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A Real Time Forest Fire Detection and Alerting System using LoRa Module

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Abstract: *The need for efficient fire detection systems is highlighted by the substantial threats that forest fires pose to both human lives and the ecosystem. Limited coverage, high false alarm rates, and delays in signal transmission are just a few of the problems traditional methods for detecting forest fires sometimes encounter. This research study suggests a unique strategy that uses longrange (LoRa) communication technology for forest fire detection to address these problems. LoRa allows for long-range, low-power wireless communication, making it appropriate for installation in sparsely populated, off-the-grid forest areas. This study investigates the development, application, and assessment of a LoRa-based forest fire detection system. The suggested system includes a network of sensor nodes outfitted with LoRa transceivers and fire detection sensors. The sensor nodes send real-time data to a centralized control center while continuously monitoring environmental variables like temperature, humidity, and smoke. Complex algorithms are used by the control center to analyses the data it receives and identify probable fire issues. When a fire is discovered, the system immediately creates notifications and sends them to the appropriate authorities and local communities. Numerous field tests were carried out in various forest settings to gauge the success of the suggested strategy. The outcomes show the system's capacity for precise fire detection, minimal false alarm rates, and quick response times. A viable option for early forest fire detection and prevention, the LoRa-based system also shown its benefits in terms of broad coverage, long-range communication, and energy economy. This study advances forest fire management systems by laying the groundwork for the creation of reliable, scalable, and affordable fire detection technologies that can lessen the devastation caused by forest fires. This research paper's main goal is to offer a thorough analysis of the development, use, and evaluation of a LoRa-based forest fire detection system.*

Keywords: Forest Fire, Detection, LoRa Module, Sensors

I. INTRODUCTION

Forest fires are a major cause for concern on a global scale since they harm ecosystems severely, threaten biodiversity, and endanger people's lives and property. The deadly impact of these fires can be lessened with prompt discovery and action. The breadth, accuracy, and response times of conventional forest fire detection techniques, such as human observation and satellite photography, are constrained. As a result, there is an increasing demand for creative solutions that can get around these obstacles and improve forest fire early warning systems. Wireless sensor networks (WSNs) have become a promising technology for disaster management and environmental monitoring in recent years. WSNs are made up of a large number of autonomous sensor nodes that can monitor different environmental conditions, gather information, and wirelessly transfer it to a centralised control point. This research focuses on the integration of Long Range (LoRa) communication technology into forest fire monitoring systems by utilising the capabilities of WSNs. LoRa technology allows for long-distance, lowpower communication, making it especially well-suited for deployment in harsh, outlying areas like woods. LoRa's increased range makes it possible to build out a widespread coverage network, guaranteeing that even vast forest regions may be properly monitored. Additionally, LoRa's low power consumption makes it possible for sensor nodes to run on battery power for an extended period, which eliminates the need for regular maintenance and power supply in isolated forest sites. The suggested system consists of a network of sensor nodes that are deployed strategically across the forest and are outfitted with LoRa transceivers and fire detection sensors. By continually monitoring environmental variables including temperature, humidity, and smoke levels, these sensor nodes allow for the early identification of possible fire issues. Real-time transmission of the sensor nodes' collected data to a centralised control centre allows for the real-time analysis of the data to look for indicators of fire. When a fire is discovered, the system quickly creates alerts and distributes them to the appropriate authorities and adjacent populations, enabling quick reaction and evacuation procedures. Extensive field experiments were carried out in various forest ecosystems, mimicking various fire scenarios, to evaluate the performance of the proposed system in terms of accuracy, false alarm rates, and response time. The test results demonstrate the effectiveness of the LoRa-based forest fire detection system by showing that it can effectively detect fires, reduce false alarms, and send out quick alerts for efficient fire management. The proposed system holds significant promise for improving early warning systems and boosting the effectiveness of forest fire detection and prevention by utilising the benefits of LoRa communication, including long-range coverage, low- power consumption, and robustness in challenging environments.

II. PROBLEM STATEMENTS

The most common hazard in forests is forests fire. Forests fires are as old as the forests themselves. They pose a threat not only to the forest wealth but also to the entire regime to fauna and flora seriously disturbing the bio- diversity and the ecology and environment of a region.

During summer, when there is no rain for months, the forests become littered with dry senescent leaves and twinges, which could burst into flames ignited by the slightest spark. The Himalayan forests, particularly, Garhwal Himalayas have been burning regularly during the last few summers, with colossal loss of vegetation cover of that region.

Forest fire causes imbalances in nature and endangers biodiversity by reducing faunal and floral wealth.

Traditional methods of fire prevention are not proving effective and it is now essential to raise public awareness on the matter, particularly among those people who live close to or in forested areas.

III. OBJECTIVES

At earlier times, forest fires were detected using watchtowers, which were not efficient because they were based on human observations. In recent history and even the present day, several forest fire detection methods have been implemented, such as watchtowers, satellite image processing methods, optical sensors, and digital camera- based methods2, although there are many drawbacks, such as inefficiency, power consumption, latency, accuracy and implementation costs. To address these drawbacks, a forest fire detection system using wireless sensor networks is proposed in this paper.

Wireless sensor networks (WSNs) are self-configured and infrastructure-free wireless networks that help monitor physical or environmental conditions and pass these data through the network to a designated location or sink where the data can be observed and analyzed3. Efficiency and low power consumption are the major advantages of a WSN. In the proposed detection system, wireless sensor nodes are deployed according to cellular architecture to cover the entire area with sensors to monitor temperature, relative humidity, light intensity level, and carbon monoxide (CO) level using a microcontroller, transceiver module, and power components. The power supply to the sensor node is provided using batteries as the primary power supply, and solar panels are used as the secondary power supply. These sensor nodes are specially designed with a spherical shape to withstand damage caused by environmental conditions as well as animals.

IV. LITERATURE REVIEW

Surapong Surit, Watchara Chatwiriya [8] proposed a method to detect fire by smoke detection in video. This approach is based on digital image processing approach with static and dynamic characteristic analysis. The proposed method is composed of following steps, the first is to detect the area of change in the current input frame in comparison with the background image, the second step Is to locate regions of interest (ROIs) by connected component algorithm, the area of ROI is calculated by convex hull algorithm and segments the area of change from image, the third step is to calculate static and dynamic characteristics, using this result we decide whether the object detected is the smoke or not. The result shows that this method accurately detects fire smoke. P. Piccinini, S. Calderara, and R. Cucchiara [2] proposed a method based on the wavelet model and a color model of the smoke. The proposed method exploits two features: the variation of energy in wavelet model and a color model of the smoke. Smoke is detected based on the decrease of energy ratio in wavelet domain between background and current. The deviation of the current pixel color is measured by the color model. Bayesian classifier is used to combine these two features to detect smoke.Fire based on Wavelet Transform. Stationary Wavelet Transform is used to detect Region of Interest. This method involves three steps preprocessing, SWT, histogram analysis. In preprocessing unwanted distortions are removed and image is resized and transformation of resized image is performed. High frequencies of an image are eliminated using SWT and the reconstruction of image is done by inverse SWT. Image indexation is performed to group the intensity colors that are closed to each other. Histogram analysis is used to determine the various levels of indexation. After analysis a comparison is made with nonsmoke frame and non-smoke images are eliminated. These three are combined and fire is detected.

V. LIMITATIONS OF EXISTING SYSTEM

Rising temperatures and intensified evaporation caused by climate change are leading to more frequent and more severe forest fires across the world. There are about 67 million hectares of forest land being burned every year from 2003 to 2012 and roughly 4.5 million fires were recorded globally in 2019 alone by Global Forest Watch (GFW). In Brazil, some 2136 VIIRS fire alerts within one week from June 21^{st} 2022 to June 28^{th} 2022 were recorded (GFW, 2022). Nearly half were detected to be high confidence alerts indicating that damage caused by each fire has been detected in multiple Landsat satellite images.

Forest fires can occur due to both natural and anthropogenic factors. One typical natural ignition source is lightning, which contributes to approximately one-third of the forest fires that take place in the global north summer months. Human activities that can result in forest fires include land clearing for agriculture and forestry. Farmers and businesses usually prefer land clearing as it is one of the easiest and most cost-efficient means for site preparation. Hence, a lack of supervision for the widely used large-scale clearing can lead to disastrous fires.

VI. RESEARCH GAPS AND CHALLENGES

Research gaps

Brazil is in world news every year due to the occurrence of large forest fires in its ecosystems. Although there is an evident need for environmental conservation in the country, no studies have identified gaps in forest fires in Protected Areas (Pas). Despite being important conservation tools, Pas have been implemented in the country without strategic planning and are often the target of fire events. Herein, we aimed to identify the patterns of publications, the improvements, and the scientific gaps regarding the occurrence of forest fires in Brazilian Pas in order to guide the direction of future research. We carried out a bibliometric review using all the research published on the theme indexed in the Scopus database up until 2020. We analyzed 135 publications distributed in 74 journals. We observed a growing interest in the theme, with greater scientific demand after the 2000s; as well as a wide network of collaboration between Brazilian and international institutions. The Cerrado was the most studied biome; however, the Caatinga, Pampa, and Pantanal biomes are not being considered in the development of these studies. The most frequent kinds of studies were publications on plants' responses to fire passage. Studies related to firefighting efficiency and to fire-climate and fire-fauna relationship require more attention. Our results will enable researchers to be directed toward key themes and will assist them in the possibility of partnerships and alliances. Greater efforts and incentives should be made to implement new research that fills the existing gaps.

Research Challenges

As we all know; the forest is considered one of the most important and indispensable resources. Forest fires represent a constant threat to ecological systems, infrastructure, and environmental aspects of a community. Forest fire detection is a very important issue in the pre- suppression process. Among the great disasters on this earth are forest fires. Many attempts to detect disaster events have been made with the aid of monitoring technology. Nevertheless, the problem is that the sensor is less responsive in detecting the presence of the fire. Moreover, sending data about fire incidents throughout the forest cannot use the existing communication podium. Thus, the design of a forest fire monitoring system is required. This technology is based on wireless, which can transmit information across the forest. To detect the presence of fire, an Arduino microcontroller is used as the brain of the research to regulate input from the AMG8833 sensor and GPS Ubox 6M. In the research, it is seen that the AMG8833 sensor is more sensitive in detecting the presence of fire as the catch range changes between 2.5 to 10 meters. In that distance range, hotspots were detected from 19.25 °C to 122.5 °C when testing of the sensor node was done

VII. SYSTEM REQUIREMENTS

Functional Requirements

Here's a more detailed breakdown of functional requirements:

Fire Detection:

- The system should be capable of detecting smoke, flames, heat signatures, and other indicators of a fire.
- It should be able to distinguish between true fire and false positives (e.g., non-fire heat sources, specific weather conditions).
- The system should be sensitive enough to detect fires at an early stage, before they become large and difficult to control.

Real-time Alerts:

- The system should send immediate alerts to designated personnel or authorities upon detection of a fire.
- Alerts should include the location of the fire, the time of detection, and potentially other relevant information.
- Alerts should be delivered reliably and promptly, even in areas with limited or no internet connectivity.

Fire Localization:

- The system should be able to pinpoint the exact location of the fire using GPS or other geolocation techniques.
- Localization accuracy should be sufficient to guide fire suppression efforts efficiently.

Non-Functional Requirements

Predictive Models:

- Machine learning models, such as Random Forest (RF), Support Vector Machines (SVM), and Multi-Layer Perceptron (MLP), are used to predict fire susceptibility based on factors like weather, terrain, and vegetation.

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The performance of these models, often evaluated using metrics like AUC (Area Under the Receiver Operating Characteristic curve), directly impacts the accuracy of fire risk assessments.

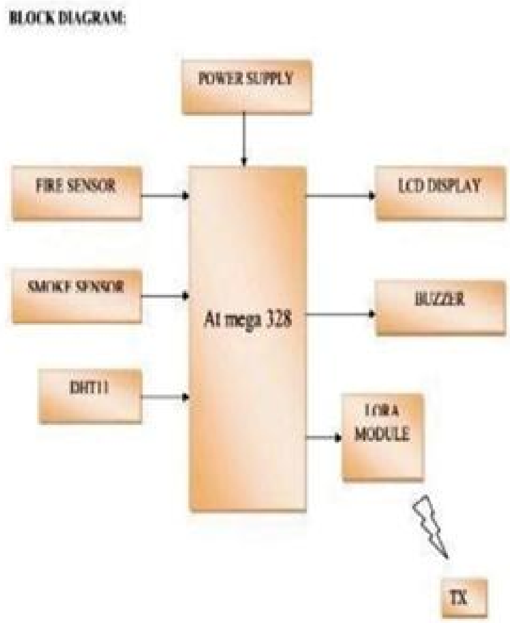
Detection Systems:

- Techniques like video-based fire detection using visible and infrared spectrums are used to identify fires in real-time.
- The performance of these systems, including their ability to distinguish between fire and other visual cues (like fog or artificial lights), affects their reliability.

Monitoring Networks:

- Internet of Things (IoT) technologies, such as LoRaWAN, are used to establish monitoring networks for detecting air quality parameters and other relevant data in remote areas. The performance of these networks, including data transmission speed and reliability, is crucial for timely fire detection and response.

VIII. PROPOSED METHODOLOGY & DESIGN



Block diagram 1: Forest unit

Proposed System

Detection & Early Warning:

- IoT-based Sensors: Deploy a network of low-cost sensors (temperature, humidity, smoke, flame) to monitor environmental conditions and detect fire ignition. Drone-Based Surveillance: Utilize drones equipped with cameras (RGB, IR) and other sensors for real-time monitoring and early detection of fire events.
- Satellite Imagery: Employ satellite imagery to monitor large areas, identify potential hotspots, and track fire spread.
- Machine Learning Models: Develop AI-powered models to analyze sensor data and predict fire risk based on weather patterns, vegetation types, and historical data

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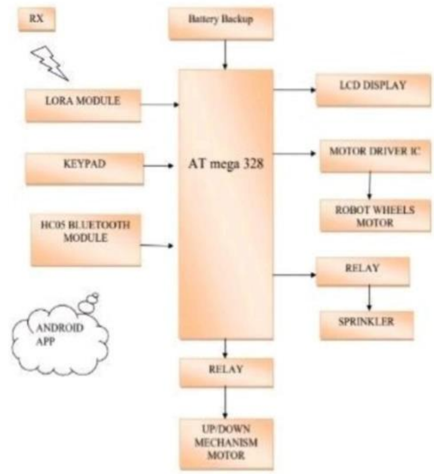


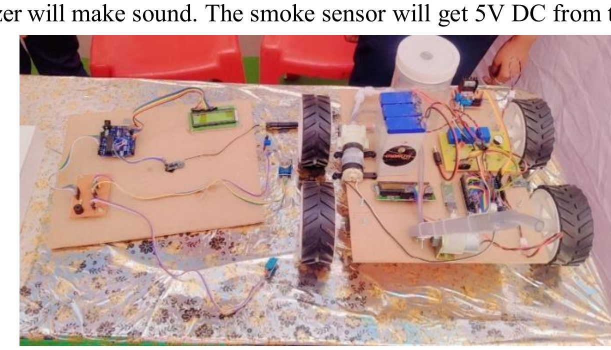
Block diagram 2: Robot unit

Proposed Methodology

A methodology to estimate the extent of areas affected by forest fires, as well as the burn severity levels using Sentinel 2 images (10 and 20 m) is proposed and applied to the fires occurred in October 2017 in Spain and Portugal. An extension larger than 250,000 ha and 4 burn severity levels (low, moderate, high and very high) have been obtained. The comparison with the European Forest Fire Information System (EFFIS), which uses MODIS images (250 m), shows that the methodology improves the area estimate by 10 % in commission area. In terms of burn severity levels, the Separability index (SI) and the Kappa statistic (k) show a high correlation between Sentinel-2 and EFFIS (SI values higher than one in all cases and k higher than 0.69, respectively).

Fire Detection :-

The components we are using for our proposed system are LoRa module, Arduino uno Microcontroller, Fire Sensor, Buzzer, LCD, Smoke Sensor, Power Supply and Temperature Sensor. We have made 2 block diagrams (Fig. 1 & Fig. 2) for this project and the explanation of working of the system is given below. There are 2 sections of the hardware, one is the sender module and other is the receiver module Both the sections communicate with each other with the help of the LoRa module. LoRa module will get 3.3V DC from the arduino module. 12V adapter is connected to the electrical socket and the circuit 1 . The sensors connected in the circuit 1 will start working. The sensors will send all information to ESP32 module, which will send all information through LoRa module to the Google Firebase. Even the same information will be displayed on the LCD i.e., in circuit 2. After all the data is transferred to the firebase cloud, then it will send those data to the UI application through its API. The fire sensor will be getting 5V DC from the power supply and the fire sensor will detect flames along with sending signal to the arduino module which will send an alert message to the application and the buzzer will make sound. The smoke sensor will get 5V DC from the power supply.



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IX. OUTCOME

Early forest fire detection, achieved through various technologies like satellite imagery and sensor networks, leads to several positive outcomes, including reduced environmental damage, improved resource management, and enhanced public safety. These systems provide real- time monitoring, allowing for faster response times to contain fires and minimize their spread.

Here's a more detailed look at the outcomes:

Reduced Environmental Impact:

Early Detection:

- Early detection enables faster intervention, preventing fires from escalating and causing widespread damage to forests and ecosystems.

Minimized Damage:

- By limiting the extent of fires, detection systems help preserve valuable resources like timber, biodiversity, and soil health.

Reduced Smoke and Pollution

- Containing fires reduces the amount of smoke and pollutants released into the atmosphere, improving air quality and reducing health risks.

Improved Resource Management:

Efficient Planning:

- Real-time fire detection provides valuable information for resource managers to make informed decisions about fire suppression strategies, including personnel deployment and resource allocation.

Cost Savings:

- By preventing large-scale fires, early detection can significantly reduce costs associated with fire suppression and long-term recovery efforts.

Better Monitoring:

- Detection systems allow for ongoing monitoring of forest health and fire activity, enabling proactive management of potential hazards.

X. RESULT

We designed experiments to evaluate the performance of the pre-trained models based on feature extraction, fine-tuning, and learning without forgetting. Since the proposed models are deeper, we have used GPU-enabled kernels from Kaggle to train them. Tensorflow and Keras frameworks are used for training the models. The models have been trained using the hyperparameters presented in Table 2. Table 3 shows the tuned values of hyperparameters that generated the best results during training. The models were run for 100 epochs, but we stopped them early. Early stopping is a method in which the model is trained for an arbitrary number of epochs and then stopped when there is no improvement in validation accuracy or reduction in validation loss. As mentioned earlier, we did two different sets of experiments. We took out the classifier from these models and added our own classifier so we could do these experiments. We added two fully connected layers and a softmax layer to VGG16. One fully connected layer and one softmax layer have been added to InceptionV3 and Xception. While fine-tuning the models, we have retrained 5, 8, and 7 top layers of VGG16, InceptionV3, and Xception respectively.

We compared the models to the test data to find out how well they worked. Table 4 gives a summary of how well all of the proposed models have been tested and validated.

XI. CONCLUSION

To mitigate the catastrophic impact of wildfires, it is critical to correctly and rapidly detect active flames in their early stages. There are a very few studies that focus on monitoring ongoing flames in near real-time using deep learning methods. In this work, we investigated the transfer learning of pre-trained models for detecting forest fire/smoke. We

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used the models to extract features and fine-tune them. The results indicate that the Xception-based model outperformed all other models with 98.72% accuracy. To preserve the characteristics of the old dataset, we employed LwF and found that it outperforms feature extraction. More interestingly, fine-tuning the new task with LwF performed comparatively well on original dataset when using fine-tuned parameters. Recent studies indicate that it is critical to detect fire mishaps quickly and accurately in their early stages to prevent them from spreading. As a consequence, we want to continue our study in this field and enhance our findings. In the future, we plan to apply the latest CNN models to rapidly identify fire occurrences with a low rate of false positives. Further, we like to explore more on LwF and multitask learning

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