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Using Wireless Sensor Networks for Reliable Forest Fires Detection

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Abstract

The improvement of the level of modernization of forest fires monitoring using information and communication technologies has strategic significance for many countries where forest fires occur frequently. Compared with the traditional techniques of forest fires detection, wireless sensor networks (WSNs) technology is a very promising green technology for the future in detecting efficiently the forest fires. In this paper we propose a comparative study between two forest fires detection methods (Canadian and Korean) using a real experimental approach. The methodology adopted for this study is provided. The related hardware schemes and implemented algorithms are given in detail for both methods. Through the preliminaries results, we conclude the effectiveness of the Canadian approach in terms of energy consumption and execution speed, and its suitability to the context of our country.

Keywords: WSN; Forest fires detection; canadian Approach; Korean approch; experimental study;

1. Introduction

Forest fires are among the disasters that have multidimensional negative effects in social, economic and ecological matters. The probability of ignition of forests is in solid increase due to climate changes and human activities. Forest fires reduce the cover of tree and lead to an increase in the gas emissions of our planet, and approximately 20% of CO_2 emissions in the atmosphere are due to forest fires. Unfortunately, Algeria is one of the countries subjected to forest fires every year. Approximately 13

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million hectares of forest are destroyed each year in the world [1], in Algeria, more than 78 hectares ravaged by fire only in 2011 [02].

Faced with these horrific numbers, it becomes very urgent to review the classical forest fires detection methods for which a key problem is that when the fire becomes large it becomes very difficult to put out. In this case, a wireless sensor network (WSN) technology could be deployed to detect a forest fire in its early stages. A number of sensor nodes need to be pre-deployed in a forest. Each sensor node can gather different types of row data from sensors, such as temperature, humidity, pressure and position. All sensing data are sent wirelessly in ad-hoc fashion to a sink station, which in turn transmits data to the control center via a transport network such as GSM, UMTS, Satellite, TCP/IP networks. The networked system must be real time; otherwise it will be of no use.

Our aim in this paper is to propose a solution based on WSN to detect reliably forest fires by using two concurrent detection systems: Canadian system and South Korean (Korean for short) system. We will conduct a comparative study based on real experiments using a sensor Test-bed based on MICA-Z plate-form from Crossbow[TM] Company. Then we will adopt the suitable system of detection of forest fires among the above systems, which is well suited to the western region of our country in general and in particular on the forest of Oran city, especially during summer seasons (see Fig 1 and Fig 2).

The reminder of this paper is organized as follows. Section 2 presents related studies on forest fires detection with WSN. Section 3 presents detection methods commonly used in practice. Section 4 describes the adopted design methodology. Section 5 gives more details on the implemented detection algorithms. Section 6 presents our experimental results. Finally, Section 7 concludes the paper and provides a discussion on future work.

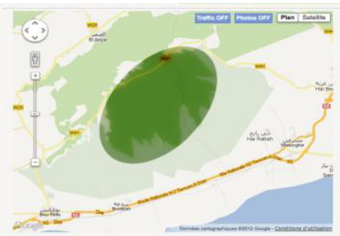


Fig 1. Area of Interest (forest m'sila ORAN - Algeria)

Fig 2. An image of the forest m'sila Oran- Algeria

2. Related Work

Traditionally, forest fires were detected using conventional techniques such as guard towers located to fire high points [5] and Osborne fire Finder [03] that is a tool consisting of a card topographic printed on a disc with edge graduated. Unfortunately these primary techniques are inefficient due to the unreliability of human observation towers and difficult life condition [21]. This has allowed some countries to use forest-fire detection systems based on the satellite imagery. MODIS (Moderate Resolution Imaging Spectroradiometer) used in CANADA [13] and AVHRR (Advanced Very High Resolution Radiometer) used in CHINA [22] are satellite-based monitoring systems. These approaches have proven to be limited by terrain, time of day, and weather conditions such as clouds, light reflections and smoke from legitimate industrial or social activities [5, 21].

Recently, the technology of wireless sensor networks (WSN) has emerged and has been adopted by several countries. This technology must consider important design goals and features such as: energy efficiency, early detection and accurate localization, forecast capability and adaptive to harsh environment [21]. Many research works from literature related to forest fires by using WSN have been conducted around the world [6, 9, 12, 15, 17, 18, 21]. Other interesting investigations have also been done in this area. Authors in [3] surveyed fire detection studies from three perspectives: residual areas, forest fires and contributions of WSN to early fire detection. South Korean project (FFSS) presented in [9] uses an experimental approach based on a networked motes but no evaluation has been made by authors on the proposed detection approach. In [19] authors have conducted simulation study under Castalia and Farsite fire simulators to detect and localize forest fires using WSN. A theoretical architecture of WSN based on Zigbee Technology has been proposed in [14] but neither simulations nor real experiments have been conducted. Research works presented in [5, 16] tried to early detect forest fires by means of cluster tree WSN using simulation and test-bed based approaches respectively. To enhance the conventional WSN detection approaches by reducing the number of false alarms, authors in [20] propose an image-based real time fire detection technique.

Unfortunately, most of these studies choose simulating their proposed solutions instead of doing experiments in real test-bed environments, since that kind of setup exposes additional difficulties. Even those using test-bed to carry out real experiments; they have not made a serious study on which detection methods could be very suitable to their context. In the context of the above studies, we propose a comparative study between two forest fires detection methods (Canadian and Korean) using a real test-bed based approach to choose the one that fits the context of our country.

3. Forest fires detection Methods

In this section we present the best-known detection systems of forest fires used in practice. We focus mainly on those chosen for the comparative study presented in this paper.

3.1 Canadian approach

The Canadian study [7, 8] proposed the calculation of the index fire according to FWI (*Fire Weather Index*). This eliminates the need to communicate all the sensor data to Sink, and only a few aggregated index are reported for reduce energy consumption.

FWI system comprises six standardized index (Fig 3). The three first shows daily variations of water content of three types of fuel forest with different speeds drying. The other three relate to fire behavior and are representative of the propagation speed, the quantity of burned fuel and intensity of the fire. The method is based solely on the determination noon daily weather: temperature, relative humidity, speed wind and rain during the last 24 hours (if there was). The month must also be specified. This method is primarily to solve a set of equations (Van Wagner and Pickett, 1985), which can be calculated with fast computer.

FFMC (table 1) and FWI (table 2) are explained in [4, 7, 8]

3.2 Korean approach

This approach is implemented on the system FFSS (Forest-fires Surveillance System) developed in [9]. 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 equation 1 as follows:

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

Where: EF is effective humidity (%), CS is solar radiation of the day (MJ/m²), P: rain (Mm).

Then, the software saves the received packets to database server and generates emergency alerts by the table 3.

Note that other systems for detecting forest fires can be found in practice such as National Fire Danger Rating System (NFDRS) and D-FLER (Distributed Fuzzy Logic Engine Rule-based WSNs) [3].

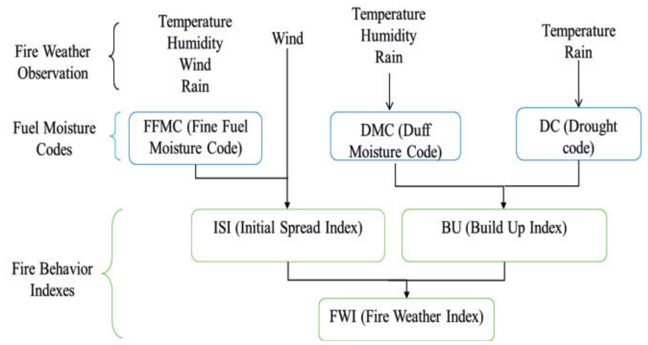


Fig 3: Structure of FWI system [4]

Table 1. Ignition Potential Based upon the FFMC [4]

Ignition potential	FFMC value range
Low	0-76
Moderate	77-84
High	85-88
Very high	89-91
Extreme	+92

Table 2. Potential Fire Danger Based on the FWI index [4]

FWI	Range	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

Table 3: Index danger of wildfire Korean

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

4. The adopted methodology

The Fig 4 shows the proposed approach of forest fires detection based on WSN. The methodology we adopted includes three major phases: data collection, communications through the network and analysis of collected data.

- *Data collection module*: This module make it possible to capture the various weather conditions necessary for the calculation of index (or formulas), this runs periodically until an event of detection of fire takes place.
- *Communication module*: It is used to route urgent data (alarms) generated by the data collection module to the analysis module within certain parameters of quality of service (QoS) such as reliability (the alarm must arrive at sink safely), temporal constraint (alarm must arrive within a reasonable time) and security (the routing path taken by the alarm must be secure against any attack or malicious behavior).
- *Analysis module*: After receiving the data in accordance with application of parameters of required QoS, the analysis module must examine the received alarms. Then, this information is processed by

the decision-making center that can judge if it is a false alarm by either using the data collected from other sensors nodes or dispatching a team to check the situation locally.

5. Detection algorithms

5.1 Canadian approach

The algorithm used to calculate the FWI index of this method is given as follows:

```
1. Canadian approach Algorithm
2. Begin
3. Write ('give the value of T and H and P V');
4. Read (temperature, 'T');
5. Read (humidity, 'H');
6. Read (rain, 'P');
7. Read (wind, 'V');
8. FFMC (T, H, P, V) // calculate Fine Fuel Moisture Code
9. ISI (FFMC, V) // calculate Initial Spread Index
10. DMC (T, H, P) // calculate Drought Moisture Code
11. DC (T, P) // calculate Drought Code
12. BUI (DMC, DC) // calculate Buildup Index
13. FWI (ISI, BUI) // calculate Fire Weather Index
14. if (FWI> = 0 and FWI <5) then
15. Write ('the danger level is low')
16. else
17. Whether (FWI > = 5 and FWI <10) then
18. Write ('the danger level is medium')
19. else 20. if (FWI > = 10 and FWI <20) then
21. write ('the danger level is high')
22. else
23. if (FWI > = 20 and FWI <30) then
24. write ('the danger level is very high')
25. else
26. if (FWI > = 30) then
27. write ('the danger level is extreme');
28. end if
29. end if
30. end if
31. end if
32. end if
33. end
```

Whereas data packet structure used by the algorithm includes the following fields:

Board_id (8)	Packet_id (8)	Node_id (8)	Rsvd (8)	Humidity (8)	Temperature (8)	FFMC (8)	DMC (8)	DC (8)	FWI (8)

Where: Board_id: identifier of the used sensor board (MTS400 in our case), Packet_id: the identifier of the package, Node_id: the identifier of sensor node (TOS_LOCAL_ADRESS), RSVD: Reserved field, FFMC, DMC, DC: intermediate indices calculated by the values of humidity, temperature, rain and wind speed, FWI: final index of this method.

5.2 Korean approach

The index of the Korean method is calculated by capturing of the humidity, light and rain, Equation (1) shows the calculation of this index. The algorithm implementing this approach is given as follow:

```
1. Korean approach Algorithm
2. Begin
3. Write ('give the value of H and P and CS');
4. Read (humidity, 'H');
5. Read (rain,'P');
6. Read (solar radiation, 'CS');
7. Y(H,P,CS) //calculate the Korean index
8. if (Y> = 10 and Y <=12) then
9. Write ('the danger level is extreme')
10. else
11. if (Y == 13 or Y ==14) then
12. Write ('the danger level is high')
13. else
14. write ('the danger level is low');
15. end if
16. end if
17. end
```

The data packet structure in this case is defined by the following fields:

Board_id (8)	Packet_id (8)	Node_id (8)	Rsvd (8)	Humidity (8)	CS (8)	Y (8)

Note that, the absence of rain and wind speed fields in the above packets is due to the technological limit of used motes which do not include these corresponding sensors. For this, we have let value 0 for rain field due to the lack of rain during the summer, and value 13 (average value of the wind speed in the summer) for wind speed field. Also, to compute FWI we must also specify the month concerned by the calculations.

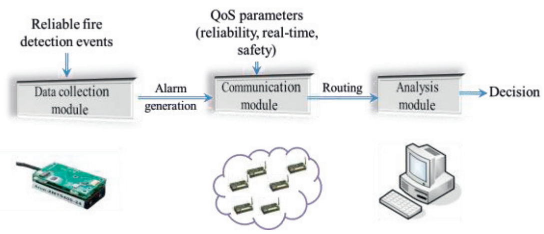


Fig 4: Block diagram of the proposed approach

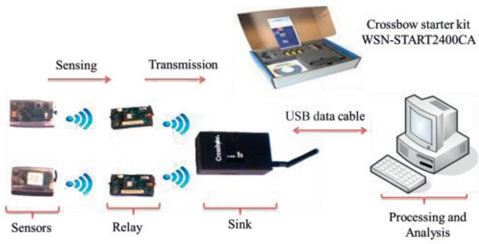


Fig 5: The used test-bed produced by Crossbow [10]

6. Experimental results

6.1 Hardware platform

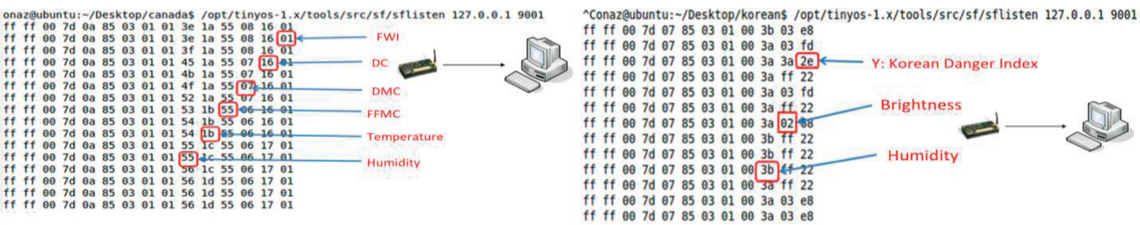
Fig 5 presents the test-bed used in this study. It includes four battery powered motes MICA-Z and one gateway MIB520. Each mote is an assembly of MTS400 sensor-board and MPR2600 board which contains mainly a microcontroller, memory and communication module with 433 Mhz frequency or IEEE 802.15.4 Zigbee model at 2,4 Ghz ISM band. Each onboard sensor measures different data such as temperature, light, acceleration, humidity, and pressure. The mote can be configured to capture, process and communicating by radio simultaneously. The gateway MIB520 is connected trough USB cable to user Computer to serve as programming interfaces of MICA platforms. All motes communicate with each other wirelessly.

6.2 Software tools

Several software tools under Windows or Linux platforms are used in the experiments [10]: MoteView tool which provides real-time information about the experienced WSN topology. MoteConfig is a tool which serves to upload the executable program in the motes. Notepad programmer's2 is the text editor combined with the ncc compiler for TinyOS. XSniffer tool allows users to monitor multi-hop communications in Xmesh. And finally, Avrora simulator [11] used to carry out some experimental measures such as energy consumed and CPU time. The previous algorithms of detection have been implemented using Nes-C programming language.

6.3 Results analysis

The results obtained in this phase are grouped into two categories. The first category is the direct manipulation of results obtained by programmed sensors with the two methods. The simulator Avrora generates second category of results.



(a) (b)

Fig. 6. Screen-shots of raw sensed data by sensors using (a) Canadian method, (b) Korean method

The results obtained in the field confirm the adaptation of Canadian detection system to local climate. The precision of the Korean method is less compared to the Canadian one, because all results obtained in the Canadian method by capturing temperature / humidity show a precise output value (FFMC, DC, DMC, FWI) in Fig 6 (a). In contrary, the values captured by Korean method (Fig 6 (b)), especially brightness, are disrupted under same conditions, causing disturbance output values for (y) (5 correct values from a total of 11 values) with a precision of 45.45%. Calculations of the energy and time CPU made by Avrora have generated Fig 7 and Fig 8.

According to Fig 8, the Korean approach consumes more CPU time than the Canadian one, but the source code of the latter contains much instructions than of the Korean (229 lines of code for Canadian and 171 for Korean). In Table 4, the difference of 377 cycles (0.000051 second) between the two systems makes the Korean system better in terms of reduced consumption time to send packets. The delay for the Canadian system is due to the number of fields (7 fields for Korean and 10 for Canadian), so Canadian system is better in this case. Finally, the Fig 7 shows clearly that the Korean system is high energy consuming compared to the other. So the Canadian system is better in terms of energy consumption.

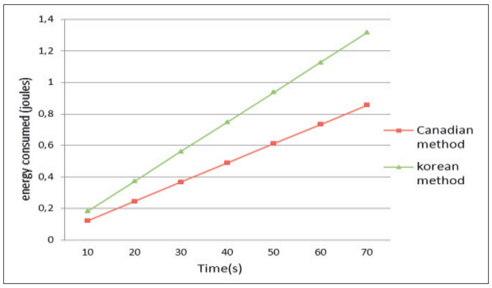


Fig. 7. Energy consumption by the two systems

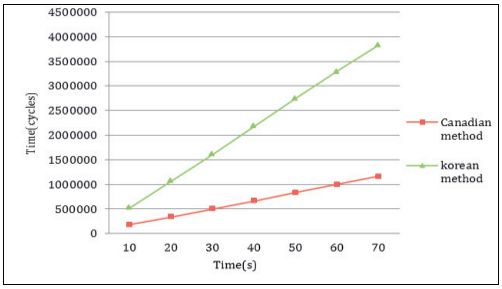


Fig. 8. Time spent by the CPU

Table 4. Comparison between the response times by the two systems

Time (s)	Canadian method	Korean method
10	73711814	73711437
20	147439814	147439437
30	221167814	221167437
40	294895814	294895437
50	368623814	368623437
60	442351814	442351437
70	516079814	516079437

7. Conclusion and future work

This study firstly reveals that WSN technology is a very promising green technology for the future in detecting efficiently the forest fires in our country. Secondly, and through the real experiments performed in the field, we conclude the effectiveness of the Canadian approach in terms of energy efficiency and algorithmic complexity compared to the Korean one, and its suitability to the context of our country mainly during summer seasons.

The more data recovered by WSN about forest fires means the more effective fire management by forest authorities. Hence, introducing the paradigm of multi-modal detection of Forest fires seams to be a good solution for the future in which scalar data and multi-media data can be collected by heterogonous sensors. Such WSN based multi-modal detection systems can resolve efficiently some outstanding problems such as more precision of detection and reducing false alarms rate [20]. Another challenging trend to be explored is the avoidance of the destruction of motes by the fire [15] or the design of adaptive routing schemes to guaranty the continuous transmission of accurate environmental data in presence of burned motes.

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