more than 2K€ was reported for a camera based system that monitors strategic areas of an entire province (see also Section 3.2.1.1 - Question 11).

Question 11: Are there any specific local regulations concerning the confidentiality of the information?

28% of the users answered that there are no local regulations concerning the information recorded and used by the FIRESENSE system, while 4% mentioned that there are local regulations of confidentiality and that information can only be used internally in the organization. The remaining 68% were not able to answer this question (see also Section 3.2.1.1 - Question 12).

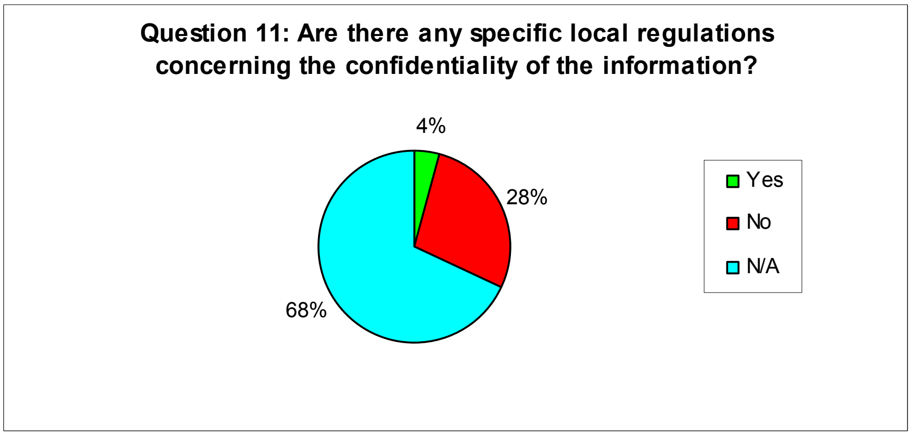


Figure 3.2-30: Analysis of answers given to Question 11

Question 12: Are there any environmental constraints to use the FIRESENSE system?

Again, 62% of the users were not able to answer this question. From the remaining 48%, 17% believes that there are no environmental constraints for using the FIRESENSE system, while 17% believes there are constraints mainly having to do with a) installing cameras, sensors and other equipment inside cultural sites or forestal areas (e.g. 70% of a specific site is part of the NATURA 2000 European network for the protection of the most seriously threatened habitats and species across Europe. Special Protection Areas (SPAs) help protect and manage areas which are important for rare and vulnerable birds because they use them for breeding, feeding, wintering or migration. Special Areas of Conservation (SACs) provide rare and vulnerable animals, plants and habitats with increased protection and management [4]), b) the unique geographical characteristics of each site, e.g. slope differences, micro climate (fog, very windy, etc), c) the site being isolated thus no electricity being available or internet connection exists (see also Section 3.2.1.1 - Question 13)..

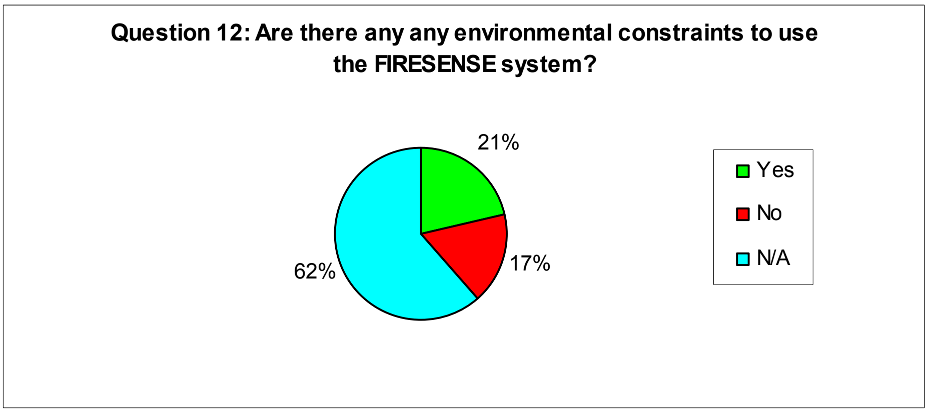


Figure 3.2-31: Analysis of answers given to Question 12

Question 13: Are there technical local supports available to regularly maintain, test and verify the FIRESENSE system?

Again 56% of the users cannot answer whether there is technical staff that could maintain or test a system like FIRESENSE. 23% believes that the existing personnel and volunteers can maintain and support the FIRESENSE system. The remaining 21% claim that current staff has neither the experience nor the education required for this work and that extra budget/ expenditures would be needed for this purpose (see also Section 3.2.1.1 - Question 14).

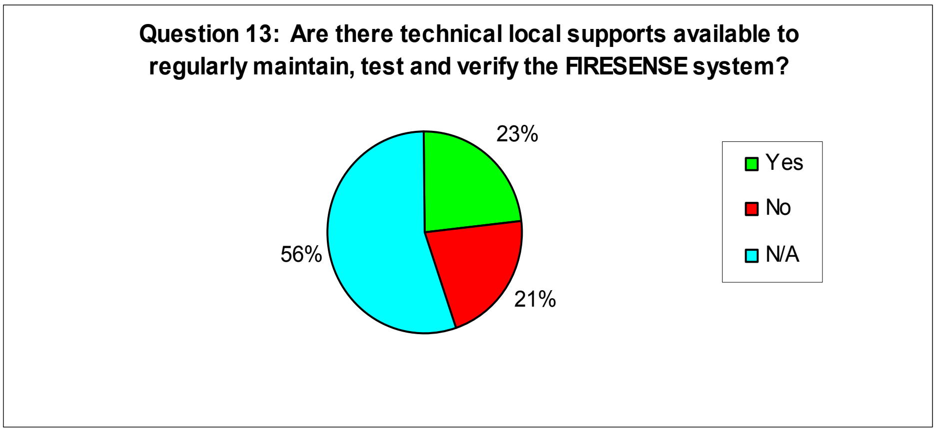


Figure 3.2-32: Analysis of answers given to Question 13

Question 14: Please estimate the cost you consider acceptable for a system like FIRESENSE

More than 70% of the users cannot estimate the cost of a system like FIRESENSE and only 27% gives an estimation of what they consider acceptable. This estimation depends on the specific characteristics of each site and mainly on the size of the supervised area. The dependency of the system cost from the number of sensors and other equipment needed is what makes the majority of users to hesitate to provide an answer (see also Section 3.2.1.1 - Question 15).

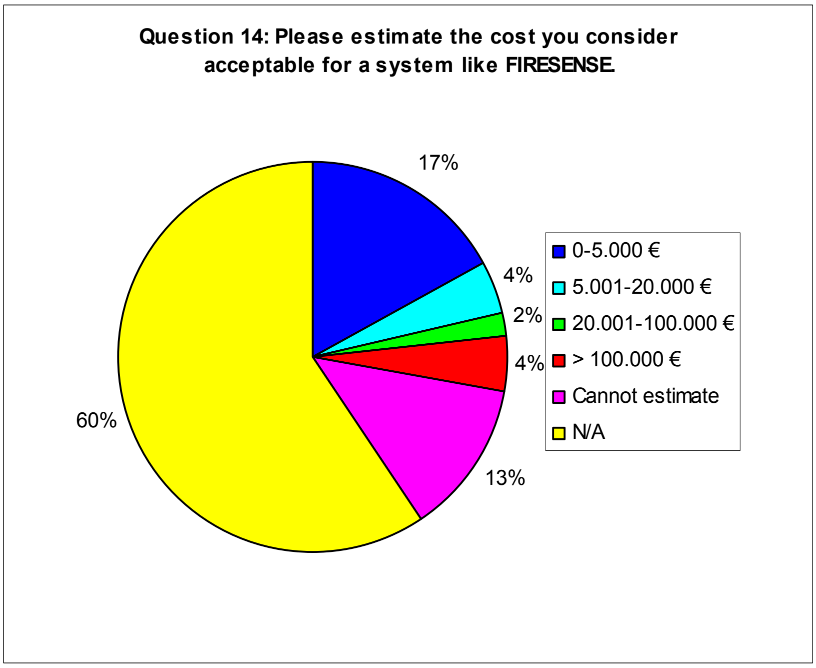


Figure 3.2-33: Analysis of answers given to Question 14

Question 15: You want to be involved in FIRESENSE to a) know about new tools, b) reinforce existing expertise and capabilities in your organization, c) participate in the development of new applications, d) other.

65% of the users want to be actively involved in the FIRESENSE. 85% of them see their involvement with FIRESENSE as an opportunity to reinforce existing expertise and capabilities in their organization. 96% of them want to learn about new tools and technologies while 77% wants to actively participate in the development of novel applications. 7% wants to be involved with FIRESENSE in order to participate in an network of experts and exchange ideas and experiences, establish synergies, or use the final system in their site (see also Section 3.2.1.1 - Question 16).

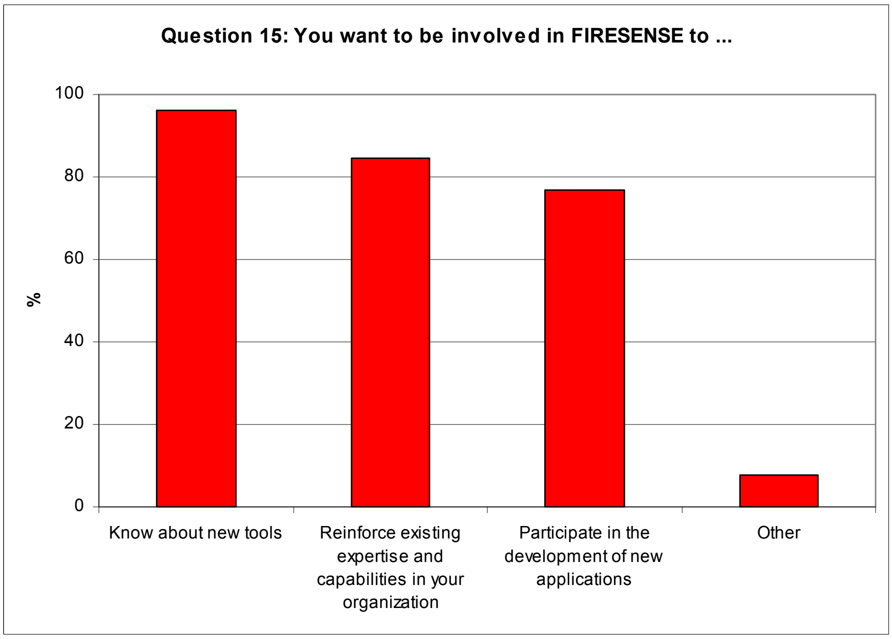


Figure 3.2-34: Analysis of answers given to Question 15

Question 16: Do you have any suggestions to improve FIRESENSE?

The majority of users (80%) did not have any suggestions, while others said that they would first like to see the system in operation. One user suggested that mobile centers for receiving FIRESENSE information could be employed, e.g. in the form of a web- page or web/mobile phone application (see also Section 3.2.1.1 - Question 17).

Question 17: What do you think could hamper the implementation and adoption of the FIRESENSE solution?

Almost 60% of users did not provide an answer. The answers given by the remaining 40% are analyzed in Figure 3.2-35. As can be seen, users are mainly concerned about the cost of the system (also cost of maintenance) and the ability of existing personnel to operate it and maintain it. Another concern is whether the system performance will be good enough (fast detection, low false alarm rate, adequate area coverage, autonomy). Problems related to the particular characteristics of each test site were also mentioned. For example, there are forestal areas that do not have electricity or internet connection (see also Section 3.2.1.1 - Question 18).

Other possible problems mentioned by users include:

- User unawareness: users, especially those with limited technological background, may be sceptical about adopting solutions they are not familiar with or find difficult to use and maintain, if they are not convinced about their effectiveness and long-term benefits.
- Supervision of large areas: the system may not be able to effectively supervise large areas with a small number of sensors. In this case, many cameras, wireless sensors and other equipment will have to be used, thus increasing system cost and maintenance workload.
- Equipment damages: vandals may cause damages or thieves may steal high-cost equipment installed in public places. This is more true for optical or infrared cameras and less for temperature or humidity sensors since the latter can be effectively camouflaged (and also have a very low cost).

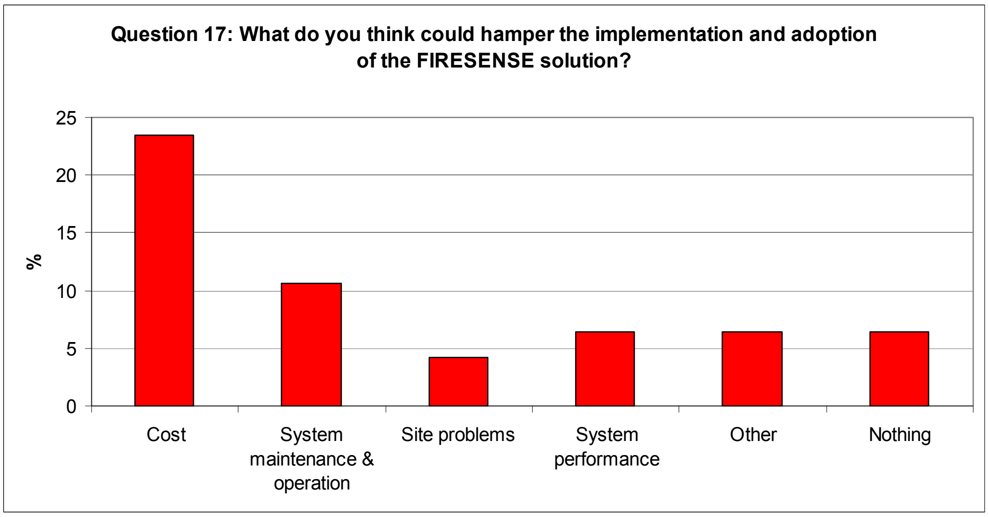


Figure 3.2-35: Analysis of answers given to Question 17

Question 18: In a Scale 1 (least significant) – 5 (highest priority), what information do you think is important for the FIRESENSE system to provide: a) views from cameras, b) wind information, c) humidity information, d) local temperature information (from the wireless sensors or infrared cameras), e) weather data forecast for local area, f) fire propagation estimation, g) GIS map with various information (sensor positions, roads, forest roads, vegetation map, buildings, fire ignition point, fire propagation information/estimation), h) visual and audio alarms for possible events, i) other.

The answers provided by users are analyzed in Figure 3.2-36. As can be seen, the vast majority of users (>=80%) give the highest priority to fire propagation estimation, use of GIS maps with various information shown, views from cameras, delivery of wind information and generation of visual and audio alarms (the percentages were computed from the number of users giving grade 4 or higher). Equally important is information about local humidity and temperature as well as the local weather forecast (71% of users). In Figure 3.2-53, more detailed statistics are shown. It is clear that according to users' opinion the most important information that the FIRESENSE system can provide is GIS maps showing fire propagation estimation information, fire ignition point, sensor positions, roads, forest roads, buildings, vegetation maps, etc. Some users suggested that information about fire trucks or firemen/volunteers positions should also be shown. As expected, generation of video/audio alarms is also very highly rated. Fire propagation estimation and views from cameras are also considered of high importance. Finally, information about local weather (wind, temperature, humidity, etc) is also significant, although it is rated somewhat lower.

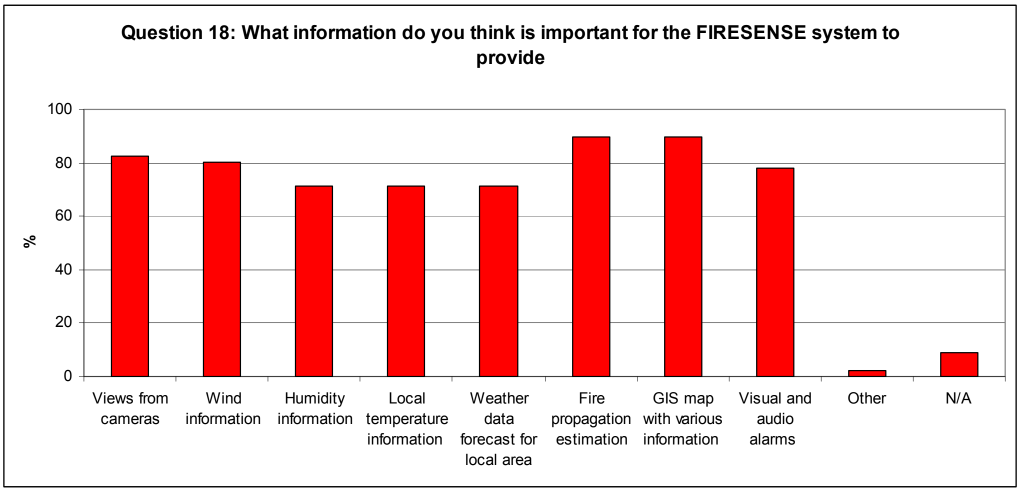


Figure 3.2-36: Analysis of answers given to Question 18

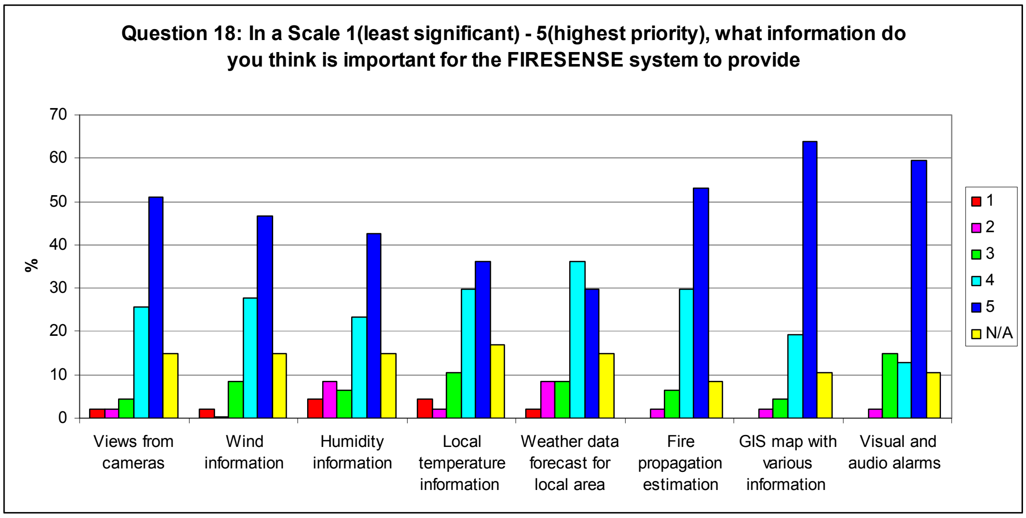


Figure 3.2-37: Analysis of answers given to Question 18

Question 19: What kind of functionalities should the control center of the FIRESENSE system support: a) zoom in/out (for cameras), b) pan/tilt (for cameras), c) recording mode (to record images, sensor values), d) other.

76%-81% of users agreed that zoom in/out, pan/tilt and recording mode should be supported by the software installed in the control center. Recording mode has received the highest percentage of positive votes, however the other two were also considered very important.

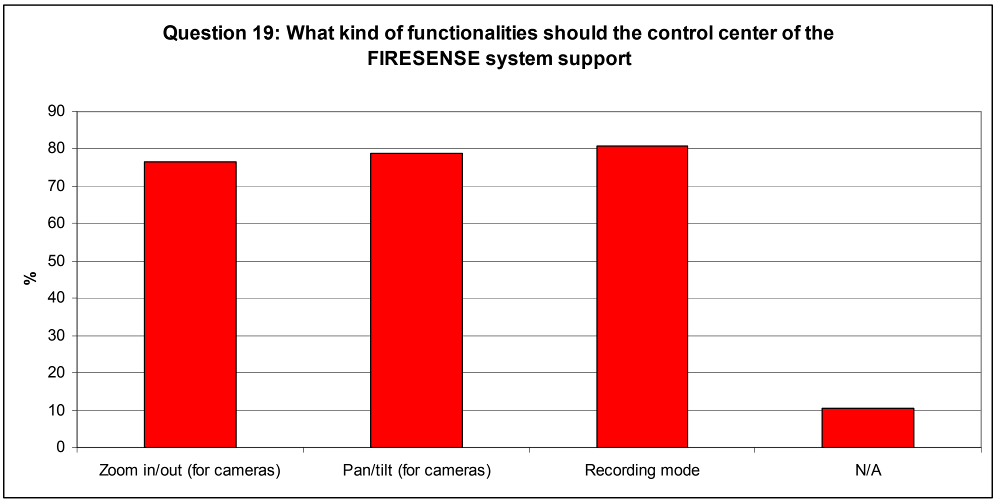


Figure 3.2-38: Analysis of answers given to Question 19

Question 20: What types of alarms/risk indicators do you wish to be supported by the FIRESENSE system?

55% of users have provided an answer to this question. From these, 88% wants the FIRESENSE system to support audio or visual alarms. A smaller percentage, almost 35%, wants alarms in the form of an SMS sent to mobile phones or a phone call (see Figure 3.2-39). Regarding to the type of risk indicators supported by the FIRESENSE system, users propose a lot of different things as can be seen in Figure 3.2-40. More than 80% of users wish that an alarm is issued when fire or smoke is detected in some area. Almost 30% of the users also want an alarm in case of high temperature or humidity or significant temperature/humidity raise. Alarms in case of strong winds or in case that an extreme weather notification is issued by a governmental agency are also desirable. Some users also want the system to notify them in case the fire propagation algorithm estimates that the fire will spread in residential areas, industrial zones, cultural heritage sites, etc. Users propose that alarms are visualized on top of GIS maps.

Finally, some users propose that the FIRESENSE system provides 3-4 alarm levels corresponding to different risk/danger levels or a risk map showing an estimated risk value for each position inside the supervised area. This map will be estimated based on available sensor and meteorological data and the output of the fire propagation estimation algorithm.

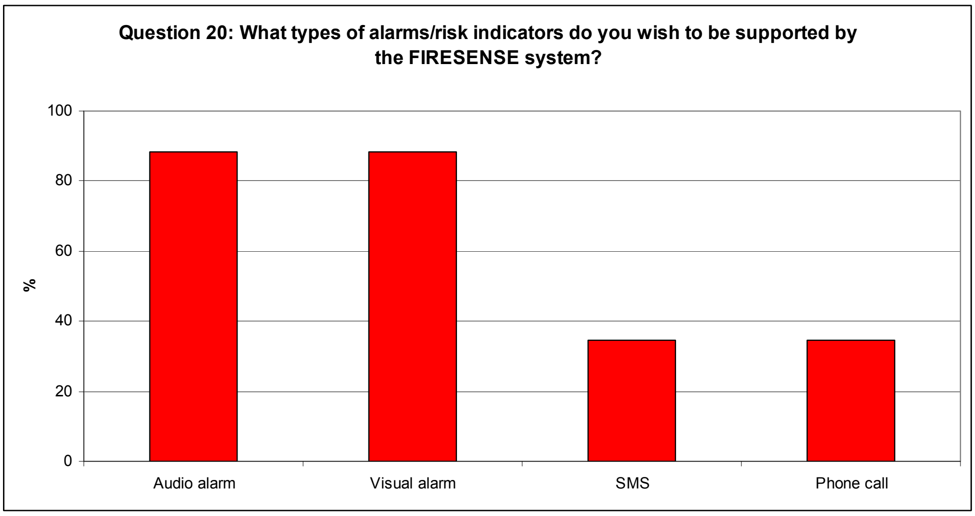


Figure 3.2-39: Analysis of answers given to Question 20

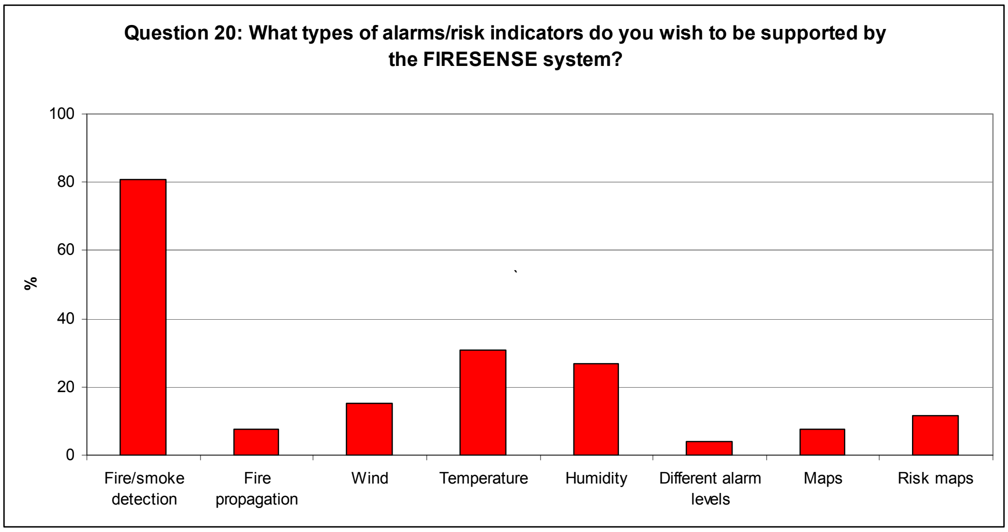


Figure 3.2-40: Analysis of answers given to Question 20

Question 21: In a Scale 1 (easy) – 5 (difficult), what do you think characterizes best the maintenance procedures needed for the FIRESENSE system? Explain.

From an inspection of the answers given in Figure 3.2-41, it is clear that most users believe that it is not easy to maintain a system like FIRESENSE. The main reasons for this are listed below:

- FIRESENSE is an integrated system combing several sensors and other equipment. Moreover, system components are not located in one room or place, but are instead installed inside the supervised area perhaps at a long distance between each other (e.g. cameras) or at a long distance from the control center.
- The maintenance workload is directly associated with the number of cameras, sensors and other equipment installed in each site. In case a large area needs to be covered then the number of system components may increase significantly thus making proper system maintenance very demanding and time-consuming.
- For some components (e.g. IR cameras, PTZ cameras, network infrastructure) there is a relative high cost in case of replacement or repair. Unfortunately, many organizations have a limited budget available and may not be able to cover such expenses.
- Users believe that the currently available technical personnel may not be able to properly maintain the system, thus new personnel with special skills & expertise will be needed.

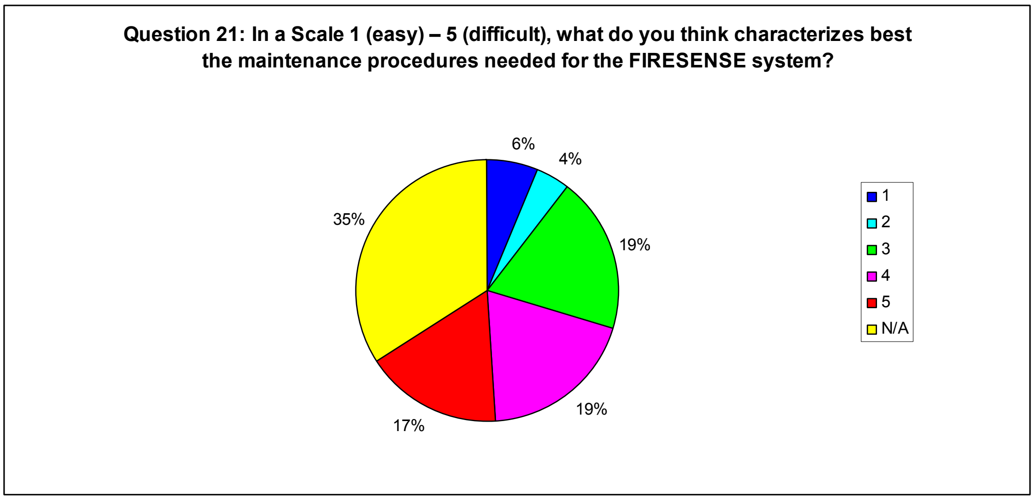


Figure 3.2-41: Analysis of answers given to Question 21

Question 22: In a Scale 1 (very easy) – 5 (very difficult), how easy do you think the personnel working in your organization will learn to use the FIRESENSE system?

The answers provided by users are illustrated in Figure 3.2-42. As can be seen, users are divided regarding this question: 23% believes that current staff will easily learn to use the FIRESENSE system (grades 1 and 2) while 28% believes that this will be difficult (grades 4 and 5). The remaining 31% believes that it is neither easy nor difficult (grade 3), while 17% did not answer this question.

It is interesting to note here that answers given to this question are highly subjective, since it was observed that in some cases people working in the same organization were giving completely different ratings (e.g. 1 and 5). This may suggest that the answer provided depends on the expertise, skills and experience of the specific user and does not reflect the expertise or experience of the entire organization. This remark may also be true for the answers provided to Question 21.

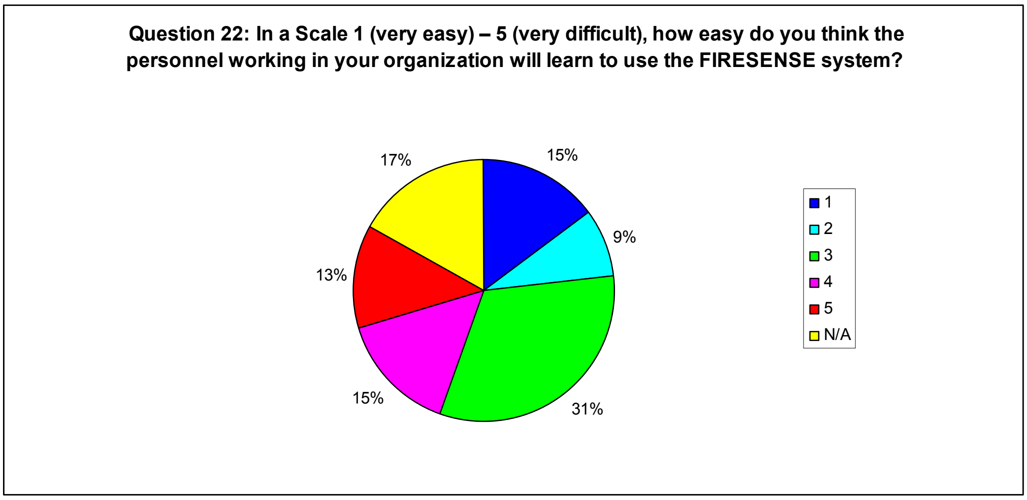


Figure 3.2-42: Analysis of answers given to Question 22

Question 23: In a Scale 1 (easy) – 5 (difficult), how possible do you think is that the FIRESENSE system could improve existing fire detection systems?

From an inspection of the results illustrated in Figure 3.2-43, we can see that users believe that FIRESENSE will improve the existing fire detection systems.

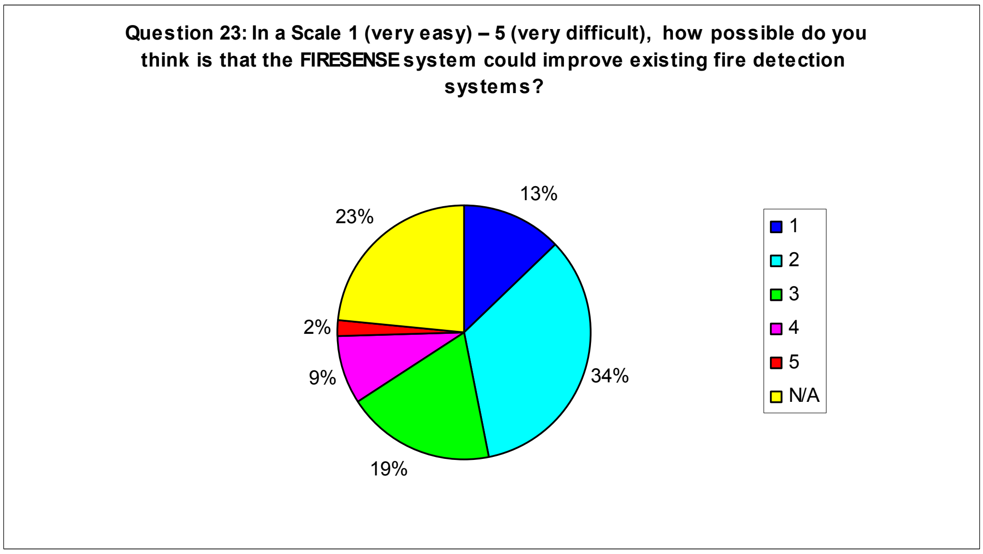


Figure 3.2-43: Analysis of answers given to Question 23

Question 24: What distance range do you think that the system should cover?

42% of the users were not able to provide an answer. From the remaining 58%, 39% believe that the system should cover a range of 3-20 km, while 13% think that a system should cover a wider area (more than 20 km). Finally, a 6% did not provide a specific number but said instead that they would like the system to cover the maximum distance range possible.

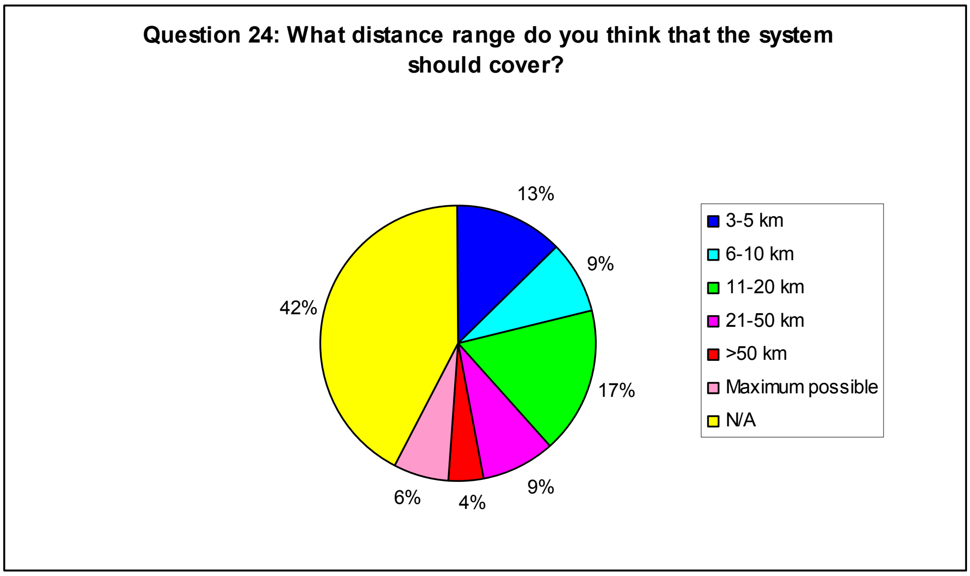


Figure 3.2-44: Analysis of answers given to Question 24

Question 25: What is the smallest size of fire that should be detected by the system?

50% of the users believe that the fire should be detected in its very early stages, i.e. when its size does not exceed $10m^2$. Another 18% increase the minimum size detected to 100 m^2. Only 4% believe that the minimum fir size detected should be more than 100 m^2. Finally, 28% of users were not able to provide an estimate.

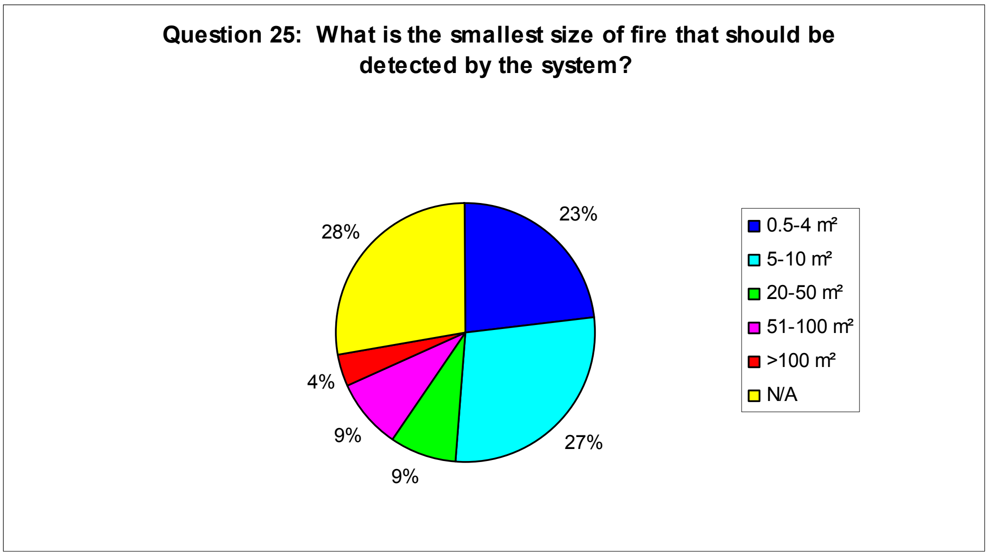


Figure 3.2-45: Analysis of answers given to Question 25

Question 26: What is the acceptable delay for the delivery of sensor data: a) for images, b) for thermal data, c) for meteorological data.

65% of users have answered this question. More specifically regarding each type of data:

- **Images**: 17% of users agreed that images should be updated every 15-30 sec. 43% of users believe that images should be updated every 1-5 minutes, while only 6% answered that 10-30 minutes is an acceptable delay for image delivery (see Figure 3.2-46).
- **Thermal data**: Similarly to the answers given for images, 11% of users believe that thermal data should be updated every 15-30 sec, while 45% of users believe that images should be updated every 1-5 minutes. Finally, the remaining 11% answered that 10-30 minutes is an acceptable delay for thermal data delivery (see **Figure** 3.2-47).
- **Meteorological data**: 21% of users believe that meteorological data should be updated every 0.5-2 min, while another 21% believe that images should be updated every 3-5 minutes. Finally, 21% answer that 10-60 minutes is an acceptable delay for meteorological data update (see Figure 3.2-48).

Summarizing the above, for images and thermal data the majority of users believe that they should be updated every 1-5 minutes. For meteorological data the acceptable delay is longer: 1-15 minutes.

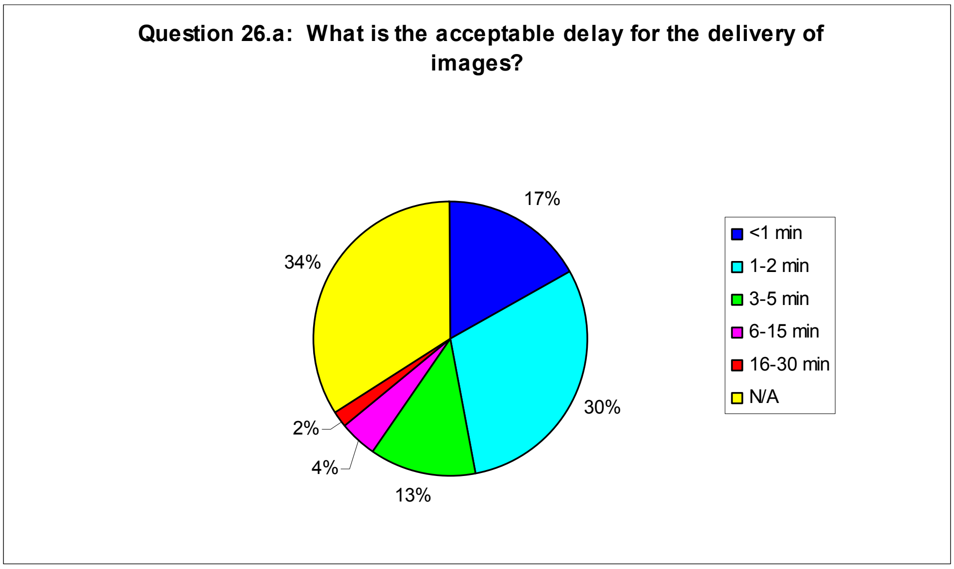


Figure 3.2-46: Analysis of answers given to Question 26.a

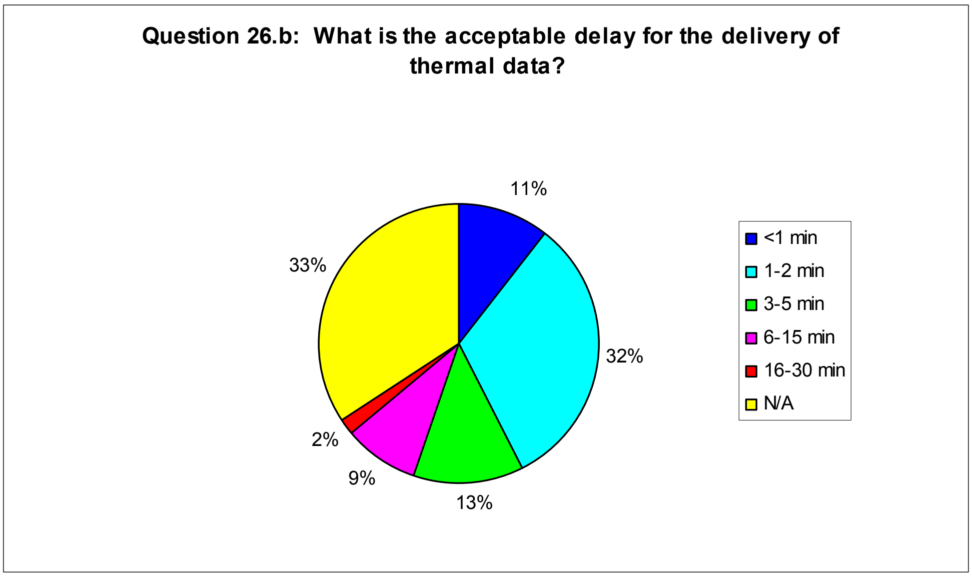


Figure 3.2-47: Analysis of answers given to Question 26.b

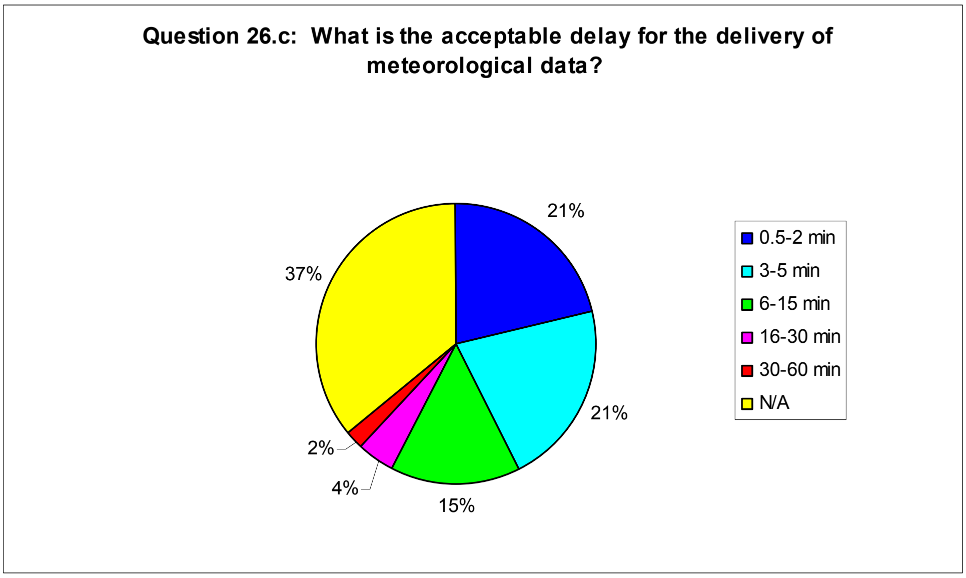


Figure 3.2-48: Analysis of answers given to Question 26.c

Question 27: What is the maximum time allowed between the ignition of a fire and the generation of fire warning?

The majority of users agrees that a fire should be detected within 10 minutes of its ignition, and if possible within the first 5 minutes (see Figure 3.2-49). More specifically, 13% of users believe that a fire should be detected the moment it breaks out, i.e. within the first 60 seconds. Another 15% believe that 1-2 minutes is an acceptable delay. The majority believes that 3-5 minutes is a sufficient time for the fire to be big enough to be easily detected, but not big enough to cause significant damages.

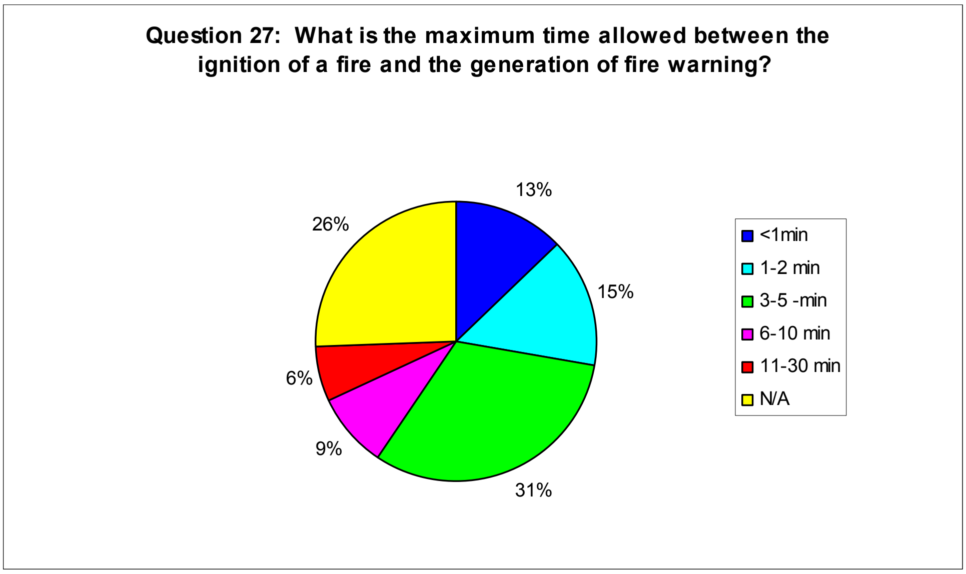


Figure 3.2-49: Analysis of answers given to Question 27

Question 28: Every how many minutes should the fire propagation simulation be updated?

Answers provided by users are shown in Figure 3.2-50. The majority of users believe that the fire propagation simulation should be updated at least once every 15 or 30 minutes (50% and 62% respectively). Some users have also suggested that the update time should depend on the alarm level, the local weather forecast and the current situation in the fire front. If it is very windy or the fire is spreading towards many directions then the simulation should be updated every 10-15 minutes, otherwise 30 minutes is an acceptable update rate.

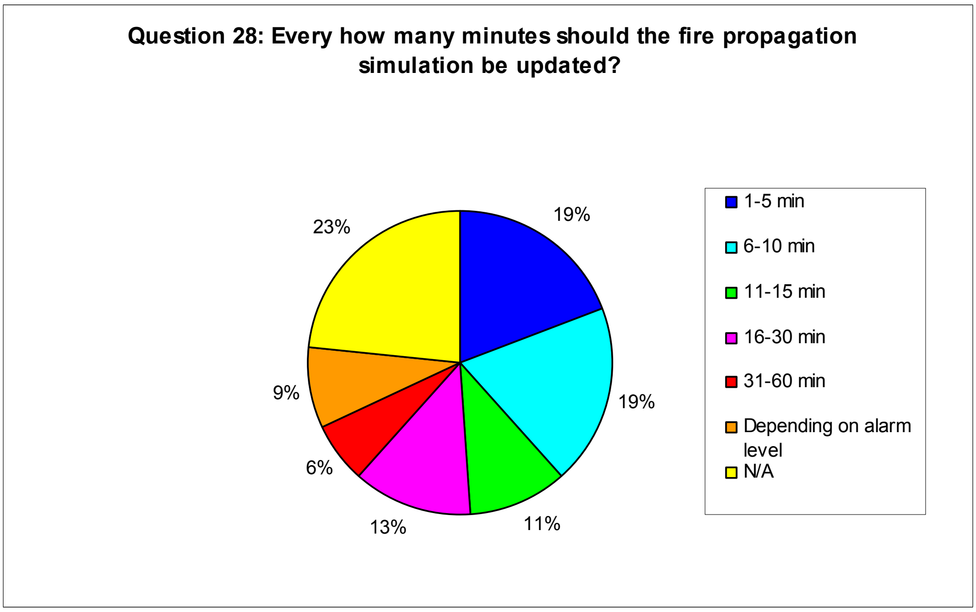


Figure 3.2-50: Analysis of answers given to Question 28

Question 29: Is there any interference problem with other communication systems, e.g. Radar, WiMAX, wireless frequency usage restriction, etc.

As can be seen in Figure 3.2-51, 40% of users were not able to answer this question. The vast majority of the remaining users said that there are no interference problems. Some users suggested that there might be problems but did not give any further explanation about the nature of these problems. Only one organization said that there might be interferences with the electronic systems of an army camp.

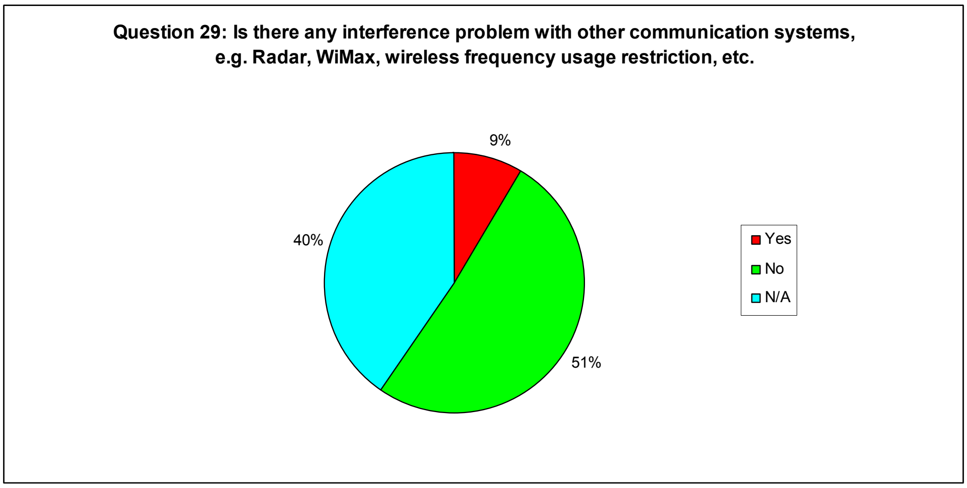


Figure 3.2-51: Analysis of answers given to Question 29

Question 30: Does FIRESENSE provide benefits for the protection of Cultural Heritage Areas? If yes, FIRESENSE improves the protection of Cultural Heritage Areas by: a) fire early warning, b) early extreme weather warning, c) disaster management, d) prevention of arsons, e) security, f) other.

90% of the users replied that they believe that FIRESENSE provides significant benefits for the protection of cultural heritage sites. The remaining 10% did not provide any answer. The answers of users replying positively are analysed in Figure 3.2-52. As can be seen, almost all users agree that FIRESENSE improves the protection of cultural heritage sites by early warning for fire. However, only 80% believes that it can protect a site by extreme weather warning. More than 80% of users believe that installation of FIRESENSE may increase the site security and also prevent arsons. Finally, more than 70% of users say that it could help so that fire management becomes more effective. These answers are similar to those given Section 3.2.1.1-Question 23. However, it seems that people related to fire protection are more convinced than those related to cultural heritage about the advantages of FIRESENSE regarding disaster management. In Figure 3.2-18 more detailed statistics are shown.

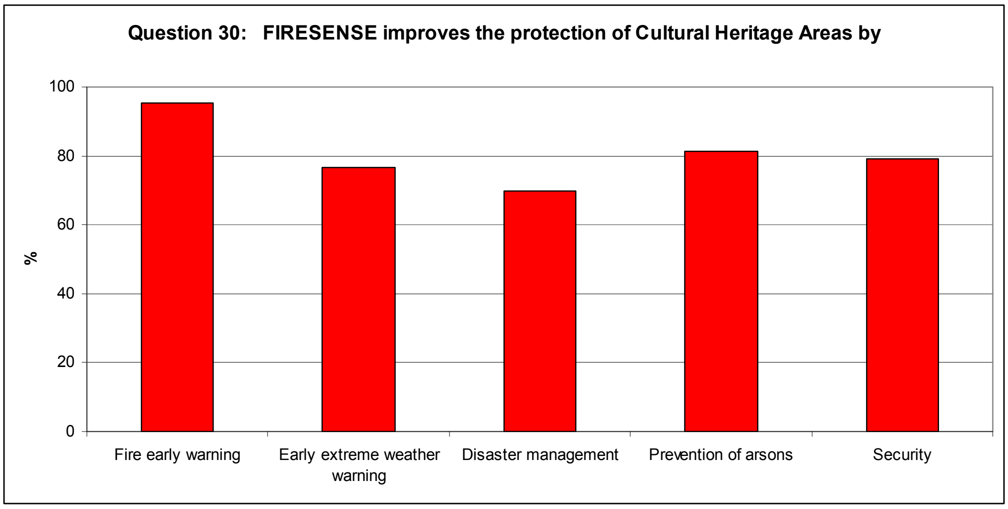


Figure 3.2-52: Analysis of answers given to Question 30

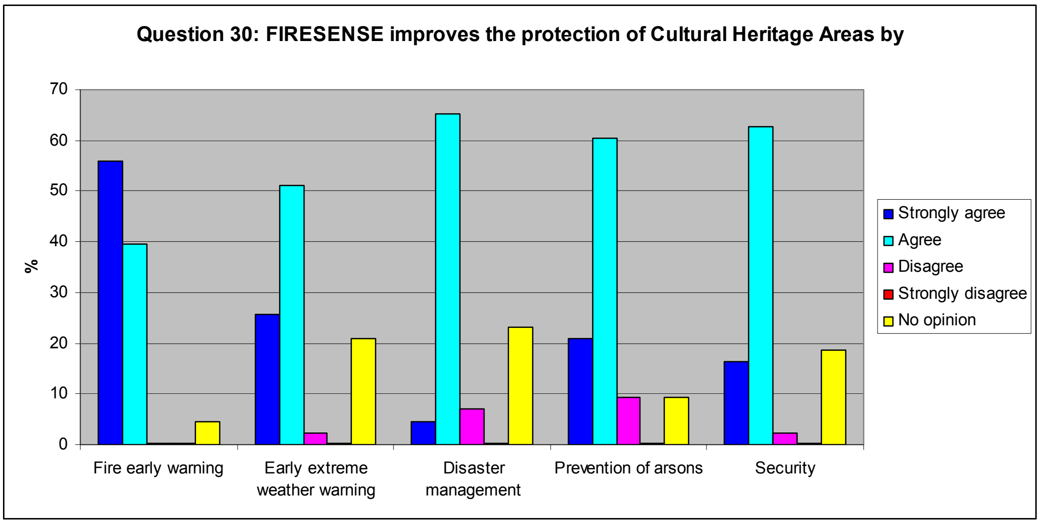


Figure 3.2-53: Analysis of answers given to Question 30

Question 31: Which of the following indirect benefits could be provided by FIRESENSE: a) cultural heritage protection, b) safer evacuation of cultural heritage sites, c) better fire-fighting capabilities, d) cost effectiveness, e) increase of security of cultural heritage sites, f) other.

From the analysis of the answers provided by users in Figure 3.2-54, it is clear that they believe that the FIRESENSE system provides significant benefits in terms of cultural heritage protection and improved fire-fighting capabilities (providing early fire warning and reliable fire propagation and 3D visualization). They also believe that provision of early warnings may decisively help to safely evacuate cultural heritage sites and save human lives. Moreover, the system can also be used as a surveillance system thus increasing the overall site security. Finally, similarly to answers given in Section 3.2.1.1-Question 23, only 28% of users think that the FIRESENSE system provides a cost effective solution.

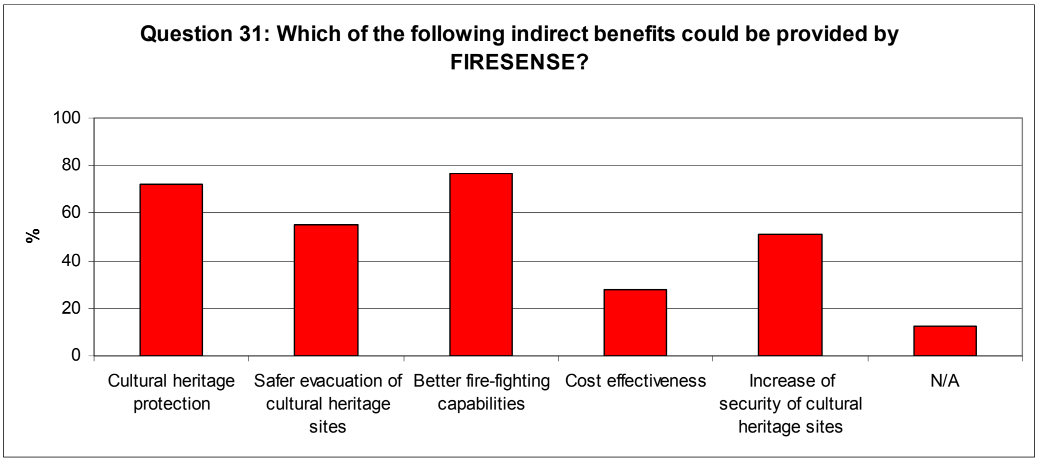


Figure 3.2-54: Analysis of answers given to Question 31

Question 32: In a Scale 1 (least important) – 5 (most Important), how important are the following factors for the FIRESENSE system: a) fast detection, b) easy installation, c) easy maintenance, d) user friendliness, e) low cost, f) independency from human operators, g) extensibility (e.g. for site surveillance against other kind of damages like vandalism, burglary, etc).

The answers provided by users are analyzed in Figure 3.2-55. As was expected, fast detection is considered to be the most important feature in a system like FIRESENSE, since it plays a crucial role in early fire/extreme weather warning making timely intervention possible and fire/disaster management more effective. This finding is in accordance with the answers provided in Questions 30 & 31. Low cost and user friendliness are also highly rated (>70%), since they are decisive factors for buying and using such a system. Another important feature is easy maintenance. Users want a system that does not require special technical skills and could be easily operated and maintained by existing personnel. Easy installation on the other hand is considered important only by 50% of users, since the system will be installed once and this procedure will be handled by system developers.

Finally, independency from human operators and extensibility are considered the least significant factors. The first can be explained by the fact that most users feel more secure if the system is supervised by a human operator. The latter can be attributed to the fact that users answering this questionnaire are related to fire protection and management and are thus not very interested in other possible system uses, e.g. for surveillance. In Figure 3.2-56, more detailed statistics are shown.

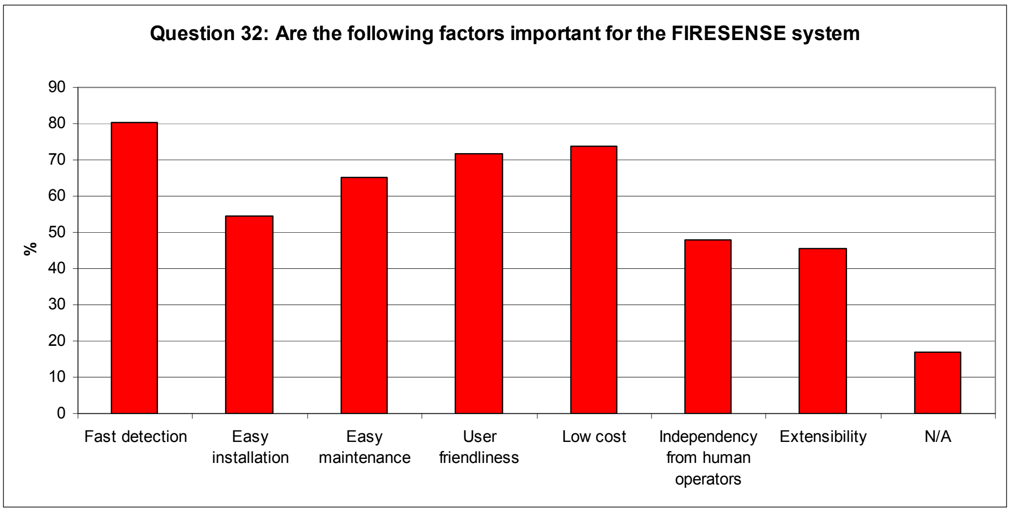


Figure 3.2-55: Analysis of answers given to Question 32

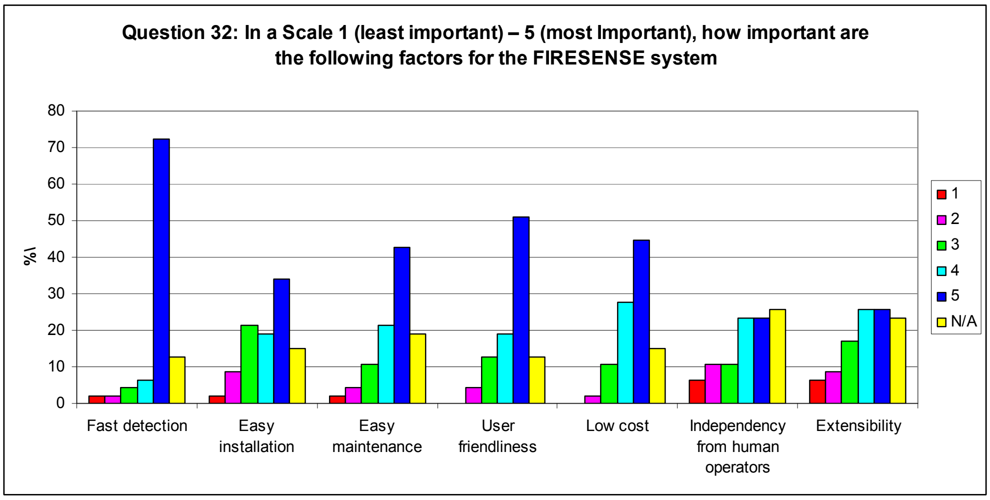


Figure 3.2-56: Analysis of answers given to Question 32

Question 33: What do you think are the strengths of FIRESENSE in general?

55% of users answered this question. From these, 65% believe that fast detection and early warning for fire and extreme weather conditions is the most significant strength/ benefit of the FIRESENSE system. Simulation of fire propagation is also very important since it can contribute significantly to efficient fire management. The continuous flow of different kinds of information and the use of many different sensors is also a significant advantage of FIRESENSE. Other users believe that FIRESENSE can increase the overall site security in many ways: protection against fire/extreme weather, protection against theft/damage/arson, environmental protection and protection of cultural heritage, better fire management, safer evacuation, etc. The fact that FIRESENSE is an automatic system independent of human operators is very appealing for some users.

Comparing the answers given to this question with the answers given by cultural heritage organizations to Question 24 in Section 3.2.1.1, the following conclusions can be drawn:

- Fast detection/early warning is considered to be the most important benefit provided by FIRESENSE. The overall site protection is also mentioned by a lot of users.
- Users related to fire protection/ suppression are very interested in fire propagation estimation and visualization. They are also interested in using many different sensors and delivering different kinds of information continuously.

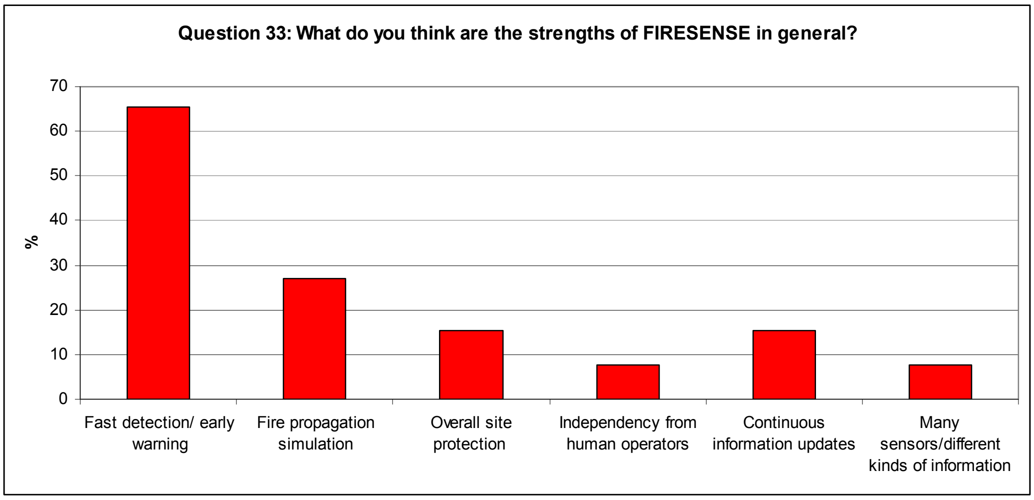


Figure 3.2-57: Analysis of answers given to Question 33

Question 34: What do you think are the weaknesses of FIRESENSE?

53% of users did not answer this question. Answers given by the remaining 47% are shown in Figure 3.2-58. As can be seen, the cost of the system is the major source of concern for potential users/buyers. This finding is in accordance with the answers given in Questions 17 and 32. Users assume that a system such as FIRESENSE using many sensors and offering many different capabilities will probably have a high cost. Moreover, a lot of people believe that such a system will have increased maintenance demands (and cost) and will require personnel with special training and skills for its operation and maintenance. Other potential problems include a) possible weakness of the system to supervise large areas with a limited number of sensors, b) problems with sensor camouflage or communication problems in isolated sites, c) environmental pollution caused by sensors being installed in forestal or other areas, d) issues of privacy protection (cameras monitoring site visitors), etc.

Similar concerns and ratings were observed by users related to cultural heritage (see Section 3.2.1.1-Question 25). High cost, need for specialized personnel and demanding maintenance are considered to be the most significant potential weaknesses of FIRESENSE.

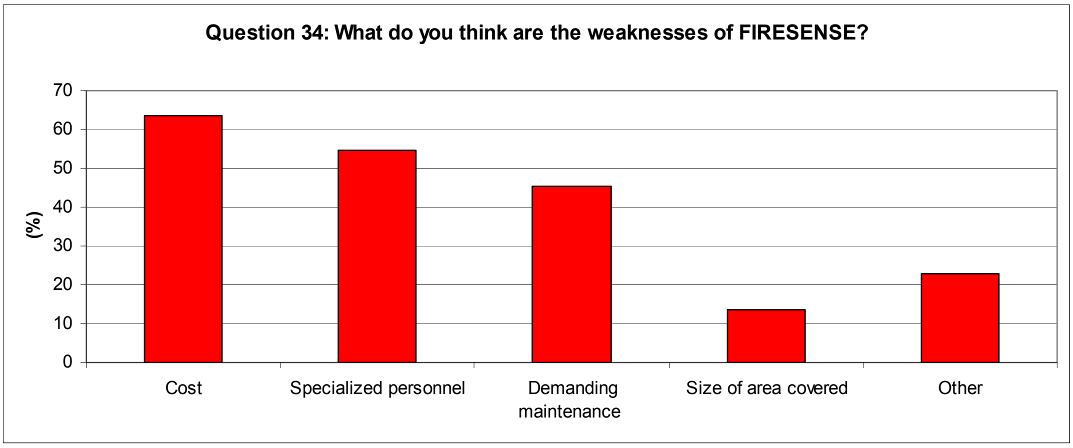


Figure 3.2-58: Analysis of answers given to Question 34

3.2.3 Conclusions drawn from questionnaires

In this Section we briefly present the main conclusions drawn from the answers provided to questionnaires by users. These are listed below:

Current status in sites of cultural heritage interest

- Fires usually start near in a nearby area and then spread in sites of cultural interest. This is especially true for open-air sites neighboring with or surrounded by forests and rich vegetation. Big damages usually happen in sites that a) are surrounded by forests (e.g. Mount Athos, Olympia), b) have no equipment/installations for fire suppression, c) are isolated and difficult to access, d) are not guarded.
- Early warning systems are only used inside buildings. They are usually based on smoke or heat detectors. Camera-based systems are installed in big museums or monuments for surveillance purposes. Open-air sites (e.g. archeological sites) are not equipped with early warning or surveillance systems.
- Fire extinguishing mechanisms are used in almost all cultural heritage sites: Buildings are equipped with portable fire extinguishers or automatic spraying systems. Open-air sites may be also equipped with fire extinguishers; however it is more effective to use fire hoses, fire hydrants or water tanks.
- Automatic fire warning systems based on cameras are used in some countries for forest protection.
- A system like FIRESENSE would be highly appreciated by people working in cultural heritage or fire fighting since only a few similar systems exist or are in use.

User requirements and needs

- Early fire warning is considered to be the most important factor for efficient fire management & fire fighting. The majority of users believe that fire should be detected in less than 10 minutes from its ignition.
- Images, sensor data, meteorological data and fire propagation estimation should be updated continuously especially in case of an incident.

- All information available should be properly visualized in a GIS system. The control center should be carefully designed in order to provide a user friendly interface.
- System should be easily operated. No special technical skills should be required.
- System maintenance should not add significant work load on technical personnel.
- The system installation cost and maintenance cost should be low.

User opinions/suggestions about FIRESENSE

- Fast detection and early fire warning is considered to be the most important feature of FIRESENSE system, along with 3D visualization of fire propagation estimation and delivery of data from different sensors. Users also believe that FIRESENSE could decisively help to protect cultural heritage sites (also personnel and visitors), improve overall site security and enhance fire management capabilities.
- System cost, special skills required for system operation, demanding and costly maintenance, weakness to cover large areas with few sensors, theft or vandalism against equipment, aesthetic or environmental pollution caused by sensors being installed in cultural heritage or forestal areas are the main concerns of potential FIRESENSE buyers and users.

3.3 Feedback from interviews and meetings

Members of the FIRESENSE project (CERTH) were invited to attend to the annual meeting of Civil Protection/ Region of Central Macedonia, which was held on 29th April 2010. This was attended by the General Secretary of the Region, Mayors and Prefects, the Chiefs of Fire-Brigade and Police as well as representatives from the department of Civil Protection, the department of Forestry and other authorities. After the meeting two members of the Civil Protection were interviewed. The conclusions of the meeting as well as the results of the interviews provided valuable insights into the needs and concerns of potential users of the system. Issues of relevance to user requirements include:

- Cleaning areas around archaeological sites, parks, groves etc. from wild vegetation. The existence of **dry vegetation** creates high risk of fire. Therefore, the monitoring of areas with dry vegetation is of high priority for FIRESENSE system.
- A lot of fire incidents are caused by **pylons of power supply** located in rural areas, especially, when there is dry vegetation in their vicinity. The existence of high and medium voltage power lines in forest areas increase the risk of fires, which can be spread to nearby cultural heritage sites.
- Governments should spend a lot of money for taking precautionary measures against fire, e.g. the purchase of suitable equipment. However, one can consider that in case of fire **the total cost is eventually more than ten times higher** than the cost required for the precautionary measures. Hence, despite the financial crisis, governments should invest on new technologies for reducing the risk of natural disasters.
- Previous experience has also showed, that a large number of fires have started from railways. Specifically, the **breaks of trains** create sparks that may cause a fire, especially when dry vegetation exists near the rails. For this reason

cleaning of rails from dry vegetation is required. The monitoring of areas near railways should be also considered by the consortium of FIRESENSE system.

- Another cause of wildfires burst over the country is the existence of **illegal rubbish dumps** or areas across roads where visitors/drivers/dwellers throw rubbishes of all kind. The identification of such areas will be of great importance during the installation of the FIRESENSE system at the test sites, since the knowledge of the causes of forest fire is a precondition for the implementation of a suitable solution.
- Statistics have shown that fire fighters needs a **half an hour** - after the have been informed - to reach the point where a wildfire has burst, without considering the time needed for the identification of the fire by human observation. Thus, early detection of the fire is extremely vital for extinguishing it.
- The **Athonic state of Agion Oros**, or officially known as Holy community of Agion Oros is an "Autonomous Monastic State" in Greece (and perhaps unique in the world, except the secular Lasa in Tibet), in the peninsula of Athos of Chalkidiki in Macedonia, which is considered the center of Orthodox monasticism. It is one of the most important parts of not only the Balkans but of Europe and of the Eastern Church due to its great national, historical, religious, secretarial and cultural value, and also considered an important center for the conservation and maintenance of rich material and rightly it is described as "shelter" and "museum" of unique treasure of Greek art and letters (see Section 3.1). The local fire service of Agion Oros is staffed by a small number of fire-fighters and due to the special regime of the Athonic state, the entrance of reinforcements, even in cases of wildfires, is not easily allowed. Hence, early detection of the fire is extremely vital for the protection of Agion Oros, since a small force of fire-fighters can quench a fire before it becomes uncontrolled.
- Finally, a deterrent factor for the installation of an early warning system is **maintenance** in terms of cost and lack of specialized personnel.

3.4 Other feedback from Public Authorities

The Headquarters of the Greek Fire Service responded to our questions with a document describing the current practices of the Greek Fire Service for forest surveillance. Until now, prevention of forest fires in Greece relied mainly on surveillance and patrols by public officers and volunteers. However, the Fire Service aims to use new technologies for forest fire prevention and management in the near future. More specifically:

❖ **Current status:** According to its fire fighting planning, the Fire Department uses a sufficient number of people and resources for forest fire prevention as follows:

  - Ground surveillance through fire posts placed in important locations spread throughout Greece and staffed with experienced fireguards.
  - Surveillance via fire fighting tankers that are properly dispersed within forests and woodlands.
  - Mixed mobile patrolling units (cooperation of Armed Forces and the Greek Police).
  - Daily patrols by officers of the Fire Department in sensitive areas.
  - Aerial patrols by aircraft over sensitive forest areas and National Parks.

- Patrols by the Greek Police and the Armed Forces.

The Fire Department cooperates with other services and ministries that, alongside their duties, also monitor forest areas, such as:

- The Civil Aviation Authority that notifies crews of civil aircraft, about possible risk of forest fires and provides alarms about possible fire incidents while flying over Greece.
- The active participation of the General Secretariat for Civil Protection which uses registered volunteers to do surveillance in forests and woodlands.
- The Ministry of Environment, Energy and Climate Change participates with patrols by Forest Department officers at their area of authority.
- The Ministry of Defence participates with surveillance from ships and aircrafts during training exercises.

The Fire Department receives information about forest fire incidents by people passing through forest areas and/or people living nearby.

Preventive measures such as cleaning, in and around archaeological sites, and/or permanent installation of fire protection systems for the protection of archaeological sites is the responsibility of the Ministry of Culture and Tourism.

❖ **New technologies**: The Fire Department has further assessed its needs and has submitted a project proposal for funding via National Sources for implementing an integrated nation-wide Fleet Management and Wildfire Fighting system that will answer the needs of the Fire Services all over Greece. The project will include the development of systems and subsystems such as:

- Geographic Information Systems (GIS)
- Fire propagation estimation model, to predict the spread of fire.
- Vehicle location tracking system
- Shortest route estimation
- Side-fire risk assessment system
- A subsystem for measuring the operational capability of vehicles, crews and hydrants
- A portal which will serve as a citizens' access to up-to-date information on fire risk or management of existing fires.

These systems will provide useful information for dealing with forest fire incidents and will be fully interoperable, thus providing many useful functionalities such as providing images from points of interest, meteorological and/or geographical data.

3.5 References

[1] UNESCO World Heritage Information Kit http://whc.unesco.org/uploads/activities/documents/activity-567-1.pdf

[2] UNESCO Mouth Athos World Heritage Site http://whc.unesco.org/en/list/454

[3] UNESCO World Heritage selection criteria http://whc.unesco.org/en/criteria/

[4] NATURA 2000 http://www.natura.org/about.html

[5] A.P. Dimitrakopoulos, D. Mitrakos and V. Christoforou, "Concepts of Wildland Fire Protection of Cultural Monuments and National Parks in Greece. Case

Study: Digital Telemetry Networks at the Forest of Ancient Olympia", Fire Technology, Vol. 38, No 4, pp. 363-372, Oct. 2002

[6] Control Centre for Collection and Processing of Alarm Signals, Greek Ministry of Culture and Tourism http://www.yppo.gr/2/g22.jsp?obj_id=5785

[7] Turkish General Directorate of Forestry: Forest Fire Management System & Forest Fire Early Warning System http://web.ogm.gov.tr/languages/English/dokumanlar/egovshare2009presentation.ppt

4 User Requirements

The following Table summarizes the list of technical User Requirements for all system components. Requirements are characterized as mandatory (M) or desirable (D).

4.1 Technical / Operational Requirements

- Power Supply

R1.1	220V AC may be required for system components that consume significant electrical power (e.g. WSN Gateway and WDN) **(M)**. Renewable energy sources will also be used (for the gateway and the sensors). **(D)**	**M/D**
R1.2	UPS should be available for power shortages.	**M**
R1.3	Solar cells and batteries shall be used in remote camera locations.	**D**
R1.4	Batteries shall be used for small Wireless Sensors (e.g. sensors measuring temperature, humidity).	**M**

- Optical Cameras

R2.1	PTZ IP cameras with rotation and preset position functionalities will be supported **(M)**. Fixed IP cameras can also be supported **(D)**.	**M/D**
R2.2	Optical cameras should be compatible to IP65 standards so that they are robust to extreme meteorological conditions (humidity, rain, temperature).	**M**
R2.3	External and internal orientation of optical cameras shall be a-priori known (for fixed cameras) or be able to be determined (for rotating PTZ cameras) by the control center.	**M**
R2.4	It should be possible to detect smoke from maximum 3km **(M)** – 8km **(D)** of viewing range. The cameras should cover 180 to 360 degrees of covering angle.	**M/D**
R2.5	M-JPEG compression (**M**) **-** MPEG4 **(D)** and 320x240 image resolution should be supported. **(M)**	**M/D**
R2.6	Frame rate should be at least 5 frames per second	**M**
R2.7	Cameras should be accessible & controllable from the control center.	**M**
R2.8	Cameras should be accessible via internet or any other means of remote access.	**D**
R2.9	Preset positions should be defined for PTZ cameras. The camera will go back to the same preset position in at least 10 minutes.	**M**
R2.10	Smoke or flame size on the video should be at least 16x16 pixels **(M)**, 8x8 pixels **(D)** for fire to be detected.	**M/D**

- Infrared Cameras

R3.1	PTZ IP cameras with rotation and preset position functionalities will be supported **(M)**. Fixed IP cameras can also be supported **(D)**.	**M/D**
R3.2	IR cameras should be compatible to IP65 standards so that they will be robust to extreme meteorological conditions (humidity, rain, temperature).*	**M**
R3.3	External and internal orientation of optical cameras shall be a-priori known (for fixed cameras) or be able to be determined (for rotating PTZ cameras) by the control center.	**D**
R3.4	With 100 mm lens, detection of a 1 m^2 fire at 1.8 km line of sight should be possible **(M)**. 180 to 360 degrees of covering angle should be supported **(M).** With 135 mm lens**, detection of a 1 m^2 fire at 2.5 km line of sight should be possible **(D)**. 180 to 360 degrees of covering angle should be supported* **(D)**.	**M/D**
R3.5	LWIR (Gobi/Raven) Resolution <= 384x288, NETD < 80 mK, Pitch = 25 um.	**M/D**
R3.6	Frame rate should be at least 5 frames per second	**M**
R3.7	IR cameras should be accessible & controllable from the control center	**M**
R3.8	IR cameras should be accessible via internet or any other means of remote access.	**D**
R3.9	Smoke or Fire size on the video should be at least 16x16 pixels **(M)**, 8x8 pixels **(D)** for fire to be detected.	**M/D**

* This does not apply to the scientific instrumentation like MultiSpectral imaging of MWIR camera.

** Adaptation of the 135 mm lens with the IP65 housing may not be possible.

- WSN / WDN / Communication Infrastructure

R4.1	Sensor nodes should be robust to extreme meteorological conditions (humidity, rain, temperature).	**M**
R4.2	Sensor nodes should be simple and extendable, so that they can potentially support further environmental measurements in the future.	**M**
R4.3	WSN shall use self-organization and robust routing mechanisms, so that destruction of some nodes still allows the system to deliver readings from sensors that are still operating. On the other hand, new sensor nodes shall be added and configured promptly and easily by an automated procedure, whenever this is required.	**M**
R4.4	Sensor readings shall be reliable and should reach the central server with minimum delay.	**M**
R4.5	The wireless sensor network architecture and operation shall try to optimize the energy efficiency of the sensor nodes so that batteries last longer and are replaced less frequently.	**M**
R4.6	The location of all sensor nodes shall be a-priori known or reported to	**M**

	the control center.	
R4.7	Cost of sensor nodes should be kept as low as possible.	**D**
R4.8	Zigbee, IEEE 802.15.4-2003 standard for wireless personal area networks (WPANs) will be used as the communication standard.	**M**
R4.9	Sensors will be camouflaged.	**M**
R4.10	Quality alkaline batteries AA sized (LR6) 2800 mAh - economical solution for keeping cost of WSN node low.	**D**
R4.11	The WSN application should support querying of up-to-date sensor data on a specific sensor.	**D**
R4.12	The WSN and WDN should support the necessary means for network monitoring and management tasks.	**D**

- Meteorological Stations

R5.1	The meteorological stations shall collect meteorological data: air temperature, relevant humidity, barometric pressure, wind velocity, wind direction and the level of rainfall.	**M**
R5.2	The meteorological information should be stored in a database.	**M**
R5.3	The station should be robust, fairly maintenance-free, have no uncertainty in the way that it samples the variables to be measured.	**M**
R5.4	Meteorological stations should be protected against lightnings.	**M**
R5.5	Meteorological stations should have flexible firmware so that managing and interrogating the sensors according to the needs of the project should be possible. Stations should be easily expandable for handling many sensors.	**M**
R5.6	Meteorological stations should be remotely accessible and controllable.	**M**
R5.7	Security measures against theft and vandalism should be taken.	**M**

- Data fusion

R6.1	Information from all optical/IR cameras, WSN and meteorological stations should be fused.	**M**
R6.2	Data from WSN and meteorological stations shall be fused to compute a fire risk index.	**M**
R6.3	All measurements shall be time-stamped, so that only consistent measurements (those falling within a specific time-window) are fused in each data fusion cycle.	**M**
R6.4	Use of OGC's Sensor Web Enablement (SWE) standard for data exchange and storage is desirable.	**D**
R6.5	The data fusion module will provide the control unit with five alert levels. 1. Nominal: everything is OK 2. Increased vigilance: anomalies detected, possibility of fire; 3. Full alert: fire detected; 4. Extreme weather warning;	**M**

	5. Sensor malfunction likely (e.g. due to low battery).	

- Control Center /System Software

R7.1	The Graphical User Interface (GUI) of the system shall be user friendly.	**M**
R7.2	A simple training for users to learn & use the system should be provided.	**D**
R7.3	Techniques for data decompression/decryption should be supported.	**D**
R7.4	The GIS system should be able at least to display the following information as separate layers: - 3-D Terrain data (DEM) **(M)** - Water sources (streams, rivers, lakes) **(M)** - Places of high cultural importance (inside or in the vicinity of the site) and/or sensitive areas (e.g. a dense forest, protected areas, etc) **(M)** - Fuel maps obtained by vegetation maps **(M)** - Road network, paths etc. **(M)** - FIRESENSE System should provide Fire and Extreme weather condition Alarms (video and acoustic alarm signal) **(M)** - Infrastructure installed by FIRESENSE (Sensors, Cameras, Meteorological Stations). **(M)** - Meteorological data **(M)** - Estimated ignition point **(M)** - Fire propagation simulation visualization **(M)** - Risk indices indicating the risk of fire or extreme weather conditions. **(M)** - Additional information useful for fire fighting: Fire preventing zones, prefectures, etc. **(D)** - Names of places, mountains etc. **(D)**	**M/D**
R7.5	WGS84 (World Geodetic System) will be used for geo-referencing of all data.	**M**
R7.6	Means of managing and controlling data display should be supported (e.g. layer hide/show, zoom in/out).	**M**
R7.7	Presentation of geographic data at multiple scales, so that in any given time display of all layers of the area of interest at the given scale is possible. Map navigation tools (zoom in/out/ move/ rotate) should be supported.	**M**
R7.8	Sensor data (including images) should be displayed at multiple windows by clicking to the corresponding sensors/stations	**M**
R7.9	Storage / export of maps in different data formats such as jpg, tiff, bmp, gif, png, emf, etc. should be supported	**D**

R7.10	The system should support reading of vector data.	**D**
R7.11	2D and 3D graphics should be supported.	**M**
R7.12	Camera/sensor/meteorological/fire propagation data should be updated at least every: • Optical images: 30 seconds • Infrared images: 30 seconds • Sensor data: 5 minutes (in alarm situations), 3hours (normal situations) • Meteorological data: 30 minutes **(D)** • Fire propagation: 15 minutes (in alarm Situations) • Risk index: 30 minutes **(D)**	**M/D**
R7.14	Alarm indications: Audio signal **(M)**, Visual signal **(M)**, Display on a map **(M)**, SMS **(D)**	**M/D**
R7.15	The probability of having more than one false alert per day should be less than 85%.	**D**
R7.16	The system will be self restartable.	**M**
R7.17	System should be operable over 97% between March and October and over 90% at winter period.	**D**
R7.18	A database should be created up to store sensor data. It should be possible to query statistics of the site data from this database.	**M**
R7.19	Video recording from selected cameras shall be possible	**M**
R7.20	Automatic start of video recording in case of an alarm.	**M**
R7.21	The system should be operable even if some sensors are destroyed.	**M**
R7.22	The system shall have self test functionality: any sensor malfunction or destruction should be automatically sensed by the control center.	**M**
R7.23	The system shall be extensible i.e. able to include new sensors or already existing infrastructure for specific sites.	**D**

- Fire Propagation and Visualization

R8.1	Given terrain data and fuel maps of the area, evolution of fire for a selected region should be possible after defining the ignition point(s).	**M**
R8.2	Ignition points should be defined either automatically given the result of fire/smoke detection or manually by users entering its geographical coordinates.	**M**
R8.3	Fire propagation should be visualized in both 2D and 3D maps **(M)**. 3D visualization should be as realistic as possible **(D)**.	**M/D**
R8.4	It should be possible to save fire propagation parameters as XML files. It should also be possible to upload fire simulation XML files and visualize them in a 3D or 2D environment.	**M**
R8.5	The EFP module should be able to provide results even if there is more than one ignition point	**M**

4.2 Maintenance

R9.1	The system should be installed and configured in such a way that essential maintenance can be carried out with minimal interruption of operation.	**D**
R9.2	The system should have low maintenance costs.	**D**
R9.3	Maintenance issues should be handled by the user from a separate window in the control center	**M**
R9.4	The WSN software (application and middleware) should be updatable over the air to keep the maintenance costs lower.	**D**

4.3 Installation / Financial issues

R10.1	Commercial off-the-shelf (COTS) components shall be used wherever possible to keep the cost of the FIRESENSE system low.	**D**
R10.2	The overall cost of the system components and the overall system shall be kept as low as possible.	**D**
R10.3	Optical and IR sensors shall be carefully mounted / calibrated to prevent measurement errors and misregistrations.	**D**

4.4 Environmental / Interference issues

R11.1	The system should not be affected by radio interference including that produced by telecommunication facilities, adjacent power cables, adverse weather and topographical conditions.	**M**
R11.2	The system shall not affect (or at least should have minimal interference) to existing telecommunication facilities.	**M**
R11.3	The system shall be protected against lightning and high voltages.	**D**
R11.4	The sensors shall be fully operable in the temperature range -20^{o}C to 55^{o}C.	**D**
R11.5	Effort should be made to use renewable energy sources (e.g. photovoltaic panels) as much as possible.	**D**
R11.6	The system installations should be unobtrusive and harmonized with the environment of the cultural heritage site (e.g. sensors camouflage).	**D**

5 Field Measurements

5.1 Fire Detection Recording Systems Configurations

5.1.1 General Description

The fire detection system could have 3 different types of system configurations depending on the objectives, the site location and the price.

The purpose of the ***first configuration*** is to build a simple data and image acquisition system that will be used for the modeling and data analysis. It will be a non-remote data acquisition system for scientific investigation. Infrared cameras that will operate at different wavebands and with different types of filters will be used for this purpose. Analysing the output data of the system will allow us to extract and select the spatial, temporal and spectral features for further processing. The output of this data analysis will help us to define architecture of the system.

The ***second configuration*** will be a remote MultiSpectral Imaging Acquisition platform that will be sending non-compressed images to the control room by telecommunication. The non-compressed images will allow the scientist to process all the information content of the images. They will be able to apply fusion algorithms at the pixel, feature and classification levels.

Using different methods, data can be processed remotely on a personal computer that can be accompanied by a coprocessor such as a GPU. The communication link between the cameras and the control room will be an Ethernet cable, a fiber optic or a microwave link. Telecomunication interface will be performance driven in this case.

The ***third configuration*** is a simple system based on one PTZ camera or several fixed cameras covering field of interests that could be overlapped or not. This configuration is mainly price driven.

The methodologies for collecting data will be based on the document Deliverable D-07-12 Common Methodologies for Collecting Data during Outside Fires from EUFIRELAB.

5.2 Field tests plan with infrared cameras

5.2.1 Internal field tests

5.2.1.1 Description

The internal field tests are carried out in order to check the cameras setup and integration. It will also help us to understand the physical aspects of the fire, the smoke as well as the background as a function of wavelength. Distance is another variable that will be further analyzed. The fire detection range of the IR cameras during various environmental and weather conditions will be examined.

5.2.1.2 MultiSpectral Cameras with Motor Control (Third Configuration)

The Meerkat PTZ is controlled through a PC. The Lens of the infrared camera is fixed and the lens of the visible camera is zoom controlled.

Figure 5.2-1: PTZ controlled platform with visible and IR cameras

This set up will allow us a quick deployment. The cameras are protected and can operate in rainy, dusty and sandy environment. The setup will be used during bad weather conditions.

5.2.1.3 Integrated MultiSpectral Cameras Set Up with Manual Control (First Configuration)

Tripod with Aluminum camera support plate is controlled manually to aim the cameras. The MWIR Oncas camera, the LWIR Gobi camera, the SWIR Bobcat camera and the color camera are mounted on a rigid aluminum plate. This configuration allows us to test different lens sizes for different range tests. The Oncas, thanks to the filter wheel, also allow precise spectral analysis in the MWIR.

Figure 5.2-2: Integrated MultiSpectral Sensor from RIT

5.2.1.4 Integrated and aligned cameras set up for fusion (Second Configuration)

The objective of this set up is to align the cameras for future co-registration. The cameras have different resolutions. They should be aligned in such a way that they see the same references or the same types of features spatially. The cameras with their lenses should be calibrated in order to avoid any misalignment.

The aligned cameras will be able to later provide co-registered image for image fusion at the pixel level. Potential fire and the smoke regions will be selected by spatial processing. This will allow us to have candidates for further temporal and spectral processing on one or several selected pixels. The visible spectrum camera will allow us to identify the regions in the scene and to estimate the unknown parameters of the target and the background. Estimating these parameters will depend on the type of detection used model. If the model requires means and covariance, a statistical approach is used. Subspace or mixing models will use geometric techniques. There are many ways to characterize the target and the background that are changing with the atmospheric conditions, noise, and variability of the material…. The MultiSpectral Images are recorded by the PC for further analysis.

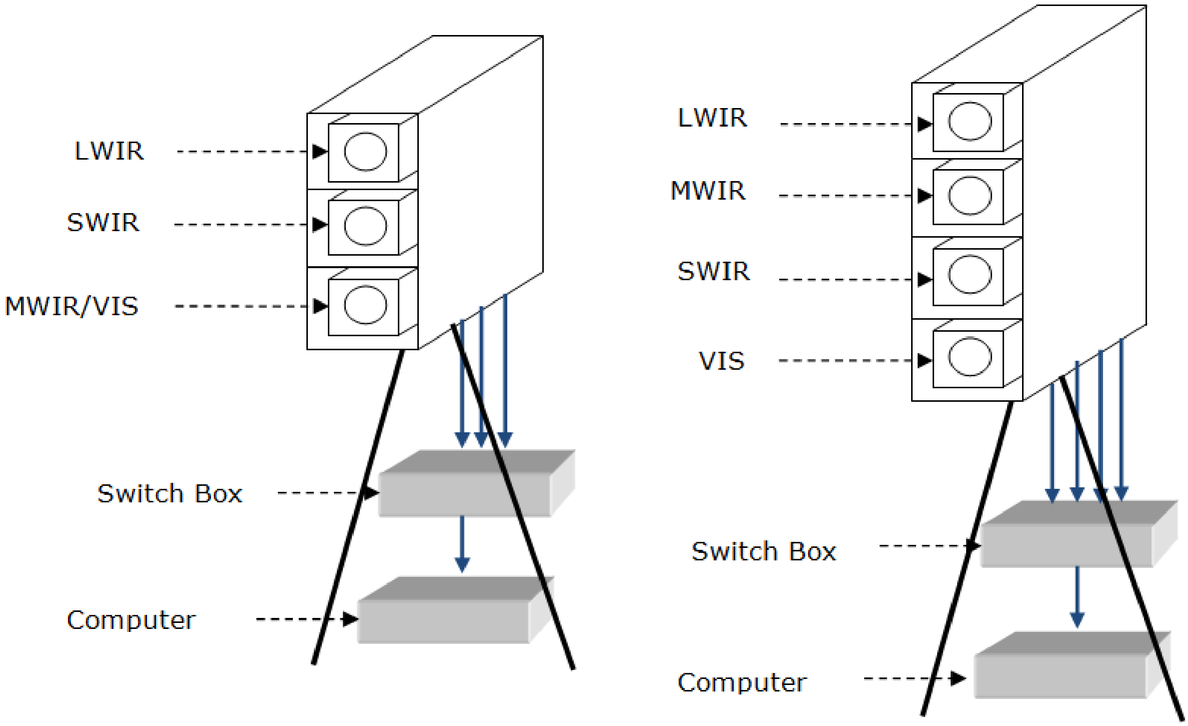


Figure 5.2-3: Integrated and Aligned MultiSpectral Cameras System

A set of small cameras (NIR/SWIR/VIS/SWIR/LWIR) will be assembled and mounted on in metallic frame for alignment. This frame will be attached to a tripod. The cameras will be connected to a switch that will be connected to the computer.

The purpose of this data acquisition system is to acquire and analyze the images at different wavelengths in order to select the right camera for the PTZ Platform.

Figure 5.2-4: Example Distance Recording

Figure 5.2-5 is an example of spectral response of three different wavelengths recorded by RIT.

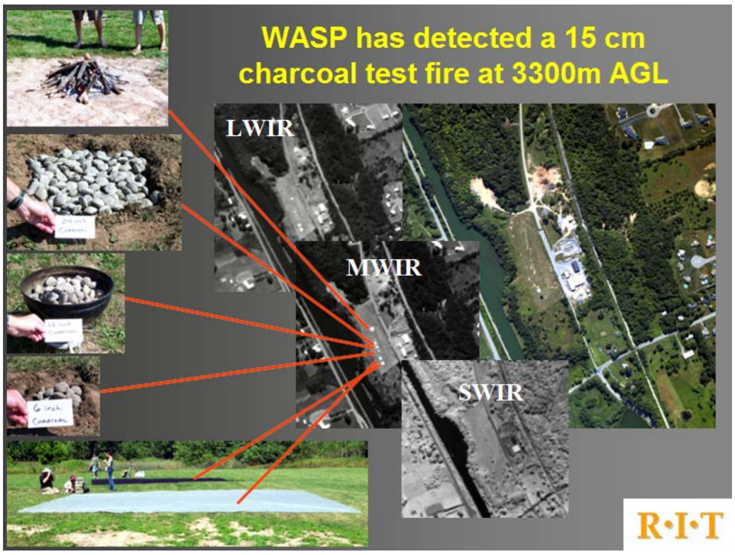


Figure 5.2-6: MultiSpectral Imaging in LWIR, MWIR and SWIR

5.2.1.5 Spectroscopic Experimental Tool (option to rent)

5.2.1.5.1 IR Molecular Spectroscopy

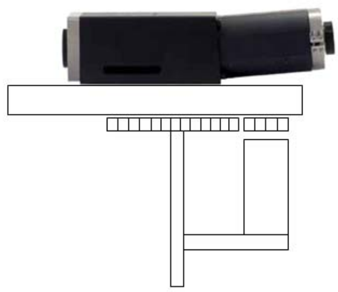


Figure 5.2-7: IR Molecular (Water, Carbon Dioxyde) Spectroscopic imager placed on a PTZ

In this setup, the light is decomposed by a prism (or Monochromator) and projected on a FPA (Focal Planar Array). It creates a set of spectral lines. If we rotate the spectrometer at a constant speed, we create a scanned spectral imaging device. The resolution is given previously in the specifications.

5.2.1.5.2 IR Atomic (Potassium) Spectroscopy

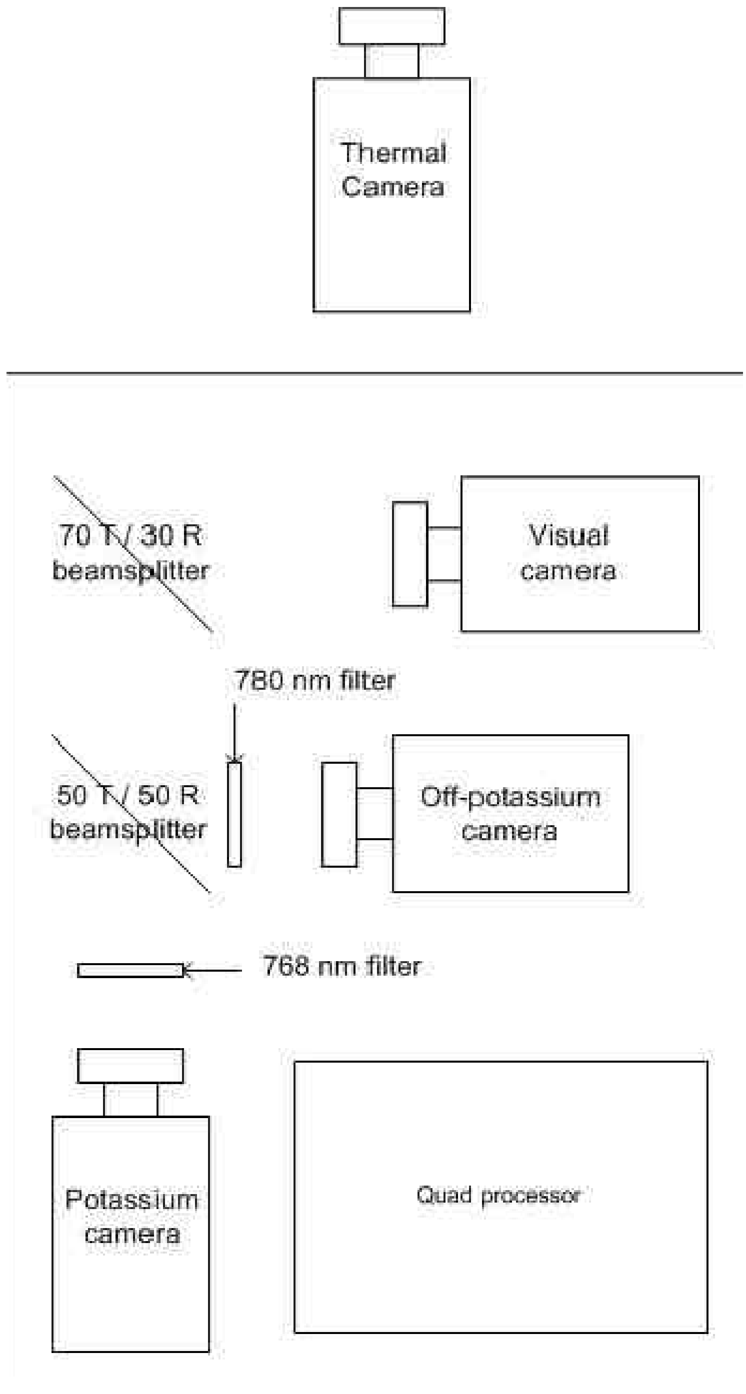


Figure 5.2-8: Infrared Atomic (Potassium) Spectroscopy

This is an example of setup realized by Rochester Institute of Technology (RIT). We can could also implement it with the help of filters. We should check if the line emission from the fire is significant enough for remote sensing. RIT also checked for the potassium lines with the help of single photodetectors.

5.2.2 External Field Tests

The objectives of the experiment are flame and smoke detection and checking of the presence of emission lines with the Infrared Cameras. The lists of main parameters are the following:

- ***Site Description:***

Terrain characteristics: Knowledge of the terrain (fire spreading), soil type.

Preparation of the field plots

Climatic characterization

Location: GPS (Latitude, Longitude)

Topography: Terrain aspect, slope, elevation and configuration

Good road access, good visibility (LOS)

Fuel complexity

GIS data

Photos

- ***Fuelbed properties:***

Fuel has a strong influence in the fire behavior mechanism as fire behavior, fire effects and smoke production.

Detailed fuel description: fuel load, porosity, surface volume ratio, fuel moisture content, crown base height, leaves, cork, small branches …

- ***Fire front properties:***

Fuel characteristics: vegetation type

Fuel Moisture Content: FMC

Fire State: Ignition and propagation, fire intensity, fire flame size, fire progression rate of spread, flame geometry, flame height, flame length, Flame Angle, Flame Depth

Fire Smoke: White, grey or black

- ***Meteorological parameters:***

Meteorological conditions near the fire and in the surrounding areas

Temperature

Humidity

Wind velocity, direction

The external test are planned to be conducted until October 2010.

The lists of tests are the following:

Table 5-1: List of Field Tests

Where	Fire	Material	Purpose
Xenics	Local fire	LWIR, SWIR Color cameras Bobcat and Cheetah	Feature content analysis
Xenics	Local fire	3 aligned cameras LWIR, Color, SWIR Computers, Cables	Fusion and fire detection. Temperature and shape. Short Ranges
Xenics	Local fire	Oncas MWIR Computers, Cables	Filters and fire detection with temperature. Smoke Emission Lines. Short Ranges
Xenics	Local fire	NIR Computers, Cables	Filters and fire detection Potassium Emission Lines Short Ranges
Xenics	Local Fire	Spectrometers Computers, Cables	Fire detection HyperSpectral Imaging Short Ranges
Xenics	Local Fire	PTZ LWIR, Color/SWIR Computers, Cables	Fire detection MultiSpectral Imaging Short Ranges
Xenics	Local Fire	Integration with weather station and recordings Computers, Cables	Fire detection MultiSpectral Imaging Short Ranges
Bilkent	Fire Rank 1	Computers, Cables	Video Based smoke detection
Bilkent	Local Fire	Computers, Cables, IR filters	Fire and smoke detection using IR filters on visible spectrum cameras
Bilkent	Local Fire	PIR sensors	Smoke and Fire detection

5.3 Cameras systems

5.3.1 System set up schematics

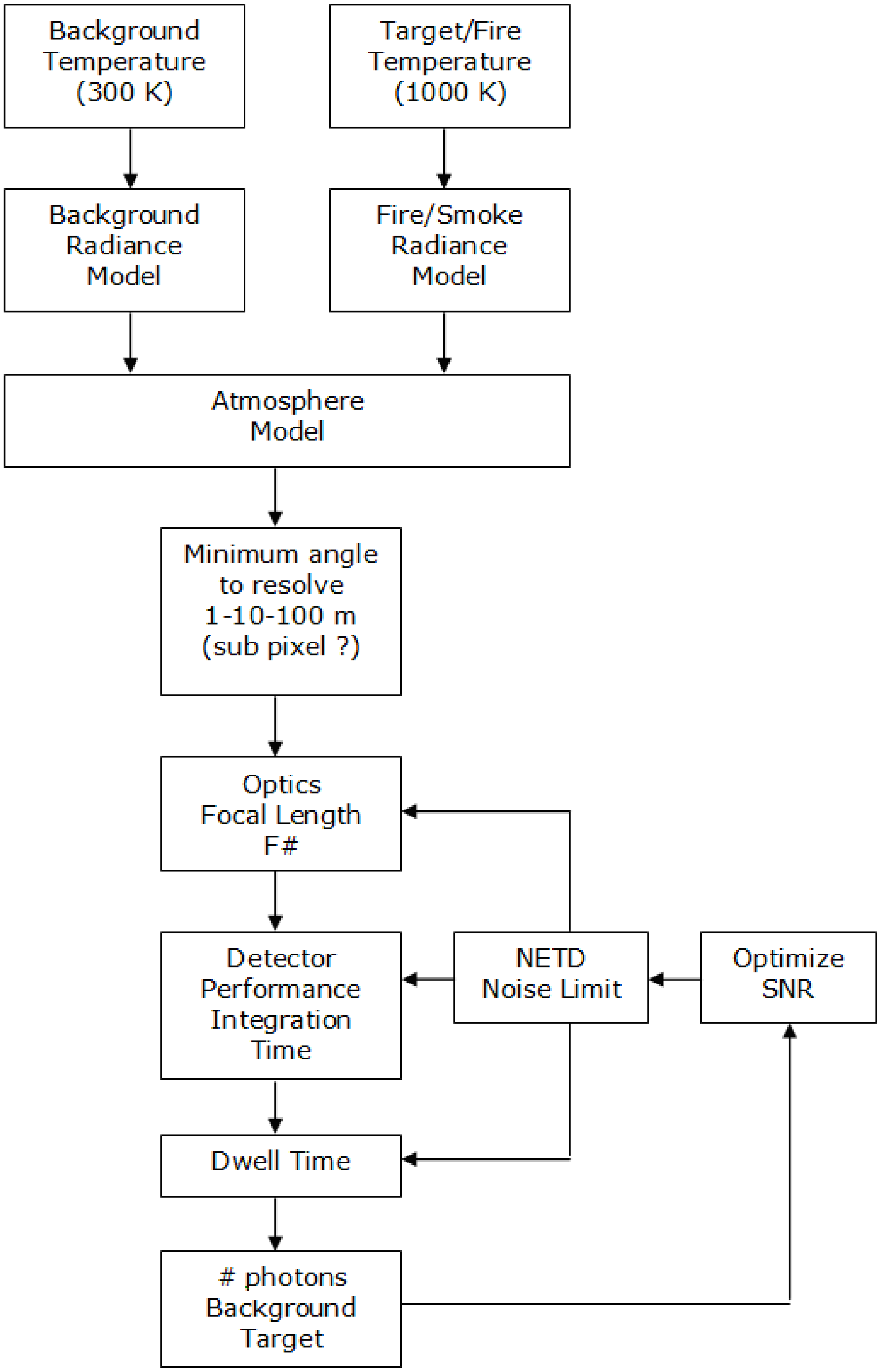


Figure 5.3-1: Schematics of the system selection

6 Appendices

Appendix A: Survey for users directly related to Cultural Heritage sites (archaeologists, curators, local authorities etc.)

Appendix B: Survey for users involved in fire fighting (fire-fighters, volunteers, related authorities)

Appendix C: Abbreviations used in Deliverable 4

FIRESENSE Project
Protection of Cultural Heritage

Appendix A – Survey for users directly related to Cultural Heritage sites (archaeologists, curators, local authorities etc.)

Dear Madam/Sir,

We are conducting a survey on the Protection of Cultural Heritage Areas from the Risk of Fire and Extreme Weather Conditions for the FIRESENSE project, which is co-funded by the European Commission's 7th Framework Programme Environment (including Climate Change) (FP7-ENV-2009-1–244088-FIRESENSE, www.firesense.eu).

The aim of the project is to develop an automatic early warning system to remotely monitor areas of archaeological and cultural interest from the risk of fire and extreme weather conditions. FIRESENSE will take advantage of recent advances in multi-sensor surveillance technologies, using a wireless sensor network capable of monitoring different modalities (e.g. temperature) and optical and infrared cameras, as well as local weather stations. The signals collected from these sensors will be transmitted to a monitoring center, which will employ intelligent computer vision and pattern recognition algorithms as well as data fusion techniques to automatically analyze sensor information. It will be capable of generating automatic warning signals for local authorities whenever a dangerous situation arises. Moreover, it will provide real-time information about the evolution of fire using wireless sensor network data and will estimate the propagation of the fire based on the fuel model of the area and other important parameters such as wind speed, slope, and aspect of the ground surface. Finally, a 3-D Geographic Information System (GIS) environment will provide visualization of the predicted fire propagation. More information can be found in the attached leaflet and the project website www.firesense.eu.

To complete our analysis, we kindly ask you to answer the following questions and return this e-mail. The completion of the whole questionnaire will take 20 minutes at most. All the information will be handled anonymously. Data will not be disclosed to any other party.

In case of problems or further questions please do not hesitate to contact me. If you wish I can also send you this questionnaire as a Word document or fax.

Best regards,

Nikos Grammalidis,

FIRESENSE project coordinator.

Questionnaire

A. Demographics

Name:……………………………………………………………………………………….

Organization you are working for:……………………………………………………..

Department:………………………………………………………..

Type of organization:………………………………………………………………………………...

Cultural Heritage Authority	*Fire Suppression Services*	*Local Authorities*	*Forestry Department*	*Civil Protection Authorities*	*Security Services*	*Volunteer*	*Environmental Organization*	*Other*
☐	☐	☐	☐	☐	☐	☐	☐	☐

Other, please specify: ..……………………………………………………………………………………

Telephone: ………………………………………………………..

E-mail:……………………………………………..

Fax:……………………………………..

B. Previous incidents

(1) In a Scale 1(least significant) - 5(highest priority), how do you evaluate the risk of Fire and Extreme Weather Conditions for the cultural heritage site you are related to?

- Grade:……………

(2) Has your site been affected by Fire in the past?

- Yes: ☐
- No: ☐
- Do not know ☐

(3) If you answered "Yes" in the previous question, please describe:

a) What and when happened: …..……………………………………………………………….

…………………………………………………………………………………………………...........

b) How much damage occurred: ..…………………………………………………………………

…………………………………………………………………………………………………...........

c) How often do such incidents occur? (If possible, also fill the following table):

…………………………………………………………………………………………………...........

…………………………………………………………………………………………………...........

Statistics	2005	2006	2007	2008	2009
Number of fires near the site and surrounding area					
Entire burned area (ha)					
Average fire size(Burned area/Number of fires)					

(4) What kind of extreme weather conditions have significant impact to a cultural heritage site:

………………………………………………………………………………………………............

………………………………………………………………………………………………............

(5) Has your site been affected by Extreme Weather Conditions in the past?

Please mark applicable selection.

- Yes
- No
- Do not know.

(6) If you answered "Yes" in the previous question, please describe:

a) What and when happened: …..……………………………………………………………….

………………………………………………………………………………………………............

b) How much damage occurred: ..………………………………………………………………

………………………………………………………………………………………………............

C. Potential actions

(7) What kind of system(s) do you use (or intend to use in the near future) for protection from the Risk of Fire and Extreme Weather Conditions at your site?

Please choose applicable selection(s).

- Early warning systems, please specify: ……………………………………………… ………………………………………………………………………………………
- Fire extinguishing mechanisms, please specify:……………………..…………………….……………………………………………
- ………………………..…………………………………………………………………….
- Other, please specify: ……………………………..………………………………….

  ………………………..…………………………………..……………………………

(8) What kind of actions do you apply (or intend to apply in the near future) for protection from the Risk of Fire and Extreme Weather Conditions at your site?

Please choose applicable selection(s).

- Cleaning the site from wild vegetation ………………………………………………
- Maintenance of fire detection mechanisms, i.e.: ..…….…………………………..
- Maintenance of fire extinguishing mechanisms, i.e.: …….…………………………..
- Use security personnel/volunteers.
  - How many: …………..……………………………..
  - Covering Area: …………..……………………………..
- Other, please specify: ..……………………………………………………………

(9) Can you provide an estimation of the Annual Cost for the protection of your site from the Risk of Fire and Extreme Weather Conditions?

………………………………………………………………………………………………...........

(10)If you gave up the use of an Early Warning System for Fire and Extreme Weather Conditions in the past, this was due to (please enter YES, if applicable):

- A demonstration:……………
- A market research:……………
- Price of the system:……………
- Feedback from experts:……………
- Other:……………

(11)If you are already using an Early Warning System for Fire and Extreme Weather Conditions, how much did this system cost? ……………

Cost for maintenance:……………

(12)Are there any specific local regulations concerning the confidentiality of the information?

……………………………………………………………………………………………..…

……………………………………………………………………………………………..…

(13)Are there any environmental constraints to use the FIRESENSE system?

……………………………………………………………………………………………..…

……………………………………………………………………………………………..…

(14)Are the technical local supports available to regularly maintain, test and verify the FIRESENSE system?

……………………………………………………………………………………………..…

……………………………………………………………………………………………………..…

(15)Please estimate the cost you consider acceptable for a system like FIRESENSE: ……………………

D. FIRESENSE system and your involvement

(16)You want to be involved in FIRESENSE to (YES/NO):

- Know about new tools:……………
- Reinforce existing expertise and capabilities in your organization:……………
- Participate in the development of new applications:……………
- Other:…………………………………………………………………………………… ……………………………..…………………………………………………………..

(17)Do you have any suggestions to improve FIRESENSE?

……………………………………………………………………………………………….……

(18)What do you think could hamper the implementation and adoption of the FIRESENSE solution?

………………………………………………………..………………………………………………

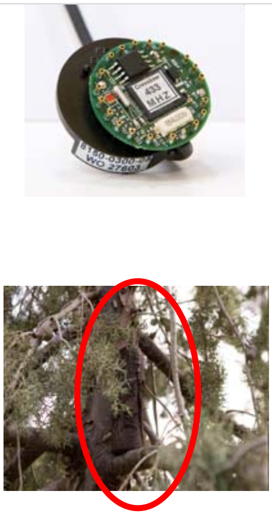
(19) What type of equipment can be installed at your site without causing problems to exhibits, personnel, visitors and the site itself?

Please choose applicable selection(s).

- Cameras inside the site: …………………………………………………
- Cameras outside the site but in a small distance (less than 1 km): ………………
- Temperature & other sensors (small camouflaged boxes) inside the site: ..………. ………………………………………………………………………………………………
- Meteorological stations outside the site (small housing, see image below): ……..………………………………………………………………………………….
- Computers and network infrastructure installed in
  - An existing building/house/room in or near the site: ……………………………………………………………………..……………….
  - A small house/room build for the task at hand in or near the site: …………………………………………..……………………………..………..

Other comments:………………………………………………………………………….……. ……………………………………………………………………………………………….........

(a) Cameras



(b) Temperature sensor

(c) Meteorological station

(20) Which types of cultural heritage assets are exposed to most significant danger in case of fire or extreme weather conditions at your site?

…………………………………………………………………………………………………..........

…………………………………………………………………………………………………..........

(21) In a Scale 1(no) - 5(definitely yes), would you consider using the FIRESENSE system at your site?

Grade: ………………………………..

(22) Does FIRESENSE provide benefits for the protection of Cultural Heritage Areas?

Yes: ☐

No: ☐

If “Yes”, FIRESENSE improves the protection of Cultural Heritage Areas by:

	Strongly agree	Agree	Disagree	Strongly disagree	No opinion
Fire Early Warning	☐	☐	☐	☐	☐
Early Extreme Weather Warning	☐	☐	☐	☐	☐
Disaster management	☐	☐	☐	☐	☐
Prevention of arsons	☐	☐	☐	☐	☐
Security	☐	☐	☐	☐	☐
Others, please specify	☐	☐	☐	☐	☐

If “No”, please provide a list of extra features/functionalities that FIRESENSE should have in order to improve protection of Cultural Heritage Areas:

……
……

(23)Which of the following indirect benefits could be provided by FIRESENSE? (multiple answers possible)

Cultural Heritage Protection	Safer Evacuation of Cultural Heritage sites	Better fire-fighting capabilities	Cost effectiveness	Increase of security of cultural heritage sites	Other
☐	☐	☐	☐	☐	☐

Others, please specify: ……………………………………………………………………………..……
………

(24)What can be the advantages of FIRESENSE system in your opinion?

………
………

(25) What can be the disadvantages of FIRESENSE system in your opinion?

………
………

Thank you very much for your cooperation and valuable contribution!

Appendix B- Survey for users involved in fire-fighting (fire-fighters, volunteers, related authorities)

Dear Madam/Sir,

We are conducting a survey on the Protection of Cultural Heritage Areas from the Risk of Fire and Extreme Weather Conditions for the FIRESENSE project, which is co-funded by the European Commission's 7th Framework Programme Environment (including Climate Change) (FP7-ENV-2009-1–244088-FIRESENSE, www.firesense.eu).

The aim of the project is to develop an automatic early warning system to remotely monitor areas of archaeological and cultural interest from the risk of fire and extreme weather conditions. FIRESENSE will take advantage of recent advances in multi-sensor surveillance technologies, using a wireless sensor network capable of monitoring different modalities (e.g. temperature) and optical and infrared cameras, as well as local weather stations. The signals collected from these sensors will be transmitted to a monitoring center, which will employ intelligent computer vision and pattern recognition algorithms as well as data fusion techniques to automatically analyze sensor information. It will be capable of generating automatic warning signals for local authorities whenever a dangerous situation arises. Moreover, it will provide real-time information about the evolution of fire using wireless sensor network data and will estimate the propagation of the fire based on the fuel model of the area and other important parameters such as wind speed, slope, and aspect of the ground surface. Finally, a 3-D Geographic Information System (GIS) environment will provide visualization of the predicted fire propagation. More information can be found in the attached leaflet and the project website www.firesense.eu.

In our continuous attempt to adopt the FIRESENSE system to your needs, we kindly ask for your participation in our survey. The completion of the whole questionnaire will take a at most 20 minutes. All the information will be handled anonymously: Data will not be disclosed to any other party.

In case of problems or further questions please do not hesitate to contact me. If you wish I can also send you this questionnaire as a Word document or fax.

Thank you very much for your cooperation!

Best regards,

Nikos Grammalidis,

FIRESENSE project coordinator.

Questionnaire

A. Demographics

Name: ……………………………………………………………………………………….

Organization you are working for: ………………………………………………………..

Department: ……………………………………………………………………………………

Type of organization: ……………………………………………………………………

Cultural Heritage Authority	*Fire Suppression Services*	*Local Authorities*	*Forestry Department*	*Civil Protection Authorities*	*Security Services*	*Volunteer*	*Environmental Organization*	*Other*
☐	☐	☐	☐	☐	☐	☐	☐	☐

Other, please specify: ..………………………………………………………………………………

Telephone: ………………………………………………………..

E-mail:……………………………………………..

Fax:……………………………………..

B. Previous incidents

(1) Do you know of any fire incidents in the recent years at cultural heritage sites within the area that you are responsible for?

Please mark applicable selection.

- Yes: ☐
- No: ☐
- Do not know ☐

(2) If you answered "Yes" in the previous question, please describe:

a) What and when happened ….……………………..……………………………………….

b) How much damage occurred: ..…………………………..…………………………………

…………………………………………………………………………………………..........

c) How often do such incidents occur (If possible, also fill the following table):

…………………………………………………………………………………………..........

…………………………………………………………………………………………..........

Statistics	**2005**	**2006**	**2007**	**2008**	**2009**
Number of fires					
Entire burned area (ha)					
Average fire size (Burned					

area/Number of fires)					

(3) According to your opinion, what kind of extreme weather conditions have significant impact to a cultural heritage site:

…………………………………………………………………………………………………..........

…………………………………………………………………………………………………..........

(4) Do you know of any incidents caused by extreme weather conditions in the recent years at **cultural heritage sites** within the area that you are responsible for?

Please mark applicable selection.

- Yes: ☐
- No: ☐
- Do not know ☐

(5) If you answered "Yes" in the previous question, please describe:

a) What and when happened: …..……………………………………………………………….

…………………………………………………………………………………………………..........

b) How much damage occurred: ..…………………………………………………………………….

…………………………………………………………………………………………………..........

C. Potential actions

(6) What kind of system(s) do you use (or intend to use in the near future) for protection of cultural sites from the Risk of Fire and Extreme Weather Conditions?

Please choose applicable selection(s).

- Early warning systems, please specify: ……………………………………………… ………………………………………………………………………………………………
- Fire extinguishing mechanisms, please specify:……………………..…………………..……………………………………………
- ……………………….……………………………………………………………………….
- Other, please specify: …………………………….………………………………….

  ……………………….………………………………….………………………

(7) In a Scale 1(least significant) - 5(highest priority), how important are the following criteria for choosing a Fire and Extreme Weather Conditions Early Warning System for the cultural heritage site you are related to?

- Cost:……………
- Robustness:……………
- Autonomy:……………
- Interoperability:……………
- Quality of data:……………

- Other (please specify):……………

(8) In a Scale 1(No confidence at all) - 5(Very satisfied), how much confidence do you have in a Fire and Extreme Weather Conditions Early Warning System?

- Grade:……………

(9) If you gave up the use of and Early Warning System for Fire and Extreme Weather Conditions in the past, this was due to (please enter YES, if applicable):

- A demonstration:……………
- A market research:……………
- Price of the system:……………
- Feedback from experts:……………
- Other:……………

(10)If you are already using an Early Warning System for Fire and Extreme Weather Conditions, how much did this system cost? ……………

Cost for maintenance:……………

(11)Are there any specific local regulations concerning the confidentiality of the information?

…………………………………………………………………………………………………..…

…………………………………………………………………………………………………..…

(12) Are there any environmental constraints to use the FIRESENSE system?

…………………………………………………………………………………………………..…

…………………………………………………………………………………………………..…

(13) Are the technical local supports available to regularly maintain, test and verify the FIRESENSE system?

…………………………………………………………………………………………………..…

…………………………………………………………………………………………………..…

(14)Please estimate the cost you consider acceptable for a system like FIRESENSE ……………………

D. FIRESENSE system and your involvement

(15)You want to be involved in FIRESENSE to (YES/NO):

- Know about new tools:……………
- Reinforce existing expertise and capabilities in your organization:……………
- Participate in the development of new applications:……………
- Other:……………

……………………………………………………………………………………………………….……

(16)Do you have any suggestions to improve FIRESENSE?

……………………………………………………………………………………………………….……

(17)What do you think could hamper the implementation and adoption of the FIRESENSE solution?

……………………………………………………….……………………………………………………

(18)In a Scale 1(least significant) - 5(highest priority), what information do you think is important for the FIRESENSE system to provide:

- Views from cameras: …………………………
- Wind information: …………………………
- Humidity information: …………………………
- Local temperature information (from the wireless sensors or infrared cameras): …………………………
- Weather data forecast for local area: …………………………
- Fire propagation estimation: …………………………
- GIS map with various information (sensor positions, roads, forest roads, vegetation map, buildings, fire ignition point, fire propagation information/estimation): …………………………
- Visual and audio alarms for possible events: …………………………
- Other, please specify: ……………………………………………………………………. ………………..…………………………………………………………………………

(19)What kind of functionalities should the control center of the FIRESENSE system support?

- Zoom in/out (for cameras): ☐
- Pan, tilt (for cameras): ☐
- Recording mode (to record images, sensor values): ☐
- Other, please specify: …………………………………………………………………….

……………………………………………………………………………………………………..

(20)What types of alarms/risk indicators do you wish to be supported by the FIRESENSE system?

………………………………………………………………………………………………..

………………………………………………………………………………………………..

(21) In a Scale 1(easy) - 5(difficult), what do you think characterizes best the maintenance procedures needed for the FIRESENSE system?

Grade: ………………………………..

Please describe:

………………………………………………………………………………………………..

………………………………………………………………………………………………..

(22)In a Scale 1(very easy) - 5(very difficult), how easy do you think the personnel working in your organization will learn to use the FIRESENSE system?

Grade: ………………………………..

(23)In a Scale 1(easy) - 5(difficult), how possible do you think is that the FIRESENSE system could improve existing fire detection systems?

Grade: ………………………………..

(24) What distance range do you think that the system should cover? ……………km

(25) What is the smallest size of fire that should be detected by the system? ……………m^2

(26) What is the acceptable delay for the delivery of sensor data?

- Images:……………min
- Thermal data: ……………min
- Meteorological data: ……………min

(27)What is the maximum time allowed between the ignition of a fire and the generation of fire warning? ……………min

(28)Every how many minutes should the fire propagation simulation be updated? ……………minutes/hours

(29) Is there any interference problem with other communication systems, e.g. Radar, WiMax, wireless frequency usage restriction, etc (YES/NO): …………………………………

Please describe: ………………………………………………………………....................

(30) Does FIRESENSE provide benefits for the protection of Cultural Heritage Areas?

Yes: ☐

No: ☐

If "Yes", FIRESENSE improves the protection of Cultural Heritage Areas by:

	Strongly agree	Agree	Disagree	Strongly disagree	No opinion
Fire Early Warning	☐	☐	☐	☐	☐
Early Extreme Weather Warning	☐	☐	☐	☐	☐
Disaster management	☐	☐	☐	☐	☐
Prevention of arsons	☐	☐	☐	☐	☐
Security	☐	☐	☐	☐	☐
Others, please specify	☐	☐	☐	☐	☐

If "No", please provide a list of extra features/functionalities that FIRESENSE should have in order to improve protection of Cultural Heritage Areas:

…...

…………………………………………………………………………………………………….

(31)Which of the following indirect benefits could be provided by FIRESENSE? (multiple answers possible)

Cultural Heritage Protection	Safer Evacuation of Cultural Heritage sites	Better fire-fighting capabilities	Cost effectiveness	Increase of security of cultural heritage sites	Other
☐	☐	☐	☐	☐	☐

Others, please specify: ……………………………………………………………………………..……

…..……

(32)In a Scale 1(least important) – 5 (most Important), how important are the following factors for the FIRESENSE system:

- Fast detection…………………………
- Easy installation…………………………
- Easy maintenance…………………………
- User friendliness …………………………
- Low cost …………………………
- Independency from human operators…………………………
- Extensibility (e.g. for site surveillance against other kind of damages like vandalism, burglary, etc…) …………………………

(33)What do you think are the strengths of FIRESENSE in general?

……………………………………………………………………………………………………..……

(34)What do you think are the weaknesses?

…………………………………………………………………………………………………….…

Thank you very much for your cooperation and valuable contribution!

Appendix C – Abbreviations used in Deliverable 4

CWI: Centrum Wiskunde & Informatica, Amsterdam
DFOV: Dual Field Of View
DR: Dimensionality Reduction
DRI: Detection, Recognition, Identification
EFL: Effective Focal Length
FMC: Fuel Moisture Content
FOV: Field Of View
GIS: Geographic Information System (e.g. Google)
GPS: Global Positionning System
HFOV: Horizontal FOV
HIS: Hyper Spectral Imaging
IFOV: Internal FOV
LOS: Line Of Sight
MSI: Multi Spectral Imaging
MTF: Modulation Transfert Function
MWIR: MiddleWave Infrared
NETD: Noise Equivalent Temperature Difference
NIR: Near InfraRed
NLDR: Nonlinear Dimensionality Reduction
PIR: Passive InfraRed
RFOV: Regard FOV
RIT: Rochester Institute of Technology
SOC: System On the Chip
SWIR: Short Wave InfraRed
USB: Universal Serial Bus
VFOV: Vertical FOV