Chapter 19
WSN-Based System for Forest Fire Detection and Mitigation

Kotish Grover, Ditsha Kahali, Shreya Verma and Balaji Subramanian

Abstract The risks, consequences and severity of wildland fires are well-known. Hence, the demand for timely, high-quality fire information in the least amount of time possible and the subsequent intimation to concerned authorities would help in scaling down the loss of life and property. This paper discusses a WSN system which collects data using multiple sensors to monitor temperature, humidity, smoke and oxygen levels in several spots in a forest environment. The forest would be divided into square-shaped clusters for monitoring, each containing a sensor system. The localisation of the node would be done using satellite communication to reduce coverage holes and ensure maximum range with the least latency. This node would communicate data to a monitoring station with its location and send alerts according to the sensed thresholds breached based on the novel logic algorithm. This paper describes the overall structure of the sensing system, detection and prediction algorithms, topology of the WSN, localisation techniques and an insight into a suggested drone-based mitigation system to localise the fire.

Keywords Wildfire · WSN · Forest fire detection · WSN in forests · Localisation techniques · Forest fire mitigation

K. Grover (✉) · D. Kahali · S. Verma · B. Subramanian
VIT, Vellore, India
e-mail: kotish97@gmail.com

D. Kahali
e-mail: ditsha.kahali@gmail.com

S. Verma
e-mail: shreyav1@gmail.com

B. Subramanian
e-mail: sbalaji@vit.ac.in

B. Subramanian et al. (eds.), *Emerging Technologies for Agriculture and Environment*, Lecture Notes on Multidisciplinary Industrial Engineering,
https://doi.org/10.1007/978-981-13-7968-0_19

19.1 Introduction

Wildfires are natural or man-made occurrences, where combustible floral areas are harmed due to fire. According to the area affected, they might be categorised into brush fire, bush fire, desert fire, forest fire, grass fire, hill fire, peat fire, vegetation fire and veld fire. At present, ground patrolling, watching tower, aerial prevention, long-distance video detection and satellite monitoring are used to prevent as a traditional forest fire.

India is not unknown to the losses of life and property caused due to forest fires. In 2016, Indian state of Uttarakhand suffered heavy causalities due to an estimated 3,500 ha (8,600 acres) of forest area burnt. The fire also had environmental consequences with the average temperature of northern India facing an increment of 0.2 °C. In the past 16 years, India has an increase of 46% in forest fires which in total is a 125% increment from 15,937 in 2003 to 35,888 in 2017. In 2017, Madhya Pradesh saw the majority of the forest fires followed by Odisha and Chhattisgarh [1]. Another incident in the Indian state of Tamil Nadu occurred where 20 young trekkers lost their lives due to a forest fire in Theni forest cover. The consequence of this was that some of the Indian states had to ban trekking in the forest areas for an indefinite period.

Hence, the need of the hour is to find systems which can detect forest fires with precision in an energy efficient and self-sustaining manner. One of the most effective ways to approach this problem is using wireless sensor networks (WSN). It generally comprised of spatially disseminated sensors to monitor physical and natural conditions, for example, temperature, smoke, flame, humidity and location data to control room.

Many models such as US Rothermel model, Australia's McArthur model, national forest fire spread model of Canada and China's Zheng Wang model have been proposed since R. Forts put forward the mathematical model of the spread of forest fire. However, the implementation of a mathematical model had limitations, especially those based on an assumption, once out of the event, there will be an error.

Forest fires anywhere in the world are primarily detected by NASA's Moderate Resolution Imaging Spectroradiometer (MODIS) and Visible Infrared Imaging Radiometer Suite (VIIRS) satellites. These are highly specialised satellites which detect fire and relay information to various responsible departments all over the world.

A few years ago, the time lapse between spotting the fire and the news reaching the responsible departments was five to six hours, but this has been reduced to about two hours recently.

In this paper, we address this pressing issue and propose an effective WSN method to resolve it which gives us accuracy and speed to react to stop the fire from spreading and harming human life and property. We propose a self-sustaining sensing mechanism with a novel algorithm and give accurate positioning of the fire within a few seconds of the fire starting using Global Positioning System-based localisation.

Table 19.1 List of components and their application in the system

Components	Specification	Remarks
Microcontroller	Node MCU	Microcontroller with ESP8266 microprocessor
Smoke sensor	MQ-2	Used for smoke and combustible das detection
Temperature and humidity sensor	DHT11	Used for measuring temperature (°C) and humidity (RH)
Flame sensor	RKI3100	This sensor is a short-range sensor which senses light between 760 and 1100 nm wavelength
Oxygen sensor	Grove gas sensor (O_2)	(Optional)
GPS module	GY-NEO6MV3	For localisation
Arduino Nano	For GPS module	**Aids localisation and communication**
SAT-202	Communication module	**For satellite communication**
Voltage regulator	LM 7805	Voltage regulation
Power supply	2.5 W 9 V Polycrystalline solar panel solar cell	For power supply of self-sustained system

19.2 Structure of the System

The structure of the system consists of two parts: a sensing system and a communication system. The sensing system, placed in the forest, acts as the nodes of the WSN and consists of the following components (Table 19.1).

The circuit diagram for each node, consisting of the above components, is given in Fig. 19.1.

The communication system is covered in Sect. 19.5.

19.3 Algorithm

As the system retrieves the data from the sensors, in every cycle it computes the conditions for temperature, humidity and flame as given by the flow chart in Fig. 19.2.

1. Indicators corresponding to each sensing parameter (e.g. temperature, smoke, etc.) get activated if its threshold is crossed.

    - Temperature indicator is switched on if temperature >50 °C.
    - Humidity indicator is switched on of humidity <40%. This prescribed value changes from place to place depending upon its geographical location, winds

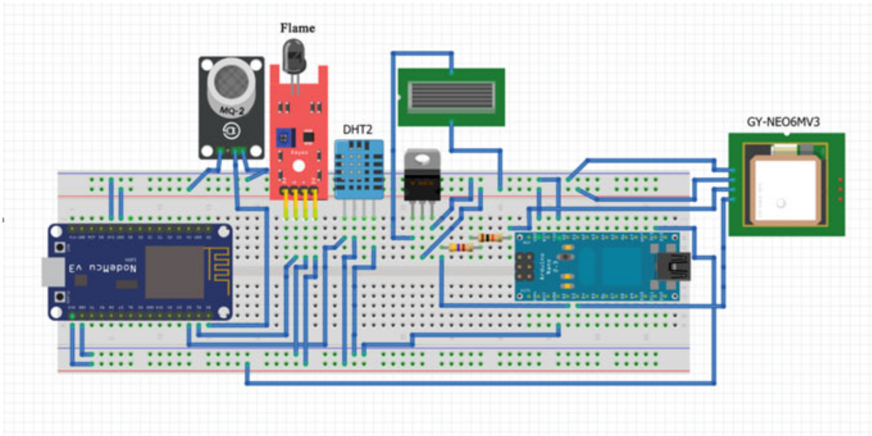

Fig. 19.1 Circuit diagram of every node

blowing and the season. This data will be different for different settings and has to be adjusted accordingly when installing the system up. For the sake of example, we have used the example of a somewhat dry area, with only seasonal rainfall, and set the threshold to be 40% relative humidity (RH).

- Smoke indicator is switched on if smoke detected.
- Flame indicator is switched on if flame is detected.

2. If the flame detector goes high, the fire alert is sent irrespective of any other sensor reading as the presence of flame at the height of tree branches is extremely dangerous and a clear indication of a wildfire.
3. If smoke is detected, as is the case in most scenarios as forest fires mostly light on the grass levels and the smoke is the first element which rises up, the temperature is tested.

   a. If the temperature is high (>50 °C), there is a clear indication of a wildfire, and alert is sent.
   b. If the temperature is low, chances are that there is a campfire whose smoke is reaching the sensors. However, if the temperature steadily rises to more than 50 °C, the fire alert is sent.
   c. If humidity is between 40 and 50% RH, a slow spreading fire detection message is sent, and if the humidity is less than 40%, a fast-spreading fire alert is sent, as fire spreads easily when the air is dry.

4. If smoke is not detected, but the temperature is high, and humidity is low, the chances of occurrence of fire are high and the corresponding alert is sent to the department.
5. If smoke is not detected, but the temperature is high, and humidity is high, the chances of occurrence of fire is low, and hence, the system is stable.

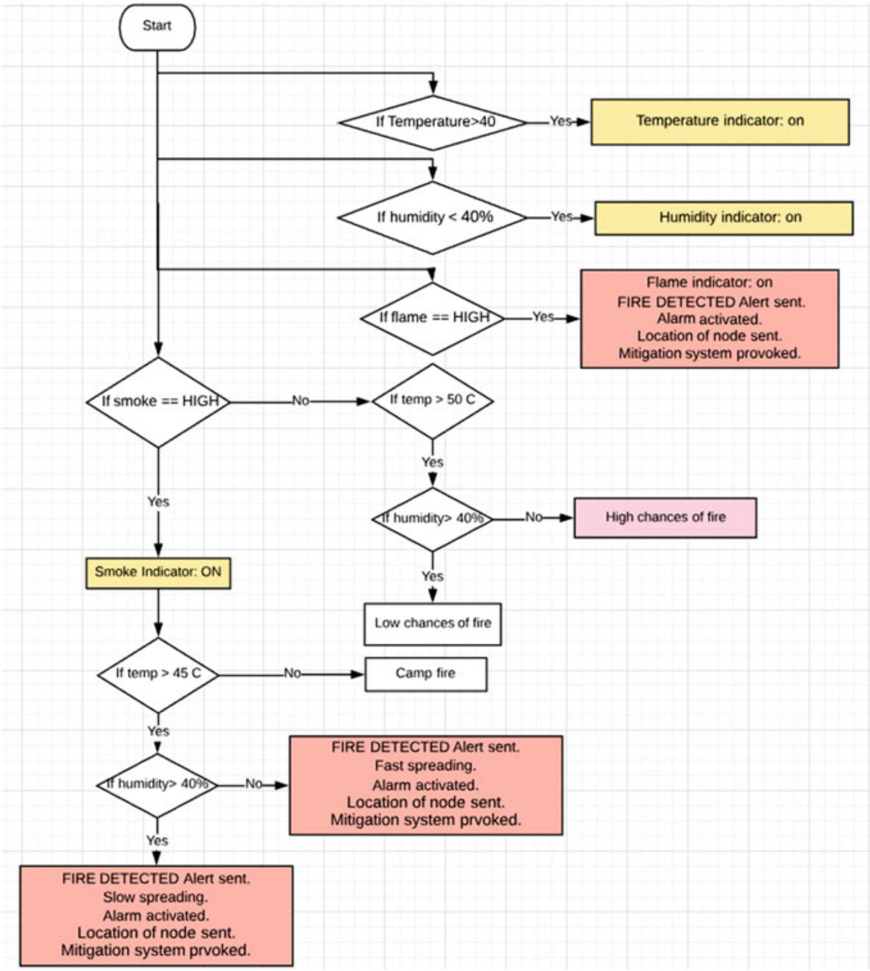

Fig. 19.2 Algorithm flow chart

6. If a temperature surge is noticed for a very brief period when humidity is high. Chances are that there was a lightning strike. Fire alert sent immediately. If it is followed by smoke, fire alert sent again.

19.4 Localisation

Once a fire has been detected, it is paramount to know its location for mitigation. In a sensor network, localisation can be best described as ‘recognising the node’s location’. For any wireless sensor network, an important factor is the accuracy of its localisation mechanism. The absolute position of sensor and between sensor estimation, for example, distance and bearing measurement, is used by network localisation algorithms to evaluate the location of sensor at first obscure data.

Localisation mechanisms can be categorised as anchor based or anchor free, GPS based or GPS free, stationary or mobile sensor nodes and range based or range free [2]. Localisation algorithm for wireless sensor networks depends on different measurement technique. Network architecture, number of nodes, signalling bandwidth and shape of the area are one of the few factors to be weighted while we design a localisation algorithm [2].

Range-based localisation uses techniques based on distance estimation and angle estimation. Received signal strength indication (RSSI), angle of arrival (AOA), time difference of arrival (TDOA) and time of arrival (TOA) are the techniques used for range-based localisation [3]. Range-free localisation uses regular radio modules and is only dependent on the received messages content. The techniques under range-free localisation are DV hop, multi-hop, centroid, gradient [4]. GPS-based localisation is categorised under absolute localisation. Sensors with known location are known as anchors, and the Global Positioning System is used to locate their position [4, 5].

From the comparison in Table 19.2, we can infer that GPS-based localisation is the most accurate technique. Accuracy is of absolute importance to our fire detection system. The Global Positioning System is a network of 24 satellites circling the earth at elevation of 20,000 km. At any point of time, four GPS satellites are visible. The information is transmitted about their position and current time at normal interim of time. GPS receiver intercepts these signals and figures the separation of each satellite in view of the time taken by the message to arrive. The distance from four or more satellite is calculated by the receiver to confirm the location of the node. GPS does not require transmission of data by the user, rather it operates independently of any telephonic or internet reception. Global coordinate system is used by the anchors to determine the position of the network. High-quality GPS receivers based on Standard Positioning System (SPS) can attain accuracies of 3 m; hence, we use Global Positioning System-based localisation mechanism to detect the position of nodes [4, 6]. Although, the technique used to compute locations and the measurement conditions in its surroundings affect the localisation accuracy of any GPS system [7].

Table 19.2 Comparison of various localisation mechanisms [2]

Technique	Cost	Accuracy	Energy efficiency
GPS	High	**High**	Less
TDOA	Low	High	High
RSSI	Low	Medium	High
TOA	High	Medium	Less
GPS free	Low	Medium	Medium
AOA	High	Low	Medium
DV hop	Low	Medium	High

19.5 Communication

For communication, we use a satellite communication model based on the Honeywell communication system. The steps of communication are illustrated in Fig. 19.3.

Honeywell provides a global IsatM2 M data service using its system of five Inmarsat geostationary satellites. Honeywell Global Tracking uses the attached SAT-202 which is a monitoring and tracking satellite terminal.

Discrete channels are used to transmit information to and fro from terminals, and which channels to use for receiving or transmitting is set when the terminal powers up for the first time. Each terminal has a unique Inmarsat Serial Number (ISN) to identify it for message delivery purposes. A unique address code (AdC) is provided by the service provider and is mapped to the ISN at the application. A unique identifier known as the service identifier is pre-programmed in the SAT-202 as it plays a vital role in sending of receiving data. Each satellite sends a 'bulletin board' on a pre-established frequency.

Output Form:

Using Inmarsat-M2 M network we send a double burst message containing two long bursts. The first burst contains the sensor values, which is sent one by one in the following manner:

- SR 1 00XX Smoke Level
- SR 2 00XX Temperature
- SR 3 10XX Humidity
- SR 4 00XX Flame
- MB D9//Transmit Data Message.

Where the 'XX' would be the 2-byte hexadecimal values from sensor 1 to 4.

The two long bursts are a custom sensor report and a standard GPS report [5].

The Message Handling System by Honeywell stores the messages sent through the satellites, by the SAT-202 terminals. Application service providers (ASP) must connect with the handling system to procure the values for monitoring [5].

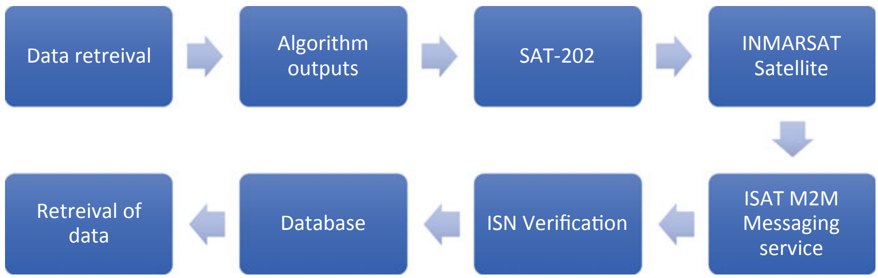

Fig. 19.3 Flow chart of the communication mechanism

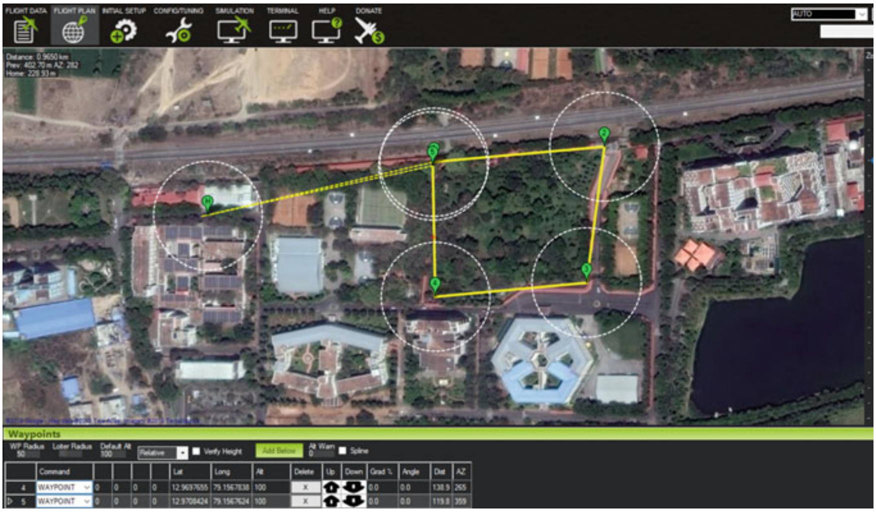

Fig. 19.4 Flight plan for localisation mechanism

19.6 Mitigation

Once the information about the initiation of fire is provided to the base station, the next step is to mitigate the fire and localise it as soon as possible. As it is difficult for the fire department to provide support, we use a multi-rotor drone for the mitigation purpose which can fly autonomously to the cluster which is under distress (Figs. 19.4 and 19.5).

As the coordinate of the given fire will be known, we use those coordinates as a feed for our drone to plot a flight path.

The drone, after reaching the cluster location, would spray a class A extinguisher around the fire to localise it, and once localisation is done, we can proceed towards extinguishing the fire.

19.7 Results and Discussions

The system discussed in this paper is an improvement on the existing NASA's MODIS system which is the current technology in use. The limitation of this system is that as the resolution of these satellites is nearly 375 m × 375 m, fire can only be detected when it reaches the resolution of half a pixel, i.e. which is roughly 7 ha. Added to this is the latency of transmission. This would imply that there is a huge latency in the detection of fire. This latency is needed to be removed, and a more efficient system is paramount. If the forest fire can be detected in seconds within its start, valuable time can be saved, and proper measures can be taken.

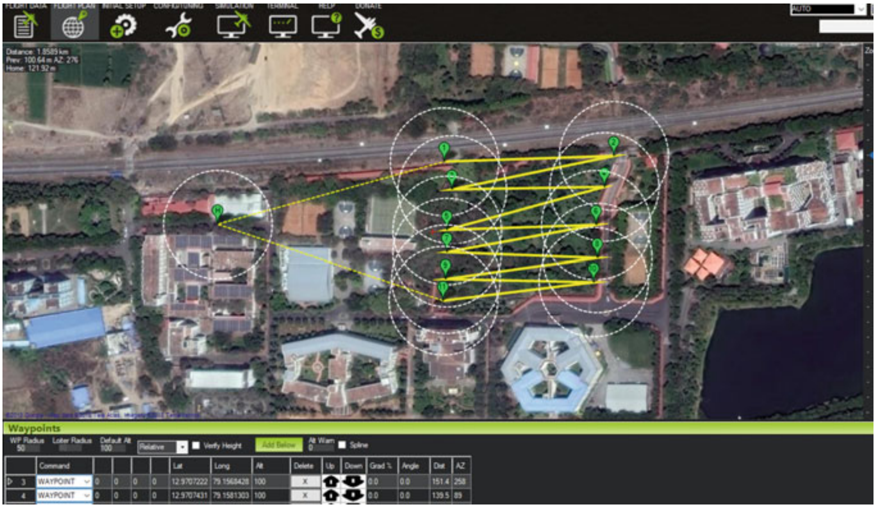

Fig. 19.5 Flight plan for extinguishing the fire mechanism

The improvement introduced in this system is that instead of detecting fire from a distant satellite, we instead detect fire from within the forest and depend on satellites only for communication. The sensors mentioned above were further calibrated in experimental conditions and tested for accuracy.

In the experiment, we tested the temperature, humidity, smoke and flame sensors. A fire was ignited on a wooden block at 20 s mark, and time taken by sensors to detect the fire was checked. The fire was extinguished at 50 s mark.

As shown in Fig. 19.6, the smoke sensor detected the fire in the very first 2 s of ignition, while the flame sensor took some time to detect the fire. When the fire was extinguished, the flame sensor immediately reacted while the smoke sensor retained its value for the next 9 s.

Figure 19.7 describes the reaction of the temperature sensor post-ignition. The temperature increased gradually at first and at 26 s mark it crossed the danger point. When the fire was extinguished at 50 s mark, it was seen that the temperature around the system gradually decreased and came below the danger point 16 s after the fire was extinguished.

Figure 19.8 describes the reaction of the humidity sensor post-ignition. The humidity around the system decreased sharply at the 23 s mark and crossed the danger point at 26 s mark. When the fire was extinguished at 50 s mark, it was seen that the relative humidity was recovered at the 90 s mark.

The timeline of the above experiment is given in Table 19.3.

It is inferred from the table that all the four sensors are active from 26 s mark to 55 s mark, and the designed system can transmit the status of mentioned sensors to the control room.

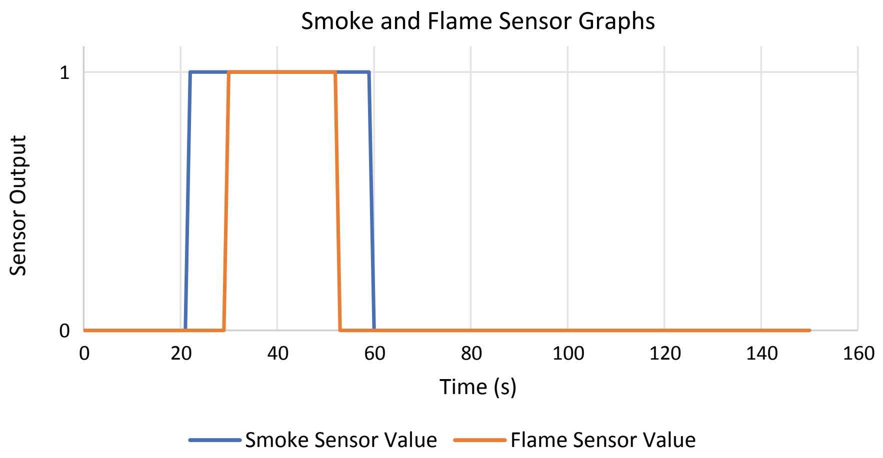

Fig. 19.6 Graph of reaction of smoke and flame sensor when introduced to fire

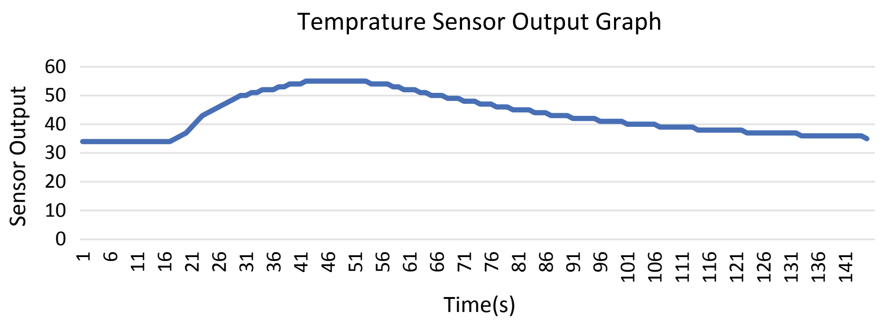

Fig. 19.7 Graph of reaction of temperature sensor when introduced to fire

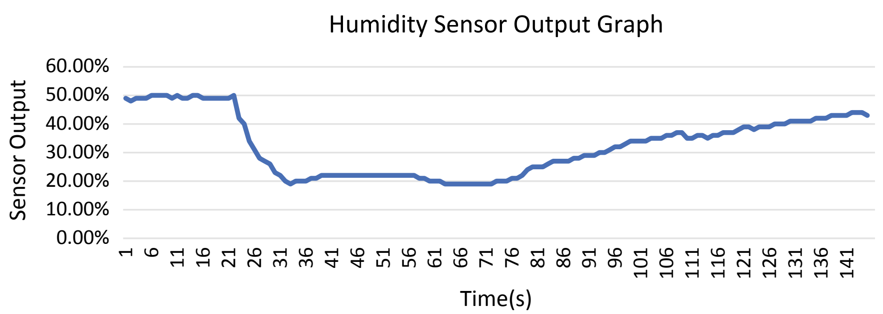

Fig. 19.8 Graph of humidity sensor when introduced to fire

Table 19.3 Timeline of system outputs received by the authorities

Time (s)	Status of sensors
1–19	Normal
19–26	Smoke indicator on
26–55	Temperature indicator on; humidity indicator on; smoke indicator on. FIRE DETECTED. Location sent. Fire alarm: ON; and provoke mitigation system.
55–91	Temperature indicator on; humidity indicator on
97–121	Humidity indicator on
127–145	Normal

The above results clearly demonstrate that the proposed system detected the fire in a faster manner than the existing system.

19.8 Conclusion

In this paper, an idea for forest fire detection has been proposed which is much quicker and efficient at early detection and warning of wildfires than the currently used methods. The implementation and working details were also included. The task was divided into five sections, namely the WSN sensor node architecture, the detection algorithm, localisation of each node, communication of sensor and position data and drone mitigation system. In this method, the fire is detected within seconds of lighting, as discussed and shown in Sect. 19.6, and the information is communicated to the authorities for timely fire extinguishing using the mitigation system proposed before it spreads and goes out of control. This system has innumerable social impacts as forest fires result in a number of deaths year-round and loss of property and also ecological impacts as forest fires result in mass green cover destruction and release of harmful greenhouse gasses and smoke particles which heavily contribute to air pollution and global warming.

References

1. Indian State of forest Report (ISFR) (2017)
2. Alrajeh, N.A., Bashir, M., Shams, B.: Localization techniques in wireless sensor networks. https://doi.org/10.1155/2013/304628 (2013)
3. Boudhir, A.A., Mohamed, B., Mohamed, B.A.: New technique of wireless sensor networks localization based on energy consumption. Int. J. Comput. Appl. **9**(12), 0975–8887 (2010)
4. Paul, A.K., Sato, T.: Localization in wireless sensor networks: a survey on algorithms, measurement techniques, applications and challenges. J. Sens. Actuator Netw. **6**(4), 24 (2017)
5. Cheng, B., Du, R., Yang, B., Yu, W., Chen, C., Guan, X.: An accurate GPS-based localization. In: Wireless Sensor Networks: A GM-WLS Method; 2011 40th International Conference on Parallel Processing Workshops. https://doi.org/10.1109/icppw.2011.32 (2011)

6. Singh, S.P., Sharma, S.C.: Range free localization techniques in wireless sensor networks: a review. Procedia Comput. Sci. **57**, 7–16. https://doi.org/10.1016/j.procs.2015.07.357 (2015)
7. Singh, Y., Saha, S., Chugh, C., Gupta, C.: Distributed event detection in wireless sensor networks for forest fires. Department of Computer Science and Engineering, Jaypee University of Information and Technology
8. Shahzada, F.: Satellite monitoring of wireless sensor networks (WSNs). In: The 5th International Symposium on Application of Ad hoc and Sensor Networks (AASENT'13), KFUPM, Dhahran
9. Zhang, J., Li, W., Yin, Z., Liu S., Guo, X.: Forest fire detection system based on wireless sensor network. School of Technology, Beijing Forestry University, Beijing