The 15th International Conference on Future Networks and Communications (FNC)
August 9-12, 2020, Leuven, Belgium

Wireless sensor network for forest fire detection

Noel Varela[a]*, Díaz-Martinez, Jorge L[b], Adalberto Ospino[c], Nelson Alberto Lizardo Zelaya[d]

a,b,c Universidad de la Costa, Barranquilla, Colombia
dUniversidad Tecnológica Centroamericana (UNITEC), San Pedro Sula, Honduras

Abstract

Some methods for fire detection include monitoring from watch towers and the use of satellite images [1] [2]. Unfortunately, these are not efficient due to several reasons, such as high infrastructure costs (sophisticated equipment), the fact that they require a large number of trained personnel and that they make real-time monitoring difficult, since when the phenomenon is detected, its speed of propagation has produced uncontrollable levels of damage. This paper proposes a method for detecting forest fires, using a network of wireless sensors and information fusion methods.

Keywords: Data analysis; Wireless sensor network; Forest fire detection.

1. Introduction

A wireless sensor network (WSN) is a distributed system composed of nodes with the ability to obtain information on environmental conditions and transmit it wirelessly to a base station for processing [3]. On the other hand, information fusion techniques allow to improve the quality of the response to an event of interest, by combining the different data sources (sensors, database, etc.) [4][5]. In this paper, a forest fire detection system is proposed in its initial stage, using a wireless sensor network and information fusion methods. The main contribution of this work is

_____

* Corresponding author. Tel.:+57-3235810446.
  E-mail address: nvarela2@cuc.edu.co

the implementation of a low-computational complexity algorithm, with the ability to detect a fire event using only the information from two sensors: temperature and humidity.

2. Proposed detection model

As part of the development of the fire detection system, the first step was to know the characteristics of the environment under normal (non-fire) and fire conditions [6]. In order to develop a robust proposal, information on temperature and relative humidity under normal conditions was collected during the summer (the stage of the year most prone to forest fires) in a forest area of the city of Bogotá, in Colombia. The information analysis yielded the following observations [7][8][9]:

1. Under normal conditions, the temperature and humidity values show a cyclical behavior during the different stages of the day.
2. Under normal conditions and fire conditions, the temperature and humidity values maintain an inverse relationship between their magnitudes; that is, when the temperature increases, the humidity decreases and vice versa.
3. Under normal conditions, temperature and humidity values vary very slowly during the different stages of the day. On the other hand, under fire conditions, the rate of variation is higher and manifests itself in much less time.
4. When a sensor node is exposed to the effects of the sun's rays, the temperature shows a rate of change similar to that produced by a fire.

Considering these observations, different techniques were investigated in order to characterize the behavior of a forest fire. In an initial proposal, a function was constructed to relate the behavior of temperature and humidity in a fire, which was named the base function. Later, this function was used to compare the values obtained by the sensors when an event that could be a fire was recorded. Through the use of interpolation techniques and the use of Dempster-Shafer's theory of evidence, it was determined whether the event was a fire or not [10]. However, although a good detection rate was obtained, the method was not robust if the environmental conditions varied greatly from those used to create the base function.

In this paper, the construction of the base function using regression analysis is proposed. Regression analysis offers among its advantages the representation of the data through the adjustment of a mathematical function (straight line, polynomial function, exponential function, etc.), besides it facilitates the estimation of unknown values [11][12][13].

Considering that the values of temperature and relative humidity maintain an inverse relationship in a fire, it was decided to build two base functions, which represent their behavior in the fire, in an independent way. From the analysis of the parameters under study, it was found that the most relevant characteristic of the fire is the reason for the change in temperature and humidity values with respect to time. For this reason, when using regression analysis to construct the base functions, time is considered as the independent variable, and temperature and humidity as dependent variables. These functions are now called T(t) and H(t), respectively, and constitute the base model [14].

For the construction of the base model, it is proposed that temperature and humidity measurements be used in fire experiments, considering some time of the year and a specific time slot. For example, base models can be built for summer, and at different stages of the day (morning and afternoon), which, according to the analysis of historical data, were those that showed the highest incidence of events. The following section will show an example of the construction of the base model [8].

However, the relationship between the variables does not always manifest itself in a linear way. For these cases, there are alternatives such as second order functions or parabolas, third order or cubic functions, and so on. A more general way of representing higher order non-linear functions is shown in Eq. 1:

$$y = \beta_0 + \beta_1 x + \beta_2 x^2 + \ldots + \beta_n x^n \tag{1}$$

The objective of the base model is to have a reference that provides greater precision when representing the existing environmental conditions in a fire. This allows the possibility of not depending on fixed magnitudes or thresholds, but

rather on the reason for change that occurs when the fire phenomenon affects the environment [6]. In other words, according to our observations during a forest fire, the values of temperature and humidity always behave in the same way: upwards for the case of temperature and downwards for the case of relative humidity, with a similar rate of change or slope, as can be seen in Figure 1. Having a model that represents this behavior (independently from the magnitudes) allows to compare the data received by the sensor nodes to confirm or discard whether the observed variation corresponds to a fire. For this purpose, the following architecture is proposed, which is composed of three modules: wireless sensor network, middleware and fire detection system.

In general terms, the proposed model works as follows: 1) The sensor nodes collect environmental measurements periodically; 2) when they detect an increase in temperature, they transmit the information to the base station; 3) the base station sends the data back to the server for storage in a database; 4) the server takes the most recent information from the database and compares the data with respect to a previously defined base model; and 5) according to the degree of similarity between the data and the base model, the system determines whether or not there is a fire in the monitored area. Each of the stages is described in more detail below.

In the wireless sensor network, each node takes a temperature reading using a constant sampling period P. Each reading is stored in a FIFO (First-In, First-Out) structure called WT that uses an n-size slider window. When WT is full, it checks whether the most recent reading T_{n+1} has shown a change (increase or decrease), through the following ratio represented by Ω [4]:
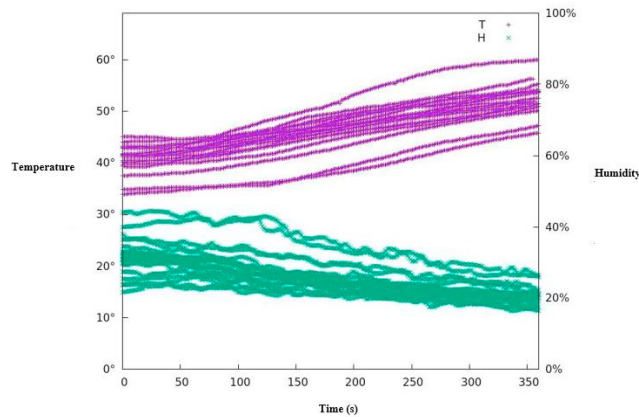
$$\Omega = T_{n+1}/\mu(W_T) \tag{2}$$

Fig. 1. Temperature and humidity values in a fire.

Where, on the other hand, $\mu(WT)$ is the average of the temperature data set stored in WT. The result from Ω will be compared with a temperature threshold called Tthreshold. If, and only if, Ω is higher than Tthreshold, the sensor node takes a reading of humidity H and then transmits a data packet to the base station with the following information: node ID, temperature sample T, humidity sample H and a time stamp t to identify the time when the event was generated. For the first packet transmitted, the value of t will be equal to zero, and for subsequent cases, the value of t will be a function of P. If the temperature threshold is not exceeded, the sensor node must continue reading and evaluating samples. This procedure is described in Algorithm 1.

Algorithm 1 Pre-processing on the sensor node Be T = temperature, P = sampling period, WT = temperature sample buffer, n = size of sliding window, Ω = 0, Tthreshold = temperature threshold, id = sensor node identifier, H = humidity, t = 0, i = 1;

1. while (1) {
2. T = Read ambient temperature;
3. if (i ⩽ n) {

```
4.     WT [i] = T ;
5.     i=i+1;
6.}    else {
7.     Ω = T/μ(WT)
8.     while (Ω> Tthreshold ) {
9.     H = Read ambient humidity;
10.    Send(id, T , H ,t);
11.    WT's Oldest T-Strip;
12.    Store latest T in WT;
13.    t = t+P ;
14.    T = Read ambient temperature;
15.    Ω =      T/μ(WT)
16.    // end of the while cycle
17.    t = 0;
18.    i = 1;
19.    } //end else
20.    } // Wait for the next period
```

When the sensor node transmits a packet to the base station, the information is stored in a database for immediate analysis. The function of the middleware is to establish communication mechanisms between the base station and the server. The middleware assigns an arrival time composed by the date and time of the server for each received packet according to the node identifier and the equivalent to its respective t-value.

Subsequently, the server obtains the most recent information from the database, taking into account that each packet obtained by the sensor nodes is composed of the following data: id, T , H and t. To describe the flow of the fire detection system, A is used as the least recent set of information or information that exceeded a temperature threshold for the first time, and B is used as the most recent information or subsequent information about environmental conditions.

The first step is to verify that the analysis time Y, is less than the limit analysis time Θ, this with the objective of analyzing during a balanced time period that allows having the necessary information to make a decision. At the beginning of the analysis $Y = 0$, result of the differences must be accumulated between $tB - tA$ to update its value, as shown in Equation 3 [6]:

$$Y = Y + (tB - tA) \tag{3}$$

Assuming that once a couple of samples (A and B) are received, their difference in time is called K, so $Y = K$. For each new sample, the procedure is repeated as long as the value of Y is less than Θ (user-defined value). Once Y is calculated and validated as less than Θ, the next step is to calculate the rate of change of the temperature and humidity values of A and B using the slope formula, i.e., mT and mH as shown in Equations 4 and 5 [8].

$$m_T = (T_B\text{-}T_A)/(t_B\text{-}t_A) \tag{4}$$

$$m_H = (H_B\text{-}H_A)/(t_B\text{-}t_A) \tag{5}$$

The derivative of the functions representing the base model, i.e. T(t) and H(t), must then be calculated. However, it should be mentioned that T'(t) and H' (t) should obtain a result equivalent to the value of Y, so they are replaced by T'(Y) and H'(Y). The technique of the average quadratic error is then used, using a number of limit evaluations called emax. The root mean square error is used to measure the error between an estimator (base model functions) and an estimate (data from the sensor node). This value is calculated as shown in Equations 6 and 7 [14]:

$$MSE_T = add(T_i(Y)\text{-}m_{T_i})^2/emax \tag{6}$$

$$MSE_H = add(H_i(Y)\text{-}m_{H_i})^2/emax \tag{7}$$

3. Evaluation

Sensor nodes with IRIS hardware platform were used to carry out the set of fire experiments, with a sensor board model MTS420/400CC [11]. This board has five types of environmental sensors: relative humidity, temperature, barometric pressure, light intensity and accelerometer. In terms of software, Ubuntu Linux version 12.04 was used in the server. The middleware was developed in Java and the database in MySQL. Finally, for the WSN, the TinyOS operating system version 2.1.2 was used.

The methodology used consisted in placing the sensor node on the middle part of a tree trunk, at a height of approximately three meters. The experiments were carried out during the months of April and May 2019. On the other hand, data collection was divided into two stages: 1) Creation of a base model and 2) Controlled fire experiments. Each of them is described below.

Table 1. Parameters used in experiments.

Parameter	Description	Value
n	WT window size	15
Tthreshold	Temperature threshold Sampling period of the sensor node	1.01
P		6 seconds
Θ	Limit analysis time	360 seconds
emax	Maximum number of evaluations for the SSM	5
α	Threshold used to determine a fire	0.7

1. Base model: In order to have enough information for the development of the base functions T(t) and H(t), in this stage, the sensor node was exposed to firework conditions using a garden torch. The duration of the experiment was 6 minutes using a sampling period of 1 second. 20 experiments were performed in this stage.
2. Controlled fire experiments: A series of experiments were carried out with different sampling periods: 3, 4, 6 and 8 seconds. The objective was to investigate the sampling period with the best performance for the detection of the event. At this stage, 32 experiments were conducted (8 for each type of sampling period). The purpose was to determine the sampling period to be used in the next stage of experiments.

To build the new base model, curve fitting by simple regression analysis was implemented with the help of IBM's SPSS statistical analysis software [15]. With the data collected, the following base model was obtained:

$$T(t) = \text{-}2.477 \times 10\text{-}7\, t3 + 1.12 \times 10\text{-}4\, t2 + 2.2441 \times 10\text{-}2\, t + 28.8861, \tag{8}$$

$$H(t) = 2.26 \times 10\text{-}8\, t3 - 1.7 \times 10\text{-}5\, t2 - 2.7444 \times 10\text{-}2\, t + 17.505 \tag{9}$$

It is worth mentioning that the determination coefficients were 0.87 for the T(t) function and 0.68 for the H(t) function.

Subsequently, 50 fire experiments were carried out, using the parameters shown in Table 1, 30 of them shadow scenarios and with sensor node exposed to fire. The remaining 20 were events without fire and with the sensor node exposed to the sun's rays, without any protection. These values were processed using the base model described by

Equations 8 and 9. The model obtained a 100% detection rate in shadow scenarios. By analyzing the data obtained by a sensor node exposed to the sun's rays, a 100% false positive rate was obtained. However, to avoid this, the sensor node can be covered with special protection to avoid direct exposure to sunlight. To check this, a new set of 50 experiments were carried out with the sensor node exposed to the sun's rays, but covering it with a shield. Using the proposed method under these conditions, a 100% detection rate was obtained.

4. Conclusions

In this study, a forest fire detection system was proposed in its initial stage using a wireless sensor network and information fusion methods. The base model is built using regression analysis. When the system detects temperature and humidity values that could represent a fire, it compares the collected values with the base model to determine whether or not a fire exists. The results of the model evaluation showed a 100% detection rate when the nodes are not directly exposed to the sun's rays. A future research will seek to extend the model considering the energy consumption of the WSN, through the distribution of nodes in clusters and the use of distributed sensing.

References

[1] Noureddine, H., & Bouabdellah, K. (2020). Field Experiment Testbed for Forest Fire Detection using Wireless Multimedia Sensor Network. International Journal of Sensors Wireless Communications and Control, 10(1), 3-14.

[2] Grover, K., Kahali, D., Verma, S., & Subramanian, B. (2020). WSN-Based System for Forest Fire Detection and Mitigation. In Emerging Technologies for Agriculture and Environment (pp. 249-260). Springer, Singapore.

[3] Chauhan, A., Semwal, S., & Chawhan, R. (2013, December). Artificial neural network-based forest fire detection system using wireless sensor network. In 2013 Annual IEEE India Conference (INDICON) (pp. 1-6). IEEE.

[4] Ghugar, U., & Pradhan, J. (2020). ML-IDS: MAC Layer Trust-Based Intrusion Detection System for Wireless Sensor Networks. In Computational Intelligence in Data Mining (pp. 427-434). Springer, Singapore.

[5] Nugroho, A. A., Iwan, I., Azizah, K. I. N., & Raswa, F. H. (2019). Peatland Forest Fire Prevention Using Wireless Sensor Network Based on Naïve Bayes Classifier. KnE Social Sciences, 20-34.

[6] Biswas, P., & Samanta, T. (2020). True Event-Driven and Fault-Tolerant Routing in Wireless Sensor Network. Wireless Personal Communications, 1-23.

[7] Dubey, V., Kumar, P., & Chauhan, N. (2019). Forest fire detection system using IoT and artificial neural network. In International Conference on Innovative Computing and Communications (pp. 323-337). Springer, Singapore.

[8] Zhang, J., Li, W., Yin, Z., Liu, S., & Guo, X. (2009, May). Forest fire detection system based on wireless sensor network. In 2009 4th IEEE conference on industrial electronics and applications (pp. 520-523). IEEE.

[9] Aliady, W. A., & Al-Ahmadi, S. A. (2019). Energy Preserving Secure Measure Against Wormhole Attack in Wireless Sensor Networks. IEEE Access, 7, 84132-84141.

[10] Hariyawan, M. Y., Gunawan, A., & Putra, E. H. (2013). Wireless sensor network for forest fire detection. Telkomnika, 11(3), 563.

[11] Mohapatra, S., & Khilar, P. M. (2020). Fault Diagnosis in Wireless Sensor Network Using Self/Non-self-Discrimination Principle. In Progress in Computing, Analytics and Networking (pp. 161-168). Springer, Singapore.

[12] Saidi, H., Gretete, D., & Addaim, A. (2020). Game Theory for Wireless Sensor Network Security. In Fourth International Congress on Information and Communication Technology (pp. 259-269). Springer, Singapore.

[13] Aliady, W. A., & Al-Ahmadi, S. A. (2019). Energy Preserving Secure Measure Against Wormhole Attack in Wireless Sensor Networks. IEEE Access, 7, 84132-84141.

[14] Viloria, A., Hernandez-P, H., Lezama, O. B. P., & Orozco, V. D. (2020). Electric Consumption Pattern from Big Data (pp. 479–485). https://doi.org/10.1007/978-981-15-3125-5_47.

[15] Sanchez, L., Vásquez, C., Viloria, A., & Cmeza-Estrada. (2018). Conglomerates of Latin American countries and public policies for the sustainable development of the electric power generation sector. In Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics) (Vol. 10943 LNCS, pp. 759–766). Springer Verlag. https://doi.org/10.1007/978-3-319-93803-5_71

Forest Fire Detection System using LoRa Technology

2 authors:

Nicoleta-Cristina Gaitan

Stefan cel Mare University of Suceava

42 PUBLICATIONS   **437** CITATIONS

SEE PROFILE

Paula Hojbota

Stefan cel Mare University of Suceava

1 PUBLICATION   **8** CITATIONS

SEE PROFILE

Some of the authors of this publication are also working on these related projects:

Experimental demonstration device for validating and testing real time nMPRA microcontroller using MIPS32 architecture - 220PED (PN-III-P2-2.1-PED-2016-1473) View project

Forest Fire Detection System using LoRa Technology

Nicoleta Cristina GAITAN[1], Paula HOJBOTA[2]

Faculty of Electrical Engineering and Computer Science, Stefan cel Mare University of Suceava[1, 2]
Integrated Center for Research, Development and Innovation in Advanced Materials, Nanotechnologies
and Distributed Systems for Fabrication and Control (MANSiD) Suceava, Romania[1]

Abstract—**Millions of hectares of forest worldwide are affected annually by fires, which can lead to the loss of human lives, materials, destruction of natural flora and fauna but also can lead to the losses of raw materials. The problem is even greater in forests that are not guarded and do not have communication systems available. Thus, in recent years, have been proposed various systems that use devices based on Internet of Things (IoT) for real-time forest fire detection. In this paper, it is proposed a system capable of quickly detecting forest fires on long wide distance. In the development of this system it is used LoRa (Long Range) technology based on LoRaWAN (Long Range Wide Area Network) protocol which is capable to connect low power devices distributed on large geographical areas being an innovative and great solution for transmissions of a low data transfer rate and a low transmission power on high ranges, and because has a great efficiency.**

Keywords—LoRa; real-time; long range wide area network; internet of things

I. INTRODUCTION

Forest fires that take place in the warm season can be caused or started by natural events or human negligence. Natural events such as burning branches or dry leave appear due to the heat generated by the sun. An example of such event is the fire from Siberia in the summer of the year 2019, resulting in the destruction of millions of hectares of vegetation. The fires generated by human negligence can result from multiple factors, such as leaving unattended fires in the forest, throwing a burning cigar etc. An example of a forest fire started due to human negligence took place in the province of South Sumatra, in 2015.

In the modern era, the technology has developed so much that it's become more and more sophisticated, making wireless transmissions real easy. The network of wireless sensors, named WSN (Wireless Sensors Network), based on the LoRa module, can be a great alternative for detecting forest fires in specific areas.

LoRa (Long Range) is a low power technology developed by Semtech and supported by LoRa Alliance. This technology is characterized by a low data transfer rate and a low transmission power on high ranges [1][2]. While the transmission range grows, LoRa keeps its low power characteristics of modulation in frequency (Frequency Shift Keying). This technology modulates symbols with a bandwidth of 125, 250 and 500 kHz (in case of European applications) with different spreading factors [3].

The LoRa Alliance defines two different layers of this technology: LoRa physical layer and LoRaWAN (Long Range Wide Area Network) protocol.

From the physical layer point of view, LoRa is a radio modulation patented technique by Semtech. In this case, the technology is going to work with frequencies under the order of GHz in the unlicensed ISM (Industrial, Scientific and Medical) band [2].

LoRaWAN protocol is standardized by the LoRa Alliance, being defined as a MAC layer protocol and a system architecture that uses LoRa's physical layer. The access control mechanism to environment offered by LoRa's allows for multiple final devices to communicate with a gateway using LoRa modulation (see Fig. 1) [2].

The Low-Power Wide-Area network ensures the connectivity of low power devices distributed on large geographical areas. These networks represent a new model of communication, successfully completing the already existent wireless communication technology such as: Bluetooth, Zig-Bee, LTE, GSM and Wi-Fi [2].

Thanks to its low power requirements and low costs of manufacturing and operating, LoRaWAN is one of the most used LPWA (Low-Power Wide-Area) technologies.
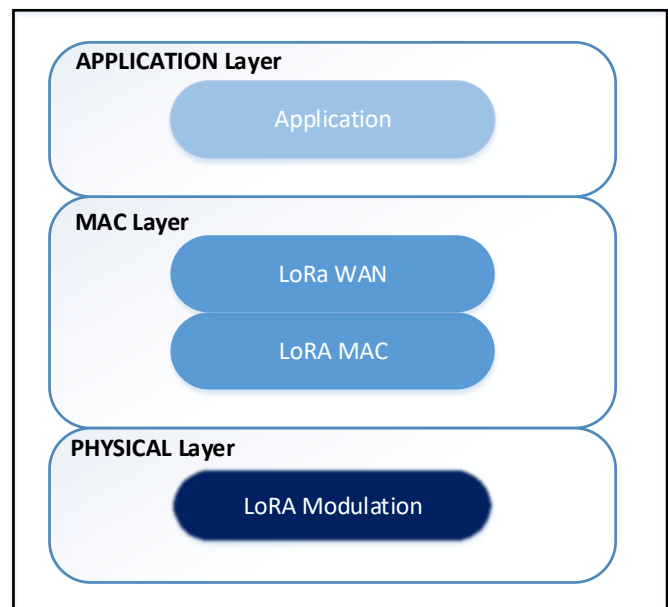

Fig. 1. Long Range Wide Area Network Stack.

The LoRa technology doesn't guarantee a long time development, but there are already available solutions based on it, unlike other technologies that could possibly disturb the global development [4].

Industrial IoT applications are based on long distance communication. The promising protocols in this domain are SigFox, LoRaWAN and the NB-IoT standard [1]. In Table I is presented a comparison between SigFox and LoRa.

TABLE I.   Sigfox Vs. LoRa Comparison

Parameter	SigFox	LoRa
Frequency Band	868, 902 [MHz]	433(US), 863-870 (EU) [MHz]
Data Rate	100 bps	10 kbps
Rural Range	30-50 km	15-20 km
Urban Range	3-10 km	2-5 km

The Internet of Things is a communication model that represents a near future solution, capable of integrating sensors and devices that can communicate directly between them without human intervention. The "things" from Internet of Things include physical devices equipped with microcontrollers, transceivers for digital communications and stacks of protocols for making possible the communication between users [5][6].

With such a great multitude of IoT applications, the LoRaWAN protocol and LoRa devices seems to be very efficient in business, contributing to make people lives well around the globe [4]. Using this technology it expecting to achieve a smart connection of the entire planet. LoRa applications are found in various field, such as, agriculture, smart cities, smart environment, healthcare, smart homes and buildings, industrial control, smart metering, smart supply chain and logistics.

In this article it is presented a study of a system that follows the integration of LoRa technology in forest fire detection.

The rest of the paper it is structured as follows. Section II summarizes some interesting systems focused on fire detectors. The proposed design is presented in Section III. Section IV presents conclusion and future work.

II. RELATED WORKS

The traditional methods of forest fire detection and prevention are based on observation through satellite images, visual observation by guards, observation by air or video detection on high ranges [7].

Considering all the disadvantages of conventional forest fire detection systems, in the last years different solutions were proposed in order to improve the monitoring systems of the environment and to create a new real time forest fire detection systems using devices based on the Internet of Things [8].

The detection through IoT based devices and online monitoring systems [9]. In this article, the authors proposed a new forest fire monitoring system by detecting temperature variations and analyzing CO_2 levels. The forest fire detection system was realized using the Arduino Uno module alongside a temperature sensor, a smoke sensor and an alarm system. The temperature sensor detects the variations in temperature and the smoke sensors detect the CO_2 levels and if it is necessary, it enables the alarm (the buzzer on the Arduino Uno board). Using the IoT technology, the system was connected to a webpage named „FireSecurity System", created in PHP and controlled by the Arduino programming environment [9].

In the article [10], the authors proposed an implementation of a forest fire detection system in the forest area using modern equipment. The system was not only meant for fire detection, but for alarming the forest officer regarding the started fire in the forest. The system's activities are controlled by a microcontroller, and the used sensors have the role of identifying the fire and its exact location. This system is based on IoT, the activities being continuously monitored, and the data being saved and shared to online websites. The forest officer regularly reviews the newly stored data, which can be verified at any time [10]. The monitoring system is usually based near the forest office or a fireman station.

A Smart Forest-Fire Early Detection Sensory System: Another Approach of Utilizing Wireless Sensor and Neural Networks [11]. This article has as its main purpose the implementation of a fast forest fire detection system using cheap and small sizes sensors that do not require surveillance. The system does not utilize large scale centralization systems, which could affect the system's robustness in vulnerable environments. The used sensors network represents a small scale cell that can be multiplied in order to cover the entire forest [11].

Wireless sensor network for forest fire detection [12]. In order to overcome to loss of thousands of forest hectares, the authors propose a forest fire detection system by using a sensor network. Each node has a microcontroller, a transmitter, a receiver and 3 sensors. The measurement methods consist of temperature measurement, detection of methane levels, hydrocarbons and CO_2 levels.

Emerging methods for early detection of forest fires using unmanned aerial vehicles and LoRaWAN sensor networks [13]. In this article, the authors propose 2 different solutions for detecting forest fires. First solution consists of aerial vehicles without pilots (UAVs) equipped with special cameras. In this papers there are presented and analyzed multiple scenarios of drone usages for forest fire detection, including a solution which uses a combination between UAV with fixed-wind and UAV with rotary-wings. The system's basic configuration presented in this article implies using a network of soil mounted cameras through which the constant monitoring of the forest is ensured. The cameras used have double lenses which offer both standard images and infrared images (IR) [13].

In other research paper [14], the authors propose a model of communication based on WSN for detecting forest fires in real time as a much more efficient method of monitoring them than the satellite [15]. Their main purpose is fast detecting of fires in order to reduce the loss of vegetation, flora and fauna. In the realization of this system, it's proposed the usage of some sensors that collect the measured dates and send them to the group of nodes for further processing by building a neuronal network. The neuronal network produces a meteorological

index that measures the probability of the weather favoring an eventual fire. The cluster headers send meteorological indexes to a node manager that has the role of deciding the potential danger for a fire considering the received indexes [15].

III. System Description

In this section of the article it is presented the proposed system and different hardware parts which are going to be implemented.

A. General Description

The capacity to detect if a fire is present is the most important part of a fire safety strategy. Without fire detection means, it cannot alert the population, it cannot take safety measure against the fire and it cannot alarm the firefighting service. The people, by our nature, are capable of feeling heat and smoke, to see the flames and to hear the fire burning. Therefore, we could be great potential fire detectors, but we are not always available or trustworthy, and for this reason, we need to use the technology to replace those abilities.

After analyzing the problems, the losses resulted from forest fires and the high costs of detection and monitoring systems, I believe it is necessary to develop some low cost systems capable of evaluating the risk of a forest fire starting, but also its presence.

The system proposed in this article is realized based on a LoPy4 development board connected to a Pycom Expansion Board 3.0 (Fig. 2), an Arduino Mega 2560 module, a temperature and humidity sensor and a flame detector.

B. Pycom LoPy and Pycom Expansion Board 3.0

The main component of the proposed forest fire detection system is the LoPy4 development board from Pycom. The LoPy4 is a development platform compatible with MicroPython (WiFi, LoRa, SigFox, and Bluetooth). This board is programmable using MicroPython and the Pymakr plugins for a fast IoT applications development. LoPy4 can be configured in LoRa mode to directly send packages between LoPy4 development boards of the same kind. It represents the best combination of implementing speed and access to the new LPWAN networks from Europe, USA, Africa and India. LoPy4 is CE, FCC, LoRaWAN and SigFox certified [16]. In order for the LoPy4 module to be programmed, we are going to use it along with the PyCom Expansion Board 3.0 development board. This board allows the creation and connection of new IoT projects with WiPy 2.0, WiPy 3.0, LoPy, LoPy4, SiPy, FiPy and Gpy. Pycom Expansion Board 3.0 has different libraries and templates, therefore, the development of an IoT solution becomes much easier and faster [17][20][21][22][23].

C. Arduino Mega 2560

Arduino Mega 2560 is a board equipped with a microcontroller and it is based on ATmega2560. The module has 54 pins for digital inputs and outputs (15 of them capable of being used for PWM outputs), 16 analogic inputs, 4 UARTs, a crystal oscillator with a frequency of 16 MHz, an USB connection, an ICSP header and a reset button. The Arduino Mega 2560 board can be programmed with the Arduino Software (IDE) [18]. I chose to use the Arduino board because it is easier to use by students and is even cheaper.

Fig. 2.   The Pycom Lopy and Pycom Expansion Board 3.0.

D. Temperature Sensor DHT11

The DHT11 is a cheap base sensor, used for measuring temperature and relative humidity at the same time. The measurement of air humidity is ensured by a capacitive humidity sensor, while the temperature is measured using a thermistor, resulting in a digital signal on the data pin. This sensor is a small sized, low power usage, recommended in applications where data acquisition with a high frequency is not required [3]. The sensor operates in cycles of 1 second. In this cycle, the Arduino module and the sensor exchange information about the temperature and humidity. The features of the DHT11 are presented in Table II.

E. Flame Detector

A flame sensor is a device used to detect the presence of either a fire source or any lightning source. The flame detection can be done from a distance of 1 meter, and the angle detection is 60 degrees. The flame detectors with infrared or with large band monitor the spectral band in infrared for specific models given by hot gasses. These are recognized using a special camera, using thermal imagistic for countering the fires, which is a thermographic camera [19].

TABLE II.   DHT11 Features

DHT11 Specifications	Values
Operating Voltage	3.5V to 5.5V
Operating current	0.3mA (measuring) 60uA (standby)
Output	Serial data
Temperature Range	0°C to 50°C
Humidity Range	20% to 90%
Resolution	Temperature and Humidity both are 16-bit
Accuracy	±1°C and ±1%

IV. CONCLUSIONS

As the IoT technology is being developed more and more, the devices capable of communicating remotely from distance without using a lot of energy have become a necessity more than ever. This challenge of the future is currently served by Long-Power Wide-Area Networks. Currently, there are a lot of applications based on the LPWA technologies, but most of them do not have LoRa module incorporated.

The global warming will constantly be contributing to increasing the number of fires and the damages caused by them. Each season, besides thousands of hectares of forest being destroyed, there are a lot of assets and properties being affected as well. Even more, both the firefighters and the civilians' lives are also in danger. This is the main reason I want to address this issue in this article, for the sole purpose of reducing and preventing devastating fires. The desire to create such a system comes from the fact my father is a forest guard and has been so for more than twenty years. One of his most important responsibilities is to watch out for the forest's well growth and make sure nothing is going to harm it.

In this article, in the Related Works section there were presented different systems of forest fires detection based on LPWA communications. The system proposed in the article is based on the LoRa technology and it has as its main component the LoPy development board from Pycom. The system can be used in extreme temperature conditions, but it can be affected if it's situated in the middle of the fire. With the help of the flame detector, the flames can be noticed from a distance of 100 centimeters. It detects and sends information regarding a possible fire starting out.

Although we know that the most environmental monitoring systems are made using Arduino boards and IoT extensions interfaces, it is desire to emphasize that the novelty of this system is the fact that it is tested with the Arduino board. It is easier to test with the Arduino board because there is online software and it is not expensive.

The decision of using LoRa technology in the proposed system is due of it capabilities to connect low power devices distributed on large geographical areas and because represents an innovative solution for long wide distance transmissions with low power on high ranges consumption and also because has a great efficiency on long-distance data transmission and low transfer power.

For future research, the proposed system can be improved, for example by integrating a surveillance camera for a more precise monitoring process and detection.

Another improvement in the development of this proposed system would be the integration of a GPS module.

REFERENCES

[1] T. Polonelli, D. Brunella, A. Girolami, G. N. Demmi și L. Benini, „A multi-protocol system forconfigurable data streaming on IoT healthcare devices," 8th International Workshop on Advances in Sensors and Interfaces (IWASI), 2019, pp. 112-117.

[2] L. Leonardi, F. Battaglia, G. Patti și L. L. Bello, „Industrial LoRa: a Novel Medium AccessStrategy for LoRa in Industry 4.0 Applications," IECON 2018 - 44th Annual Conference of the IEEE Industrial Electronics Society, Washington, DC, 2018, pp.4141-4146.

[3] S. Sendra, P. Romero-Díaz, J. Navarro-Ortiz și J. Lloret, „Smart Infant Incubator Based onLoRa Networks," 15th International Conference on Computer Systems and Applications (AICCSA), Aqaba, 2018, pp. 1-6.

[4] Semtech Company (LoRa). [Interactiv] 7 February 2020. https://www.semtech.com/lora/why-lora.

[5] A. Zanella, N. Bui, A. Castellani și L. V. a. M. Zorzi, „Internet of Things for Smart Cities," IEEE Internet of Things Journal , vol.I, pp. 22-32, 2014.

[6] L. Atzori, A. Iera și G. Morabito, „Internet of Things security: A survey," Computer Networks: The International Journal of Computer and Telecommunications Networking, vol. LIV, 2010, pp 2787–2805. DOI:https://doi.org/10.1016/j.comnet.2010.05.010.

[7] A. Herutomo, M. Abdurohman, N. A. Suwastika, S. Prabowo și C. W. Wijiutomo, „Forest firedetection system reliability test using wireless sensor network and OpenMTC communication platform," 2015.

[8] J. Toledo-Castro, P. Caballero-Gil, N. Rodríguez-Pérez, I. Santos-González și C. H.-G. a. R.Aguasca-Colomo, „Forest Fire Prevention, Detection, and Fighting Based on Fuzzy Logic and Wireless Sensor Networks".

[9] A. K. Sharma, M. F. R. Ansari, M. F. Siddiqui și M. A. Baig, „IoT Enabled Forest Firedetection and Online Monitoring System," International Journal of Current Trends in Engineering & Research (IJCTER), Volume 3, Issue 5, pp50-54, 2017.

[10] K. Jayaram, K. Janani, R. Jeyaguru și R. K. a. N. Muralidharan, „Forest Fire Alerting SystemWith GPS Co-ordinates Using IoT," 2019 5th International Conference on Advanced Computing & Communication Systems (ICACCS), pp 488-491, 2019.

[11] H. Soliman, K. Sudan și A. Mishra, „A Smart Forest-Fire Early Detection Sensory System:Another Approach of Utilizing Wireless Sensor and Neural Networks", in Sensors, 2010 IEEE. IEEE, pp. 1900–1904, 2010.

[12] M. Hariyawan și A. G. a. E. Putra, „Wireless Sensor Network for Forest Fire Detection," vol. II, 2013.

[13] G. Hristov, J. Raychev și D. K. a. P. Zahariev, „Emerging methods for early detection of forestfires using unmanned aerial vehicles and LoRaWAN sensor networks," 2018.

[14] L. Yu, N. Wang și X. Meng, „Real-time Forest Fire Detection with Wireless Sensor," pp1-4, 2005.

[15] R. Vega-Rodríguez, S. Sendra, J. Lloret și P. R.-D. a. J. L. Garcia-Navas, „Low Cost LoRa based Network for Forest Fire Detection," 2019.

[16] „Pycom," [Interactiv]. Available: https://pycom.io/product/lopy4/. [Accesat 15 February 2020].

[17] „Sparkfun," [Interactiv]. Available: https://www.sparkfun.com /products/14675. [Accesat 9February 2020].

[18] „Arduino," 25 February 2020. [Interactiv]. Available: https://store. arduino.cc/arduino-mega-2560-rev3.

[19] „Wikipedia," 29 February 2020. [Interactiv]. Available:https://en. wikipedia.org/wiki/Flame_detector.

[20] A. Lavric și A. l. Petrariu, „LoRaWAN Communication Protocol: The New Era of IoT," Conference: 2018 International Conference on Development and Application Systems (DAS), 2018, pp 74-77.

[21] A. Lavric, V. Popa, „A LoRaWAN: Long Range Wide Area Networks Study", 11-th International Conference on Electromechanical and Power Systems, pp. 435-438, 2017.

[22] O. Khutsoane și B. I. a. A. M. Abu-Mahfouz, „IoT devices and applications based onLoRa/LoRaWAN," IECON 2017 - 43rd Annual Conference of the IEEE Industrial Electronics Society, Beijing, pp. 6107-6112, 2017.

[23] B. Sarwar, I. S. Bajwa, N. Jamil și S. R. a. N. Sarwar, „An Intelligent Fire Warning ApplicationUsing IoT and an Adaptive Neuro-Fuzzy Inference System," Sensors 19(14):3150, doi:10.3390/s19143150, 2019.

Review Article

A Review on Forest Fire Detection Techniques

Ahmad A. A. Alkhatib

The University of South Wales, UK

Correspondence should be addressed to Ahmad A. A. Alkhatib; hamadhcumm@yahoo.com

Context. Apart from causing tragic loss of lives and valuable natural and individual properties including thousands of hectares of forest and hundreds of houses, forest fires are a great menace to ecologically healthy grown forests and protection of the environment. Every year, thousands of forest fires across the globe cause disasters beyond measure and description. This issue has been the research interest for many years; there are a huge amount of very well studied solutions available out there for testing or even ready for use to resolve this problem. *Aim*. This work will summarise all the technologies that have been used for forest fire detection with exhaustive surveys of their techniques/methods used in this application. *Methods*. A lot of methods and systems are available in the market and for research. The paper reviews all the methods and discusses examples of research experiment results and some market product methods for better understanding. *Result*. Each technique has its own advantages and disadvantages. A full discussions provided after each type. *Conclusion*. A full table is provided at the end to summarise a comparison between the four methods.

1. Introduction

Forests are the protectors of earth's ecological balance. Unfortunately, the forest fire is usually only observed when it has already spread over a large area, making its control and stoppage arduous and even impossible at times. The result is devastating loss and irreparable damage to the environment and atmosphere (30% of carbon dioxide (CO_2) in the atmosphere comes from forest fires) [1], in addition to irreparable damage to the ecology (huge amounts of smoke and carbon dioxide (CO_2) in the atmosphere). Among other terrible consequences of forest fires are long-term disastrous effects such as impacts on local weather patterns, global warming, and extinction of rare species of the flora and fauna.

The problem with forest fires is that the forests are usually remote, abandoned/unmanaged areas filled with trees, dry and parching wood, leaves, and so forth that act as a fuel source. These elements form a highly combustible material and represent the perfect context for initial-fire ignition and act as fuel for later stages of the fire. The fire ignition may be caused through human actions like smoking or barbeque parties or by natural reasons such as high temperature in a hot summer day or a broken glass working as a collective lens

focusing the sun light on a small spot for a length of time thus leading to fire-ignition. Once ignition starts, combustible material may easily fuel to feed the fires central spot which then becomes bigger and wider. The initial stage of ignition is normally referred to as "surface fire" stage. This may then lead to feeding on adjoining trees and the fire flame becomes higher and higher, thus becoming "crown fire." Mostly, at this stage, the fire becomes uncontrollable and damage to the landscape may become excessive and could last for a very long time depending on prevailing weather conditions and the terrain.

Millions of hectares of forest are destroyed by fire every year. Areas destroyed by these fires are large and produce more carbon monoxide than the overall automobile traffic. Monitoring of the potential risk areas and an early detection of fire can significantly shorten the reaction time and also reduce the potential damage as well as the cost of fire fighting. Known rules apply here: 1 minute—1 cup of water, 2 minutes—100 litres of water, 10 minutes—1,000 litres of water. The objective is to detect the fire as fast as possible and its exact localization and early notification to the fire units is vital. This is the deficiency that the present Invention attempts to remedy, by means of detection of a forest fire at the very

early stage, so as to enhance or ensure the chance to put it out before it has grown beyond control or causes any significant damage.

There are a number of detection and monitoring systems used by authorities. These include observers in the form of patrols or monitoring towers, aerial and satellite monitoring and increasingly promoted detection and monitoring systems based on optical camera sensors, and different types of detection sensors or their combination.

The following part presents a brief overview of automatic and semiautomatic detection and monitoring systems of fire protection in the world, experience with these systems in practical operation, and their evaluation in terms of efficiency, accuracy, versatility, and other key attributes.

2. Authorities Fire Suppression and Detection Techniques

The most frequently used fire detection and suppression techniques employed by authorities can be summarised as follows:

  (i) controlled burning,

 (ii) fire weather forecasts and estimates of fuel and moisture,

 (iii) watch towers,

 (iv) optical smoke detection,

  (v) lightning detectors which detect the coordinates of the strike,

 (vi) infrared,

(vii) spotter planes,

(viii) water tankers,

 (ix) mobile/smart phone calls becoming increasingly common for detecting fires early, and

  (x) education through Fire Watch or similar schemes for house owners.

Detection and monitoring systems are divided into the following two basic groups:

 (a) volunteer reporting-public reporting of fires, public aircraft, and ground based field staff,

 (b) operational detection systems: fire towers, aerial patrols, electronic lightning detectors, and automatic detection systems.

Some of the techniques used in fire suppression include burning dry areas under the management of fire fighters rather than having a crisis later or using flying water tankers like in Canada. Interestingly, others sweep away everything within a planned wide line to surround the fire with a dead end of unfuelled areas like in the Middle East. In some parts of Australia, providing the fire does not harm any humans or properties, it is left to burn, until it dies alone.

2.1. Discussion. Wildfires are high on the political agenda of all the main continents. There are key debates concerning prevention through reduction of forest fuel, managed burnings, and suppression by effectively putting out fires as they occur. Coupled with climate change, resources over the last decade, mainly due to budget cuts and reorganisation of departments, have been focused on "suppression" which in turn allows fuel levels to continue to increase, thus providing the basis for catastrophic fires to occur.

Through contacting a cross section of stake holders and influencers across Australia, Canada, USA, and Europe covering government, forestry management groups, fire chiefs, wildland fire research organisations, international trade association for wildfire, press/conference organisers, insurance trade associations catastrophic events, and sensor suppliers, it actually turned out that each country has many separate organisations, each of them responsible for a certain territory, with its own budget. These authorities' techniques are based on the probability of human observation or the forecast predictions for forest fires, but it is not a reliable solution that can stop this problem or reduce it. They do not interfere with the fire as long as it does not pose a danger to humans or properties. They believe if they received any warning from public figures, only then it might endanger human life; they do not consider the environmental impact as a priority.

3. Satellite-Based Systems

Earth-orbiting satellites and even air-floating devices have been employed for observation and detection of forest fires. Satellite images gathered by two main satellites launched for forest fire detection purposes, the advanced very high resolution radiometer (AVHRR) [2], launched in 1998, and the moderate resolution imaging spectroradiometer (MODIS), launched in 1999, have been used [3, 4]. Unfortunately, these satellites can provide images of the regions of the earth every two days and that is a long time for fire scanning; besides the quality of satellite images can be affected by weather conditions [5].

3.1. Discussion. Any existing satellite-based observations for forest fires suffer from severe limitations resulting in a failure in speedy and effective control for forest areas. Some of the limitations in an approach based on direct observation of forest fires from geostationary (GEO) or Low Earth Orbit (LEO) satellite are as follows: it might be impossible to provide a full satellite coverage or even intermittent coverage.

Geo and Leo satellites are located on orbits over 22,800 miles above the earth's surface. The optical and the infrared (heat) radiation emitted by flames in early stages, before its spread over a wide region, may be too feeble in intensity to be detected by a satellite. The intensity decreases as the inverse square of the distance, in addition to being sensitive to the angle between the direction of the arriving beam of radiation and normal to the receiving surface-mirror, camera, antenna, and detector; therefore, the position and orientation of the satellite might be far from optimal for detecting a forest fire at an early phase.

The satellite might not be equipped with transponders, antennas, amplification reception, regeneration, frequency translation, and downlink transmission suited for detection of forest fires. In fact, there may not yet be formal allocation of the appropriate frequency and bandwidth for forest fire detection.

A satellite is usually designed to perform many diverse functions (telecommunications, remote-sensing for broad features of the earth's surface or the atmosphere, etc.) and it is not cost-effective to add to it the capability to detect forest fires. The operation of a satellite system is bound by many national and international regulations and agreements and may be less than suitable for the task of forest fire observation.

4. Optical Sensor and Digital Camera

Nowadays, two different types of sensor networks are available for fire detection, camera surveillance and wireless sensor network. The development of sensors, digital camera, image processing, and industrial computers resulted in the development of a system for optical, automated early recognition and warning of forest fires.

Different types of detection sensors can be used in terrestrial systems [6]:

(i) video-camera, sensitive to visible spectrum of smoke recognisable during the day and a fire recognisable at night,

(ii) infrared (IR), thermal imaging cameras based on the detection of heat flow of the fire,

(iii) IR spectrometers to identify the spectral characteristics of smoke,

(iv) light detection and ranging systems—LIDAR (detection of light and range) that measure laser rays reflected from the smoke particles.

The variant optical systems working according to different algorithms designed by the producers, all have the same general concept in smoke and fire glow detection. Simply, the camera produces images every while. The image consists of a number of pixels, where the processing unit tracks the motion in images and checks how many pixels contain smoke or fire glow and then the processing unit sends the results for another algorithm to decide whether or not to produce an alarm for the operator. Most of the optical systems need to be integrated with geographical maps for localisation reasons. See Figure 1.

Use of a given type of camera or sensor depends not only on the specific conditions of the operation but also on the financial resources available.

AlarmEYE is a video imaging system for forest fires early detection integrated with infrared, black and white and colour frequency detection. Its infrared option can distinguish between flame image and heat vapour. This system was produced and deployed in Thailand [6–8].

EYEfi SPARC. Optical sensors produced by EYEfi, Australia, for forest fire detection consist of

FIGURE 1: ForestWatch system [9].

(i) camera (colour during the day and ultralow light gray scale at night),

(ii) weather station,

(iii) lightening detection sensor,

(iv) communication unit (0.25 Mpbs),

(v) power system.

Thermal camera or pan tilt zoom cameras can be added to the system. EYEfi does not offer automatic detection of smoke but plans to introduce it sometime in the near future. Simply, EYEfi can provide images for fire agencies whenever the operator notices smoke and can use EYEfi software to use the GIS map and locate the smoke position on the ground. A weather station and lightening detector are included in the system for more accuracy [6, 8].

UraFire system is based on identifying smoke by clustering motions with a time input to reduce the number of false alarms and is used and produced in France [6, 10, 11].

Forest Fire Finder. This optical system has totally different techniques and is a system based on intelligent analysis of the atmosphere instead of detecting the smoke or fire glow. Forest Fire Finder tracks the way the atmosphere absorbs the sun light, which depends on the chemical composition in the atmosphere. Different composition has different absorption behaviour, so Forest Fire Finder can recognise the organic smoke from burnt trees and the industrial smoke in range of 15 Km. The equipment can be installed in tree crowns for faster detection and this system is used in Portuguese forests [6, 12]. See Figure 2.

ForestWatch is an optical camera sensor system which provides a semiautomatic fire detection produced by Enviro-Vision Solutions, South Africa. A tower camera scans the area for smoke during day and fire glow during night. It can detect smoke in range of 16–20 Km and then report it over 0.25 Mpbs 3G or microwave connections [8]. Forestwatch consists of [9]

(i) a Pan tilt camera to allow a 360° rotation and +33 to −83 tilt from horizon, with 24x optical zoom,

(ii) image sampling engine,

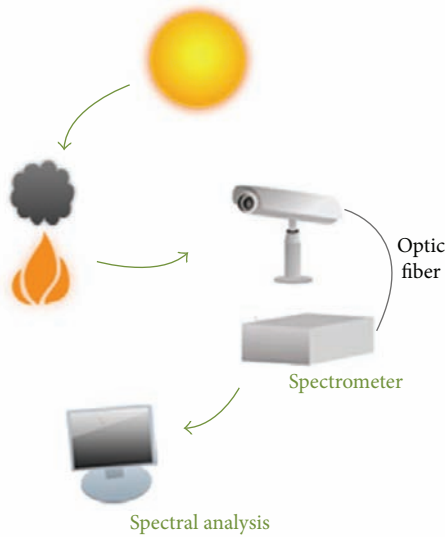(iii) communications system, such as 3G, microwave, or satellite,

Figure 2: Forest Fire Finder [12].

(iv) ForestWatch software to process the received data and produce sufficient evaluation for the operator to make the final decision.

Schroeder (2004), in his article "Operational trial of the FireWatch wildfire smoke detection system," argued that the microwave links are inexpensive and do not require a licence. However, these systems require a very high line of side transmitter and receiver every 50 Km. Schroeder suggested that satellite connection might be more effective and cheaper [13].

ForestWatch is the most popular system in forest fire detection and only Canada has a documentation test. Forest-Watch performed adequately in this test: fires were reliably detected up to a 20 km range but false alarms were also generated. Operational Forest Watch systems are in use in South Africa (83 towers), Swaziland (5 towers), USA (22 towers), Canada (4 towers), Chile (20 towers), and Slovakia (4 towers). A pilot scale operation (two towers) is installed in Greece. The related Harbour Watch system has been deployed in South Africa and Namibia [8].

FireHawk. A risk management system which provides fire location consists of the following three layers [6]:

(i) imaging layer represents installing cameras on suitable places,

(ii) communication layers set up the wireless link,

(iii) machine vision layer is the layer where FirHawk uses the ForestWatch software and GIS to provide a location and the shortest path to the fire.

Currently, Firehawk is installed in two areas in South Africa [14].

FireWatch is an automatic smoke detection system which can identify smoke within a range of 10–40 km. It has been studied for years (since 1992) in Germany, and now it is produced by German Aerospace Institute (DLR).
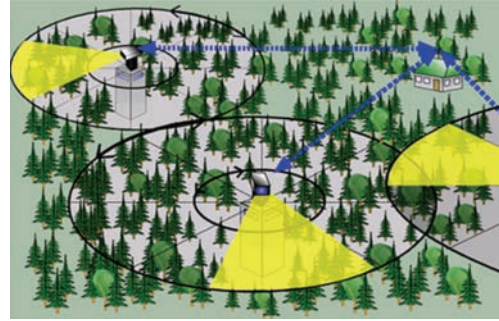

Figure 3: FireWatch [15].

Operational FireWatch systems are in use in Germany (178 towers, 22 control rooms), Estonia (5 towers, 1 control room), Cyprus (2 towers, 1 control room), and Mexico (1 tower, 1 control room). Pilot scale systems (1 or 2 towers) are in use in the Czech Republic, Portugal, Spain, Italy, Greece, and the USA [8].

FireWatch system overview is as follows [15].

(i) Optical sensor system (OSS): each OSS rotates 360 every 4 to 6 minutes in day time and 8–12 minutes during the night in 10 degree steps.

(ii) Data transfer: OSS at the tower has a wireless connection to the officer computer.

(iii) Central office: the forest workers are provided with work space (computers, monitors, and printer). See Figure 3.

If the sensor detects a cloud or a column of smoke, the information is transmitted to a central forest fire control office via ISDN (64 bits) or radio transmission of 1 Mpbs; it can be transmitted over 3G but not recommended [8].

4.1. Discussion. Two systems are considered relevant for a real employment in conditions in most of the European countries FireWatch and ForestWatch. Both systems have a long-term development and are still being improved; both of them have been tested and commercially used in many countries around the world.

A very interesting report was produced by the Australian government in collaboration with the Bushfire Cooperative Research Centre on Australian experience of three optical systems for forest fire detection. They designed a project to test the performance of each one of the three optical sensor systems compared by human staffed observation tower performance. Mathews et al. [8] produced a full report about the project details, tests environment, experiment results, and analysis.

The three systems are EYEfi, FireWatch, and ForestWatch, all of which had been tested on three types of fires: research burning, private burning, and agency burning in Tumut in NSW and Otway Ranges in Victoria in 2010. See Figure 4.

Some of the results explored by Mathews et al. [8] on the NSW tests are shown in Table 1 as follows.

Table 1: NSW tests.

Test type	Number of reported fires			
	EYEfi	ForestWatch	FireWatch	Tower observer
Six research fires ignited in Tumut	0	0	1	6
Six stationary fires including 2 at night	0	3	3	—

Figure 4: Tower in Tumut, Australia, with the three systems [8].

(i) Over 250 private fires (mostly agricultural burning off) occurred across the study areas. The camera systems reported many fires but in comparison with tower observations in NSW a high proportion of private burns were not reported.

(ii) 37 prescribed fires and burn-off fires were conducted as part of normal land management tasks during the postfire season burning period by Forests NSW, NSW National Parks and Wildlife Service, and Victorian Department of Sustainability and Environment. One unplanned bushfire was reported in Victoria and none in NSW.

Mathews et al. claimed in their report that all the systems detection was slower and less reliable than a trained human tower observer and it is not possible to rely on cameras only. However, it might be useful to use these systems as tools to improve the tower observer's performance or in remote un-staffed towers.

They argued that FireWatch was better than forest watch in fire detection reporting where FireWatch was the only camera system to report any of the forest burns, although the detection was 35 minutes later than the observer detection and the fire was 5 times larger. Furthermore, they pointed out that the detection performance was partially a function of fire size and distance from camera; large burns were detected at long distances (70 Km) while moderate burns (10–20 km) were missed.

They stated that the three systems have small localisation error percentages. The cameras are unable to take the topography of the land into localisation calculations. The causes for that are shown in Figure 5.
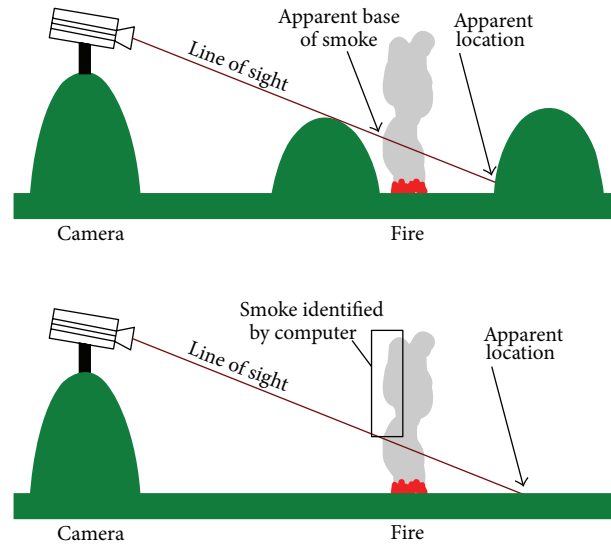

Figure 5: Localisation error reason [8].

They concluded the report with the following points.

(i) Cameras are very likely to perform worse than human observers; they are not suitable replacements for human tower observers.

(ii) Human observers and the three systems were tested to report forest fires by detecting a column of smoke, where it required a long delay from the ignition moment to produce noticeable smoke that can be detected by human or sensor cameras.

(iii) Atmospheric conditions, landscape appearance, and smoke characteristics were in different parts of the world.

Optical sensors or camera systems in general need to be improved in order to reduce the number of false alarms due to various dynamic phenomena such as wind-tossed trees, cloud shadows, reflections, and human activity. The difficulties of processing landscape images are due to their varying nature and to the large number of dynamic events that may appear under various illuminating conditions depending on weather, distance, time of day, masking objects, and so forth. These events produce dynamic envelopes, which are not always caused by motion, and consist of time-varying gray levels of connected pixels in several image regions.

This kind of technology only provides a line of sight vision, where high trees or the hills and mountains can block the vision; plus, it might be impossible to provide images for the point of ignition. Optical systems were designed

to cover large areas with a minimum number of camera towers; each tower has to detect smoke in range of 15–80 Km, where it requires a long delay after the ignition to produce a watchable smoke cloud that can be detected by the camera. Weather condition and night vision reflect on the camera performance.

Camera surveillance systems with short distance links were tried, but this also proved an ineffective method for fire detection in regard to the need for manual installment for each camera in an appropriate position rather than the line of sight images, night images, bad weather image problems, and high possibility of false alarms because of the following:

(i) daily motion of the sun,

(ii) moving clouds,

(iii) variation of atmospheric extinction,

(iv) vegetation.

Finally, these systems are very expensive; the camera tower can be worth more than thirty thousand dollars per tower, and there is a need to build these towers and install a communication infrastructure in the remote areas inside the forests.

5. Wireless Sensor Networks

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 has started to be applied in forest fire detection. The wireless nodes integrate on the same printed circuit board, the sensors, the data processing, and the wireless transceiver and they all consume power from the same source 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, pressure and humidity, as well as chemical parameters such as carbon monoxide, carbon dioxide, and nitrogen dioxide. The sensors operate in a self-healing and self-organising wireless networking environment. One type of wireless technology is ZigBee which is a new industrial standard based on IEEE 802.15.4. This technology emphasises low cost battery powered application and small solar panels and is suited for low data rates and small range communications. Wireless sensor networks have seen rapid developments in a large number of applications. This kind of technology has the potential to be applied almost everywhere; this is why the research interest in sensor networks is becoming bigger and bigger every year.

Forest fire detection and prevention are another real problem faced by a number of countries. Different methods for monitoring the emergence of fires have been proposed. The early methods were based on manned observation towers but this technique was inefficient and not entirely effective. Subsequently, camera surveillance systems and satellite imaging technologies were tried but this also proved ineffective at being able to efficiently monitor the initial start of the surface fire. For example, camera networks can be installed in different positions in the forests but these provide only line of sight pictures and may be affected by weather conditions and/or physical obstacles.

The revolution of WSN technology in recent years has made it possible to apply this technology with a potential for early forest fire detection. These sensors need to be self-organised and follow an efficient algorithm, interfaced with other technologies or networks. A number of studies have considered using WSN in wood fire systems.

Lloret et al. [16] suggested deploying a mesh network of sensors provided with internet protocol (IP) cameras in Spain. Here, the sensors detect the fire at the beginning and send an alarm signal to the sink. The sink then sends back a message to switch the closest camera "on" to provide real images of the fire and avoid false alarms. Their paper is based on testing the performance of four IP cameras and their energy consumption. The problem with this system is that the transfer of images is a heavy load for wireless sensor networks in relation to their limited resources of power, memory, and buffer rather than IP cameras which can only provide a line of sight images and are not efficient in dark and in foggy and raining weather. IP cameras require installing each one of them manually in the appropriate position.

Son et al. [17] propose a project for fire detection in South Korean Forest Fire Surveillance System (FFSS) using wireless sensor networks connected to the internet. They used a MCF (minimum cost path forwarding) as a routing protocol, which required a routing table for each node to find the minimum path to the sink. General information about the network architecture was provided in their paper. Sensor nodes sense the temperature, humidity, and illumination to forward it to the base station node and then to the gateway. The gateway is connected with a middleware and web application database to create some calculations based on daily humidity records in order to evaluate the hazards of the fire. Son's network is a scalable and real-time system, but their paper is more concerned with fire calculations and decision making than the network communication reliability. They did not discuss the network coverage and sensors distribution or fire localisation issues.

Hartung et al. [18] in their paper present FireWxNet, a multitiered portable wireless system for monitoring weather conditions in rugged wildland fire environments. They used wireless sensor network for wood fire detection as a hybrid with web cameras. The main target of their studies was to investigate fire behaviour in forests rather than detecting fire in early stages. They used wireless sensor network to provide data for weather status and web cameras to provide images for the fire. FireWxNet provides the fire fighters with the ability to measure fire and weather conditions. The system uses a tiered structure which starts with directional antennas on the top of mountains and ends with multihope sensor network to observe the required environmental parameters. Hartung et al. stated that they used web cameras to provide vision data as well and that they equipped the sensors with a small GPS device to provide the location information. See Figure 6.

Doolin and Sitar [20] experimented a network of 10 Crossbow Mica2 mote sensors operated by TinyOS operating
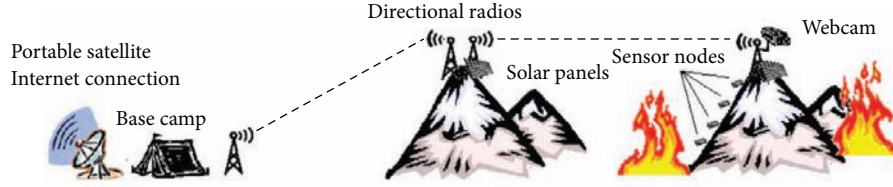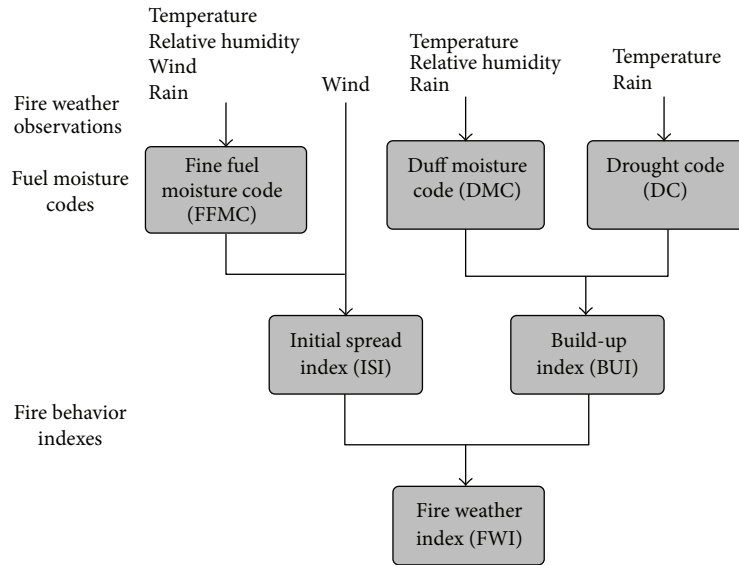
FIGURE 6: FireWxNet [18].

FIGURE 7: FWI system [19].

systems written in nesC language. The motes were provided with GPS devices and tested on grassy areas, about ten/acre to sense temperature and humidity pressure and send this data back to the base station. The base station was connected to a MySQL database and clients for alarm monitoring. The problem with this system is that the distance between sensors is too far (approximately 1 km); in case of node failure, a connection between some sensors and the sink might be lost and that could leave a gap in the network coverage; plus, adding a GPS device to each sensor will make the network more expensive and reduce the network life time as a GPS will consume more power. Furthermore, in Doolin's project, each node has to be installed and fixed manually and this is almost impossible for large forests.

Aslan [5] proposed a good fire detection framework which consists of

(i) Sensor deployment scheme: represented in the distance between sensors, minimum collision, and minimum number of sensors deployed with full coverage.

(ii) Network architecture: the cluster scheme used as network topology.

(iii) Intracluster communication protocol: the communication between nodes and clusters divided into: initialisation phase, risk free phase, fire threat phase, and progressed fire phase. Nodes enter or change their phase according to danger rate calculation, which

depends on NFDRS (National Fire Danger Rating System), temperature, and humidity ranges.

(iv) Intercluster protocol: the main target for this protocol is the power balancing for cluster heads.

Hefeeda and Bagheri [19] present a very smart system. They based their network action on fire weather index (FWI). This index includes the probability of fire ignition and fire spread rate as well. FWI provides the moisture content in relation to weather observation and the fuel codes which is divided into the following three types to describe the soil content of forest ground.

(i) Fine Fuel Code (FFMC) represents the litter and fine fuels for 2 cm deep.

(ii) Duff Moisture Code (DMC) represents moisture content of decomposing organic material for 5–10 cm deep.

(iii) Drought Code (DC) represents the moisture organic content for 10–20 cm deep. See Figure 7.

Hafeeda's system required a lot of work before deploying the network. It required a long analysis of the forest surface component in the forest's different parts to understand how to build the fuel code model for this area. Their work is more concerned with weather and fuel modelling for fire danger assessment than the network and coverage issues.
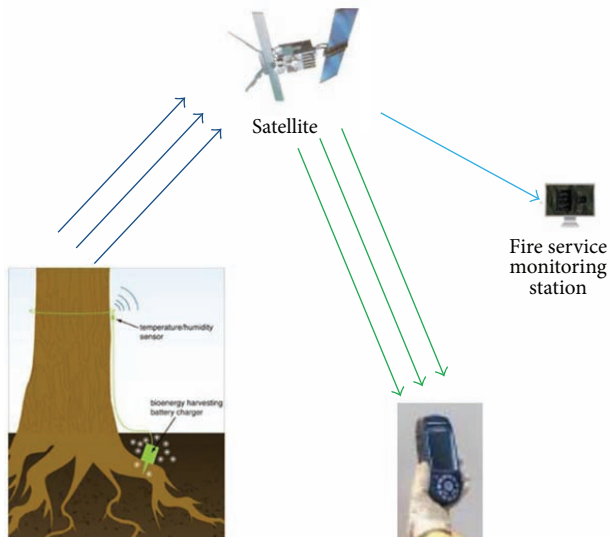
Figure 8: Pennsylvania project [21].

Conrad et al. [21] produced a business case for the Enhanced Forest Fire Detection System with a GPS project in Pennsylvania. They claimed that forest fires damage 2,554 acres per year in Pennsylvania, which causes economic loss and potential loss of human life and environment. They proposed to create a fire detection system using fire sensors and GPS devices instead of the present fire detection systems such as the public phone lines, fine look-out towers, and ground or aerial patrol. They claimed that these techniques were outdated and it is time to use the technology for this problem. They targeted two aims for this project: (a) to use the already existing technology and (b) replace all the existing fire detection techniques with more efficient ones.

Conard et al. planned to purchase the GPS handheld devices and radio wave sensors, where the sensor reacts to a fixed temperature by transmitting signals to the GPS system. Each signal would carry the devices unique identity code to increase the system efficiency and allow the system to identify the position. The project planned on installing 12,000 units within forty-eight months, 4,000 devices every 12 to 15 months. When fire or smoke was detected, the sensor would send a signal to GPS satellite, and then the GPS satellite would duplicate the signal to the handheld GPS device and the central monitoring database to display the fire location on the installed map for that area. See Figure 8.

It looks like a very interesting work; unfortunately, the file does not contain any results or proof of the project efficiency. The project expenditure is very high as they have to install each one of the units manually after they finalise the configuration and calibration. GPS devices consume more energy and reduce the nodes life time.

The researchers defined more than 27 mathematical models to describe the fire behaviour where they stated that those models developed according to different countries experience of forest fire and each model is different according to the input parameters and the environments nature (fuel indexing [22, 23]). The researchers of forest fires manage to use some of

these models in simulations or even create their own methods to create maps that can be used to analyse the fire behaviour at any time in the future so that they can help the fire fighters to determine the best method to extinguish the fire, such as BehavePlus, FlamMap, FARSITE, Geodatabase, and ArcSDE. On the contrary, researchers are trying to initiate a reliable technology that can detect the fire, localise the fire, and help in decision making in terms of requiring an immediate reaction in case of crisis possibility or a high fire risk situation. As a result, the fire can be extinguished in early stages within a short time to minimise the damage save lives, environment, fire fighter equipment, time and effort.

Hongye et al. [24] in their research of forest fire in inner magnolia discussed a very smart structure for the system which is divided into monitoring system of the forest fire, database system of information management, and decision making system of management of the forest fire proofing. Where the monitoring system at the end provides a quick location for the fire by simulating the fire in 2D map, images come from the field used into 3D maps by using Geodatabase and ArcSDE programs for fire simulation. Although the logical architecture is smart, this system is not easy to build and image observation is not the smartest method for fire detection and simulation.

Ngai et al. [25] provide a general reliability-centric framework for event reporting in wireless sensor networks which can also be used in forest fire detection systems. They consider the accuracy, importance, and freshness of the reported data in environmental event detection systems. They present a data aggregation algorithm for filtering important data and a delay-aware data transmission protocol for rapidly carrying the data to the sink node.

Wenning et al. [26] propose a proactive routing method for wireless sensor networks to be used in disaster detection. The protocol is developed to be aware of a node's destruction threat and it can adapt the routes in case of a sensor node's death. The method can also adapt the routing state based on a possible failure threat indicated by a sensed phenomenon.

García et al. [27] present a simulation environment that can create a model for a fire by analysing the data reported by sensor nodes and by using some geographical information about the area. The use of topography of the environment distinguishes the study from some other solutions. The estimation of the spread of a fire is sent to handheld devices of fire fighters to help them in fighting the fire in field.

FIRESENSE (Fire Detection and Management through a Multisensor Network for the Protection of Cultural Heritage Areas from the Risk of Fire and Extreme Weather Conditions, FP7-ENV-2009-1-244088-FIRESENSE) [28] is a Specific Targeted Research Project of the European Union's 7th Framework Programme Environment (including climate change).

The FIRESENSE FP7 project aims to implement an automatic early warning system to remotely monitor areas of archaeological and cultural interest from the risk of fire and extreme weather conditions.

FIRESENSE is a very complicated system; it consists of multisensors, optical, IR, and PTZ cameras in addition to temperature sensors, and weather stations. In this system,
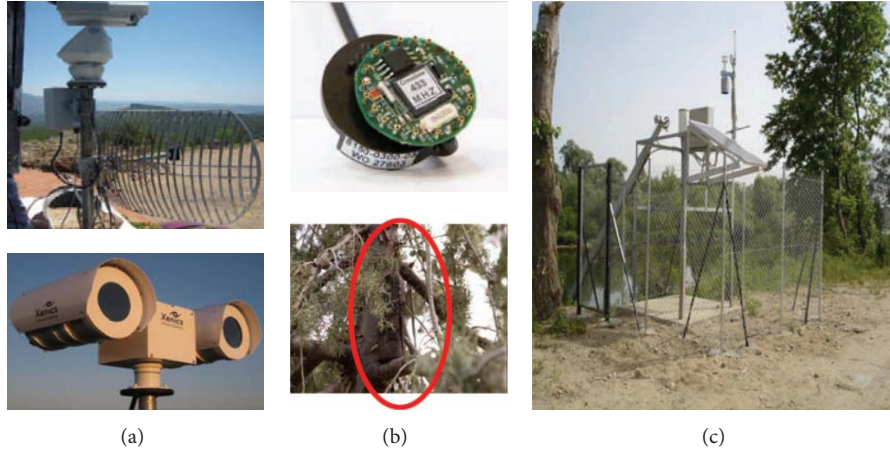
(a) (b) (c)

FIGURE 9: FireSense system [28].

each sensor collects the data and applies some processing techniques and different models and data fusion algorithms in order to provide a clear understanding for the event to the local authority. Demonstrator deployments will be operated in selected sites in Greece, Turkey, Tunisia, and Italy. See Figure 9.

This project builds on very complicated scientific models, algorithms, concepts, and comparisons, such as the following.

  (i) Scene model: the fire and smoke, heat flux or emitted thermal (Planck's radiation formula), the fire flickering, the reflectance, absorption emission lines, and analysis of the atoms (e.g., potassium) and the molecules (water and carbon dioxide) are characteristics to be investigated.

 (ii) The background emits the thermal heat, the reflectance of sunlight, the clouds (clouds shadow) the buildings and the sky polarisation.

(iii) The atmosphere has a number of gases (N_2, O_2, CO, CO_2, H_2O, etc.); each one has its own absorption and reflection behaviour. Water vapour concentration could vary as a result. Carbon dioxide is more uniformly distributed but its value is larger over industrial cities and vegetation fields than over oceans and deserts.
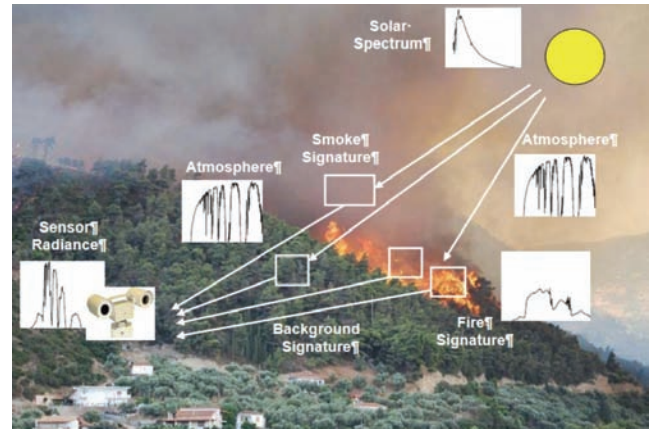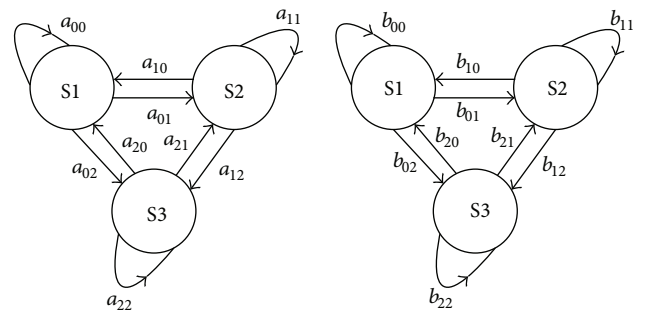
Figure 10 describes the physical aspects related to forest fire detection.

The atmosphere strongly influences the radiation transfer of the forest fire by absorbing and scattering radiation. 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.

After that, further processing is applied to the images by using Markov model. In this model Markov defines three states for each flame and nonflame moving pixel. See Figure 11.

FIGURE 10: How FiresSense Analyse Images [28].

FIGURE 11: Three-state Markov models for flame and nonflame moving pixels, respectively [28].

Yu et al. [29] present a real-time forest fire detection system by using neural wireless sensor networks. They relied on the clustering algorithm as routing techniques to collect the measurement from the scattered sensors such as humidity, temperature, smoke, and wind speed where this data was used as input for The United States National Fire Danger Rating System.

TABLE 2: Comparison between forest fire detection systems.

Human based observation	Satellite system	Optical cameras	Wireless sensor networks
	Any existing satellite-based observations for forest fire suffer from severe limitations resulting in a failure in speedy and effective control for forest areas.	Optical sensors or camera systems in general need to be improved in order to reduce the number of false alarms due to various dynamic phenomena, such as wind-tossed trees, cloud shadows, reflections, and human activity.	Best available solution for forest fire detection.
	The satellite coverage of the full region of the forest may not be available or the coverage may be only intermittent (not continuous in time), with substantial gaps in time when the satellite is not within the field of view from certain regions or spots of the forest.	The difficulties of processing landscape images are due to their varying nature and to the large number of dynamic events that may appear under various illumination conditions, depending on weather, distance, time of day, masking objects, and so forth. These events produce dynamic envelopes, which are not always caused by motion, and consist of time-varying gray levels of connected pixels in several image regions.	They can provide all required information that influences the environment at any moment accurately.
Last decade, mainly budget cuts and reorganisation of departments have been focused on "suppression" which in turn allows fuel levels to continue to increase, thus providing the basis for catastrophic fires to occur.	The optical and the infrared (heat) spectral radiation emitted by a small flame, the early phase of a forest prior to its spread over a wide region, may be too feeble in intensity to be detected by a satellite. The intensity decreases as the inverse square of the distance, in addition to being sensitive to the angle between the direction of the arriving beam of radiation and the normal to the receiving surface-mirror, camera, antenna, and detector so that position and orientation of the satellite may usually be far from optimal for detecting a forest fire at an early phase.	This kind of technology only provides a line of sight vision; where high trees or the hills and mountains can block the vision; plus it might be impossible to provide images for ignition place.	They can cover any area size, plus its scalable network.
Authorities' techniques are based on the probability of human observation or the forecast predictions for forest fires, but it is not the reliable solution that can stop this problem or reduce it.	The satellite may not be equipped with transponders and antennas designed to perform the reception, amplification, regeneration, frequency translation, and downlink transmission to the ground-optimally suited for detection of forest fires. In fact there may not yet be formal allocation of the appropriate frequency and bandwidth for forest fire detection and pertinent information transmission and processing (onboard or at the ground terminal or earth station).	Optical systems were designed to cover large areas with minimum numbers of camera towers; each tower has to detect smoke in range of 15–80 Km, where it requires a long delay after the ignition to produce a watchable smoke cloud that can be detected by the camera.	They can observe and influence the physical world around them
They do not consider the environmental impact as a priority.	A satellite is usually designed to perform many diverse functions (telecommunications, remote-sensing for broad features of the earth's surface or the atmosphere, etc.) and it is not cost-effective to add to it the capability to detect forest fire.	Weather condition and night vision reflect on the camera performance.	They can be connected to many devices and can add many kinds of sensors to measure different parameters.
High probability of faulty alarms.	The operation of a satellite system may not be real time in order to instantaneously provide information about the occurrence of a forest fire anywhere within the forest region.	Camera surveillance systems with short distance links were tried, but this also proved an ineffective method for fire detection in regard to the need for manual installment for each camera in an appropriate position rather than the line of sight images, night images, bad weather images problems, and high possibility of false alarms because of the daily motion of sun light, clouds, atmospheric extinction, and vegetation.	There is no need to build towers or set up complicated communication links.
	The operation of a satellite system is bound by many national and international regulations and agreements and may be less than suitable for the task of forest fire observation.	Finally, these systems are very expensive; the camera tower can be worth more than thirty thousand dollars per tower, and there is a need to build these towers and install a communication infrastructure in the remote areas inside the forests.	They can be deployed anywhere even in inaccessible places.

Comparison	Human based observation	Satellite system	Optical cameras	Wireless sensor networks
Cost	Low	Very high	High	Medium
Efficiency and practicality	Low	Low	Medium	High
Faulty alarms repetition	Low	Low	Medium	Medium
Fire localising accuracy	Low	Medium	Medium	High
Detection delay	Long	Very long	Long	Small
Fire behaviour information	—	Yes	—	Yes
Can be used for other purposes	No	Yes	No	Yes

FIGURE 12: Waspmote and Gas Board [30].

Wang and Meng network required a very high density of deployed nodes and a very complicated routing and processing procedure to send the required data for the central unit. The main focus of this study is data aggregation methods; hence energy consumption issues are not discussed.

Zhu et al. [31] created a monitoring system for forest fires based on wireless sensor networks and GPRS network. They relied on clustering systems to provide real-time monitoring for smoke, temperature, humidity, and some other environmental parameters. The collected data from the nodes will be transmitted in multihop fashion to the central nodec and then to the monitoring center to produce reports, graphs, and curves to help the fire fighters make an appropriate decision.

Libelium [30] is one of the wireless sensor network companies based in spain. They call their nodes Waspmote and they introduce many applications for their products such as smart cities, forest fire detection, and many other applications. In forest fire application, they used their Waspmote nodes and a GPS device to localise those nodes. They provided the nodes with gas boards to measure temperature, humidity, carbon monoxide (CO), and carbon dioxide (CO_2) to detect the fire.

Libelium created a very good system; as their experiment shows, they deployed 90 sensors to measure the four parameters every five minutes, and they attached solar panels for power scavenging. Waspmote nodes and the gas board made the device in bulky size, which was required to be installed manually one by one in appropriate positions; this is not efficient in large areas. The gas board will lead to more power consumption, thus reflecting on the network life span. See Figure 12.

5.1. Discussion. The previous part details several of the principal study sources that have inspired the development of the research work in this thesis. It proves that the best available solution for forest fire detection is using sensor networks, because it can provide all required information that influences the environment at any moment accurately.

Wireless sensor network technology normally deploys large number of small, low cost sensors fairly densely that can observe and influence the physical world around them by gathering physical information, transforming it into electrical signals, sending it to a remote location to do some analysis, and deploying the results in different applications. By this way there is no need to build towers or set up complicated communication links such as microwave and satellite. It can be deployed anywhere even in inaccessible places.

This technology can provide real-time monitoring, where it can provide information at the ignition instance or at very small delays, depending on the node used in wake-up/sleep schedule.

This technology works on short communication links fashion. As a result, more accurate information with less delay can be provided for the fire fighters.

Using this technology for forest fire application requires a large number of randomly deployed nodes to provide a reliable network. Based on what has been discussed above, it can define the key issues of this network for this application in the following points.

(i) Localisation: all the previous work used a GPS or fixed the nodes in a known place.

(ii) Coverage: the nodes deployed randomly a full coverage almost impossible.

(iii) Network life span: For sensor nodes working on batteries, it is impossible to go back to each node in the forest and recharge it again.

(iv) Fire detection method: this is the heart of the application; it should be precise and reliable.

In the previous work they used other kinds of sensors like IP cameras or other technologies like satellite images or superoptical tower cameras. They integrated the sensor nodes information with data bases, weather stations, fuel and weather indexing models, and many other models and processing techniques to reduce the number of false alarms. In order to detect the fire, each node was provided with many sensors to get the environment parameters such as temperature, wind speed, relative humidity, and fire flickering to define a fire incident in the first place.

6. Summary of the Systems

See Tables 2 and 3.

Conflict of Interests

Ahmad A. A. Alkhatib has no conflict of interests to disclose.

Acknowledgment

The author would like to thank the reviewers for their helpful comments on this paper.

References

[1] An Inconvenient Truth, "Directed by Davis Guggenheim about former United States Vice President Al Gore's campaign [Documentary]," Los Angeles, NY, USA.

[2] NOAA satellite and information service, "Advanced Very High Resolution Radiometer—AVHRR," 2012, http://noaasis.noaa.gov/NOAASIS/ml/avhrr.html.

[3] NASA, "MOIDS, National Aeronautics and space administration," 1999, http://modis.gsfc.nasa.gov/.

[4] K. Nakau, M. Fukuda, K. Kushida, H. Hayasaka, K. Kimura, and H. Tani, "Forest Fire Detection Based on MODIS Satellite Imagery, and Comparison of NOAA Satellite Imagery with Fire Fighters Information," 2006.

[5] Y. Aslan, *A framework for the use of wireless sensor networks in the forest fire detection and monitoring [M.S. thesis]*, Department of Computer Engineering, The Institute of Engineering and Science Bilkent University, 2010.

[6] *EUFOFINET Project Detection Synthesis of Good Practices*, National Forest Centre, Zvolen, Slovakia.

[7] InnoSys Industries Inc, "Forest Fire," 2013, http://www.innosys-ind.com/product_detail/innosysind2/index.php?Product_SN=114436&PHPSESSID=62g6260o92g259q8n68rrndrp1&Company_SN=19641&Product_Site_Classify_SN=23299.

[8] S. Mathews, P. Ellis, and J. H. Hurle, *Evaluatuion of Three Systems*, Bushfire Cooperative Research Centre, Australia, 2010.

[9] K. Hough, "Vision Systems for Wide Area Survillance: Forest-Watch—along range outdoor wildfire detection system," Wildfire, 2007.

[10] Uratek, "Urafire is a software for fire forest early detection," 2013, http://www.uratek.com/applications.php?5.

[11] P. Guillemant and J. Vicente, "Real-time identification of smoke images by clustering motions on a fractal curve with a temporal embedding method," France, 2001.

[12] NGNS, "Forest Fire Finder," 2013, http://www.ngns-is.com/eng/FFF_eng.html.

[13] D. Schroeder, "Evaluation of Three Wildfire Smoke Detection Systems," FERIC5, 2004.

[14] ALASIA Marketing, "Fire Hawk ForestWatch," 2013, http://www.firehawk.co.za/.

[15] FireWatch, "An Early Warning System for Forest Fires, successfully in the global use," 2013, http://www.fire-watch.de/system-overview.

[16] J. Lloret, M. Garcia, D. Bri, and S. Sendra, "A wireless sensor network deployment for rural and forest fire detection and verification," *Sensors*, vol. 9, no. 11, pp. 8722–8747, 2009.

[17] B. Son, Y. Her, and K. Kim, "A Design and Implementation of Forest-Fires Surveillance System based on Wireless Sensor Networks for South Korea Mountains," *International Journal of Computer Science and Network Security*, vol. 6, no. 9, pp. 124–130, 2006.

[18] C. Hartung, R. Han, C. Seielstad, and S. Holbrook, "FireWxNet: A multi-tiered portable wireless system for monitoring weather conditions in wildland fire environments," in *Proceedings of the 4th International Conference on Mobile Systems, Applications and Services (MobiSys '06)*, pp. 28–41, ACM, Uppsala, Sweden, June 2006.

[19] M. Hefeeda and M. Bagheri, "Wireless sensor networks for early detection of forest fires," in *Proceedings of the IEEE Internatonal Conference on Mobile Adhoc and Sensor Systems (MASS '07)*, October 2007.

[20] D. Doolin and N. Sitar, *Wireless Sensors for Wild Fire Monitoring*, Smart Strucure and Material, San Diego, Calif, USA, 2005.

[21] A. Conrad, Q. Liu, J. Russell, and J. Lalla, "Enhanced Forest Fire Detection System with GPS Pennsylvania," 2009.

[22] M. A. Finney, "FARSITE: Fire Area Simulater- Model Development and Evaluation," f. s. US department for agriculture, USDA: research parer RMRS-RP-4 Revised, 2004.

[23] E. Pastor, E. Zarate, and J. Arnaldos, "Mathmatical Models and Calculation System for Study of Wildland Fire Behaviour," Sience Direct, 2003.

[24] H. Yang, Q. He, and Y. Liu, "Research of forest fire in Inner Mongolia based on CA and GIS," in *Proceedings of the 5th International Conference on Wireless Communications, Networking and Mobile Computing (WiCOM '09)*, September 2009.

[25] E. Ngai, Y. Zhou, M. R. Lyu, and J. Liu, "A delay-aware reliable event reporting framework for wireless sensor-actuator networks," *Ad Hoc Networks*, vol. 8, no. 7, pp. 694–707, 2010.

[26] B.-L. Wenning, D. Pesch, A. Timm-Giel, and C. Görg, "Environmental monitoring aware routing: Making environmental sensor networks more robust," *Telecommunication Systems*, vol. 43, no. 1-2, pp. 3–11, 2010.

[27] E. M. García, M. Á. Serna, A. Bermúdez, and R. Casado, "Simulating a WSN-based wildfire fighting support system," in *Proceedings of the International Symposium on Parallel and Distributed Processing with Applications (ISPA '08)*, pp. 896–902, December 2008.

[28] K. Kose, F. Tsalakanidou, H. Besbes et al., "FireSense: fire detection and managment through a multi-sensor network for protection of cultural heritage areas from the risk of fire and extreme weather conditions," in *Proceedings of the 7th Framework Programme for Research and Technological Development*, 2010.

[29] L. Yu, N. Wang, and X. Meng, "Real-time forest fire detection with wireless sensor networks," in *Proceedings of the International Conference on Wireless Communications, Networking and Mobile Computing (WCNM '05)*, pp. 1214–1217, September 2005.

[30] J. Solobera, "Detecting Forest Fires using Wireless Sensor Networks with Waspmote," Libelium, 2010.

[31] Y. Zhu, L. Xie, and T. Yuan, "Monitoring system for forest fire based on wireless sensor network," in *Proceedings of the 10th World Congress on Intelligent Control and Automation (WCICA '10)*, 2012.