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Research Article

A Design and Development of the Smart Forest Alert Monitoring System Using IoT

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Forest is one of the main sources of living organisms. Its needs start from the human breath to usage of the wood. But due to many reasons, area occupied by the forest is reducing every year. The reasons behind these environmental impacts are natural disasters (forest fires), deforestation activities, and unlawful actions. Forest fire could be creating most serious threat to wild animals and resources of human welfares. The primary phenomenon of the wild fire occurrence is circumstance hotness of the forest. The dry and hot atmosphere caused the fire in the forest. The deforestation and smuggling activities are also tridents to the available forest. The main consideration of this article is to detect wildfires in advance and protect forest resources from social crimes through advanced sensor integration in the IoT (Internet of Things) environment. A smart forest alert monitoring system has been proposed in this article to avoid forest mishap over by automated self-decision-making protective actions such as parameter measures and alert and implementing the harm mitigation actions related to the hot temperature, humidity, smoke, and smuggling of trees. All the sensors work as per the algorithm designed by the specific application of IoT (Internet of Things). The accurate predictions of the forest fire events and ensuring the forest safety have been tested and verified by a conducted case study on the real forest zone environment.

1. Introduction

Forest fires are a widespread threat in forests, wreaking havoc on wildlife and the environment. It may be avoided if a reliable technology could be established in forest areas to detect fires and warning to firefighting authorities, who will be available to take the rapid action [1]. The goal of this propose system is to create an IOT-based forest fire detection system that will identify the fire and transmit an emergency instantaneous notice to the authorities by the system integrated sensor components. Deploying a wireless sensor network in forest fire prevention is identification and execution of the quick solutions to mitigate social harm of the forest [2, 3].

The accuracy of the fire prevention and identification has observed low in satellite measuring system, due to the passing clouds and uncertainty with spot capturing of image pixel [4]. The lagging sensitivity of fire identification has been happened sometimes as late sensing after the forest gets on fire. It will be mitigating by installation of spot sensors on the locations, and transforming the information without delay has been observed as a field solution [5].

The recent work on this area has been analyzed twofold, one is in terms of the importance of forest protection, and another one is a useful technology to make sustainable forest activities. Many researchers have done work for fire prevention and detection, but not on the reasonable practical scale

Table 1: State of the art related to wild fire forecasting [14, 16–19].

Main objective	Measuring parameter	Communication used	Computing technology	Limitation
Wildfire forecasting [14]	Humidity and temperature	ZigBee module	Fog/cloud	Limited range of connectivity
Early prediction of forest fire [16]	Humidity, temperature, and wind speed	Digi XBee module	Cloud/fog	Short range of transmission
Identification of tree cuts and fire [17]	Smoke and light sensor	Wi-Fi	Not available	Challenges with connectivity
Fire detection [18]	Flame and temperature sensor	LoRa	Not available	Lack of computing unit
Fire detection [19]	Not available	ESP 8266 Wi-Fi	Centralized server	High power consumed of remote unit
Prediction of fire including deforestation activities	Temperature, humidity, smoke, and smuggling	Combinations of short- and long-range communications	Centralized and cloud-based data computing	Proposed IoT-based SFAMS

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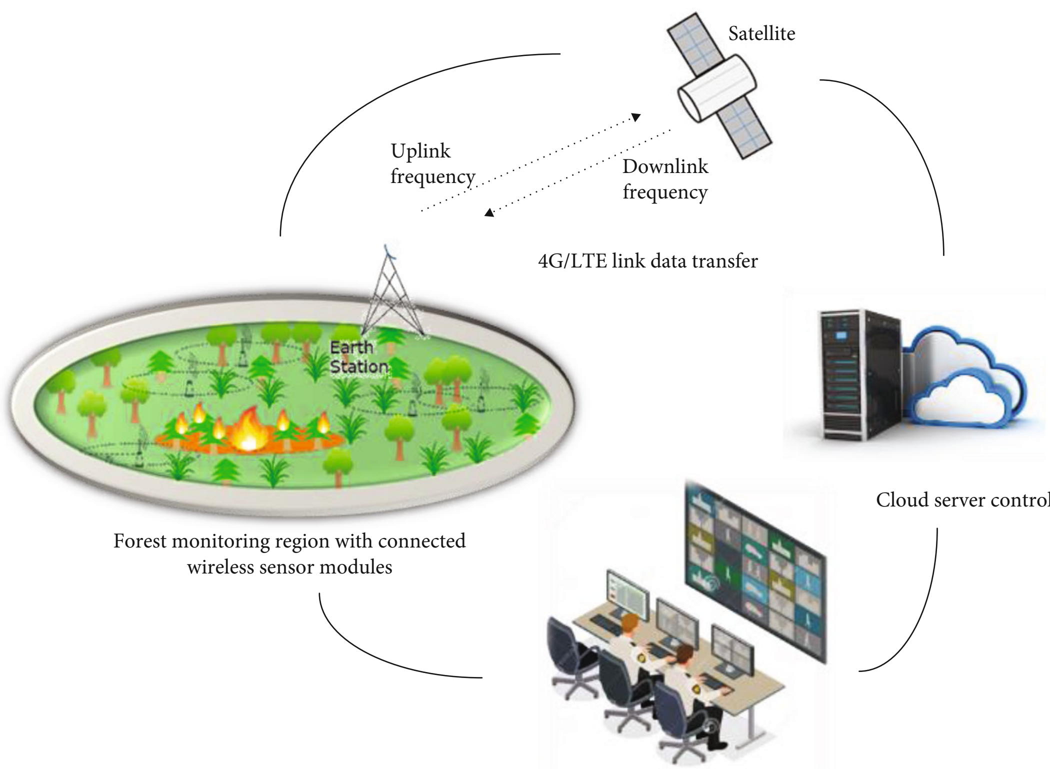

Figure 1: Architecture of the proposed forest alert monitoring system.

of applications. A high version of the wildfire preventer has been proposed to be implemented. The referred articles [6, 7] have implemented a node MCU for transferring data thought to use this because it has a lot of advantages. But an extra module for Wi-Fi is not preferable to designing a power supply circuit. The obtainable projects on this field have more limitations with inbuilt detection and prevention techniques of smoke, temperature, and fire sensing and detection. In later years, the satellite has reduced the burden of forest monitoring systems [8]; that system consists of various detection and monitoring techniques. But it needs more investment in the protection system infrastructure development. Here, the main investment issues have been mitigated by using recent updates of IoT technologies such as connected optical sensors and digital cameras. Here, it consists of some sensors used to detect the fire and temperature rise and the digital camera to check whether the fire is present or not. This method of detection technique provides many advantages such as checking live 24×7 monitoring and continuous data logging to the cloud storage for the betterment of the prediction process including the human interventions in the forest area. If anyone enters the forest, it shows an alert message at the receiving end due to liked WSN technique with the nRF module for transmitting data [8]. The forest is regarded as one of the most important and necessary resources [9], and that forest fires are a constant threat to biological systems and environmental factors. Forest fire detection has become a critical issue in the presuppression phase, necessitating the urgent need to detect forest fires as quickly as possible. This literature has been emphatic in its professional use of wireless sensor networks as a possible explanation for the objective of a forest fire. To complete the solution process, the suggested system relies on several sensors linked to it as well as data from the wireless transmission. These sensor data are sent to a ground station where they are analyzed by a small satellite in the system. For the previous finding of forest fire, the discourse strategy relies on data from wireless sensor reticulation [10]. The usage of WSN in forest fire detection could be used in various transmitting modules to a receiving end [11]. So, the further implementation of the ZigBee technique provides additional access benefits to the forest area. The combinations of transmitting the nRF module with the Node.js application platform have ensured the exact location of the forest hazards to prevent wildfires easily [12]. It has been found in a survey that 80 percentage losses caused due to fire and promptly alert has reduce the mishap in early [13].

The previous work related to the wildfire study is having limitations with analog metering and sluggish event capturing capabilities [14]. The transformation of digital sensors and Internet-based integration of different sensors can provide the solution for these issues. The missing of human to forest interaction is the main cause of the major wildfire accident [13]. The usage of cyberphysical system (CPS) helps to visualize the events and prediction of the fire and executing the harm mitigation actions. The trustful data-based system operations increased the accuracy of the system performance [15]. The big data and cloud computing processes with artificial intelligence help to accurate fire detection and prevention. The recent field state of the art is shown in Table 1.

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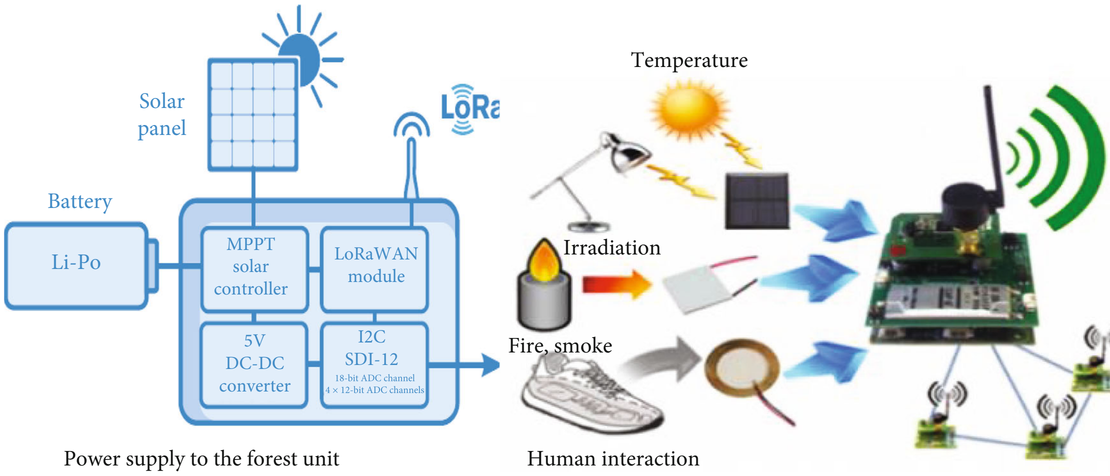

Figure 2: The elements of the remote access forest unit.

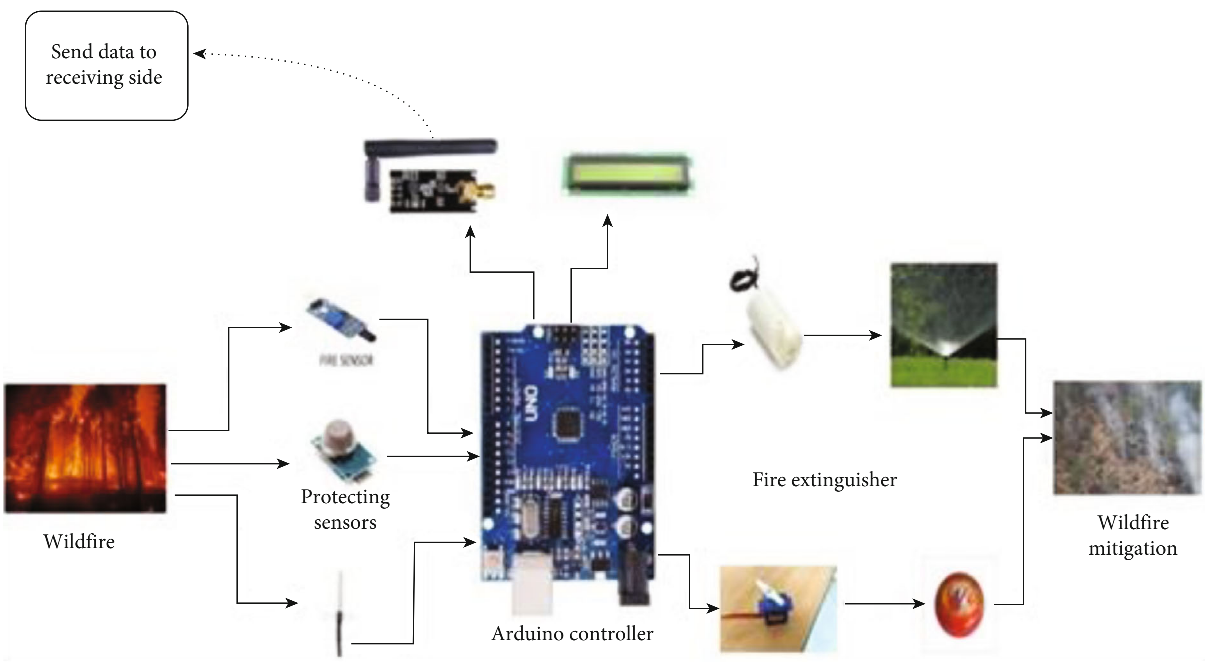

Figure 3: Signal/data controller of the forest unit.

The above state of the art clearly expressed the scope of the effective wildfire monitoring system and smart alert with automated harm mitigating action process executions. In this study, the proposed system is ensuring the high performance in monitoring, quickness in the information transferring, and execution of the social harm mitigation actions. The temperature sensor starts its alert when the temperature rises more than its threshold value. And also, smoke sensor detects when smoke helps to spread the fire like petrol and LPG. A fire sensor is the main one that detects the fire instantly when a fire occurs. These sensors when any sensor gets alerted the whole system got alert and transfer an alert message to receiving end. The proposed system has the proficiency to activate the self-actuators over by spot sensors; when cutting of trees, switch on the water storage tank motors and CO_2 fire extinguisher to prevent the fire. The possible improved solutions towards the identified field research gaps by this study are listed as follows:

(i) The summative attainment of the IoT aided communication protocols, its technical requirements were designated, and performance accuracies were verified with conducted wildfire case study

(ii) The case study outcomes have expressed the significance of the Internet sensor modules with real-time data logging and tracking and monitoring to fulfil the task allocated

(iii) The implementation steps for a smart forest alert monitoring system with self-decision-making

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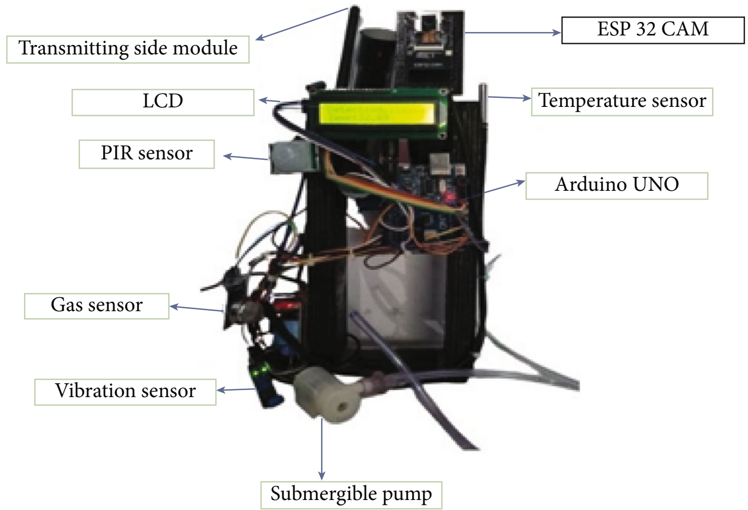

Figure 4: RAU (remote access unit) for the forest alert monitoring system.

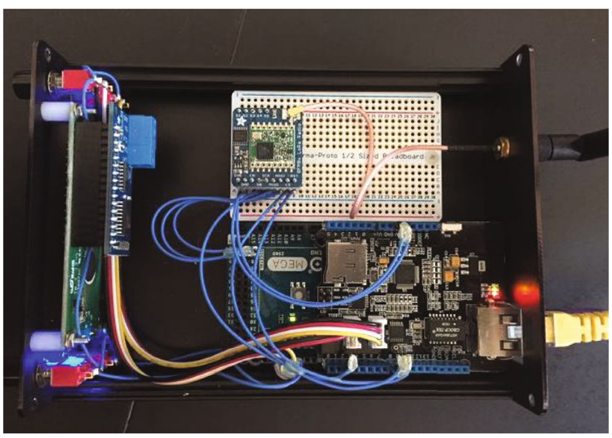

Figure 5: Smart alert RTU signal gateway for LoRa.

protective actions related to parameter measures and alert and implementing the harm mitigation actions were established with installed model prototype

In this article, Section 2 illustrates the proposed design methodology. The complete system configuration and component detail have elaborated in its subsection. The conducted case study and observed outcomes and system's performance justifications are presented in the Sections 3 and 4. The further conclusion of the proposed work has been expressed in the final section.

2. Proposed Design Methodology

The advancement of the Internet of Things (IoT) has been implemented for the application of forest alert monitoring systems. The natural and manipulated hazards in the forest need continuous monitoring to avoid fire and deforestation activities. The fast and quick complaint responses are the additional provision here. The defined forest area regions were concentrated with the various wireless sensors such as flame sensors, humidity sensors, and temperature measuring elements including CCTV cameras. The collected data from the various sensors have been transferred through a 4G/LTE link to the cloud server. The real-time forest observations have been monitored by the authorities in the control room. The automated fire extinguishment and deforestation prevention activity has been initiated by the smart alert system's activator operations based on the harm severity and priority values generated by the field sensors. Figure 1 illustrates the proposed architecture of the forest alert monitoring system [14, 16–18].

2.1. The Elements of Forest Remote Access Unit (RAU). The forest remote access unit's power supply has been taken from the solar PV arrangement. The complete regain of the protected forest is equipped with advanced wireless sensors such as flame identifier, humidity, temperature analyzer, and vibration sensors. These sensors observed the forest live and transferred the data to the available cloud platform through by 4G/LTE module. The uninterrupt of the system has been ensured by the Li-Po type of battery energy storage setup. The liveness of the forest has been monitored by the authority in the control room through the LoRaWAN networking module [19]. This automated alert system has the additional proficiency of fire extinguishing and prevention of deforesting action done by preprogrammed Adriano controller operations. Each sensor's unit outcome signals have been classified as per the severity and action priority levels. The sensor observed range and controlled accuracy could be calibrated by machine learning-based training and execution practice. Figure 2 shows the needful components regarding constant forest remote access unit.

The main objective of this work is to implement the fast and quick technique which helps to detect and prevent wildfires using a wireless sensor network. When wildfires occur, the temperature sensor detects the fire and it will alert the system. When the system got alerted by the nRF module and sends the data to the receiver side in parallel, it helps to mitigate the wildfire by using a submerged pump water

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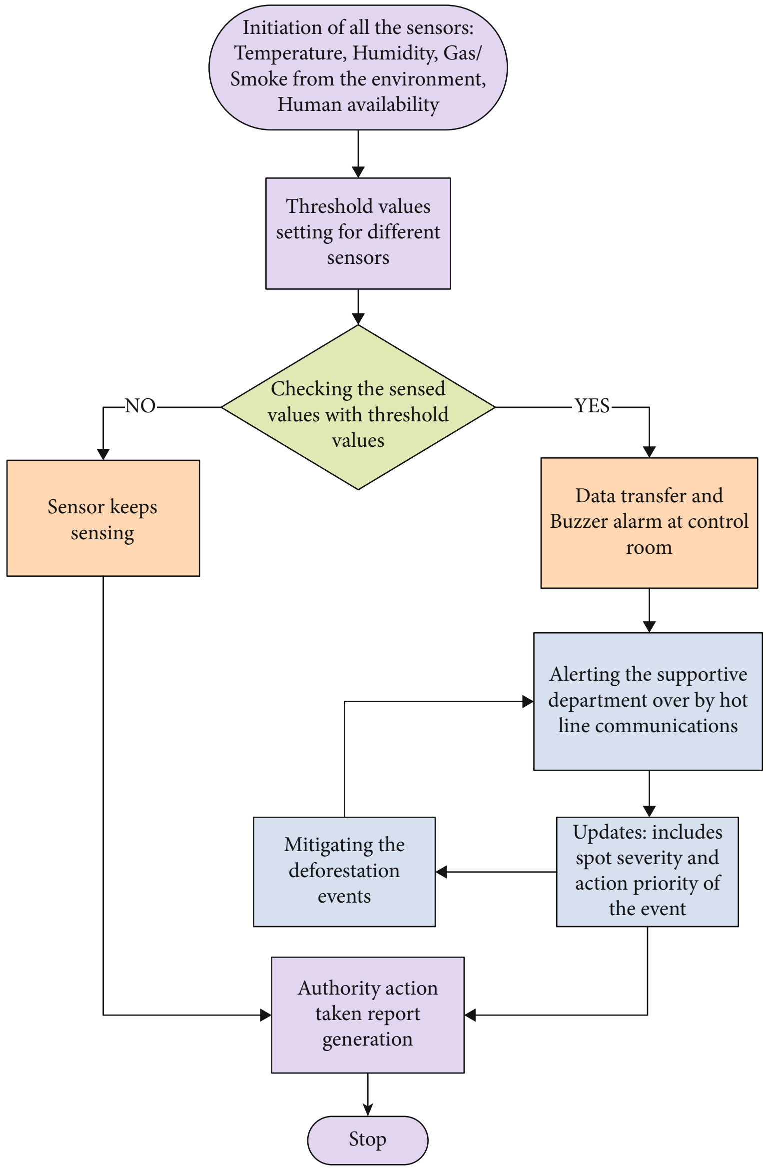

Figure 6: Proposed deforestation-mitigation action flow.

sprinkler. The high range of fire could be controlled by a servo motor-operated fireball extinguisher. The future extension of these combinations might be used in various fire accidents and possible places such as industries, parks, and shopping malls. The auto mode operation of the alert system gives the alarm alert to the fire safety department and ensured to reach the fire location via the shortest route map. It helps with fire prevention in the early stages. As per the forest protection code of behavior, the collected data has been received by the forest department. From the forest department, additional supportive disaster management actions could be initiated. The fire sensor protection range starts from 180 degrees to 360 degrees to detect wildfires. In the summer seasons, due to high temperatures, the forest soil gets heated and the water evaporates from the soil. Trees get dried and caught the heat, but we cannot instantly prevent it because huge areas and fires spread over the forest within minutes. So, the forest department has started trying to detect things with the help of satellite pictures, but they also have a delay in it. The protection system needs to detect the fire using electronic components like sensors, and it could be placed in a tower in the forest. The human interference in the forest is also monitored to avoid deforestation activity, so these sensors could be fixed at ground levels. The CCTV and vibration sensors help for this protection. This module is used to find the human images and infrared range-based detection [13, 15, 20–24].

2.2. Protection against Deforestation. When humans start to cut the trees using tree cutters as an unethical based, the vibration sensors start to send the signals to the control room, and the control authority can initiate the steps towards the deforestation activity. After identifying the wildfire, the prevention process has initiated through water

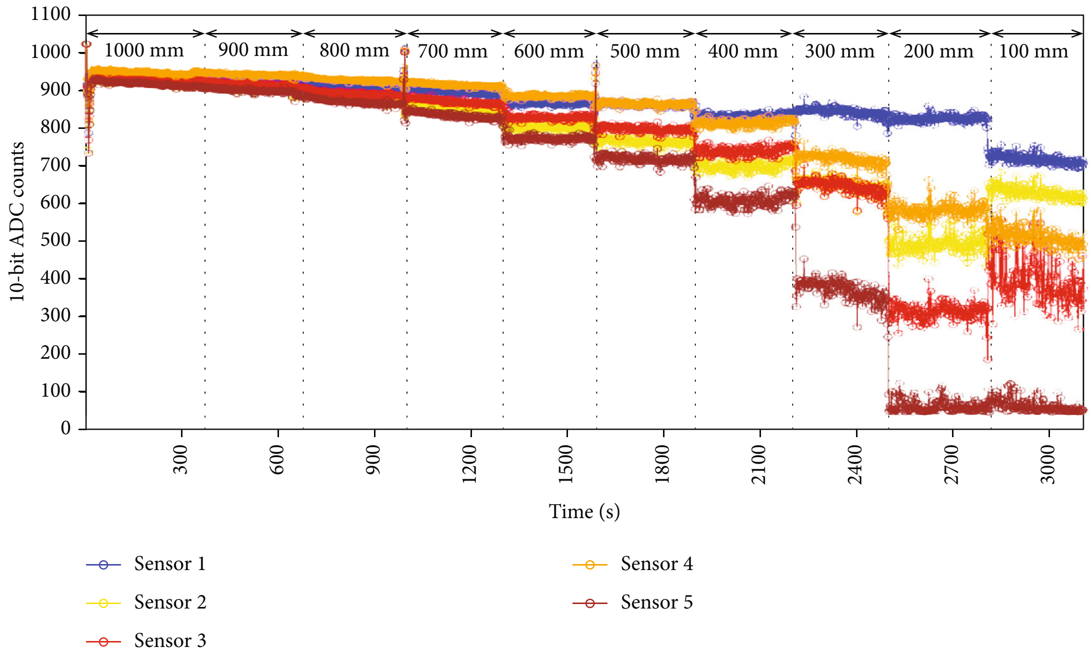

Figure 7: Typical fire sensor's simulation performance.

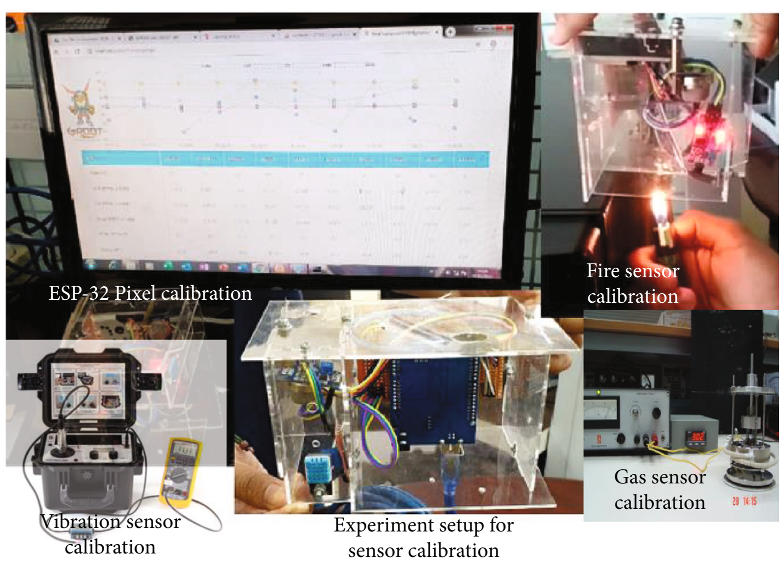

Figure 8: Calibrations of sensor's threshold values.

Table 2: Calibration of sensors as per event severity.

Sensor type	Severity levels Level 1 (low)	Level 2 (medium)	Level 3 (high)
Atmospheric temperature	≥30°C	≥38°C	≥42°C
Air humidity	≤30%	≤20%	≤10%
Level of CO_2	≥36 ppm	≥2000 ppm	≥5000 ppm
Level of CO	≥10 ppm	≥30 ppm	≥50 ppm

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Table 3: Count of sensor used vs. data size and computational time.

Used sensor count	Data size (in MB)	Computational time (in sec)
10	3.5	24
20	4.9	32
30	7.9	44
40	11.9	53
50	14.9	61

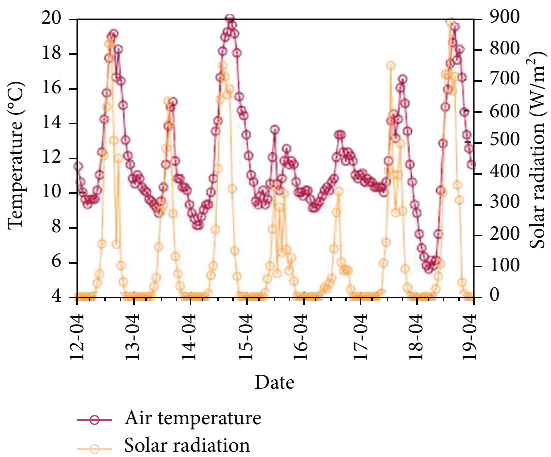

Figure 9: Typical weekly profile of air temperature and solar radiation as per cloud storage.

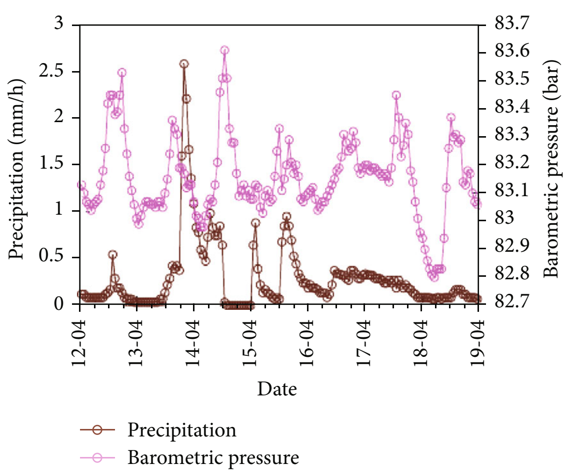

Figure 10: Typical weekly profile of air precipitation and barometric pressure as per cloud storage.

sprinklers and automated target fixed fire extinguisher CO_2 ball throwers. The minimal viable forest remote access unit is illustrated in Figure 3.

2.3. RTU Signal Gateway for LoRa Network Module. The forest monitoring control room consists of the data received from the forest RAU (remote access unit as shown in Figure 4) and emergency disaster management tools and corresponding action procedure follow-up setups. When a wildfire is found, immediate alert messages and related descriptions of the fire's nature could be sent to the control centre through by RTU signal gateway. The nRF module helps to receive the data from RAU on time. The received data has to be quickly analyzed by the trained algorithm and classified as the nature of events as per the severity and step priority.

The action-taken steps and follow-up procedures will be communicated with the related management authorities. The continuous live location observation details have to be updated every 5 minutes to quick up the action procedures. Human detection and any vibration occur in the forest like cutting trees; the unwanted intervention of humans is also captured by the control room monitoring system. The minimal viable product of control room receiving assembling is illustrated in Figure 5.

3. Case Study

In this section, the conducted case study in the Shamshabad region, Hyderabad, India, has been discussed. The portion (3000 square feet) of the forest area has selected and installed 5 numbers of needful sensors, such as temperature, humidity, gas, vibration, and PIR sensors, that have been fixed with the necessary level of heights in the selected locations. The actions required for deforestation mitigation are defined as an action flow chart (Figure 6). All the sensors are energized with a standalone solar PV power supply with a battery backup system. Sensors have initiated and enabled the data collections by Arduino and node MCU configuration. The different sensor data capturing capability concerning reached period at the control circuit has been illustrated in Figure 7. Most sensors can generate the signals with high range 10 bit ADC counts at starting of periods. And its values going to reach minimum count at the maximum allowed range of periods. The further operation setup is also ensured by driven codes of the Arduino controller when a sensor gets alerted by fire; then, it follows that the flow chart alerts the system and shows the alert message in the LCD and then automatically started to water sprinkling which is stored in the water tank. Based on fire severity, the connected servo motors release the fire extinguisher balls into the fire site. The PIR sensor detects the object based on infrared radiation ranges, and an extended version of an ESP-32 type of camera was used to capture the human's entries into the forest. The complete gathered information has been transferred to the central server through 4G/LTE links and available cloud platforms. The combination of hard and soft tool mix helps to develop the forest monitoring system. With help of the headers, plug and functioning of Arduino have been initiated. The PINs are written in white adjacent to the headers on the board. Pin 13 controls the onboard LED to control. The development of Arduino coding has been done in the C++ programming language. The setup () and loop () void methods are required in every sketch (). No value is returned by a void type function. When Arduino is turned on, the setup () method is called once, and then after, loop method () is called repeatedly. The initialization steps are to be written in setup () and then want to run the code in loop () sketch.

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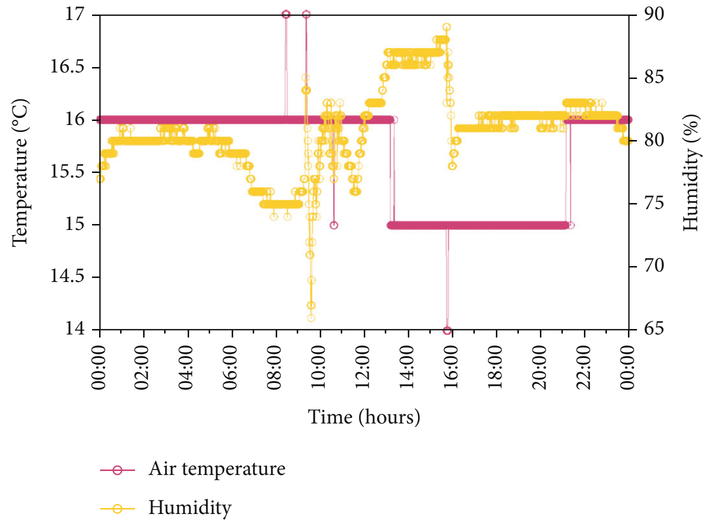

FIGURE 11: Day temperature and humidity data collected by RAU sensor at alert monitoring screen.

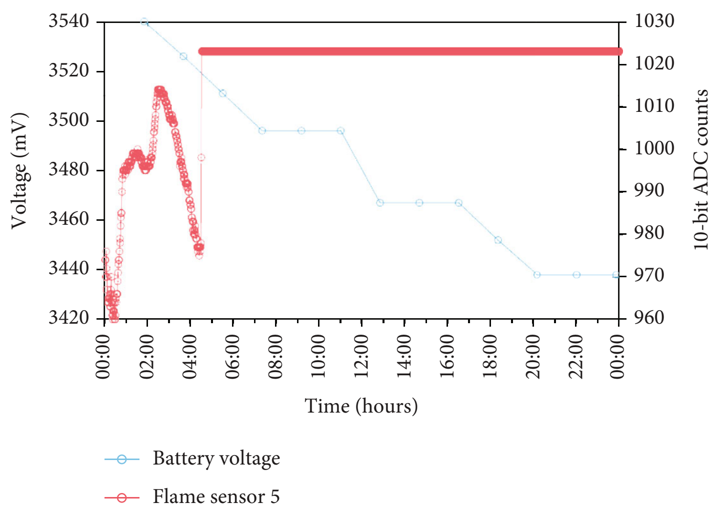

FIGURE 12: Real-time RSU's battery voltage and flame sensor data at alert monitoring screen.

TABLE 4: Event predictions based on various sensing data set provided by the site sensors.

Forest event	Precision	MSE	RMSE	MAPE	Accuracy
No fire	1.000	0.002	0.044	0.2	0.992
In fire	1.000	0.001	0.033	0.1	0.992
Post fire	0.990	0.005	0.071	0.5	0.992
Unsafe forest	1.000	0.0017	0.042	0.01	0.992

4. Result and Discussion

The evaluation of this proposed work has been carried out twofold. A first fold calibration of sensors has done with standard test conditions at the laboratory test bench setup (shown in Figure 8). In this stage, the calibration of the different sensors and their expected function has been defined with its threshold value setting.

4.1. Calibrations of Sensor's Threshold Values and Its Performance. Mainly, the measuring indexes of all the components have been defined, and their corresponding values are to be embedded with Arduino control coding for real site observations and monitoring. In the second fold, the component's performance and accuracy have been verified with the help of created trail events. The different possible deforestation events have been created manually, and corresponding data sets are to be stored for training the system. The threshold values for the different sensors and the nature of severity of events have fixed as shown in Table 2.

Generally, the complexity of system performance has increased, when no sensors came to the role for data capturing. These issues could be clear here instead of individual sensor data collection and transfer; the combined data handing process could be followed here. So-called data transferred time duration has become narrow. Due to the compact form of the data set structure, it can be

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	Sensors Decisions						Final system Observations#	Activators conditions		
	Temperature Sensor	Smoke Sensor	Gas Sensor	Vibration Sensor	PIR Sensor	ESP-32 Camera		Submerging water pump	Fire extinguisher balls launcher	Communication to disaster management
1	Fire	Fire	Fire	Yes	Yes	Yes	Fire and Unsafe	On	On	On
2	Fire	Fire	Fire	No	No	No	Fire	Off	Off	On
3	Fire	Fire	No	No	No	No	Fire	On	Off	Off
4	Fire	No	No	No	No	No	Normal	Off	Off	Off
5	No	No	No	No	No	No	Normal	Off	Off	Off
6	Fire	No	Fire	Yes	Yes	Yes	Fire and Unsafe	On	On	On
7	Fire	Fire	Fire	Yes	No	No	Fire	On	On	On
8	No	No	No	Yes	Yes	Yes	Unsafe	Off	Off	On
9	No	No	No	No	Yes	Yes	Unsafe	Off	Off	On
10	No	No	No	No	No	Yes	Unsafe	Off	Off	On

Normal   Unsafe

Fire   Fire &Unsafe

FIGURE 13: The summary of the sensor decisions with conditions of the system activators.

transferrable with a low range of network bandwidth. The computational time and expected data transfer packet size concerning different count of alert sensors has been illustrated in Table 3.

4.2. Data Set Management and Event Prediction. The primary objective of the proposed work is a fast alert monitoring system that includes event prediction and avoidance of deforestation issues. Attainment of this task could be done by the previous method of data mining and handling towards the quick decision hopes including avoidance of the false fire and unsafe conations of the forest. The connected temperature sensor and solar irradiation measurement units have been updating the site measured values to the cloud's data storage platform for every minute interval. The typical day observations of site temperature and solar irradiation values are illustrated in Figure 9. This data observation gave hints regarding seasonal annual variations of the weather and event predictions as per post-event-registered data sets. The solar irradiation value observation helps the energy availability to operate the RAU independently without conventional energy supply.

The precipitation and atmospheric pressure are also important indexes to design the forest alert monitoring system in terms of avoidance of the false alarm and the present working status of the installed sensors and their performance levels. Less precipitation is providing better working nature to the sensors. The biometric pressure monitoring helps the system for event prediction and the follow-up measures toward deforestation. This observation has been illustrated in Figure 10.

With data monitoring and data acquisition, the proposed forest alert system has the additional proficiency of real-time monitoring. The continuous battery voltage and flame sensor data set help the endurance of the system stability towards uncertainty issue avoidance with the RAU's power supply. Figure 11 expresses the real-time typical day site temperature and air humidity data at the control room monitor. Figure 12 illustrates the real-time battery voltage and flame sensor 5 data at the forest alert and control room screen.

4.3. Proposed System Performance on Various Sensing Parameters. The proposed forest alert monitoring system has the trust to predict the forest event exactly as it happened without false alarm to the control authority. Due to the high level of accuracy predictions, the rescue team can do their service without any panic.

There are many previous solutions available in this field, but due to single sensor dependency, many possibilities of fake calls and fault alerts happened. In this work, every event has conformed to multisensors and its functions are also trained with all site possible events. The cloud registry data set-based prediction technology leads the system's accuracy

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Table 5: Performance comparisons among the different wildfire prediction techniques.

Wildfire prediction methodology	Notification delay	False alarm	Fire localization error	Information on fire behavior	Detection device mobility	Cost
Animals as mobile sensor techniques [25]	Long	High	High	Yes	Mobile	High
Radio acoustic-based techniques [26]	Small	High	High	No	Fixed	Medium
Image processing techniques (camera based) [27]	Long	Medium	High	No	Fixed or mobile	High
Neural and fuzzy logic-based techniques [28, 29]	Small	Medium	Low	Yes	Fixed	Low
Proposed sensor-based techniques (wireless sensor network)	Small	Low	Low	Yes	Fixed	Low

to a high level of 0.992. The mean average percentage error (MAPE) of the predicted data set is between 0.01 and 0.5%. The precision level of forest events is between 0.99 and 1.0 values. Table 4 provides the forest event predictions based on on-site sensor data sets. Figure 13 illustrates the relations among the different sensors' decisions with the operating states of the activators, which were used to avoidance of deforestation activities. The performance comparisons among the different wildfire prediction techniques are illustrated in Table 5.

5. Conclusion

The deep observation of the forest is the way to save that from natural and manmade calamities. The present sustainability goals and policies highly depend on green forest development. That mission could be simply attained by this proposed design and development of a smart forest alert mentoring system. Due to the IoT advancements and data analytic techniques, the efficient forest fire fighting infrastructure could be proposed here. Its effectiveness in the fast and quick alert of forest fire and avoidance of unsafe forest events has proved over by conducting a case study on a real forest zone. The forest unsafe events are also predicted here with a high level of accuracy rate of 0.992, and the minimum range of MAPE values is in between 0.01 and 0.5 without false alerts to the control authorities. This multi-sensor-based forest safe assurance system framework will be used in other application sectors such as industries, parks, and shopping malls for their safety from fire hazards.

Data Availability

Data will be available on request. For the data-related queries, kindly contact Baseem Khan (baseem.khan1987@gmail.com).

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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