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Design and implementation of a LoRa-based system for warning of forest fire

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ABSTRACT

This paper presents the design and implementation of a forest fire monitoring and warning system based on long range (LoRa) technology, a novel ultra-low power consumption and long-range wireless communication technology for remote sensing applications. The proposed system includes a wireless sensor network that records environmental parameters such as temperature, humidity, wind speed, and carbon dioxide (CO_2) concentration in the air, as well as taking infrared photos. The data collected at each sensor node will be transmitted to the gateway via LoRa wireless transmission. Data will be collected, processed, and uploaded to a cloud database at the gateway. An Android smartphone application that allows anyone to easily view the recorded data has been developed. When a fire is detected, the system will sound a siren and send a warning message to the responsible personnel, instructing them to take appropriate action. Experiments in Tram Chim Park, Vietnam, have been conducted to verify and evaluate the operation of the system.

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1. INTRODUCTION

Forests are extremely important in the lives of organisms on earth because of the many benefits they provide, such as keeping the air clean by absorbing carbon dioxide, providing oxygen, preventing soil erosion, reducing wind force and water flow rate, and so on. However, the forest area is shrinking at an alarming rate, with 129 million hectares lost between 1990 and 2015 [1]. Forests have been gradually destroyed for a variety of reasons, including deforestation for agricultural land, logging, forest degradation caused by climate change, and, most alarmingly, forest fires. Aside from the objective causes of recent forest fires caused by prolonged hot weather, strong southwesterly winds, and forests with many types of trees containing flammable essential oils, the subjective cause is to burn the hive to kill the bees and extract the honey; unintentionally burning vegetation causes the fire to spread into the forest.

Currently, the main method in Vietnam is to use a high guard tower to observe the situation through military binoculars to detect fire if there is smoke and notify forces to deal with it as soon as possible. However, because it is primarily based on human factors, it has several limitations, such as limited visibility when observing in bad weather. Furthermore, it is difficult to monitor the situation at night and can only detect when the fire is large enough. As a result, it is extremely difficult to maneuver in time to deal with the fire [2], [3].

Many studies on routing algorithms and protocols have been conducted in order to improve the performance of forest fire sensing networks, which is one approach to reducing the risk and damage caused by forest fires [4], [5]. Furthermore, numerous recent studies on the development of forest fire monitoring, detection, and warning systems using image processing, sensor networks, and IoT technology have been conducted [6]-[20]. Cloud-edge computing and unmanned aerial vehicle-Internet of Things (UAV-IoT) networks are also proposed as effective methods for detecting and forecasting wildfire behavior [20]-[22]. Long range (LoRa) communication technology, in particular, with its low power consumption and long transmission distance, has been studied and applied in a wide range of environmental monitoring and remote control applications [23]-[27]. Recent research has focused on the use of LoRa wireless sensor networks for forest fire monitoring, detection, and warning systems [28]-[33]. However, in these projects, only system design was carried out, with no experiments to evaluate the system's effectiveness under actual on-site operating conditions. Besides, the application of artificial intelligence, machine learning, and decision support systems is being considered as a potential solution for early warning of fire risks as well as contributing to improving the efficiency of forest management, which is attracting the attention of many scientists [34]-[36].

The goal of this study is to propose a forest fire warning system that allows monitoring in large areas, particularly areas with high fire risk and a lack of telecommunications infrastructure. The system monitors environmental parameters such as soil temperature and humidity, wind speed, and CO_2 concentration in the air using wireless sensor network technology. Furthermore, the infrared camera used can capture images of the area to be monitored both during the day and at night. The system's wireless network employs a star topology, allowing direct communication between sensor nodes and the gateway. This not only reduces power consumption when compared to mesh networks [28], but it also makes it easier to set up and expand the number of sensor nodes (number of locations to be monitored). The rest of this paper is structured as: section 1 summarizes the current state of forest fires in Vietnam as well as related research on forest fire warning systems. Section 2 describes the system's design and implementation steps, including the LoRa wireless sensor network and an Android application for monitoring forest fires. Section 3 describes the experiments, followed by section 4 which summarizes and evaluates the results and discusses future development directions.

2. METHOD

This study will design and implement a standard LoRa wireless sensor network consisting of two sensor nodes using an ESP32-CAM microcontroller to read environmental parameters and take pictures at the locations to be monitored. A gateway with an ESP32-CAM and a wireless-fidelity (Wi-Fi) connection collects data from the sensor network and sends it to the cloud storage for firebase. Besides, a smartphone application was developed that allows the display of the collected data, as can be seen in Figure 1. When the temperature, humidity, and CO_2 concentration of the vegetation exceed the allowable threshold, the siren will sound and a warning message will be sent those responsible.

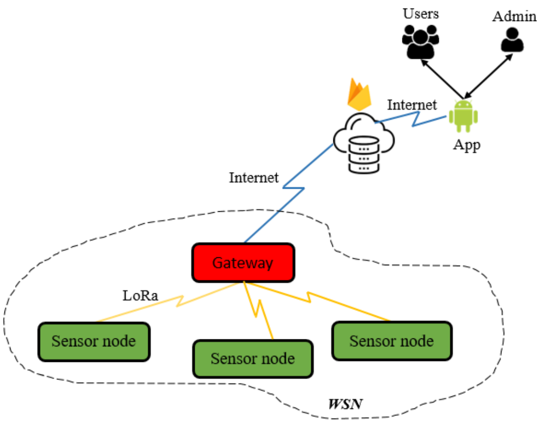

Figure 1. The architecture of the system for monitoring fire forest

2.1. Hardware design

In Figure 2, every sensor node collects and processes environmental data before transmitting it to the gateway via LoRa wireless links. The gateway receives data from all sensor nodes in the network and uploads it to the database via Wi-Fi. The operational status of the gateway is displayed on an liquid crystal displays (LCD) for observation easily. The ESP32-CAM is the main control board for the gateway and sensor node. Since an Internet connection is required to upload data into the database, a Wi-Fi transceiver function onboard can be used to send data efficiently. In addition, with the built-in camera on the module, the ESP32-CAM is suitable for capturing infrared images.

Every sensor node collects and processes environmental data before transmitting it via LoRa wireless links to the gateway. The gateway manages the entire wireless network, including receiving data from all sensor nodes in the network and uploading it to the database via Wi-Fi. The gateway's operational status is easily visible on an LCD. The main control boards for the gateway and sensor nodes are the ESP32-CAM modules, which consist of a low-power 32-bit CPU with a clock speed of up to 160 MHz. Furthermore, the ESP32-CAM, with a single-chip UXGA (1632×1232) camera and image processor, is suitable for capturing infrared images in a small-footprint package [33].

The main microcontroller and peripherals are depicted in the block diagram of the gateway. The microcontroller communicates with the peripherals via the PWM and SPI communication standards to collect data from the wind speed sensor and receive data from the sensor nodes. The sensor MH-Z19b and the sensor SHT20 are used to measure the CO_2 concentration in the air and the temperature and humidity of the soil, respectively. The sensor node block diagram is similar to the gateway block diagram, with the exception that it has a low-voltage complementary metal-oxide-semiconductor (CMOS) image sensor for taking infrared images but no wind speed sensors. The power supply circuit design includes two voltage levels, 5 V, and 3.3 V, to provide adequate power to the circuit's various components. Photographs of the gateway and sensor node are shown in Figure 3 and Figure 4, respectively.

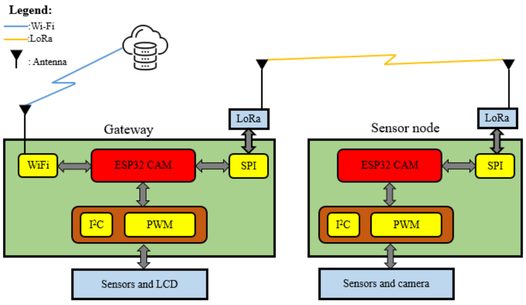

Figure 2. The general block diagram describes the basic components and communication between the root node and the sensor node

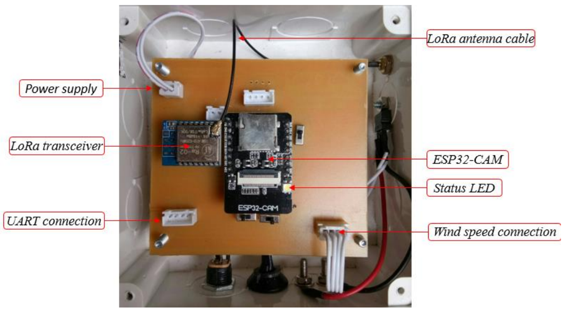

Figure 3. The electronic circuit of the gateway

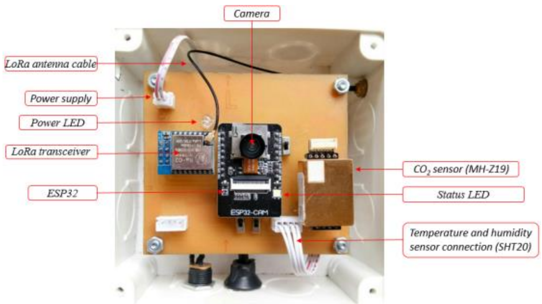

Figure 4. A sensor node's circuit is placed in an IP65 plastic box

2.2. Software development

Figure 5 describes the program execution at the gateway of the proposed wireless sensor network. The program begins by initializing the program variables, operating the LoRa transmission module, and communicating with the wind speed sensor and the firebase database. After the system has been initialized, the gateway begins its data collection and alerting process by sending a data request to the first sensor node and waiting for a response. If there is still no response from the sensor node after the predetermined waiting time, the gateway will skip and move on to collect data at the next sensor node. In contrast, the gateway receives and processes the received data. If the received temperature value exceeds the allowable threshold (for example, more than 40 °C), the buzzer will sound and the sensor button information will be displayed on the LCD. Otherwise, data will be collected at the next sensor node. The gateway will read the wind speed value from the sensor after collecting data from all nodes in the network, then pack and upload all of the data to the cloud database. Thus, the recorded wind speed value is regarded as representative of the entire area where the forest fire monitoring sensor network is deployed. The gateway program is set up to repeat the above-mentioned data collection and alarm process.

The photos were taken at the sensor nodes using the OV2640 sensor, which is a low-voltage CMOS image sensor that provides the full functionality of a single-chip UXGA (1632×1232) camera and image processor. Although the image is captured and saved at the sensor node every 3 minutes, it is only sent to the gateway upon request. The image-sending process is shown in the flowchart (see Figure 6). Sending the image size will be sent first. For example, in the experiments, the size of the image data to be sent is 200 bytes. Then the image data will be sent, one after another, until the end. If the gateway receives image data equal to the image size, the image is considered to be successfully sent. This image will be stored temporarily in the gateway's memory before being uploaded to the image database.

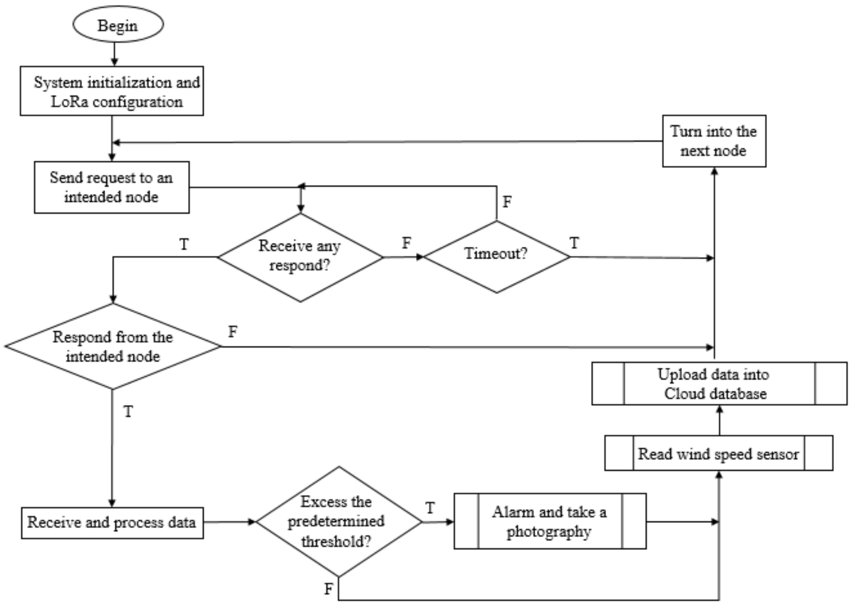

Figure 5. Flow chart of the program at the gateway

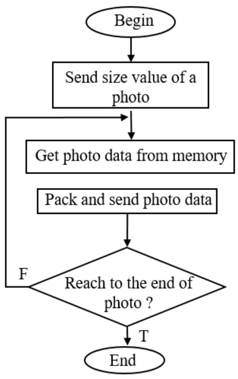

Figure 6. Flow chart of the program for receiving an infrared image

3. RESULTS AND DISCUSSION

After being designed and implemented, the system is tested for operation and corrected for measured values in the laboratory before being installed at the experimental site. Tram Chim National Park, which covers 7600 hectares and is located in Tam Nong District, Dong Thap Province, Vietnam, requires better fire management to preserve its ecosystem [37]. Figure 7 to Figure 9 are some pictures taken during the experiment in Tram Chim Park. In the forest area to be monitored, the sensor network consists of two sensor nodes and a gateway. It should be noted that the condition sensor at the gateway measures the actual wind speed in the experimental area. Environmental data such as temperature, soil moisture, CO_2 concentration, and images are collected from sensor nodes within a 2 kilometer radius of the gateway. The sensor nodes are located about 80 cm above ground, and the gateway is located 12 meters up on the watchtower. It is possible to ensure stable data transmission in the presence of many trees and obstacles using such a configuration.

The results of the experiments show that images taken in well-lit conditions (Figure 10(a)) produce clear images. However, in low-light photos (Figure 10(b)), image details are barely visible. However, with the above image data, it has ensured that the requirements of observing the area to be protected are met, such as providing information on the illegal entry of strangers or early detection of forest fires.

Figure 11 and Figure 12 depict a developed Android application that allows the monitoring of environmental parameter values recorded by sensor nodes. The application will present the value of the parameters recorded over time after the gateway saves to the cloud database in the form of visual graphs to help users easily observe. Furthermore, this application includes a tool for quickly and effectively searching and viewing captured photos for management. The gateway in the above design must be located in a location where Internet connection services can be accessed, whereas the sensor nodes of the LoRa wireless sensor network can be deployed at any location in the forest where forest fires must be prevented and monitored. The experiment was carried out in a densely forested area, for the longest data transmission distance of about 500 meters in dry weather, with the transmitting antenna 1.5 meters and the receiving antenna about 10 meters above ground, corresponding to the configuration SF12, bandwidth 125 kHz, and output power +20 dBm. When it rains, the transmission distance is significant reduced to about 250 meters.

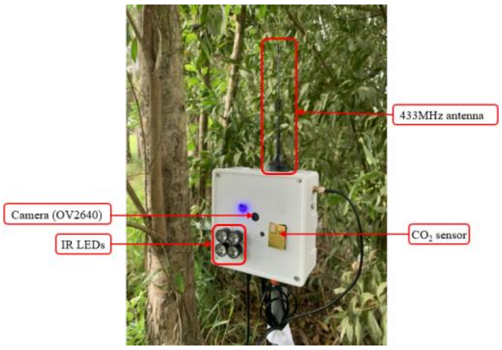

Figure 7. A photograph of the sensor node in the experiment

Figure 8. Setting up a sensor node for capturing environment values

Figure 9. In the experimental area, the gateway circuit is equipped with a wind speed sensor

(a) (b)

Figure 10. The images were captured by the OV2640 camera: (a) in well-lit conditions during the day and (b) in low-light conditions at night

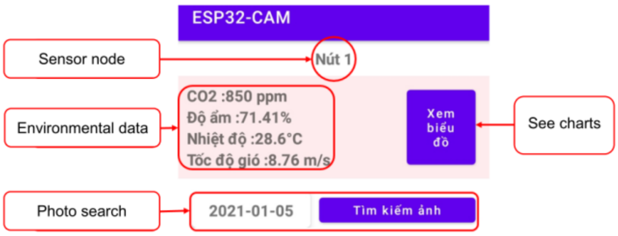

Figure 11. A snapshot of the Android application for monitoring forest fire risk

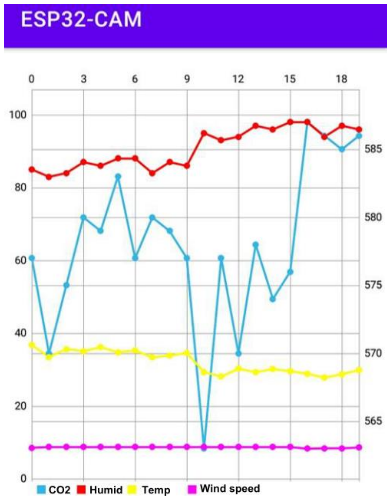

Figure 12. Charts of environmental values in an experiment

4. CONCLUSION

This article describes the steps involved in designing and implementing a wireless sensor network based on LoRa technology for monitoring and warning of forest fires. It is proposed in this project to detect forest fires by using sensors to record environmental parameters (temperature, humidity, CO_2, and wind speed) and take infrared images at the monitoring location. The system is compact in size and low in deployment and operation costs to aid in the continuous monitoring of important environmental parameters for the timely detection and warning of forest fires. When no fire is detected, the camera takes a picture and saves it to the memory card. If a fire is detected, the sensor node will capture and send an image to the gateway. Furthermore, the system employs LoRa technology, innovative ultra-low power consumption, and long-range communication technology, in the establishment of wireless sensor networks. Consequently, it enables efficient monitoring in large areas, including remote areas without telecommunications infrastructure. This not only allows for real-time detection of fires and lowers power consumption, but it also provides accurate information to aid in determining the extent of the fire, the direction of fire spread, and the cause of the fire, contributing to improved forest management efficiency. Some experiments have yielded positive results, providing an incentive for further improvements and deployment in many areas with high forest fire risk.

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