Early Forest Fire Detection with Low Power Wireless Sensors Networks

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Abstract. Early detection and preventive measures is the primary way of minimizing the damage and casualties caused to natural and human resources. However, the disasters caused by fires require an immediate response. The work presented in this paper describes a proposal to make a short-term forest fire risk assessment, this is to improve the response time of time of emergency corps and existing forest fire prevention, detection, and monitoring systems. In order to do it, the introduction and implementation of Wireless Sensor Networks will enable real - time environmental monitoring of dynamic forest fire risk factors.

Keywords: Forest fires · Wireless sensor network · Detection system · LPWAN

1 Introduction

Forests are part of the important and indispensable resources for human survival and social development that protect the balance of the earth ecology. Forest fires reduce the cover of tree and lead to an increase in the gas emissions of our planet, and emit about 20% of CO2 into the atmosphere.

In recent years, the frequency of forest fires has increased considerably due to climate change, human activities and other factors.

Approximately 13 million hectares of forest are destroyed each year in the world [1].

In the Mediterranean basin as a whole, forest fires are now around 50 000 per year, the total area burned can be estimated at about 600 000 ha per year, twice as much than in the 70 s [2].

However, Forest fires cause massive damage to natural resources as well as public safety. The early detection of forest fires is crucial.

After the evolution of the new communication and information technologies, many means of surveillance have emerged.

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The first method was based on satellite monitoring [3]; and the second uses wireless sensor networks (WSN). The common objective of these two techniques is the collection of a maximum number of information, to identify the real state of the forest, in order to anticipate the emergence of fires, and consequently, to intervene in a record time. Several works and systems have been realized around the world using WSNs but all of them do not respond to both the prediction of the level of alert and the location of the fires in real time because of the deployment of these sensors in a large space [4–6].

The main idea of our work is to use a fast and localized system to determine the level and location of risk. This approach is based on several detection levels using wireless sensor networks (WSN) in a fixed and mobile way. First we determine the level of alert using the meteorological data, secondly with using the alert level we will deploy sensor networks fixed in several places to determine the state of the forest and the risk of a fire. The last step is to deploy the same sensors embedded in drones if the danger is eminent in a particular place. These drones will have the role of giving more precision on the black point in order to localize eventually the fire.

In this paper, we propose a solution based on WSN to detect reliably forest fires. We present the architecture and evaluation of a wireless sensor network for early detection of forest fires based on a network of low-power wireless sensors connected to the public network through a gateway. Our architecture is based on solid forestry research conducted by the Canadian Forest. The rest of the paper is organized as follows. In Sect. 2, we discuss the background and related work. Sect. 3 describes the architecture of the proposed forest fire detection system. The management and implementation of System which is the basis of our design are presented in Sect. 4. Section 5 shows the conclusion and future works.

2 Background and Related Work

2.1 Forest Fire Detection Methods

In this part we present two approaches to calculate the level of fire alert in the most used forests in the practical case.

Korean Approach
This approach is implemented on the system FFSS (Forest-fires Surveillance System) developed in [7].The FFSS senses environment state and determines forest-fires risk-level by formula of the Office of Forestry. The middleware developed in this study receives and processes packets from the transceiver and displays its results.

The results contain the level of risk of forest fires. This level is calculated by the formula defined by the Eq. 1 as follows:

$$Y = 6.87 + (0.64 * P) + (0.15 * EF) + (1774,94/CS) \tag{1}$$

Where: EF = Effective humidity (%), CS = Solar radiation of the day(MJ/m^2), P = Precipitation (mm). Then, the FFSS provide automatic alarm by the Table 1.

Table 1. Index danger of wildfire Korean.

Y	Danger index	Range of fire danger	State and color
10	100	81–100	Extreme (red)
11	90		
12	80		
13	70	61–80	High (yellow)
14	60		
15	50	under 60	Low (Blue)

Canadian Approach

Canadian approach uses the Fire Weather Index (FWI) System developed by the Canadian Forest Service (CFS).

The FWI index indicates fire intensity by combining the rate of fire spread with the amount of fuel being consumed. As shown in Fig. 1 the Fire Weather Index (FWI) estimates the moisture content of three different fuel classes using weather observations. These estimates are then used to generate a set of indicators: fire ignition potential, fire intensity, and fuel consumption (Table 2).

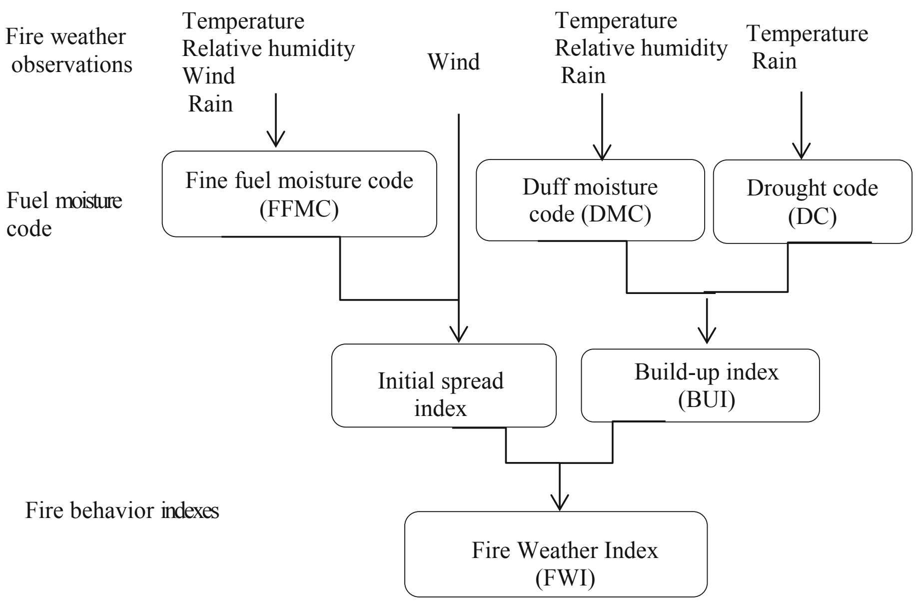

Fig. 1. Structure of the Fire Weather Index (FWI) System [8].

Previously, we have implemented the both codes on the same processor, and we have confirmed that the Canadian approach is more precise, faster and less energy consuming [10]. That's why we opted for the Canadian approach in the rest of our work.

Table 2. Potential Fire Danger Based on the FWI index [9]

FWI	Range of fire danger	Type of fire
Low	0–5	Creeping surface fire
Moderate	5–10	Low vigor surface fire
High	10–20	Moderately vigorous surface fire
Very high	20–30	Very intense surface fire
Extreme	30+	Developing active fire

2.2 Low-Power Wide Area Network

A low-power wide-area network (LPWAN) is a type of wireless protocol that provides longer reach between multiple devices with low power consumption. LPWANs operate at low bit rate to connect sensors to a central system through a wireless gateway. This protocol is used more and more in solutions IoT (Intenet of Things) to overcome physical constraints (implantation in dangerous environments, in places difficult to access, within the human body …).

LoRaWAN is an LPWAN protocol that allows you to connect multiple IoT objects using LoRa wireless technology. LoRa uses unlicensed ISM frequencies worldwide for public and private denominations. LoRa and LoRaWAN technologies compared to other LPWAN technologies are used in wide product ranges with minimum battery consumption and bidirectional communications between equipment and base station with excellent penetration inside Internet of Things solutions (IoT).

LoRaWAN uses proprietary Chirp Spread Spectrum spread spectrum modulation called LoRa. This modulation is carried out mainly on the ISM radio bands and it allows a distance between a bridge and equipment up to 5 km in urban area and 15 km in rural area. Spectrum spreading techniques such as LoRa use a higher bandwidth than is ideally required for a given bit rate but take advantage of this frequency spread to operate with a weak or highly noisy signal.

For our system, we have used a low cost Lora32u card to acquire sensors data and transfer it to the network. The LoRa32u4 card is a lightweight, low-power card, ideal for creating long-range wireless networks, more flexible than Bluetooth LE and does not require high power unlike Wifi and others. It is an ATmega32u4-based card running at 3.3 V and 8 MHz, with an HPD13 LoRa wireless module, using the SX1276 design of the highly integrated RF transceiver chip. This board is equipped with a Li-Po and Li-ion charging circuit and a standard battery interface, and is compatible with the Arduino development environment.

2.3 Network Model

Efficient and effective operation of a WSN depends also on the architecture and logical topology of the network. There are two types of network topology: flat topology and hierarchical topology. A flat wireless sensor network is a homogeneous network where all nodes are identical in terms of battery and hardware complexity and have the same role, except for the base station that acts as a gateway and is responsible for the transmission of the information collected to the end user. In a hierarchical clustered topology, the network is partitioned into clusters. A cluster consists of a cluster head and its members. The nodes members transmit their data to the cluster head, which will transmit to the base station.

3 The Architecture of the Proposed Forest Fire Detection System

The architecture of the precision Forest fire detection system based on wireless sensor networks consists of the monitoring nodes, base stations, communications systems, Internet access and the structure of monitoring hardware and software system.

A large number of the different sensors can be placed in the field. The proposed system adopts the cluster topology and hierarchical routing protocols.

Clustered topology has benefits in terms of achieving effective control of nodes depending on changing conditions, rapid reaction to fire threat, energy and bandwidth efficiency [11, 12].

For a first approach we estimate a distance of 1 km between sensors nodes.

Each cluster is equivalent to a relatively fixed self-organizing network. All sensor nodes are divided to some cluster. In a hierarchical clustered topology, some nodes are designated as cluster-heads with more responsibility to control other member ordinary nodes.

The common nodes will collect the data which transmitted to the cluster-head node. A future study can be done to find a compromise between the shortest path and the sensor that has sufficient energy compared to other sensors in the context of optimizing energy and achieving the low power wireless sensors network.

As showing in Fig. 2, sensor nodes measure temperature, humidity, CO and CO2. They are also assumed to know their location information by equipment such as Management and implementation of the proposed forest fire detection system.

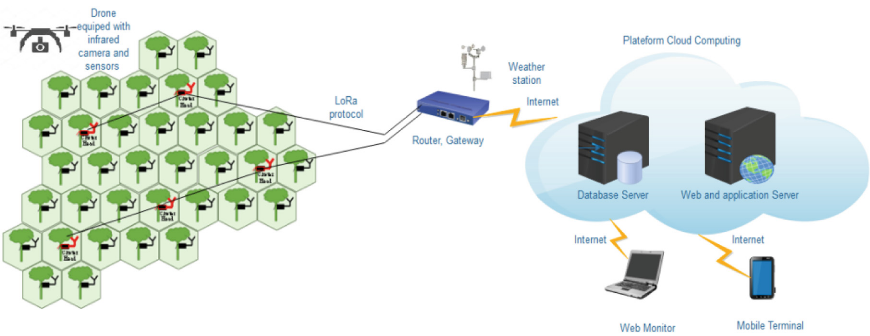

Fig. 2. Structure of the proposed forest fire detection system.

4 Management and Implementation of Proposed System

The flowchart of the fire detection algorithm is shown in Fig. 3. This flowchart has three steps to predict the level of alert and locate the fire if any. We will then detail each step of the detection process.

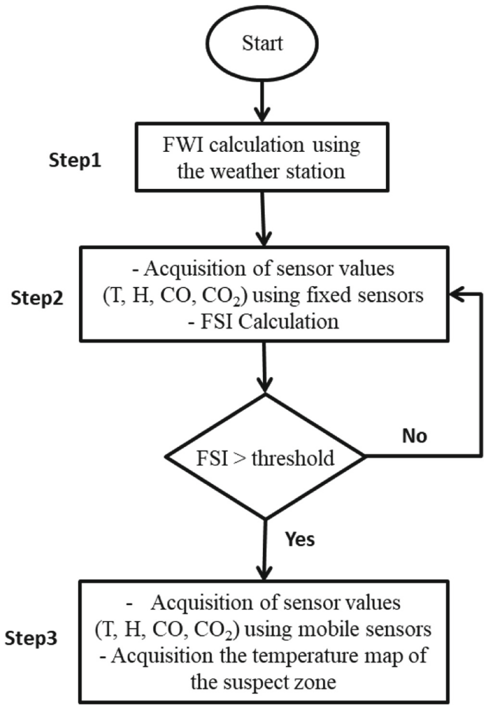

Fig. 3. Flowchart of the forest fire detection algorithm

4.1 Step1: Calculation of the Index FWI

The first step being the calculation of the index FWI from the values provided by the nearest weather station.

The value of FWI allows having an alert level among five levels. This level will be sent to all LoRaWAN network nodes.

4.2 Step2: Acquisition of Data from Fixed Sensors

A second step after calculating the FWI index is to acquire temperature, humidity, CO and CO2, data from fixed sensors in the node LoRoa32u4. According to the state of FWI we propose a measurement frequency time for the sensors.

- Low we calculate values each 180 mn;
- Moderate we calculate values each 60 mn;
- High we calculate values each 30 mn;
- Very high we calculate values each 10 mn;
- Extreme we calculate values each 5 mn;

Between two acquisitions, the LoRa card goes into sleep mode to save battery power. This information is sent to the cluster head.

After defining the routing path, the information is stored in the database implementing in a cloud and will be processed by the web and mobile applications hosted at the application server.

From these four measures we have determined another index to detect the presence of a fire (Fire Sensors Index FSI). For that we trigger a small fire for 15 min and we

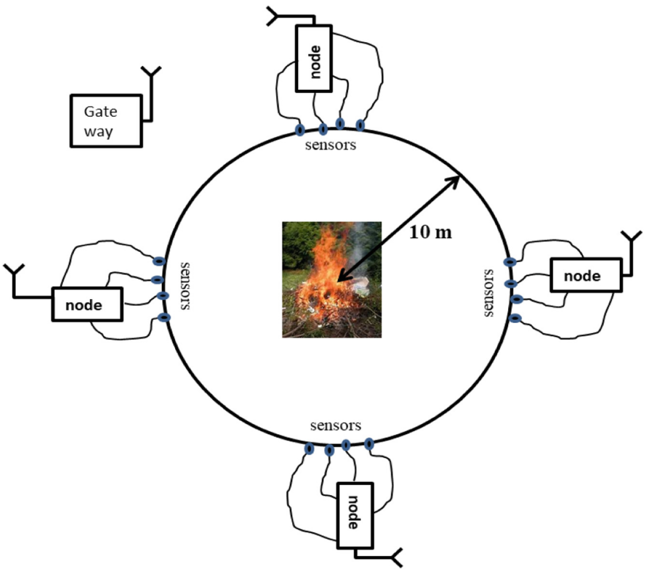

Fig. 4. The nodes are distributed in a circular fashion around the location of the fire.

measured the values of these four sensors every minute. A distance of 10 m is measured between the fire and near nodes as showing in Fig. 4 with a wind speed of 3 km/h. Figures 5 shows the evolution of temperature, humidity, CO2 and CO.

$$FSI = \frac{|CO\,msr - CO\,nor|}{CO\,nor} + \frac{|CO2\,msr - CO2\,nor|}{CO2\,nor} + \frac{|T\,msr - T\,nor|}{T\,nor} + \frac{|H\,msr - H\,nor|}{H\,nor}$$

X msr: corresponds to the value measured. **X nor:** Corresponds to the normal value

The determination of a threshold to detect the presence of fire requires several parametric studies to determine the importance of each evolution. We plan to determine it in future works.

4.3 Step3: Acquisition of Data from Mobile Sensors

If the FSI is above a threshold for predicting the presence of a fire in a particular area of the forest, we plan to launch a drone to measure the values of these four sensors in more detail in a mobile manner. In addition the drone can board an infrared camera to have a map of the temperature. All these information received by the drone will be sent to the control tower to trigger all means for extinguishing the fire if necessary.

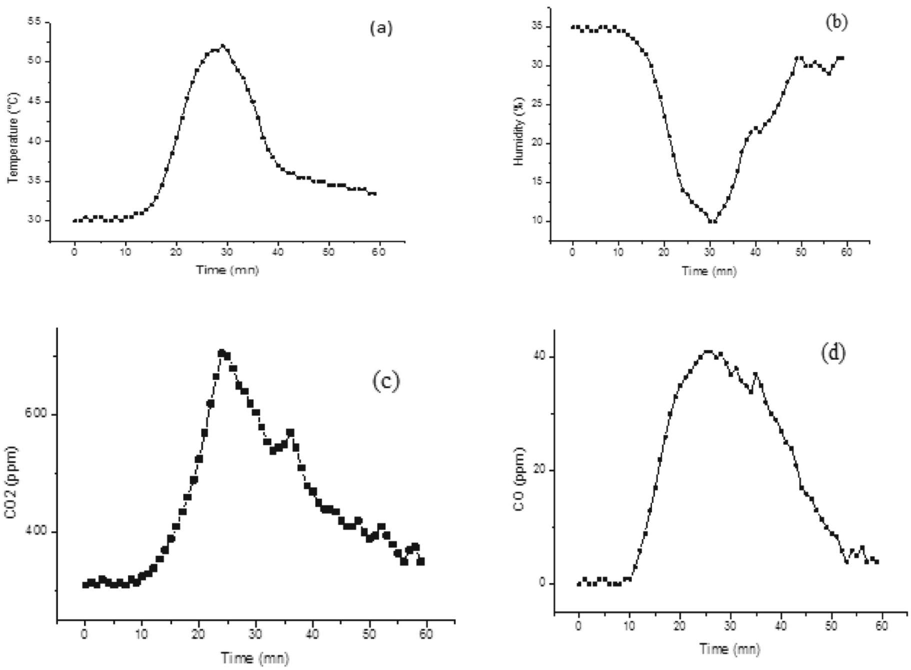

Fig. 5. The evolution of Temperature (a), humidity (b), CO (c) and CO2(d) according to time.

5 Conclusion and Future Works

This work describes a proposal system forest fire detection and prevention.

The objective of this work was to validate the use of wireless sensor networks in the framework of the problem of forest fires. The early detection of forest fires is and construction of a system that regards the low energy capacity of sensor nodes are the major goal. The deployment of Our framework goes through three main stages: calculation of the index FWI, acquisition of data from fixed sensors and acquisition of data from Mobile sensors.

The experimental part is a complementary element essential to our study.

The sensor node deployment scheme and cluster communication protocols the sensor node deployment scheme and ending with cluster communication protocols.

The quality and the security of the data collected, the calculation of the threshold of values of temperature, humidity, CO and CO2, deployment of a learning method, point that deserve to be completed in future work.

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