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Smart WSN-based System for Forest Fire Detection with Reduced False Alarms

Ferdaous Abdessemed[1], Souheila Bouam[2], Chafik Arar[3]

[1,2,3] LAMIE laboratory, Computer science department, University of Batna2, 05000, Algeria

E-mail: [1]ferdous.abdessemed@univ-batna2.dz, [2]s.bouam@univ-batna2.dz, [3]chafik.arar@univ-batna2.dz

Abstract

Every year, huge areas of forests are destroyed by fires, which have a particularly significant effect on forests and nature. To help combat fires, previous monitoring and detection methods rely heavily on human observation, which is not very effective due to the large areas of forest that need to be monitored. To increase efficiency, it is necessary to implement automatic fire detection systems that can quickly detect fires and enable rapid firefighting responses. Recent advances in sensor technology have made it possible to develop more accurate and automated forest fire detection systems. This research discusses a Wireless Sensor Network-based system that could be used for early fire detection. The proposed system has the capability to lower false alarms by 10% compared to the existing systems that solely rely on temperature and smoke sensors for detecting fires.

Keywords: Wireless sensor networks, False alarms, Fire detection, Real-Time system.

1. Introduction

Forest fires are natural events that occur in various regions of the world whether from natural causes like lightning or from human activities, such as careless disposal of cigarettes or intentional burning of debris [1]. With global warming, the number and intensity of these fires are expected to increase. This can lead to the destruction of assets, property, and other public areas, as well as put civilian lives in danger. To fight against forest fires, new technologies are being developed. These technologies help in generating real-time data about wildfires and in detecting them easier. Forest fire detection using Wireless Sensor Networks (WSN) is a method for detecting and monitoring wildfires in remote areas using a network of wireless sensors. This approach leverages the power of wireless communication technology to enable the sensors

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to transmit real-time information about environmental conditions such as temperature, humidity, and smoke concentration to a central base station.

In addition to its real-time monitoring capabilities, forest fire detection using WSN has several advantages over traditional fire detection methods. WSN can also provide information about the intensity and direction of the fire [2], which is useful for firefighters to plan their actions. Taking advantage of WSNs, a preliminary fire detection system has been suggested for early detection, which is crucial for preventing the spread of fire, as extinguishing fires that have spread can be very challenging. The proposed system detects the presence of carbon dioxide and high temperature, which are the two primary fire indicators. Additionally, the system is enhanced by incorporating a Light Dependent Resistor (LDR) to improve accuracy and reduce the number of false alarms.

2. Related Works

One of the most important tasks in managing a forest is detecting and preventing fires from spreading to larger areas and causing serious damage. There are many ways to detect fires, and each has its advantages and disadvantages. Human spotters are the traditional method of detecting fires but are often inaccurate and difficult to use in remote areas. As an alternative to monitor, detect, and forecast forest fires autonomously, new techniques such as satellite systems, cameras, Unmanned Aerial Vehicles (UAVs), and WSNs have been proposed. The authors of [3] used satellite data to detect fires. The study aimed to evaluate existing remote-sensing data to gain a more comprehensive understanding of the geographical and temporal spread of fires.

Analogously, the authors of [4] used satellites for fire monitoring to observe fires in real-time and offer prompt fire statistics throughout Canada. When the cloud cover is limited, the algorithm can detect a significant number of actual fires. The challenges associated with using satellites are, their long scanning cycle, low image resolution, and inability to detect fires during unfavorable weather conditions. Other researchers have used cameras instead of satellites to detect and monitor forest fires.

A method for infrared forest fire detection that reduces false alarms was presented in [5] through a segmentation process, an adaptive infrared threshold, and a neural network model. On the other hand, the authors of [6] used IR video to tackle optical cameras' inability to detect low-brightness fires in the visible range. Several researchers also recognized the use of UAVs as an effective tool in detecting and monitoring forest fires, playing a significant role in this process. UAVs and aerial imagery were used in [7] for a forest fire detection system. This technology is useful because of its quick response time, low cost, and promotes personnel safety. The system employed a camera that was installed on the UAV to capture pictures from the environment and analyze them to check for fire. However, UAVs are unable to provide a continuous monitoring system; therefore, they are unable to identify fires in their early stage.

Meanwhile, WSNs have gained widespread use in recent years and have proven to be effective through their ability to provide real-time monitoring, cost-effectiveness, scalability, robustness, and low power consumption. Ahmed Imteaj et al., [8] have created a system for detecting fires in factories using a Raspberry-PI3 device, temperature sensors, flame sensors, and smoke sensors. The system can put out fire within 20 seconds. To do this, it utilizes the already installed air-conditioning system. Abhinav Kumar et al., [9] also proposed a system to detect forest fires by monitoring the levels of Carbon dioxide and temperature. A fire detector was created using a Raspberry Pi, a temperature sensor, a smoke sensor, and a buzzer. The fire detector works by responding to smoke produced by the fire. With the help of the Internet of Things (IoT) technology, the entire monitoring process was connected to a “Fire Security System” webpage which was created using PHP tools and Arduino programming.

Authors of [10] proposed a device that can detect the poaching of animals and trees as well as prevent forest fires. This device had sensors to alert officials in the case of a forest fire, and a Wi-Fi module for real-time data. This device was compact, easy to install and maintain, and cost-effective compared to separate devices for detecting each attribute. It was also mentioned that the device could be powered by solar energy in the future, which would give an alternative energy source.

3. Proposed Work

This proposed work aims to provide a more detailed explanation of how false alarms are effectively reduced in the system. The use of the LDR can prevent false alarms resulting from the rise of temperature due to sunlight exposure on the node. Being in direct sunlight can result in a perceived increase in temperature due to the sun's radiant energy. This direct exposure can make the air feel as much as 10-15 degrees warmer than the actual air temperature measured in the shade [11]. The integration of the LDR sensor with the temperature and smoke sensors, enabling comprehensive analysis of the collected environmental data using a

Microcontroller Unit (MCU) is further elaborated. This integration allows for a thorough evaluation of sensor inputs, leading to a reduction in false alarms by accurately differentiating between fire risks and instances where temperature increases are solely due to sunlight exposure.

In order to ensure the accuracy of alarms and minimize unnecessary interventions, the proposed system adopts a dual-threshold approach. Two thresholds employed: one based on temperature measured in the shade, and the other specific to direct exposure to sunlight, are elaborated. This study provides a detailed explanation of how these thresholds are determined, taking into account the unique environmental conditions and potential variations caused by sunlight. To enhance the decision-making process of the system, the employed algorithm to analyze the combined sensor data, including temperature, smoke, and sunlight exposure, is described. By leveraging these insights, the system effectively determines when an alarm should be triggered, resulting in reduced false alarms and improved reliability.

3.1 Structural Design

A WSN consists of several components working together. The main component is the sensor node, which senses the changing parameters in the environment and sends the information to a base station. The node consists of a transceiver, a microcontroller, sensors, and a power source. The sensors collect the data while the microcontroller takes this data, processes it, and sends it through the transceiver to the base station, while the power source provides the power, which makes all this possible. It is crucial to construct an energy efficient WSN since sensor nodes are often passively powered with limited energy and poor computational capacity. The base station otherwise called as “sink”, is a key part of wireless sensor networks. It is responsible for receiving information from the node and delivering it to the end user. It acts as a bridge between the sensor node and the user. The base station unit is made up of a few components such as a transceiver (helps in communication), a microcontroller (helps in making decisions based on the data collected), and a battery (powers the microcontroller and transceiver).

Developing an optimal WSN is a challenging undertaking; however, network topology control is an effective solution to address this issue. In general, topology control refers to an underlying technology for network topology conversion, with the objective of enhancing system performance or minimizing routing costs [6]. A popular and efficient network topology scheme among topology control technologies is clustering. Additionally, the clustering-based routing algorithm helps sensor nodes conserve energy, extending the network lifetime [12]. Figure 1 illustrates a simple clustering topology structure. Each cluster contains many Cluster Member (CM) nodes and one Cluster Head (CH) node. The CM is used to gather data, and it is fitted with a microcontroller of low processing capacity. In this research, CM does some basic processing, collects fire monitoring parameters such as temperature and smoke and compares the collected data with the given thresholds, then communicates the result to the CH. The CH then processes the data, determines if a fire has been detected or there is a risk of fire, and forwards it to the base station through direct connection or multi-hop transmission.

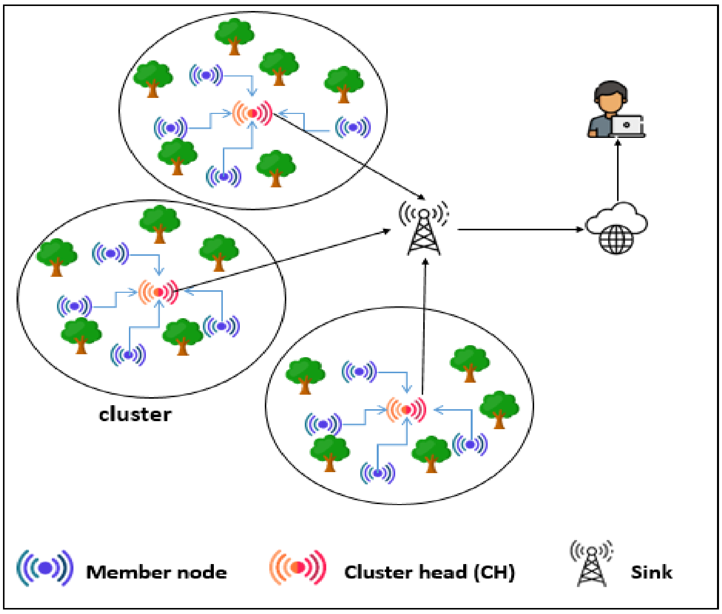

Figure 1. Structure of the Proposed Forest Fire Detection System

3.2 Hardware and Software Specification

The proposed system incorporates a range of hardware components that synergistically contribute to designing an effective fire detection and prevention component. The table below provides a concise overview of the key hardware requirements for the system.

Table 1. Hardware Specifications

Component	**Description**
Temperature Sensor	Measures ambient temperature
Smoke Sensor	Detects the presence of smoke or fire
Light Dependent Resistor (LDR) Sensor	Detects sunlight exposure
Microcontroller Unit (MCU)	Analyzes sensor data and controls system operations
LCD	Provides real-time status and alerts
Zigbee Module	Enables wireless communication between nodes

These hardware components play vital roles in achieving accurate fire detection and prevention. The temperature sensor monitors ambient temperature, while the smoke sensor swiftly identifies the presence of smoke or fire. To address false alarms caused by sunlight exposure, the LDR sensor detects and accounts for direct sunlight. The MCU processes sensor data, controlling system operations based on predefined algorithms. The LCD provides real-time status updates and alerts to ensure prompt user notification. The Zigbee module enables seamless wireless communication between system nodes, facilitating efficient data transmission. Lastly, a reliable power supply ensures the uninterrupted operation of the entire system.

To validate the functionality and performance of the proposed hardware design, the Proteus simulator is utilized. Proteus provides a realistic simulation environment, enabling to integrate and test the hardware components virtually. This allows to evaluate the system's functionality, analyze sensor data, and assess the effectiveness of wireless communication using the Zigbee module. The use of the Proteus simulator enhances the understanding of the proposed hardware system and facilitates comprehensive testing before physical implementation.

By combining these hardware components and leveraging the Proteus simulator, the proposed system offers enhanced fire detection capabilities, reduced false alarms, and improved overall performance.

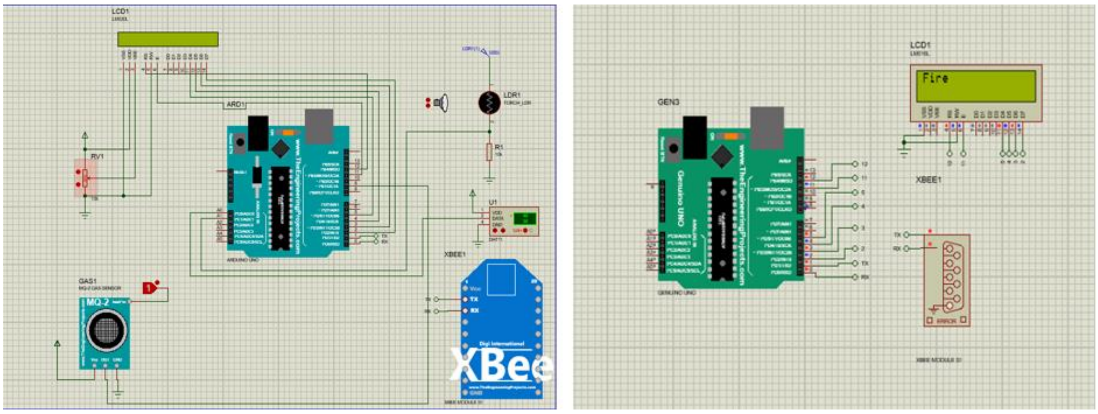

Figure 2. Simulation of Fire Detection System

3.3 Fire Detection System

In this research, a WSN node that would be used to detect and respond to a fire is proposed. The WSN node includes several different types of sensors such as smoke, temperature, and light sensors. When smoke is detected, an alert is directly sent to the base station. According to [13], smoke sensors more likely detect fires before it really starts compared to heat detectors, which are slower in response because the temperature rises slowly. When a temperature sensor detects a high temperature, it is first confirmed if this detected temperature is caused by direct exposure to sunlight or not using LDR, in order to reduce false alarms. To properly address this situation, it is necessary to be aware of two threshold values. The initial threshold pertains to the temperature without any exposure to sunlight, which is referred as "TH". The second threshold is when the sensor is directly exposed to sunlight, which is referred as "STH". The following diagram represents the algorithm of the proposed forest fire detection system.

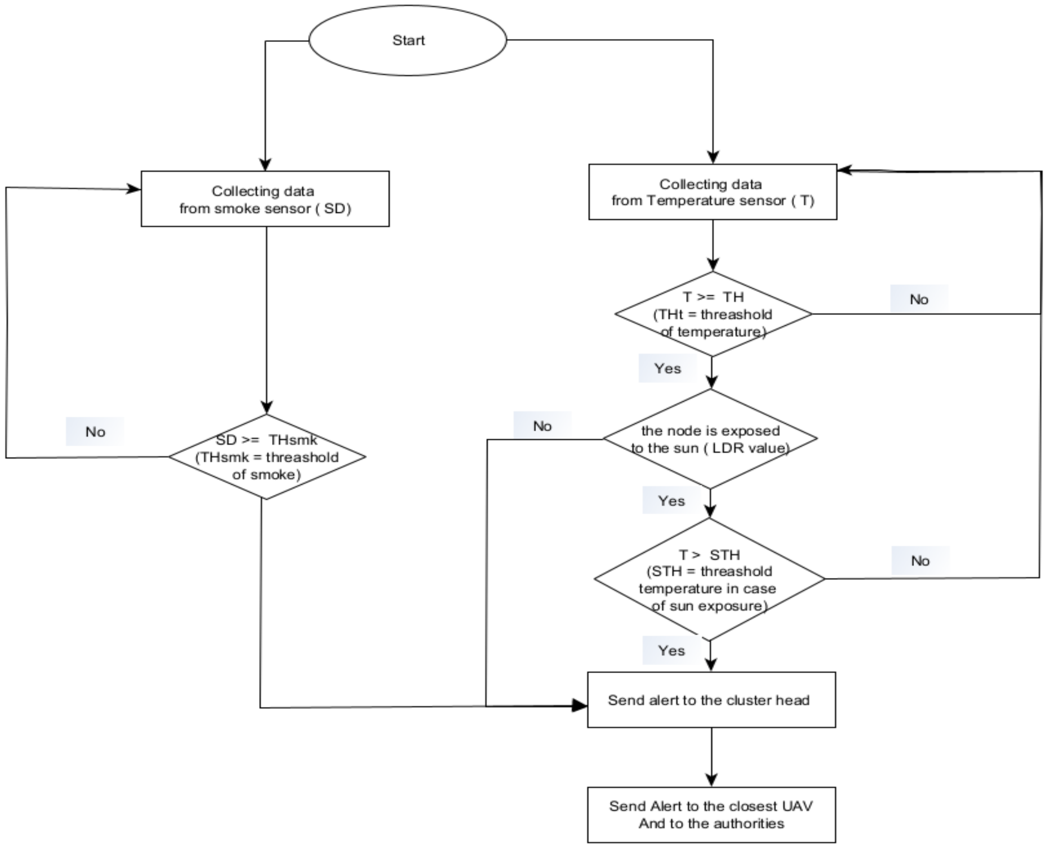

Figure 3. Proposed Flow Chart

- If smoke is detected, an alert is directly sent to the cluster head.
- When a high temperature is detected by a temperature sensor, the LDR verifies if the node is in a sunlight area or not. If the node is directly exposed to the sunlight, it compares the detected temperature with “STH”.
    - If the detected temperature is low than ‘STH’, then, no alert is sent to the CH.
    - If the detected temperature is high than ‘STH’, then the node sends an alert to the CH.
- If the temperature is higher than the threshold under no sunlight, an alert is sent to the CH.
- If the CH receives an alert at a time 't', it will wait until 't+1' and then compare the temperature reading from the next alert of the same node.

- If the temperature has increased, it will send an alert to both the base stations to monitor the area, and to the nearest Unmanned Aerial Vehicle (UAV) to confirm the presence of fire.
- The cluster head sends an alert to the UAV with the location of the fire sensor detection. The UAV is equipped with bomb extinguishers and a camera. Once the UAV verifies the existence of fire using the camera, it drops a bomb in that area to put out the flames and prevent them from spreading.

Numerous researchers who utilize clustering, send the collected data to the cluster head periodically to compare the values against certain thresholds and determine whether there is a fire. But depending on the authors of [14], the consumed energy during communication is the major contributor to the total energy expenditure, which can result in significant energy consumption even when such transmissions are unnecessary. By processing the collected data locally at each node instead of sending it to the cluster head, substantial energy savings may be achieved. To accomplish this, the proposed system only sends an alert to the cluster head when the processed data on the node indicates the presence of fire.

4. Result and Discussion

This section can be highlighted that the inclusion of the LDR sensor in the second system allows for more comprehensive comparisons in making decisions, resulting in a reduction in false alarms. By incorporating the LDR sensor, the system considers not only the temperature but also the presence of sunlight exposure, ensuring that high temperatures caused by sunlight do not trigger false fire alarms. The following tables illustrate the decisions made by the two systems:

Table 2. System 1 (smoke and temperature sensors only)

Smoke	**Temperature**	**Decision**
Yes	High	Fire
No	High	Fire
Yes	Low	Fire
No	Low	No fire

Table 3. System 2 (the proposed system that includes smoke, temperature, and LDR sensors)

Smoke	**Temperature threshold 1**	**LDR**	**Temperature threshold 2**	**Decision**
Yes	Low	Yes	Low	Fire
Yes	Low	No	Low	Fire
Yes	High	No	Low	Fire
Yes	High	No	High	Fire
Yes	High	Yes	Low	Fire
Yes	High	Yes	High	Fire
No	High	No	Low	Fire
No	High	No	High	Fire
No	High	Yes	Low	No fire

No	High	Yes	High	Fire
No	Low	No	Low	No fire
No	Low	Yes	Low	No fire

By comparing the tables, it is evident that System 2, which utilizes the LDR sensor and the second temperature threshold, makes more accurate decisions in distinguishing between actual fire incidents and situations where high-temperature readings are caused by sunlight exposure. This additional comparison mechanism significantly reduces false alarms, enhancing the reliability and effectiveness of the system in fire detection.

To evaluate the proposed fire detection systems, the confusion matrix and performance metrics are used to assess their performance and highlight the differences between them. The confusion matrix provides a comprehensive overview of the systems' classification results, including True Positives (TP), True Negatives (TN), False Positives (FP), and False Negatives (FN). By comparing these matrices, how well each system detects fires and reduces false alarms can be analyzed.

Additionally, performance metrics such as accuracy, precision, recall, and specificity are computed to further evaluate the systems. These metrics measure the systems' overall correctness, ability to detect fires accurately, and ability to identify non-fire events correctly. By employing these evaluation measures, the performance of the systems can be objectively compared and the impact of incorporating the LDR sensor and second temperature threshold can be determined. The use of the confusion matrix and performance metrics is essential in demonstrating the significance of the proposed enhancements and illustrating the differentiation between the two systems. This evaluation framework provides objective and quantitative insights into the systems' effectiveness and reliability in fire detection and false alarm reduction. Table 4 provides a comparison of the two methods in terms of TP, TN, FP, FN, accuracy, precision, recall, and f-score, while Figure 4 and Figure 5 display the resulting confusion matrix.

Table 4. Performance Evaluation of Fire Detection Systems

Method	TP	TN	FP	FN	Precision	Recall	F-score	Accuracy
Systems 1	8	2	1	0	0.88	1.00	0.93	0.90
System 2 (proposed)	8	3	0	0	1.00	1.00	1.00	1.00

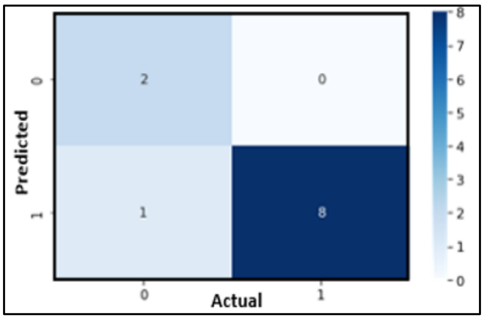

Figure 4. Confusion Matrix of System 1

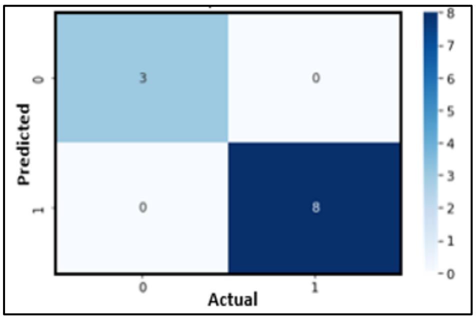

Figure 5. Confusion Matrix of System 2 (proposed)

By referring to Table 4, it can be observed that the proposed method attains an F-Score, precision, and accuracy of 1.00, which are 0.07, 0.12, and 0.1 higher, respectively, than the existing method. Consequently, the proposed method is more precise in detecting fires and reduces false alarms by 10% compared to the previous method used in [15], [16], [17], and [18].

In order to improve the effectiveness of the system, various scenarios to compare the performance of the two systems were explored. The first system utilizes a single temperature threshold set at 35°C. This system solely relies on the temperature measurement to determine if a fire event has occurred. Conversely, the second system incorporates an additional level of sophistication. It considers the first temperature threshold of 35°C but also take into account the presence of sunlight exposure. In scenarios where sunlight exposure is detected, the second system applies a second temperature threshold of 45°C to verify if the recorded temperature is attributed to the intense heat caused by sunlight rather than an actual fire. This approach aims to minimize false alarms triggered by sunlight-induced temperature fluctuations. By comparing the decisions made by the two systems across different scenarios, the efficacy of incorporating the second threshold and sunlight exposure analysis in reducing false alarms and enhancing the accuracy of fire detection, can be assessed.

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Table 5. Assessing the Effectiveness of Two Fire Detection Systems in Various Scenario Settings

Scenario	**Smoke**	**Temperature**	**Sunlight Exposure**	**System 1 Decision**	**System 2 (proposed) Decision**
Scenario 1	Yes	High (40°C)	Yes	Fire	Fire
Scenario 2	No	Low	No	No Fire	No Fire
Scenario 3	No	High (45°C)	Yes	Fire	No Fire
Scenario 4	Yes	Low	No	Fire	Fire
Scenario 5	No	High (36°C)	Yes	Fire	No Fire
Scenario 6	Yes	Low	Yes	Fire	Fire
Scenario 7	No	Low	Yes	No Fire	No Fire
Scenario 8	Yes	High (35°C)	No	Fire	Fire
Scenario 9	No	High (35°C)	Yes	Fire	No Fire
Scenario 10	No	Low	Yes	No Fire	No Fire
Scenario 11	No	High (38°C)	Yes	Fire	No Fire

These additional scenarios highlight the decision differences between the two systems when considering the second threshold and sunlight exposure in System 2. The table 5 helps to showcase the impact of incorporating the LDR sensor and the second threshold in reducing false alarms and improving the accuracy of fire detection, demonstrating the effectiveness of the second system compared to the first system as shown in Figure 6.

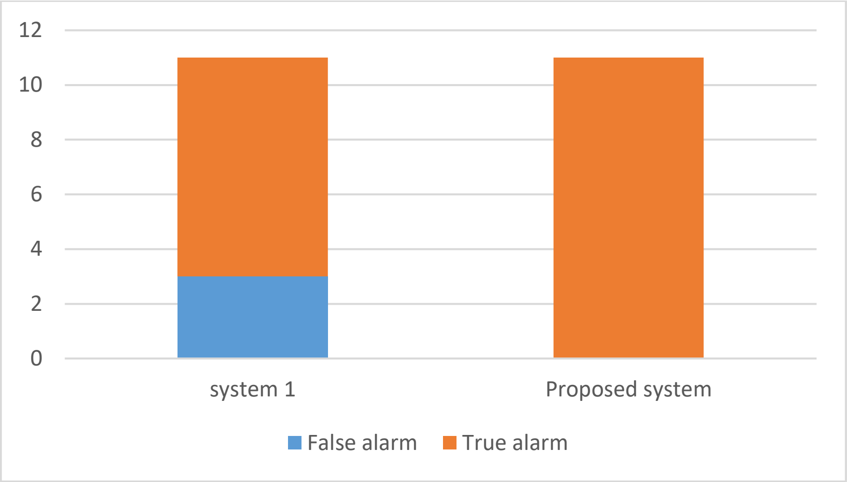

Figure 6. Evaluating the Performance of True and False Alarms

This suggested system utilizes the concept of identifying fires by analyzing the environmental factors in the surrounding area. The system is distinct from other systems due to the unique algorithm that not only detects fires but also reduces false alarms, which can lead to wasted time and financial costs.

5. Conclusion

The best way to prevent severe losses and environmental and social damages from a fire outbreak is through early warning and prompt response. Thus, the essential goals of fire monitoring are to detect and control the fire quickly and accurately. This research presents a system designed for detecting and preventing forest fires. The main goal of the study is to detect forest fires using WSN technology and confirm its suitability in addressing the issue of forest fires. To increase the precision of the system, an additional component has been proposed, which confirms the existence of fire before alerting the authorities. This enhancement has resulted in a more accurate and reliable system, with a reduced rate of false alarms. Another aspect intended to be addressed in the future is the delay in transmitting the alert. The future endeavors will aim to reduce this delay and ensure that authorities will be promptly alerted about forest fires, since it is a crucial aspect that requires real-time attention.

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Author's Biography

Ferdaous Abdessemed is currently pursuing her Ph.D. in the computer science department at Batna 2 University in Algeria. In 2018, she completed her master's degree in computer science at the same university. Her research focuses on areas such as Wireless Networks and Real-Time Communication Systems. She is actively involved as a member of the LAMIE Laboratory.

Dr.Souheila Bouam is a lecturer in the Computer Science Department at the University of Batna-2. She holds a Ph.D. in Computer Science with a specialization in Wireless Networks at Versailles St Quentin University (France). Her research focuses on sensor networks, particularly in the context of Smart farming. She has teaching experience at universities in France and has obtained her University Habilitation. Dr. Bouam's work aims to meet the needs of sensor-based applications through energy-saving techniques and intelligent remote monitoring.

Dr.Chafik Arar holds a position as a lecturer in the Computer Science Department at the University of Batna-2. He completed his Engineering diploma in Computer Science at the Institute of Computer Science in Batna and further pursued his studies at Batna 2 University, where he successfully obtained a Ph.D. in Computer Science. In 2018, he achieved his University Habilitation, and his research efforts are primarily directed toward Networks, Real-Time Communication Systems, Embedded Systems, and Fault Tolerance.