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PREVENTING FOREST FIRES USING A WIRELESS SENSOR NETWORK

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ABSTRACT: Forest fires are a major global concern, and the use of wireless sensor networks (WSNs) has emerged as a promising solution for prevention. The purpose of this article is to propose a WSN model based on the ZigBee protocol for forest fire monitoring and prevention. Existing methods and systems for forest fire hazard forecasting and monitoring are analyzed, and the advantages of the proposed approach are presented. The system employs self-powered wireless sensors to monitor environmental parameters such as carbon monoxide concentration, temperature, and humidity in real-time. The proposed system structure, which is an adaptation of the clustered tree topology, is more memory-efficient and easier to create than the traditional reticular structure. The performance and usefulness of the neural system are illustrated, and it is suggested that it can be used as an addition to existing methods for monitoring and preventing forest fires. Future work will address issues such as power consumption, node placement, and clock synchronization to improve the technology for monitoring forest fires.

Keywords: Environmental monitoring, Artificial neural networks, Forecasting, ZigBee, Fire hazard

1. INTRODUCTION

Preventing and monitoring forest fires has become a global problem in forest fire prevention organizations. Fire-related loss of trees significantly increased (Figure 1). At present, methods of forest fire prevention mainly consist of patrolling, observation from watchtowers and subsequent satellite monitoring [1, 2]. There are many problems with the fire protection personnel, such as inattention, absence from duty, inability to monitor in real-time and limited coverage. The scope of satellite detection systems is also limited by a number of factors, which reduce their effectiveness in detecting forest fires [3-6].

The Zigbee system can monitor real-time parameters. The collected data will be analyzed and processed by a computer. Thus, the proposed approach implies placing a carbon monoxide sensor on the sensor platform; this is an unambiguous marker of intense combustion and, moreover, this gas is relatively easy to detect with relatively simple sensors [8-10]. Compared to conventional meteorological information and basic forest resource data, such a system can quickly assess potential fire hazards (Figure 2). Even before the source of ignition becomes noticeable for satellite observation, traces of carbon monoxide will signal combustion, in combination with meteorological data (temperature and humidity), one can not only judge an increase in fire hazard but also in the event of a fire, predict the speed and direction of fire propagation [11-13].

It is worth noting that in a traditional reticular structure, the nodes in the network are arranged in a grid-like pattern, with each node communicating directly with its neighboring nodes. In contrast, the WSN model based on the ZigBee protocol for forest fire monitoring and prevention typically uses a mesh network structure. In a mesh network, the nodes are not arranged in a strict grid pattern, and instead, each node can communicate with any other node within range. This allows for more flexibility in the placement of the nodes and can help to ensure that there is always a communication path available between any two nodes. Additionally, the ZigBee protocol allows for the formation of multiple communication paths between nodes, which can help to improve the reliability and resilience of the network. This is particularly important in a forest fire monitoring and prevention system, where the nodes may be subjected to harsh environmental conditions, such as extreme heat, smoke, or physical damage.

Thus, in recent years, forest fires have become a global problem, causing significant environmental and economic damage. Current methods for preventing forest fires have limitations and are often inadequate in detecting and preventing fires in a timely manner. These difficulties have led researchers to explore new approaches for early detection and prevention of forest fires. The proposed ZigBee wireless sensor network system provides a promising solution to these challenges by monitoring real-time parameters and detecting carbon monoxide, which is an unambiguous marker of intense combustion. This approach has the potential to improve the speed and accuracy of forest fire detection and prediction, as well as reduce the impact of forest fires on the environment and local communities.

Relative humidity and air temperature are considered two main factors that affect the moisture content of the combustible material (Table 1). In this study, the authors propose a ZigBee system that can monitor real-time parameters and provide quick assessments of potential fire hazards. To achieve this, the authors propose placing a carbon monoxide sensor on the sensor platform to signal intense combustion and sensors of relative humidity, temperature, and wind force to provide data to assess the risk of fire. Artificial intelligence (AI) based on neural networks can cope with this task, and it is the presentation of the integrity and completeness of this approach that will be the aim of this study. The study aims to present the integrity and completeness of this approach, which is crucial for preventing and monitoring forest fires in the present and future.

Table 1 Factors that affect the moisture content of the combustible material

Factor	Description
Relative Humidity Air Temperature	Two main factors that affect the moisture content of the combustible material. Monitored by a sensor placed on the ZigBee system to assess the risk of fire.
Carbon Monoxide	This could indicate a potential fire hazard.
Wind Force	Provides data to assess the risk of fire.
AI	Utilizes neural networks to cope with the task of assessing the risk of fire.
Real-time Monitoring	Offers real-time monitoring of environmental parameters

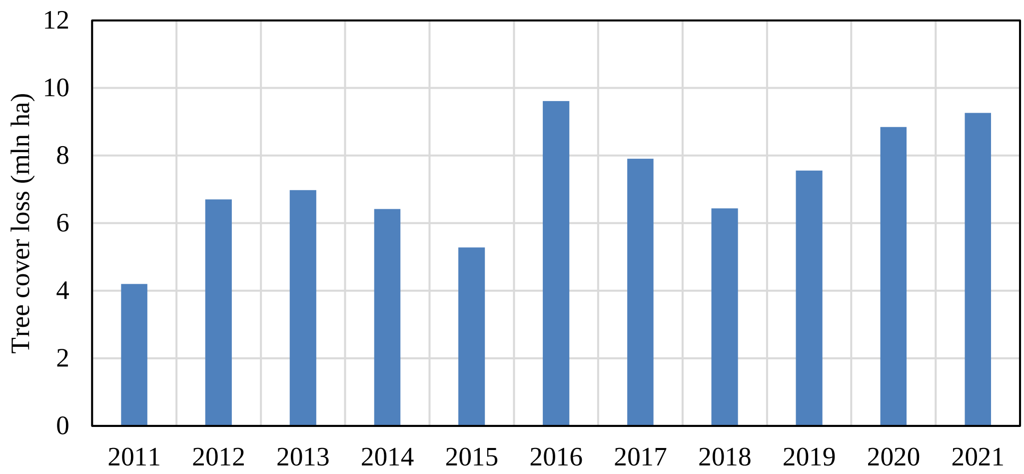

Fig.1 Tree cover loss due to fires in 2011-2021 [7]

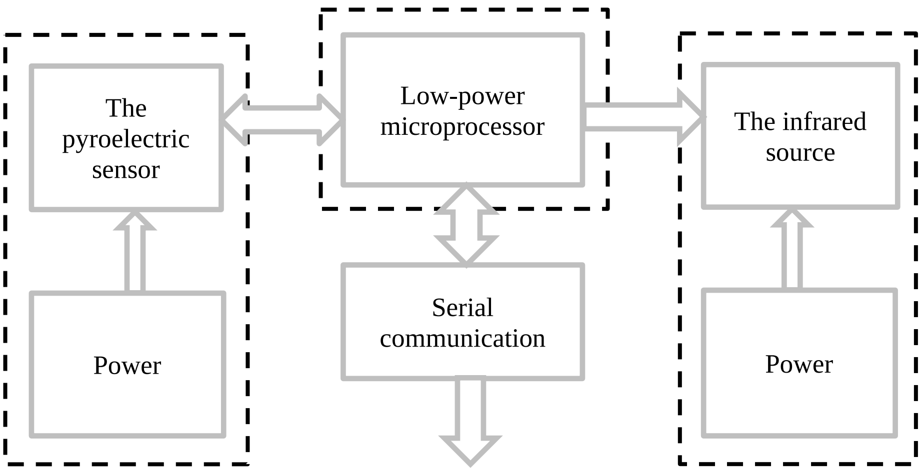

Fig.2 The main modules of gas monitoring sensors [8]

Compared to traditional methods of forest fire detection, the proposed system based on wireless sensor networks and artificial neural networks offers real-time monitoring of environmental parameters, such as the concentration of carbon monoxide, temperature, and humidity, which can quickly assess potential fire hazards and predict the speed and direction of fire propagation. By focusing on a small number of key factors, this system provides a comprehensive approach to countering forest fire threats.

This article includes an Introduction, Research Significance, Materials and Methods, Results and Discussion, and Conclusions. The "Materials and Methods" section describes the ZigBee-based wireless sensor network model and methods used. Research Significance highlights the system's role in forest fire prevention and mitigating climate change. Results and Discussion illustrate the system's advantages, and the Conclusions section summarizes potential applications and future research.

2. RESEARCH SIGNIFICANCE

This study proposes a wireless sensor network for early detection and prevention of forest fires, which has the potential to reduce loss of life, property, and natural habitats. The study emphasizes the technology's role in mitigating the effects of climate change by providing an early warning system for forest fires. The ZigBee system's use enables accurate real-time monitoring of parameters, giving a quick assessment of potential hazards and predicting fire speed and direction. This comprehensive approach provides more accurate results than previous studies, which relied on traditional methods of forest fire prevention. The study highlights research gaps and future applications in this area, which could have significant implications for preserving the natural environment.

3. MATERIALS AND METHODS

The theoretical basis of the study was the works of leading scientists in the field of the greening of forestry activities. The study used methods: analysis, system-structural, economic-statistical, comparative, and modeling. Through the analysis of the system of state forest management, the authors highlighted a number of key issues that require legal and institutional settlement. The system-structural method was used to study the essence and content of the organizational and economic mechanism of the greening of the forest complex. The economic-statistical method was used in the ecological and economic analysis of the current state and efficiency of the forest complex. The comparative method was used to estimate the existing systems for forecasting forest fire hazards on remote sensing and their limitations. The modeling was used to visualize the situation. The object of the study is a wireless sensor network model based on the ZigBee protocol (Figure 3).

The wireless sensor network is made up of numerous and ubiquitous microsensor nodes that have the ability to communicate and predict. Figures 4, 5 show the structure of the sensor assembly. ZigBee is a low-speed, low-cost, and low-power short-range wireless communication protocol. The main feature of ZigBee technology is that, with low power consumption, it supports not only simple network topologies (point-to-point, tree and star), but also a self-organizing and self-healing mesh topology with forwarding and routing of messages. In addition, the ZigBee specification contains the ability to select a routing algorithm depending on application requirements and network conditions, an application standardization mechanism – application profiles, a library of standard clusters, endpoints, bindings, a flexible security mechanism, and also provides ease of deployment, maintenance and modernization.

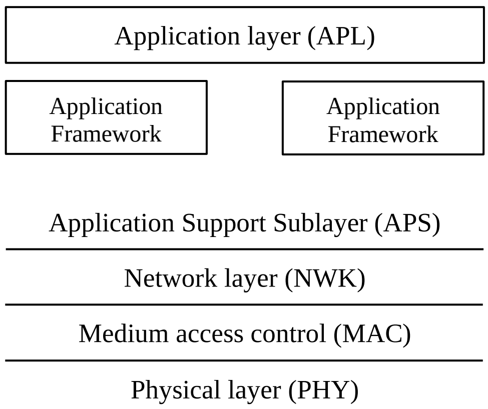

Fig.3 The ZigBee protocol [14]

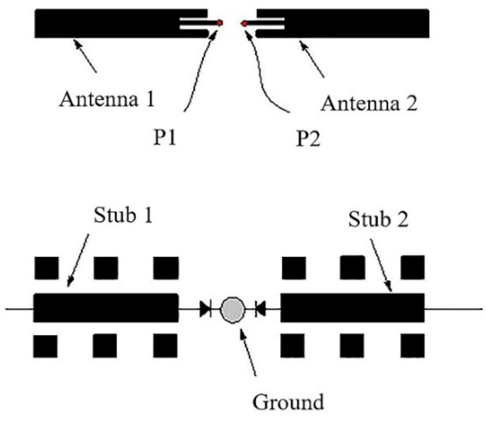

Fig.4 Microstrip antenna diagram, front and back views

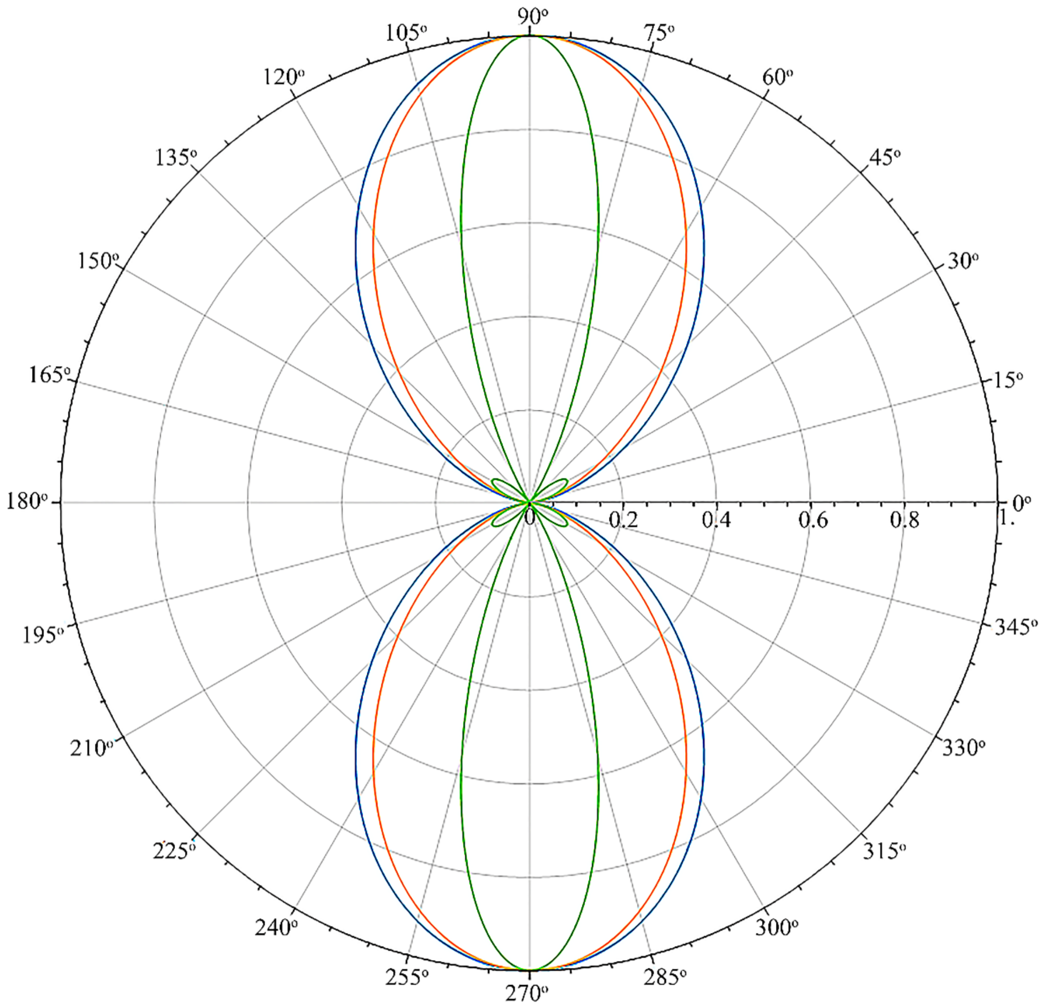

Fig.5 The radiation pattern of the proposed antenna, "narrower" lobes – for higher frequencies

4. RESULTS AND DISCUSSION

The design of the sensor unit in Figure 6 shows a schematic diagram of the transducer assembly. The CC2430 chip, recently released by Chipcon, is the main chip used in node hardware design. It is a SoC CMOS chip, which has a high performance, low power consumption 8051 microprocessor chip, a built-in 14-bit A/D conversion ADC, and a 2.4 GHz RF transceiver complying with IEEE802.15.4 standard. This chip has good wireless reception sensitivity and excellent anti-interference capability. In the receiving and transmitting modes, the current loss is less than 27 or 25 mA, respectively. SHT11, an integrated I2C bus digital relative humidity and temperature sensor manufactured by Sensirion, Switzerland, is used in the sensor assembly. This sensor has some of the most advanced features, such as a digital output, requires no setup or calibration, has an automatic dormant state, and can be completely submerged in water.

The system is completely based on measuring the readings of carbon monoxide sensors, humidity, and temperature in the vicinity of the installed mini-station using built-in sensors. The measured value data is transmitted to the servers via a real-time reconfigurable wireless network. The collected data, after processing, is used to optimize and manage the forestry cleaning process. Data on temperature and humidity help to highlight locations with an increased fire hazard; such locations move to the first places in the list of assigned tasks for clearing teams. Clearing teams arriving at the specified location perform work that minimises the fire hazard. These works may include but are not limited to the removal of dead wood, the creation of fire ditches if there is a peat bog at the location, washing-down the territory with water. Thanks to this automated decision-making system, the clearing team gets new routes every day to visit and clean up forestry sites if necessary and to ensure that dead wood does not accumulate uncontrollably. The end result is a cleaner, safer forest with lower expenses and less manual labour. The collected data is used to statistically analyze the likelihood of a forest fire and to assess possible factors in reducing the fire hazard.

Data collected from local sensors are organized into data systems using software such as MySQL. Based on the collected data, statistical analysis helps to determine the possible speed of the spread of a forest fire on the ground to draw up a probable map of the spread of fire in accordance with the weather conditions that occurred on the date of the forecast and the weather conditions forecast for the next ten days. In this case, the weather conditions on the forecast date are taken directly from the field sensor networks. The AI also simulates the most appropriate routes that the clearing team must regularly follow. In addition, the timing of data collection from sensors on the ground emphasizes that at different times and under different weather conditions, priority should be given to different places, locations and routes. In some places, more accelerated drying of wood residues occurs than in others, and this is primarily due to the direction of the prevailing winds and the amount of precipitation; in summer, precipitation can be highly uneven. For example, locations were observed separated by a hundred meters of distance, in which after a short rain, the relative humidity of the coniferous litter differed by tens of percent. In addition, there are some anthropogenic locations that require the most careful monitoring and cleaning compared to open areas with less human presence.

Thus, as soon as AI is introduced into the system, routes are determined and optimized depending on the time and the corresponding need. Optimization techniques: Using the recorded data, the system uses AI and optimization techniques. This is optimized for traffic as well as distance and travel time. As a result of the optimization, the vehicle drivers of the clearing team receive a highly efficient route, complemented by GPS positioning services, and forestry gets fire prevention. The main advantages and disadvantages of this approach are indicated in Table 2. Fire hazard conditions are the most important part of integrated fire management [15, 16] due to their widespread application (e.g., forest preconditions, the definition of the prescribed combustion zone, reduction of intensive survey operations, rapid fire detection and deployment of fire departments, etc.), thus the study at hand is in the mainstream of the development of problems. Over the past several decades, remote sensing-based techniques have been investigated for fire hazard management operations [1]. These methods are divided into two main groups: fire hazard monitoring systems and fire hazard prediction systems. In this context, the study combines these two approaches. In particular, for monitoring fire hazard conditions, some environmental variables are extracted from optical, thermal and radar images and studied separately and/or in combination [17, 18], while our approach involves collecting data from a network of sensors located in the field, furthermore, since fire hazard conditions determine the likelihood of a fire occurring, these methods are unsuccessful as they attempt to capture hazardous conditions during and/or after a fire occurs.

However, for forest fire disaster monitoring, fire detection data based on the considered approach will be available on a daily time scale that is fully operational and used by fire managers for fire suppression strategies. The application of remote sensing techniques to predict fire hazard conditions will thus lag behind developments, while the considered approach will provide relevant agencies with the most relevant information [19-21]. Other studies related to forest monitoring and prevention systems include [1; 4] hotspot classification for forest fire prediction using the C5.0 algorithm, [2; 8; 22; 23] forest fire monitoring via uncrewed aerial vehicle image processing based on a modified machine learning algorithm, and [3; 6; 12] a generalized net model of forest zone monitoring by unmanned aerial vehicles.

Table 2 The advantages and disadvantages of the use of WSN model based on the ZigBee protocol for forest fire monitoring and prevention

No	Advantages		Disadvantages	
1	Low Power Consumption	It enables the network to operate for a longer duration without the need for frequent battery replacements or recharging.	Limited range	Compared to other wireless communication technologies, ZigBee protocol-based WSNs may require more nodes to cover a larger area.
2	Cost-effective	The cost of ZigBee-based WSNs is relatively low, making it more accessible.	Interference	The ZigBee protocol operates in the 2.4 GHz frequency range, which can be subject to interference from other wireless devices.
3	Mesh network topology	It provides multiple communication paths between nodes, which can increase the reliability and fault tolerance of the network.	Security concerns	The use of wireless communication may pose security risks such as unauthorized access, data tampering, and eavesdropping.
4	Robustness	ZigBee protocol is highly robust and can tolerate harsh environmental conditions, such as high temperatures, humidity, and smoke.	Complexity	The deployment and maintenance require specialized skills and knowledge, which may increase the complexity and cost of the system.
5	Scalability	It allows for the addition of new nodes to the network easily	Latency	Latency issues may affect the response time of the system during an emergency situation.

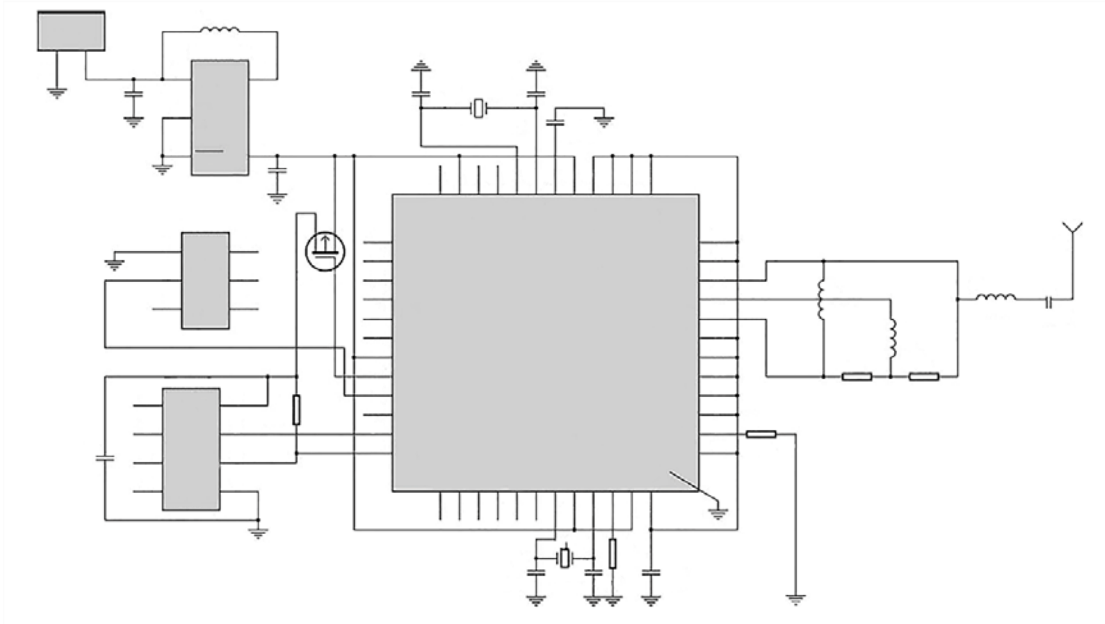

Fig.6 Field sensor schematic diagram

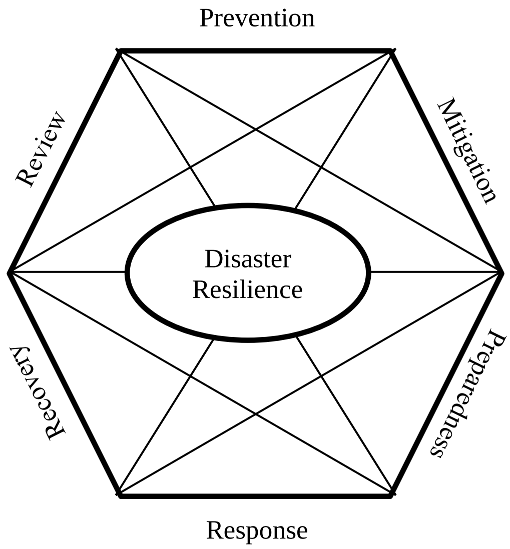

Fig.7 Wildfire management phases [15]

Compared to most fire prediction systems that have moderate range and coarse spatial resolution, the proposed system measures data in situ, providing a faster response time. The study highlights the advantages of in situ data collection over remote sensing techniques. The proposed system has significant potential to reduce the likelihood of forest fires and lowering expenses associated with manual labor.

Furthermore, the proposed system can also be integrated with existing forest management practices to provide a comprehensive approach to forest fire prevention. For example, in addition to fire hazard monitoring and prediction, the proposed system can also provide real-time data on weather conditions, which is a critical factor in fire prevention [15], [17], [24]. This information can be used to determine when to implement fire restrictions and to allocate firefighting resources.

In addition to forestry, the proposed system can be applied to other sectors, such as agriculture, where it can be used to monitor crop conditions and detect potential hazards such as pests and diseases [6; 25]. Similarly, it can be used in urban areas to monitor air quality and detect potential fire hazards in buildings [16; 26].

By combining data collection with advanced monitoring and prediction techniques, the system provides a faster and more effective response to potential fire hazards. As such, it has the potential to save lives and reduce the economic and environmental impact of forest fires.

5. CONCLUSIONS

This study proposes a new approach to prevent and monitor forest fires using a neural system with wireless sensor networks. This system can monitor real-time parameters such as temperature, carbon monoxide, wind force, and humidity to evaluate potential fire hazards and predict fire speed and direction. The system's cluster tree topology structure is advantageous over traditional reticular structures in creating a smaller memory footprint and being easier to set up.

The use of AI based on neural networks helps to cope with the task of assessing the risk of fire. The proposed system offers real-time monitoring of environmental parameters and provides a comprehensive approach to countering forest fire threats by focusing on a small number of key factors. Compared to traditional methods of forest fire detection, the system based on wireless sensor networks and artificial neural networks can quickly assess potential fire hazards and predict the speed and direction of fire propagation, which is crucial for preventing and monitoring forest fires in the present and future. Overall, the proposed approach shows the integrity and completeness needed to combat the growing threat of forest fires.

The system is a valuable addition to current forest fire prevention and monitoring methods with the potential to preserve natural habitats, property, and human lives. However, there are several challenges to address, such as power consumption, node placement, and clock synchronization. In addition to the technical challenges, there are also social and economic challenges that need to be addressed in implementing the proposed system. For example, the system requires significant investment in terms of hardware and infrastructure, and it may be difficult to convince stakeholders of the value of this investment, particularly in areas where forest fires are rare.

To address these challenges, it is important to engage with stakeholders and local communities to raise awareness of the benefits of the system and to involve them in the design and implementation process. Collaboration between different sectors, such as government, academia, industry, and civil society, can also help to address the social and economic challenges and to ensure that the system is sustainable in the long term.

Future research could focus on developing more efficient algorithms for data analysis and incorporating more sophisticated machine-learning models. Integrating the system with other technologies, such as unmanned aerial vehicles, can enhance its monitoring capabilities. Further research could investigate the potential of this system for environmental monitoring and disaster response beyond forest fire prevention. This study is a significant step forward in developing wireless sensor networks for monitoring and preventing forest fires, highlighting the potential of technology to mitigate the effects of climate change.

The manuscript contributes to the academic dialogue on the topic of forest fire prevention by proposing a new approach based on wireless sensor networks using the ZigBee protocol. The existing methods and systems for forest fire hazard forecasting and monitoring are analyzed and the advantages of the proposed approach are highlighted. The manuscript also provides evidence of the performance and usefulness of the proposed system, suggesting that it can be used as an addition to existing methods for monitoring and preventing forest fires. The manuscript promotes academic dialogue by contributing a new approach to the field of forest fire prevention and highlighting the advantages of using WSNs based on the ZigBee protocol. It also presents potential future work that can be done to improve the technology for monitoring forest fires, such as addressing power consumption, node placement, and clock synchronization.

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