Performance Analysis of Forest Fire Detection Techniques- A Review

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Abstract- *Forest Fire and House fire is one of the major concerns for designers, builders, and residents of property. In the case of detecting fire, individual sensors have been used for a long time, but they cannot detect the level of fire and notify the emergency response units. To solve this problem, this study attempts to propose an intelligent early fire detection system that would not only detect the fire by using integrated sensors but also notify the appropriate authorities including fire department, ambulance services, and local police station simultaneously to protect valuable lives and properties. Signals from the integrated detectors e.g., temperature, smoke, and flame go through the machine learning algorithms to check the potentiality of the fire as well as broadcast the predicted result to various parties using a GSM modem. To consolidate the predicted output, structured forest for fast edge detection has also been applied. The final outcome of this development also minimized false alarms, thus making this system more reliable.*

Keywords- Wireless sensor networks, Internet of Things, Artificial Nural Network, Long Short-Term Memory

I. INTRODUCTION

With the rapid spread of urbanization in the world, both the number of permanent residents in cities and the population density are increasing. When a fire occurs, it seriously threatens people's lives and causes major economic losses. According to incomplete statistics, there were 312,000 fires in the country in 2016, with 1,582 people killed and 1,065 injured, and a direct property loss of 3.72 billion dollars [1, 2]. In March and April of 2019, there were many large scalefire accidents around the world, such as forest fires in Liangshan, China, the Notre Dame fire in France, forest fires in Italy, and the grassland fire in Russia, which caused great damage to people's lives and property. Before, fire detection is vitally important to protecting people's lives and property. Current detection methods in cities rely on various sensors for detection, including smoke alarms, temperature alarms, and infrared ray alarms. Although these alarms can play a role, they have major flaws. First, a certain concentration of particles in the air must be reached to trigger an alarm. When an alarm is triggered, a fire may already be too strong to control, defeating the purpose of early warning. Second, most of the alarms can only be functional in a closed environment, which is ineffective for a wide space, such as outdoors or public spaces. Ird, there may be false alarms. When the n non-fire particle concentration reaches the alarm concentration, it was automatically sound the alarm. Human beings cannot intervene and get the latest information in time. To prevent fires and hinder their rapid growth, it is necessary to establish a monitoring system that can detect early fires.

There are several techniques used for forest fire detection, each employing different technologies and approaches. Here are some commonly used techniques:

1. Remote Sensing: Remote sensing involves the use of satellites or airborne sensors to gather information about the Earth's surface. Satellites equipped with thermal infrared sensors candetect the presence of fires by measuring the emitted heat radiation. These sensors can identify hotspots and provide real-time information about fire locations and intensities.
2. Image Processing: Image processing techniques, as discussed earlier, analyses images or videos captured by cameras placed in or above the forested areas. These techniques involve pre-processing, segmentation, feature extraction, and classification to identify and locate regions of fire within the images.
3. Infrared and Thermal Imaging: Infrared (IR) and thermal imaging cameras can detect the thermal radiation emitted by fires, even in conditions where smoke or other visual obstructions may hinder traditional image processing methods. These cameras can detect the high-temperature signatures associated with fires, allowing for early detection and accurate fire mapping.
4. Wireless Sensor Networks: Wireless sensor networks consist of a network of interconnected sensor nodes deployed in forested areas. These nodes are equipped with various sensors to monitor environmental parameters such as temperature, humidity, and smoke. Deviations from normal values can indicate the presence of a fire, triggering an alert to the monitoring station.

5. Acoustic Sensors: Acoustic sensors can be deployed in forested areas to detect the distinct sound patterns produced by fires. These sensors can capture the crackling and popping sounds generated by burning vegetation, providing early warnings of fire outbreaks.
6. Gas and Smoke Detection: Forest fires release various gases and smoke particles that can be detected using specialized sensors. Thesesensors can measure the concentration of gases such as carbon monoxide, carbon dioxide, and volatile organic compounds (VOCs) in the air, indicating the presence and severity of a fire.
7. Unmanned Aerial Vehicles (UAVs): UAVs, commonly known as drones, equipped with various sensors and cameras, can be deployed for forest fire detection. They can capture high-resolution images and videos, monitor fire behavior, and relay real-time data to fire management teams for rapid response and decision-making.
8. Artificial Intelligence (AI) and Machine Learning: AI and machine learning techniques can be applied to various data sources, including satellite imagery, camera feeds, and sensor data, to develop models for automated forest fire detection. These models can learn patterns and features associated with fires, enabling accurate and timely detection.
9. Multispectral Imaging: Multispectral imaging involves capturing images in multiple spectral bands beyond the visible spectrum, such as near-infrared (NIR) and short-wave infrared (SWIR). By analyzing the reflectance patterns in different spectral bands, it is possible to identify the unique characteristics of burned areas and distinguish them from unburned regions.
10. LiDAR (Light Detection and Ranging): LiDAR technology uses laser beams to measure the distance and elevation of objects on the Earth's surface. By combining LiDAR data with other remote sensing data, such as imagery or thermal information, it is possible to detect changes in the forest structure caused by fire, such as canopy damage or changes in vegetation height.
11. IoT (Internet of Things) Networks: Internet of Things networks can be established in forestedareas with strategically placed sensors that monitor environmental conditions such as temperature, humidity, wind speed, and air quality. Sudden changes or abnormal readings can indicate the presence of a fire and trigger an alert.
12. Wireless Communication Networks: Wireless communication networks can be deployed in remote forested areas to establish connectivity between different monitoring systems, such as cameras, sensors, and control centers. These networks enable real-time data transmission, facilitating coordinated fire detection and response efforts.
13. GIS (Geographic Information System): Geographic Information System technology can integrate data from various sources, including satellite imagery, topographic maps, and weather data, to create a comprehensive spatial database. By overlaying fire-related data onto these maps, it becomes easier to visualize, analyze, and manage fire incidents.
14. Social Media and Crowdsourcing: Social media platforms and crowdsourcing techniques can be used to gather real-time information about fire incidents from people on the ground. Reports, images, and videos shared by users can provide valuable insights and enhance situational awareness for fire management teams.
15. Early Warning Systems: Early warning systems combine data from multiple sources, such as weather forecasts, fire history, and real-time sensor data, to assess the risk of fire outbreaks. By analyzing these factors, these systems can issue alerts and warnings to stakeholders, helping them prepare for potential fire incidents.
16. Fire Radiative Power (FRP) Detection: FRP is a measure of the rate at which a fire emits energy. Satellites equipped with sensors sensitive to thermal radiation can estimate FRP, providing valuable information about fire intensity and spread. This data helps in assessing the severity of the fire and allocating firefighting resources effectively.
17. Wireless Mesh Networks: Wireless mesh networks establish a self-configuring network of interconnected devices, such as sensors and communication nodes. These networks can transmit real-time data from various sensors, enabling continuous monitoring of temperature, humidity, smoke, and other fire-related parameters.
18. Hyperspectral Imaging: Hyperspectral imaging captures images in numerous narrow and contiguous spectral bands. This technique can reveal subtle changes in vegetation health and identify anomalies caused by fire, such as changes in plant pigments or water content. Hyperspectral data helps in detecting and mapping fire-affected areas.
19. Fire Detection Systems with AI Integration: Integrating artificial intelligence (AI) algorithms into fire detection systems enhances their accuracy and efficiency. AI-based models can learn from large datasets and adapt to various fire conditions, improving the system's ability to differentiate between real fire incidents and false alarms.

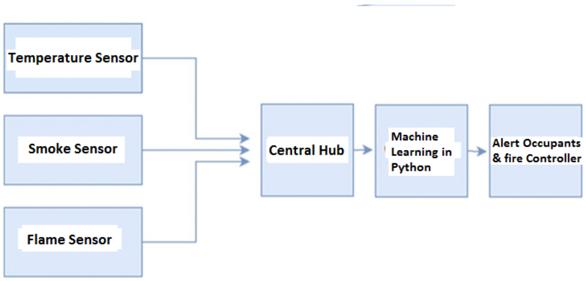
20. Unmanned Ground Vehicles (UGVs): UGVs equipped with sensors and cameras can be deployed in challenging terrains to detect fire outbreaks. These autonomous or remote-controlled vehicles can navigate through forests, gathering data and images for analysis.UGVs can also be equipped with firefighting capabilities to suppress small fires or provide support to human firefighting teams.
21. Satellite Monitoring: Satellites equipped with various sensors, including optical, thermal, and microwave sensors, can provide continuous and wide-area coverage for monitoring forested regions. These satellites can detect heat signatures, smoke, and other fire-related indicators, allowing for timely detection and monitoring of fire incidents.
22. Citizen Science Initiatives: Engaging citizens in fire detection efforts through mobile applications or online platforms can significantly enhance early detection. Citizens can report fire incidents, share images or videos, and provide geolocation data, contributing to a collective effort in monitoring and detecting forest fires.

1.a. Forest Fire

1.b. Forest Fire

II. ARCHITECTURE OF BASIC DETECTION SYSTEM

This section describes the architecture of a basic fire detection system that can be thought of close to practical system using any one of the techniques. Fig1. describes the architecture of system which can be implemented for fire detection if the region of interest for detection is limited. Example of limited region of interest may be a village in the middle of a forest or a building surrounded by dense trees. In such case a k-barrier coverage technique as discussed in [14]. In this fire is treated as an intrusion between two fixed points and nodes will be placed on points which are orthogonal to it. Barriers will be formed between these two nodes as shown in the figure. If any intrusion happens from any one of the fixed points, then it can be detected by the barrier network. The nodes placed on the orthogonal points are called as virtual nodes and the path established between these two virtual nodes will be a result communication between physically existing nodes along the paths.



The architecture of the fire alarm system.

III. FIELD TESTING

The initial testing of the system was performed at land adjoining the Kanneliya Forest Reserve [6.183120723327043, 80.4165345965101], Sri Lanka, and the other was at land adjoining the Knuckles Mountain Range Wildlife Reserve [7.45857419273649, 80.77990606784306], Sri Lanka, which are often subjected to frequent forest fires. A controlled fire was created, and sensor nodes were placed to detect the fire. One cluster head and the base node were implemented for the transmission of data and further analysis. In both locations, the tests were performed in the morning, afternoon, and night to check the system applicability to different times of the day. [15]

After performing many tests, the 5 m range was observed as the effective area that a single sensor node can cover. The variation in average delay vs height was observed, as depicted in Fig. 2; hence, the height of the mounting point from the ground level was determined to be 1 m. On training the machine learning regression model using 80% of the dataset with 7000 samples and testing it by the remaining 20%, the theoretical accuracy of the final output obtained was 81%. After testing the system for twenty-two fire scenarios and twenty-eight no-fre scenarios, node accuracy, practical accuracy of the machine learning model, and overall system accuracy (considering all fire and no fire situations) were calculated, and the data are presented in Table 1 and Fig. 2.A statistical t-test was performed to determine the significance of the parameters that were utilized to detect fire conditions. the test wasconducted for all four parameters: temperature, relative humidity, light intensity level, and carbon monoxide level considering fire and no fire situations. the probability values obtained for all four parameters were less than the critical value ($\propto$ = 0.05), as indicated in Table 3. In advance, the probability values [1]

Scenario	Total instances	Accurate instances	Erroneous instances	Accuracy rate (%)	Error rate (%)
Node					
Fire	22	22	0	100	0
No FIRE	28	18	10	64.28	35.72
Total instances	50	40	10	80	20
ML					
Fire	22	19	3	86.36	13.64
No fire	10	8	2	80.00	20.00
Total instances	38	33	5	86.84	13.15
Overall system					
Fire	22	19	3	86.36	13.64
No fire	28	26	2	92.85	7.15
Total instances	50	45	5	90	10

Table.1 Accuracy graph of system, node and machine learning model [1]

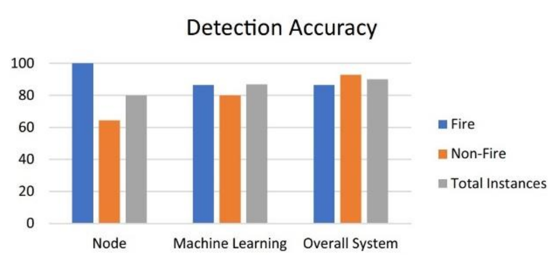


Fig.2 Accuracy graph of system, node and machine learning model [1]

IV. CONCLUSION

The proposed system for forest fire detection, utilizing wireless sensor networks and machine learning, demonstrated high effectiveness in accurately detecting fires in forest areas. The system ensures minimal latency by conducting analysis both at the sensor node and the base station. To accommodate various weather conditions, climates, and areas, a threshold ratio is introduced for analysis within the sensor node. The system allows for flexible node deployment, even in areas without preinstalled network connectivity, thanks to the transceiver module's dedicated built-in network infrastructure. It can operate independently for extended periods due to its primary power supply from rechargeable batteries supplemented by solar power. In real tropical forest sites, the proposed system, integrated with the communication infrastructure, consistently alerted relevant authorities with faster response times compared to existing systems, as confirmed through multiple test trials.

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