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IOT-BASED FOREST FIRE DETECTION AND AUTONOMOUS FIREFIGHTING ROBOT USING ESP8266 AND SENSOR INTELLIGENCE

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Abstract:

The IoT-based Forest Fire Detection and Autonomous Firefighting Robot using ESP8266 and Sensor Intelligence is a fascinating project that combines technology to address a critical issue. In this project, the ESP8266, a popular Wi-Fi module, is utilized for IoT connectivity. The system incorporates sensors that can detect the presence of a fire in a forest area. When a fire is detected, the system triggers the autonomous firefighting robot. This robot is designed to move towards the fire location automatically. It can be equipped with mechanisms like water sprayers to extinguish the fire. The intelligence of the robot lies in its ability to navigate through the forest terrain and approach the fire source effectively. The system leverages a network of sensors to monitor environmental parameters such as temperature, smoke, humidity, and gas concentrations, all of which are indicative of a forest fire. These sensors are connected to an ESP8266 module, which is responsible for transmitting real-time data to a cloud platform. The cloud platform processes the data, providing early warnings and enabling remote monitoring of fire conditions.

Keywords: **Forest Fire Detection, ZigBee, ESP8266, Real-Time Monitoring, Intelligence, Autonomous Firefighting Robot.**

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. However, because of some uncontrolled anthropogenic activities and abnormal natural conditions, forest fires occur frequently. These fires are among the most serious disasters to forest resources and the human environment. In recent years, the frequency of forest fires has increased considerably due to climate change, human activities and other factors. The prevention and monitoring of forest fires has become a global concern in forest fire prevention organizations. Currently, forest fire prevention methods largely consist of patrols, observation from watch towers and lately satellite monitoring (Lai, 2004; Huang et al., 2005). Although observation from watch towers is easy and feasible, it has several defects. In the first place, this method requires many financial and material resources and a trained labor force. Second, many problems with fire protection personnel abound, such as carelessness, absence from the post, inability for real-time monitoring and the limited area coverage. The scope of application of satellite detection systems is also restricted by a number of factors, which reduces its effectiveness in forest fire detection. For example, a satellite monitoring system has a long scanning cycle and the resolution of its saturated pixel dots of images is low. Another problem is cloud layers may mask images during the scanning period and the real-time mathematical quantification of fire parameters is very difficult to achieve (Shu et al., 2005; Yu et al., 2005; Calle et al., 2006). Given these shortcomings of traditional monitoring, we suggest the ZigBee wireless sensor network technology and explain its application as a monitoring system. This system can monitor real-time related parameters, e.g., temperature, relative humidity, and send the data immediately to the computer of the monitoring center. The collected data will be analyzed and managed by the computer. Compared with the normal meteorological information and basic forest resource data, the system can make a quick assessment of a potential fire danger. The analytical results will then be sent to the relevant department as the policy-making basis by which the department will make the decision of fire fighting or fire prevention. Forest Fires are one of the most important and prevalent type of disasters and they can create a great deal of Environmental Impacts due to which their early detection is very vital. The main need for choosing this particular application for the detection of forest fires is to overcome the demerits present in the existing technologies of MODIS and Basic Wireless Sensor Network-based Forest Fire Detection Systems and an advanced system is developed for the detection of forest fires. The two main modules present in the project are the Monitoring Area Module and the Forest Area Module. All these together are split into five sub-modules for step-by-step development and implementation. Those include Sensors' Module, Serial Communication Module using Zigbee, Optimized Solar Energy Harvester using Maximum Power Point Tracking (MPPT), PC-based Web Server and Mechanical Modeling. The first three sub-modules belong to the Forest Area Module. They are integrated together and mechanical modeling is done to place it in the forest, whereas, the PC-based Web Server is developed for the Monitoring Area. The outcome of the above implementations reveal that various sensors used in addition to the temperature sensor improves security level for areas located near the forests. It also shows that the Optimized Solar Energy Harvester increases the efficiency to about 85 % and the use of PC-based Web Server reduces the bulkiness and cost of the entire system. Forests are part of the important and indispensable resources for human survival and social development that protect the balance of the earth ecology. However, because of some uncontrolled anthropogenic activities and abnormal natural conditions, Forest Fires occur frequently. These fires are among the most serious disasters to forest resources and the human environment. In recent years, the frequency of forest fires has increased considerably due to climate changes, human activities and other factors. The prevention and monitoring of Forest Fires has become a global concern in Forest Fire prevention organizations. Currently, Forest Fire prevention methods largely

consist of Patrols, Observation from watch towers, Satellite Monitoring (Fu et al.) and lately Wireless Sensor Networks (Han et al.). Although observation from watch towers is easy and feasible, it has several defects. In the first place, this method requires many financial and material resources and a trained labor force. Second, many problems with fire protection personnel abound, such as carelessness, absence from the post, inability for real-time monitoring and the limited area coverage.

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2. LITERATURE SURVEY

In 2012, P.S. Jadhav and V.U. Deshmukh suggested a ZigBee Wireless Sensor Network Forest Fire Monitoring System.[1], which includes of monitoring nodes base stations, communication systems, internet access, and the monitoring hardware and software system structure, is designed for habit monitoring automation, agricultural, and security. The author has constructed a device based on the WSN protocol that contains temperature, smoke, and humidity sensors, as well as the processor LPC2138 and ZigBee as an RF device. The processor module in this system is in charge of controlling the sensor nodes, as well as storing and processing the data they acquire. U. Arun Ganesh, M. Anand, S. Arun, M. Dinesh, P. Gunaseelan, and R. Karthik presented Forest Fire Detection Using Optimized Solar-Powered ZigBee Wireless Sensor Networks [5] in 2013. When the temperature surpasses a particular threshold, an alert is sent to the base station through SMS (Short Message Service) and a call is made using the GSM module, according to the suggested system solution for early forest fire detection. GSM modems were employed in all previous study efforts to notify the forest department of the forest's danger situation. The ZigBee module is utilised in this system to perform serial communication between two nodes, allowing forest fire information to be conveniently relayed. The suggested system has the potential to save the lives of countless humans and animals, as well as important forest. Three factors compose the basis of a forest fire: the fire source, environmental elements and combustible material. A forest fire usually occurs as the result of their combined effects (Song et al., 2006). According to the Canada Fire Weather Index Forecast Model, the moisture content of the combustible material plays an important role in forest fires, which means the probability of forest fires depends on the moisture content (Tian et al., 2006). Therefore, the moisture content of combustible materials is a major point of assessment and predicts whether a fire will take place. The moisture content has much to do with relative humidity in the atmosphere, air temperature, wind and similar factors (Shu et al., 2003; Zhang, 2004). Water evaporation can be directly affected by relative humidity. At the same time, the physical properties of combustible materials can be changed indirectly by air temperature. Thus, relative humidity and air temperature are regarded as the two main factors which affect the moisture content of the fuel. Therefore, to reflect the moisture content indirectly, these two parameters are the main objects of our investigation, which should provide an important basis for the prediction and monitoring of forest fires. Certainly, forest fires are also caused by other factors, such as the active degree of thunder and lightning above the forest, human factors, wind speed, and condition of area vegetation. However, these factors will be ignored in our discussion. A ZigBee wireless sensor network system includes sensor nodes, gateways (routers) and a monitoring host computer. To decrease the loss of energy and data packets, a cluster tree network topology structure (Tillett et al., 2004) (shown as Fig. 1) is applied in this design. Sensor nodes fitted with microprocessors of low processing capacity are distributed randomly in the forest and nearby areas to collect fire monitoring parameters such as relative humidity and atmospheric temperature (Zenon and Fady, 2005). Depending on the part the different sensor nodes play in the whole network, they are divided into three categories: ordinary bottom nodes, cluster heads and network coordinators. Data collected is transmitted to its own cluster head by an ordinary bottom node. A cluster head mainly handles data fusion and data packet transmission. Via the cluster head, data collected by ordinary bottom nodes in the cluster can be fused and transmitted to the nearest network coordinator and data packets transmitted by the network coordinator can be broadcast to related clusters. A network coordinator mainly deals with basic network. The sensor module is responsible for data analog-digital conversion and collecting parameters such as relative humidity of the atmosphere and air temperature. The processing module is responsible for controlling the operation of the whole sensor node and saving and coping with data collected by its own node and the binary information transmitted from other nodes. The wireless communication module is responsible for communication with other nodes and exchanging control information and receiving or transmitting data. The power module supplies power for the other three modules and drives the nodes, making it the key factor for the effective operation of the network (Ren et al., 2003).

The sensor node is a basic unit and platform of the wireless sensor network. A sensor node is commonly composed of a sensor module, a processing module, a wireless communication module and a power module. Figure 2 shows the structure of the sensor node. The sensor module is responsible for data analog digital conversion and collecting parameters such as relative humidity of the atmosphere and air temperature. The processing module is responsible for controlling the operation of the whole sensor node and saving and coping with data collected by its own node and the binary information transmitted from other nodes. The wireless communication module is responsible for communication with other nodes and exchanging control information and receiving or transmitting data. The power module supplies power for the other three modules and drives the nodes, making it the key factor for the effective operation of the network (Ren et al., 2003).
Nowadays, many natural disasters have been caused in various way all over the world. Forest fire are one of the most important disasters and they can create a great deal of environmental impacts due to which their early detection is very vital. As the number of causing forest fire is rapidly increased in the world, the number of fire accident also increased that is huge problem for the world. Most of people, animals are died because firefighting or fire prevention cannot be provided in time and forest fire information cannot be provided the emergency facilities to the fire department as soon as possible. This proposed system was constructed with sensors (temperature, humidity and gas). They detect the forest condition and send the signal to the main station and report information. In this proposed system, there are three nodes (node1, node2 and main node). Each node has temperature sensor (LM35), humidity sensor (DHT-11) and gas sensor (MQ2) along with the Arduino and ZigBee wireless module. ZigBee wireless module is used to communicate with other nodes and send and receive data. In this work, program will be developed on Arduino Mega board using the Arduino IDE software. For this system, ZigBee is a suitable technology to be adopted as the communication infrastructure in fire detection and monitoring system. In this way, many people and animals of lives can be saved Some of the previous important literatures that have been studied are discussed below. P: Jadhav , V:U. Deshmukh, 2012 proposed Forest Fire Monitoring System Based on ZigBee Wireless Sensor Network [1]. The purpose of this system aims at using for habit monitoring automation, agriculture and security and

it consists monitoring nodes base stations, communication systems, internet access and the structure of monitoring hardware and software system. The author better has designed based on WSN protocol includes sensors such as temperature, smoke, humidity along with the processor LPC2138and ZigBeeas aRF device. In this system, the processor module controls the operation of the sensor nodes, stores and processes the collected data. Wireless communication module communicates with other nodes, exchanges control information and sends and receive data. The power modular provides the energy to the sensor module, processing module and wireless communication module. U. Arun Ganesh, M. Anand, S. Arun, M. Dinesh, P. Gunaseelan and R. Karthik 2013 proposed Forest Fire Detection Using Optimized Solar- Powered ZigBee Wireless Sensor Networks [5]. This system consists of two part the monitoring area module part and the forest area module part. The hardware includes sensor's module, serial communication module using ZigBee, Optimized solar energy harvester using maximum power point tracking (MPPT). Wireless Sensor Network Technology was used to detect forest fires and send the information to computer in the Monitoring centers. The collected data will be analyzed and managed by the computer. Harjinder, 2016 presented Forest Fire Detection using Wireless Sensor [3]. This paper highlights the powerful feature of wireless sensors for forest fire detection.

3. PROPOSED METHODOLOGY

The autonomous firefighting robot integrates advanced navigation technologies, including GPS for accurate positioning and path planning. The system employs ultrasonic sensors and LIDAR for real-time obstacle detection and avoidance, enabling smooth navigation through complex terrains. A combination of Raspberry Pi Pico and ESP32 controllers ensures efficient data processing and control over the robot's movement and functionalities.The robot is equipped with fire sensors that continuously monitor the environment for temperature anomalies and fire outbreaks. Once a fire is detected, the system activates a water-spraying mechanism or a fire-retardant dispersal system to contain the fire before it escalates. A buzzer is included for alert notifications, ensuring timely intervention when required.The system employs an IoT-based remote monitoring framework, utilizing ZigBee and cloud connectivity for real-time data transmission. The firefighting system consists of three nodes, Fire sensors continuously collect data on fire parameters and transmit the readings to Node 2 via ZigBee wireless communication. This node acts as both a transmitter and a receiver. It collects sensor data from Node 1, processes it, and forwards the information to the main control station. The main node gathers sensor data from Node 1 and Node 2, displays it on an LCD screen, and uploads it to the server using IoT for remote access.

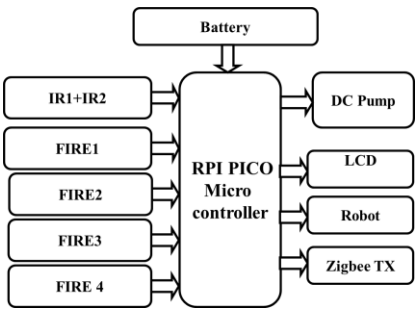

Figure 1: Proposed System (Transmitter)

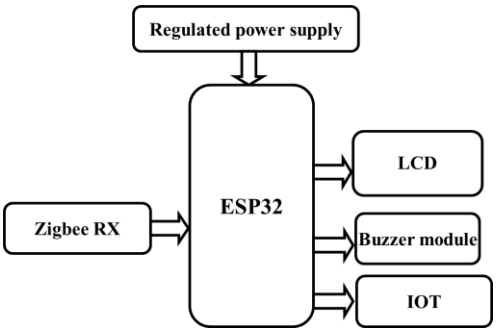

Figure 2: Proposed System (Receiver)

The system uses the XCore2530 ZigBee module, based on CC2530F256, for efficient wireless data transmission. ZigBee is preferred for its low cost, high security, low power consumption, and seamless integration with IoT networks. These controllers facilitate sensor data acquisition, cloud communication, and real-time system control.

The system can be controlled and monitored remotely through a mobile application or web interface. Operators can track the robot's real-time status, location, and firefighting actions. The integration of IoT enables government departments and emergency responders to make swift decisions based on live data.

Continuous sensor monitoring allows immediate detection of fire hazards, enabling proactive firefighting measures. The robotic system independently navigates towards the fire and activates its extinguishing mechanism without human intervention. ZigBee and IoT connectivity ensure seamless communication between sensor nodes and the base station, enhancing firefighting efficiency. The cloud-based monitoring system aids emergency response teams in making quick, informed decisions to prevent large-scale fire disasters.

Applications:

- **Early Fire Detection:** Sensors detect fire conditions (temperature, smoke) early, enabling faster responses to prevent large-scale forest fires.
- **Autonomous Firefighting:** The robot can autonomously reach fire locations, especially in dangerous or inaccessible areas, and use firefighting mechanisms to contain the fire.
- **Real-Time Monitoring:** Continuous data on environmental factors like temperature, humidity, and wind speed helps assess fire risk and optimize firefighting strategies.
- **Preventing Large-Scale Fires:** Quick intervention at the first sign of fire helps prevent escalation and minimizes damage.
- **Sustainable Forest Management:** Reduces the need for human intervention in hazardous situations, enabling safer and more efficient forest management.

Advantages:

- **Early Fire Detection:** Real-time monitoring with sensors enables the early identification of fires, allowing for rapid response and minimizing the spread of fires.
- **Autonomous Operation:** The robot autonomously navigates to fire locations, reducing human risk and enabling firefighting in dangerous, hard-to-reach areas.

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- **Cost Efficiency:** Reduces the need for expensive firefighting equipment and human resources by using cost-effective sensors and autonomous robots.
- **Increased Safety:** The robot operates in hazardous environments, keeping human firefighters safe and preventing injury or loss of life.
- **Real-Time Data**: Provides continuous environmental monitoring (e.g., temperature, humidity, wind speed), which aids in risk assessment and improves firefighting strategies.

4. EXPERIMENTAL ANALYSIS

Figure 3: Proposed System Title

Figure 4: Proposed System Title

The figure 3 and 4 displays the title name on the lcd display when the supply is given.

Figure 5: Fire sensors are OFF

S.No	Fire1	Fire2	Fire3	Fire4	Date
1	OFF	OFF	OFF	ON	2025-01-27 12:59:14
2	OFF	OFF	OFF	OFF	2025-01-27 12:58:48
3	OFF	OFF	OFF	OFF	2025-01-27 12:58:22
4	OFF	OFF	ON	OFF	2025-01-27 12:57:56
5	OFF	OFF	OFF	OFF	2025-01-27 12:57:29
6	OFF	OFF	OFF	OFF	2025-01-27 12:56:51
7	OFF	OFF	OFF	OFF	2025-01-27 12:48:14
8	OFF	OFF	OFF	OFF	2025-01-27 12:47:48
9	OFF	OFF	OFF	OFF	2025-01-27 12:47:22
10	OFF	OFF	OFF	OFF	2025-01-27 12:46:56
11	OFF	OFF	OFF	OFF	2025-01-27 12:46:30
12	OFF	OFF	OFF	OFF	2025-01-27 12:46:04
13	OFF	OFF	OFF	OFF	2025-01-27 12:45:38
14	OFF	OFF	OFF	OFF	2025-01-27 12:45:12
15	OFF	OFF	ON	OFF	2025-01-27 12:44:46
16	OFF	OFF	OFF	ON	2025-01-27 12:44:20
17	ON	OFF	OFF	ON	2025-01-27 12:43:43
18					2025-01-27 12:43:17
19					2025-01-27 12:42:51
20	OFF	OFF	OFF	OFF	2025-01-25 11:34:01

Figure 6: the data is uploaded in server

Initially when there is no fire all the three fire sensors are in OFF state as shown in figure 5similarly even if one fire sensor is ON then buzzer is activated and get updated into server for every 5 secs.

5. CONCLUSION

The IoT-based Forest Fire Detection and Autonomous Firefighting Robot using ESP8266 and sensor intelligence offers a transformative approach to wildfire management by integrating cutting-edge technology for rapid detection and response. The system's ability to continuously monitor environmental conditions using advanced sensors enables early fire detection, reducing the risk of large-scale forest destruction. Once a fire is detected, the autonomous firefighting robot is immediately deployed to the fire location. Equipped with navigation capabilities, it can maneuver through challenging forest terrains and effectively reach the fire source. The robot's extinguishing mechanism, such as water sprayers or fire-retardant dispersal systems, ensures quick suppression of flames before they escalate. The integration of the ESP8266 module allows real-time data transmission to remote monitoring stations, enabling authorities to track fire incidents and robot operations efficiently. The use of IoT enhances decision-making by providing instant alerts and updates, allowing for timely interventions and resource allocation. Overall, this system represents a significant advancement in fire prevention and control, reducing human intervention risks while increasing response accuracy and efficiency. By combining IoT, autonomous navigation, and real-time monitoring, this project paves the way for smarter and more effective forest fire management strategies, ultimately contributing to environmental conservation and public safety.

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