Forest Fire Detection System based on Low-Cost Wireless Sensor Network and Internet of Things

ALI AL-DAHOUD
Department of Computer Science,
Al Zaytoonah University of Jordan,
Airport St, Amman,
JORDAN

MOHAMED FEZARI
Department of Computer Science,
Badji Mokhtar Annaba University,
ALGERIA

AHMAD AA ALKHATIB
Department of Cyber Security,
Al Zaytoonah University of Jordan,
Airport St, Amman,
JORDAN

MOHAMED NADIR SOLTANI
Department of Computer Science,
Badji Mokhtar Annaba University,
ALGERIA

AHMED AL-DAHOUD
Faculty of Architecture and Design, Department of Multimedia,
Al Zaytoonah University of Jordan,
Airport St, Amman,
JORDAN

Abstract: - Forest fires are one of the most devastating natural disasters that can have a significant impact on the environment, economy, and human lives. Early detection and prompt response are crucial to minimize the damage caused by forest fires. In recent years, Wireless Sensor Networks (WSN) and Internet of Things (IoT) technologies have emerged as promising solutions for forest fire detection due to their low-cost and efficient monitoring capabilities. This paper proposes a low-cost forest fire detection system based on WSN and IoT. The system uses a network of sensor nodes that are strategically placed in the forest to monitor environmental conditions such as temperature, humidity, and smoke. The sensor data is transmitted to a central server, where advanced algorithms are used to detect and predict the occurrence of forest fires. The system provides real-time alerts to forest authorities and users using a mobile application that shows the fire maps and the current updates. The proposed system has been evaluated using based on experiments, and the results show that it can effectively detect forest fires with high accuracy, low false alarms, and low cost. This system has the potential to provide an efficient and cost-effective solution for forest fire detection and can play a vital role in protecting the environment and saving lives.

Key-Words: - Wireless Sensor Networks, Sensors, Internet of Things, Forest Fire Detection

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1 Introduction

Throughout 2021 and the summer of 2022, the planet experienced a significant number of destructive forest fires that spread across various regions and inflicted massive harm and damage to the environment. These fires caused the intrusion of thousands of miles and emitted greenhouse gases. Forest fires in July 2021, for instance, resulted in the release of 350 million tons of CO2, marking the highest level on record, while Siberia's hundreds of forests also discharged record amounts of CO2. In the same vein, Algeria suffered a series of fires in the north of the country in July and August 2021, causing substantial destruction. These forest fires destroyed over 89,000 hectares of land in 35 wilayas of the country, including areas like Tizi Ouzou, Bejaia, Bouira, Setif, Blida, Médéa, El-Tarf, Khenchela, Guelma, Tébessa, Tiaret, and Skikda, where local authorities and the Ministry of Defense recorded a total of 1,186 fires that claimed at least 90 lives, including 33 soldiers. The fires also ravaged the agro-pastoral sector, wiping out vegetation cover and animal resources. The extent of the damage caused by the fires fluctuates from year to year, with the yearly losses relating to the commercial value of wood and cork estimated at between 1 and 1.5 billion DA, according to the Ministry of Agriculture, [1].

Satellite monitoring systems are utilized for identifying forest fires, but they are only capable of detecting fires when they have already spread over a vast region. As a result, these methods are not very effective, and approximately 80% of losses occur due to the delayed detection of fires, as per a survey. To tackle this issue, wireless sensor networks (WSN) and Internet of Things (IoT) technologies are being employed, [2], [3].

In an IoT-based system for detecting forest fires, diverse sensors are deployed across the forest area. Each node tracks the surrounding area of the forest and gathers details such as temperature, humidity, and gas levels. The collected data is then transmitted to centralized cluster heads, and this process continues until the information reaches the router. Each cluster head supervises its designated region and acts as a go-between for exchanging data between neighbors and the router. The router collects all the data gathered within the Rural Community Security Framework (RCSF) and transfers it to the receiver or base station through the cloud, [4].

The work aims to propose a low-cost forest fire detection system using Wireless Sensor Networks (WSN) and Internet of Things (IoT) technologies. The system utilizes a network of strategically placed sensor nodes in the forest to monitor environmental conditions and detect the occurrence of forest fires. The data is transmitted to a central server, where advanced algorithms are used to predict and detect forest fires. The proposed system aims to provide real-time alerts to forest authorities and users using a mobile application that shows fire maps and current updates.

2 Literature Review

In recent years, there has been an increasing interest in the development of low-cost and efficient forest fire detection systems using Wireless Sensor Networks (WSN) and Internet of Things (IoT) technologies. The primary goal of these systems is to detect forest fires early and prevent them from causing significant damage to the environment, economy, and human lives, [5].

One of the significant advantages of WSN-based forest fire detection systems is their ability to monitor environmental conditions such as temperature, humidity, and smoke levels in real-time. This allows for the early detection of potential forest fires, enabling authorities to take immediate action to prevent them from spreading. Several studies have proposed WSN-based forest fire detection systems that utilize various environmental sensors to detect changes in temperature, humidity, and smoke levels, [6].

For instance, [7], proposed a forest fire detection system based on a wireless sensor network that utilizes temperature, humidity, and smoke sensors to detect and locate forest fires accurately. The system employs a novel algorithm that combines wavelet packet decomposition and principal component analysis to detect the fire signals accurately, [7].

In addition to WSN, IoT technologies have also been proposed for forest fire detection systems. The integration of IoT devices and cloud computing platforms can provide a powerful solution for forest fire detection and management. For example, [8] proposed an IoT-based forest fire detection system that utilizes environmental sensors and a cloud computing platform to detect and track forest fires in real-time. The system employs an image recognition algorithm that can detect the presence of smoke and fire in real-time images captured by cameras installed in the forest. [8].

The literature review by [9], provides a comprehensive overview of various forest fire detection techniques, including visual detection, infrared detection, and acoustic detection. The review also discusses wireless sensor networks

(WSNs) and their potential for forest fire detection, [9].

In [10], the author proposes a smart and low-cost technique for forest fire detection using WSNs. The proposed technique uses temperature, humidity, and light sensors to detect fire and send an alert to a base station, [10].

In another paper, [11], the author proposes a WSN-based forest fire detection and decision-making system. The system consists of a sensor network that collects data and sends it to a decision-making module, which uses fuzzy logic to analyze the data and decide whether a fire has occurred, [11].

In [12], the authors present a smart system for forest fire detection using a WSN. The proposed system uses temperature and smoke sensors to detect fires and send alerts to a control centre, [12].

In the book chapter. [13], the authors discuss forest fire monitoring and the role of WSNs in early detection and prevention, [13].

Finally, [14], propose a multivariate outlier detection technique to improve the accuracy of forest fire data aggregation in WSNs. The proposed technique uses principal component analysis and the Mahalanobis distance to detect outliers in the collected data, [14].

Overall, the literature by [9], [10], [11], [12], [13], [14], emphasizes the potential of WSNs for forest fire detection and proposes various techniques and systems to improve the accuracy and efficiency of detection.

Moreover, several studies have proposed the use of machine learning algorithms to enhance the accuracy of WSN and IoT-based forest fire detection systems. For instance, [15], proposed a forest fire detection system that utilizes an artificial neural network (ANN) algorithm to detect forest fires accurately. The system utilizes temperature and humidity sensors to collect environmental data, which is then fed to the ANN algorithm for fire detection, [15].

In conclusion, WSN and IoT-based forest fire detection systems have the potential to provide an efficient and cost-effective solution for early forest fire detection and prevention. These systems utilize environmental sensors, machine learning algorithms, and cloud computing platforms to detect and locate forest fires accurately, enabling authorities to take immediate action to mitigate the damage caused by forest fires.

The main difference that distinguishes our study is that the first one proposes a low-cost forest fire detection system based on WSN and IoT, which uses a network of sensor nodes that monitor environmental conditions such as temperature, humidity, and smoke levels, and transmit the data to a central server for real-time analysis and alerts. The proposed system employs advanced algorithms with simple components to detect and predict the occurrence of forest fires and provides real-time alerts to forest authorities and users through a mobile application.

3 Proposed Solution

In the forest of El-Kala, located in the extreme northeast of Algeria, a dense network of sensor nodes has been installed. These nodes are organized into clusters, with each node having a corresponding "cluster head." The sensors are capable of measuring ambient temperature, relative humidity, and smoke levels. To determine their locations, each sensor node is geotagged using Google Maps. Every node sends its measurement data, along with its location information (an identifier), to its corresponding group header. The group header then collects the data from all the nodes in its group and transmits it to the gateway. This gateway is connected to the internet and transfers all the collected data from the network via WiFi. Additionally, users have the option of inquiring about the current temperature and humidity data for a specific cluster area through Cloud-IOT. Further details concerning sensor nodes and WSN management will be covered in subsequent pages of this document.

Figure 1 shows bellow the proposed system

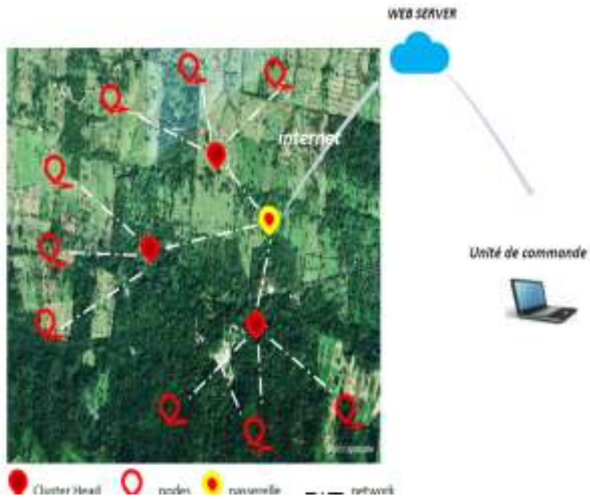

Fig. 1: Proposed WSN solution for Forest fire detection

4 Hardware Description

Based on the main architecture used in WSN design, [16], [17], the principal parts of the node in our design, as shown in Figure 2, are the CPU, sensors, communication mode, and power module.

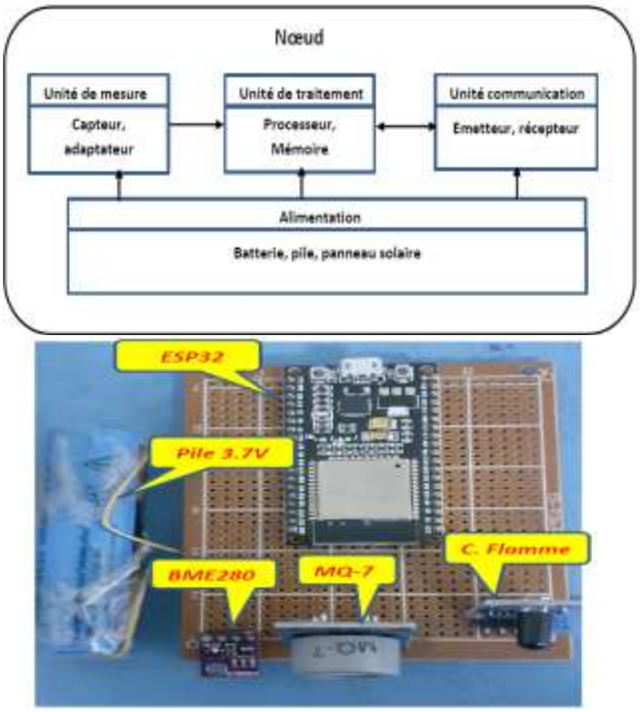

Fig. 2: WSN node architecture and designed prototype

a. The ESP-32 is the main component of the node design. The ESP32-WROOM-32, [18], is a highly capable, generic Wi-Fi+BT+BLE MCU module designed by Espressif Systems. This series of system-on-a-chip (SoC) microcontrollers are based on Tensilica's Xtensa LX6 architecture and integrate dual-mode Wi-Fi and Bluetooth management, as well as a DSP. It is the successor to the ESP8266 and is ideal for wearable and mobile electronics, as well as Internet of Things (IoT) applications. Its features range from low-power sensor networks to high-performance tasks such as voice encoding, music streaming, and MP3 decoding. The ESP32 includes two low-power 32-bit LX6 Xtensa microprocessors operating at either 160 MHz or 240 MHz. Its internal memory consists of [19], [20]:

448 KB of ROM for boot and main functions.
520 KB of on-chip SRAM for data and instructions.
8 KB of SRAM in RTC (Real-Time Clock) that is called RTC FAST Memory, which can be used for data storage and is accessed by the main CPU during RTC boot from Deep-sleep mode.
8 Kbit of SRAM in RTC that is called RTC SLOW Memory and is accessed by the ULP (Ultra-Low Power) coprocessor during Deep-sleep mode.
1 Kbit of Fuse, with 256 bits used for the system (MAC address and chip configuration), and the remaining 768 bits reserved for client applications, including flash encryption and chip ID.

b. Main sensors used in the application:
B1. Flame Sensor: This is a sensor capable of detecting flames with wavelengths between 760 nm and 1100 nm. This sensor uses infrared as a transducer to detect flame conditions. This fire sensor has a reading angle of 60 degrees and normally operates at a temperature of 25 to 85 degrees Celsius, [21].

B2. The interface of the BME280 sensor measures temperature, humidity, and pressure, and it is straightforward to use since it does not require any extra components and comes pre-calibrated. This means that you can start measuring relative humidity, temperature, barometric pressure, and even approximate altitude very quickly. The BME280 sensor is manufactured by Bosch and is a next-generation digital temperature, humidity, and pressure sensor that supersedes previous sensors such as BMP180, BMP085, and BMP183, [22].

B3. The MQ-2 Gas Sensor is a low-cost sensor that can detect various flammable vapors such as propane and smoke, as well as natural gas. It is highly sensitive and suitable for detecting smoke. The sensor's sensitive material, SnO_2, has lower conductivity in pure air, but when flammable gas is present, the sensor's conductivity increases with the gas concentration. A straightforward circuit can convert the change in conductivity to an output signal that corresponds to the gas concentration, making it easy for users to obtain gas concentration information, [23], [24].
To conserve energy, the sensor nodes send short message packets. Each packet includes a unique identification number (NI) for each card, starting at 1. The ID number is sent along with the temperature and humidity variables, which are floating-point variables that occupy 8 bytes. The flame, smoke, and prediction indicators are each composed of a vector of 32 characters, occupying a total size of 32 bytes (with each character occupying 1 byte).
The data packet structure is defined by the following variables: Identification number (NI) - 4 bytes, Temperature in °C - 8 bytes, Humidity in % - 8 bytes, Flame indicator - 32 bytes, Smoke indicator -

32 bytes, Prediction - 32 bytes, Number of readings - 4 bytes.

The temperature and humidity variables are floating-point numbers that occupy 8 bytes each, while the flame, smoke, and prediction indicators are 32-character vectors occupying 32 bytes each. The "number of readings" variable is an integer with a size of 4 bytes.
Here is the flowchart of implemented software in Figure 3:

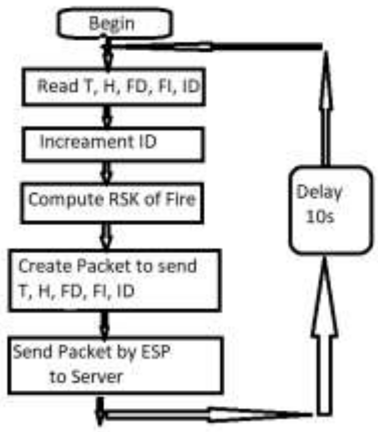

Fig. 3: Implemented software on ESP-32
T: temperature, H: Humidity, Fd: fire detect, Fl: Flame, ID: id node

4 Fire Prediction (Risk Rate)

Based on statistics related to fire detection in these forest regions, we have developed a model of risk rate. As the nodes retrieve data in each cycle, they capture temperature, humidity, and flame parameters, and calculate the percentage of risk of fire presence. This information is then sent to the group header as shown in below.

The indicators corresponding to each detection parameter (Flame, Humidity, Temperature, Smoke) are set to 1 if their threshold is crossed.
The temperature indicator is set to 1 if the temperature is greater than or equal to 40°C.
The humidity indicator is true if the humidity is less than 40%.
The smoke indicator turns on if smoke is detected.
The flame indicator lights up if a flame is detected.

The specified values for the system installation are dependent on factors such as location, wind patterns, and season. Hence, they must be customized accordingly. To illustrate, in the case of a region that experiences seasonal precipitation and relatively low humidity, we have set the limits for humidity at 40% RH, and the threshold for heat in the shade at 40°C.
-If the flame detector rises high, the fire alert is increased by 50% because the presence of flames at tree branch height is extremely dangerous and a clear indication of a forest fire.
-If smoke is detected, which is the case in most scenarios because forest fires ignite mainly at grass level, and smoke is the first element that rises, the fire risk increases by 25% by putting it in the second priority position after the flame.
-If the temperature measured by the BME280 is high (> 40°C), the indication of a forest fire increases by 12.5%.
-If the humidity is less than 40%, the fire warning is raised to 6.25% because fires spread easily when the air is dry.

Therefore, the risk of fire occurrence can be divided into three zones:

a. Green zone: If no smoke or flame is detected, the percentage of fire occurrence in this zone is between 0% and 25%.
b. Orange zone: If no flame is detected, but the smoke indicator is high, the risk of fire occurrence is between 25% and 50%.
c. Red zone: If only the flame indicator is detected and the smoke indicator is low or both parameters are detected, the percentage of fire is between 50% and 100%.

The threshold crossing of temperature and humidity influences each zone. The percentage of influence of temperature is higher than that of humidity. For example, if the temperature is low, there is a chance that there is a campfire whose smoke reaches the sensors. However, if the temperature regularly rises above 40°C, the fire alarm is increased. If no flames or smoke are detected, but the temperature is high and the humidity is low, the risk of fire is increased, and the corresponding alert is sent.

5 Experiment

A series of experiments were performed with a sampling period of 3 seconds. The objective was to study the best performance for fire detection under certain climatic conditions. In this stage, a sensor node was installed outside in the shade in the absence of fire. The values of the parameters presented below were obtained using the "serial monitor" of the Arduino IDE software. In a second scenario, the node was exposed to fire, and the values of the same parameters were recorded. Then, the data processing done at each node with the ESP32 gives the percentage of the presence of a fire. The graphs in Figure 4 illustrate the results of temperature and humidity in the experiment of the realized model: The x-axis contains the number of readings taken every 3 seconds, and the y-axis contains the temperature and humidity level as a function of the number of readings. As the number of iterations increases, the accuracy of the model improves.

The test was carried out during the afternoon for four parameters: temperature, relative humidity, flame, and smoke, taking into account the climatic conditions in the absence of fire, where the approximation is: temperature = 27°C; humidity = 49%, flame: not detected, smoke: not detected. The experiment lasted 75 seconds. The fire was lit after 15 seconds (5th reading number) at a distance of one meter from the sensor node. The flame was detected instantly, and the temperature and humidity values began to change slowly. After 18 seconds, the smoke indicator lit up, and the temperature rapidly rose to 48°C while the humidity dropped to 21%. The risk rate changes according to the threshold clearance of environmental parameters, including temperature, relative humidity, flame, and smoke, which are monitored by the system under the previously mentioned climatic conditions.

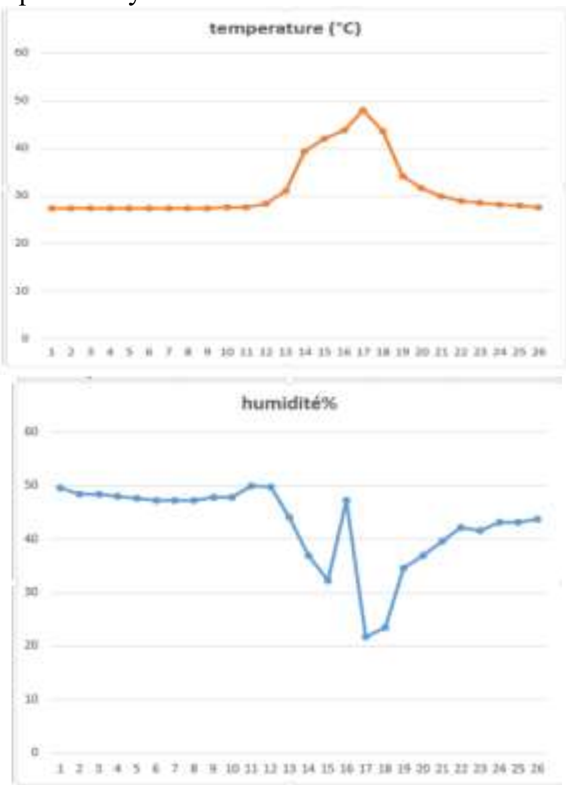

Fig. 4: Humidity and temperature evolution in experiment case

6 Web Platform Design

The monitoring of the monitored area can be done from any location. It is enough for the user to be connected to the Internet, enter the website, and view the results. The server created at the gateway has the role of transmitting the data to the base station. The variables of each node of the network illustrated in figure 4 are displayed to the user in five frames. The first frame concerns the prediction interval where the risk rate in % is expressed in figure 5 A "Flame detected!" alert message will be sent to the base station, displayed in the second frame of the platform. A "Smoke detected!" alert message will be sent to the base station in the third frame. In the fourth and fifth frames, the temperature in °C, the humidity in %, and the "Reading Number:" are displayed as shown in Figure 5.

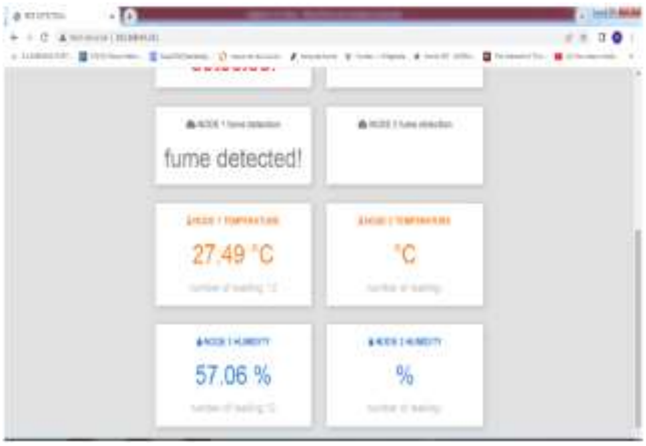

Fig. 5: Web interface GUI designed

7 Conclusion

This study shows that WSN technology is a promising and eco-friendly option for effectively detecting forest fires in the country with more accurate results. The study also concludes that the proposed algorithm for calculating fire risk rate is efficient and algorithmically simple compared to others, as demonstrated through a real field experiment during summer seasons. Future research will focus on extending the model to include an experimental evaluation of energy consumption to keep the network operational for longer periods, which could be achieved through a secondary power supply with rechargeable batteries powered by a solar panel. Additionally, distributing nodes into groups and utilizing distributed sensing to find the best information paths for real-time communication could improve the system. Finally, embedding an artificial intelligence algorithm could further enhance the system design.

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Contribution of Individual Authors to the Creation of a Scientific Article (Ghostwriting Policy)

The authors equally contributed to the present research, at all stages from the formulation of the problem to the final findings and solution.

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Conflict of Interest

The authors have no conflicts of interest to declare that are relevant to the content of this article.