A Review to Forest Fires and Its Detection Techniques Using Wireless Sensor Network

Roopali Dogra, Shalli Rani, and Bhisham Sharma

Abstract Recently reported technological growth in wireless sensor network (WSN) has extended its application in various disastrous applications. One of the most concerned issues is the forest fires occurring across the globe. Every year thousands of hectares of forest are burnt in the forest fires occurring due to one or the other reasons. Although numerous attempts have been made for the detection of forest fires at the earliest, there is still scope for the utilization of optimum technique for the same. This paper aims to report a review of taxonomy of some of the significant forest fire detection techniques encountered in the literature so far. Moreover, scenario of the forest fires prevailing in India is also discussed. In this paper, the comprehensive tabular study of the state-of-art techniques is given which will help in the appropriate selection of methods to be employed for the real-time detection of forest fire.

Keywords Wireless sensor network · Forest fire detection · Routing protocols · Forest fire causes · Early detection

1 Introduction

One of the prominent environmental problems is the forest fire that mostly leads to the number of dangerous catastrophes that further disgruntled human lives. Retrospectively, historical data and meteorological factors were taken into consideration

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for the estimation of probability of danger caused by fire [1]. The forest fires are a global occurrence that happens throughout the year in different parts of the world. However, a number of fires are not reported on a common platform to keep an eye on the global status of forest fire suffering countries [2]. Extinguishing the forest fires normally costs billions of dollars to the victim nation [3].

Forest not only brings ecological balance to the earth but also helps in many different ways to the corresponding nation. It is quite unfortunate that the fires caused in forests are mostly discovered when are they are spreading over the large area, which makes it possible for human being to have a control over it. Consequently, devastating loss and irreparable damage are caused to the particular atmosphere as 30% of the carbon dioxide is generated from the atmosphere [4]. Other than causing eventual loss to the forest resources, the long-term adverse effects are also seen due to the forest fires that may include the devastation of flora and fauna [5].

The remote areas, abandoned/unmanaged areas filled with trees, and region with dry leaves act as a fuel to cause forest fire. In addition to this, human actions may cause forest fires that include smoking or barbeque parties, the temperature rise in the hot weather and sometimes the piece of glass that makes the sunlight focusing on the single point causing it to catch a fire. Such fire at the initial stage is termed as 'surface fire'; however, as soon as it catches the other trees and leading to the high flames of fire it is termed as 'crown fire.' At this stage, it becomes quite difficult to control fire and it lasts for a long time causing heavy damage to the forest resources.

The amount of land being destroyed due to the forest fire is in millions of hectares. It is quite unfortunate to know that the carbon dioxide released due to the forest fire is more as compared to that of automobile traffic. Early detection of forest fires could reduce the amount of loss that would have occurred in the case of fire. To make the things easier to understand, the following example can be considered. Let us suppose for an instance of fire, 1 min of fire, 1 cup of water is required, for next minute, i.e., for two minutes, 1000 L of water are required and 10 min of fire make the requirement of water to be 10,000 L [4]. Therefore, it is imperative to detect fire as early as possible to minimize the loss that would be caused by the forest fire.

1.1 The Scenario of Forest Fire in India

In accordance with the report of the Food and Agricultural Organization (FAO) [4], the humans contribute to 80% of total forest fires. The harms caused by the forest fires are much more than the harms caused due to the insects causing damage to the woods. India is the seventh-largest country in terms of area it owns. The total forest covers it owns around 7 lacs square km covering almost 21% area of the country. The fires affect much of the forest cover. The forest fires occur in tropical and subtropical areas. Dry deciduous forests and manufactured plantations are mostly victim of forest fire [1].

As shown in Fig. 1, in the year 2017 the forest fires are enhanced to the tremendous amount, i.e., 35,888, which is much more than what it was in the year 2011 [2]. In

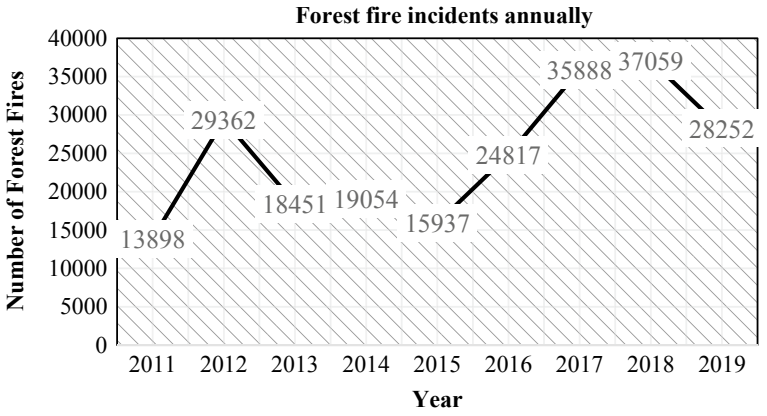

Fig. 1 Scenario of forest fire in India [1]

the British time, the first time the negative effect of forest fire was reported. It was reported that one-half to three-quarters of mature trees in plains was hollowed due to the forest fires. That caused heavy damage to the forest resources in India [4]. It is not only India; in fact many countries across the globe suffering from forest fires. The status of forest fires in world can be studied from [5]. It is important to note that the virtues of forest fires are the growth of plants that contain many nutrients. The negative effects still overcome positive effects. The hard rules have not been implemented; therefore, appropriate strategies are needed to be devised to protect our environment, human health, biodiversity. Forest fire policies need to be cemented and need to be grounded [6].

1.2 The Different Genres of Forest Fires and Their Causes The Scenario of Forest Fire in India

Forest fires are caused by the three essential elements act altogether; these elements or sources are fuel, air, and some ignition source. The classification of the forest fire causing factors can be done as follows and also shown in Fig. 2 [7].

Natural

There are some natural reasons, which are not in the control of human beings. For example, whenever there is lightening hitting in dry areas where the availability of grass and logs is at higher magnitude, the chances of fire in those areas become maximum. Whenever there is high-temperature weather, under those circumstances, the needles, peel are dried down and become favorite to forest fires. Sometimes, such fires are caused in no man's land, and in those scenarios, the bacterial breathing becomes responsible as it emits enough energy that causes fire. The term 'ghost

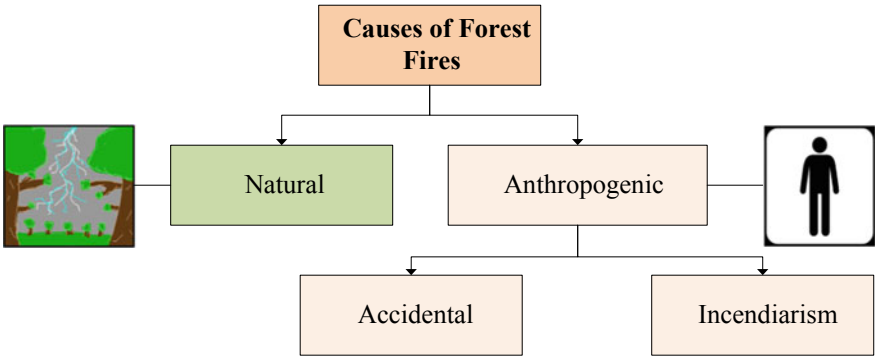

Fig. 2 Causes of forest fires

fire' is used for such generated fires. In addition to these circumstances, when two quartzite stones hit each other and create a spark that may contribute in causing fire. The important thing here that is to be noticed is the fact that chances of such fires are very few.

Anthropogenic

The anthropogenic component of forest fire includes the 'accidental and incendiarism' reasons that result in causing the fires in the forest. These factors are discussed as follows.

Accidental

Mostly, the human activities cause forest fires and the surprising fact is that it is due to more than 80% of the total causes for forest fire that is responsible for forest fires, and they are categorized under accidental forest fires [2]. These are discussed as follows.

(a) In some scenarios, when cigarette or a *bidi* is thrown into the forest, the crown fires are resulted.
(b) Railways contribute to forest fires due to their locomotive engines; however, such incidents are very low due to the replacement of such engines with diesel engines.
(c) To avail the lights in the dark nights, the part of wooden is burnt that leads to the forest fires in the worst-case scenarios.
(d) The farmers burn the old residue of crop to plant new seeds for new cultivation that also results in forest fires.
(e) In India, people burn tendu leaves to have enhancement in the production of tendu leaves.
(f) Charcoal making and alcohol extraction are the others prominent reasons of causing fires in forest.
(g) Fires from the transformers installed nearby to the forest lead to the forest fires in some adverse scenarios.

(h) There are some religious beliefs that prompt the residents to light fire in some portion of the forest that sometimes expands in uncontrolled fashion.

Incendiarism

Incendiarism can be a reason for forest fires in some locations where forest offenders can light trees to hide illegal felling and other forest crimes. Forest fires are also induced by hunters and poachers to promote the killing of wild animals. Frustrated villagers burn forests/plants unless their real requirements for grasslands, fuel, wood, and other liberties are met. Often land grabbers/innovationists deliberately burn forest regions adjacent to their planted lands and orchards to illegally expand their holdings in public forest fields.

2 Existing Forest Fire Detection Techniques

The detection of forest fire is one of the essential concerns that every other nation is experiencing. Although the huge number of attempts have been reported to detect the fires to the earliest, the control on the crown fires is still not acceptable in consideration of the damage that is being caused by these fires. The techniques for forest fire detection have been briefly discussed as follows.

2.1 Wireless Sensor Network (WSN)

Wireless sensor network (WSN) is the network constructed from the various nodes deployed in mostly remote areas to sense the surrounding and the gathered data is forwarded to the sink [8–10]. Since its development, the WSN has been playing a significant role in handling the remote and attended area monitoring through its various applications [11, 12]. The routing of the data packets sensed from the different environment helps in uplifting the quality of monitoring the target area. It is the sink from where the alarm signals are sent to the user or the rescue team for the necessary steps to douse the fire. The various essential methods have been discussed that helps in dousing the fire at the earliest.

The sensor nodes that are deployed have four main components: battery, microcontroller, transceiver, and sensing device [13]. The one thing that bothers the user while employing WSN is the limited battery of the sensor nodes which cannot be replaced once its exhausted [14]. Therefore, the efficient utilization of these sensor nodes becomes one of the primitive tasks for the users working toward forest fire detection [15].

Once these sensor nodes are deployed, they connect to each other. These sensor nodes have sensing device that can have different sensors, namely temperature, moisture, vibrational, etc. It entirely depends upon the application for which the WSN is

made to work. In forest fire detection, it is the temperature sensor that is used and in case of an event that crosses the upper limit to the predefined hard threshold for the temperature; subsequently, an alarm is generated [16].

These sensor nodes communicate wirelessly with some wireless technology like Zigbee with IEEE Standard of 802.15.4 [17–22]. Many countries have started to utilize the sensor nodes for the detection of forest fires so as the damage could be minimized.

The devastation caused by the forest fires is of great magnitude and that too occurring all over the world [23].

The numerous studies have been reported so far that have been utilized WSN for the forest fire detection. Some of the extensive reviews that are reported for deciding upon any selected suitable technique are discussed as follows.

In [24], Bahrepour et al. reviewed the crucial aspects that demonstrate the fire detection for different regions like residential or commercial areas. Shahid et al. in [25] presented the features of outlier detection techniques for WSNs that too targeting the harsh environment. Alkhatib et al. in [26] discussed various methods that help in detecting the forest fire.

Comparative analysis of forest fire detection methods in WSN

We have devised a Table 2 that incoporates different methods that cover forest fire. Further, their key findings and research gap are also highlighted.

2.2 Satellite-Based Systems

In the modern technological world, the satellites have also been used for the detection of forest fires. These satellites are Earth-orbiting satellites and in addition, some air floating device has been also used for the detection of forest fire. Advanced very high-resolution radiometer (AVHRR) [27] and the MODerate resolution Imaging Spectroradiometer (MODIS) gathered images for the forest fire detection [28, 29]. But the most unfortunate fact about using these satellites is that the images are delivered after two days which would be an unacceptable delay to deal with crown fires. Furthermore, while these satellites are put into practice, the weather conditions can disturb the image capturing by the satellites [30].

2.3 Optical Sensor and Digital Camera

In modern technology, various sensors are available for fire detection. The optical, automated early recognition and warning of forest fires are developed due to the production of huge number of sensors for the same purpose of fire detection. Various sensors are employed in terrestrial systems [31] that are mentioned as follows.

Table 1 Table captions should be placed above the tables

Metrics	Satellite System	Optical Cameras	WSN
Detection latency	Very long	Long	Small
Information related to fire behavior	Yes	_	Yes
Fire localizing accuracy	Medium	Medium	High
Efficiency	Low	Medium	High
Repetition of faulty alarm	Low	Medium	Medium

(a) Many applications use video camera that recognizes the smoke in a day and fire at night.
(b) Thermal imaging camera that depicts the flow of heat from the present sources.
(c) IR spectrometers helps in the identification of spectral components of smoke.

2.4 Comparative Analysis and Discussion

Among the aforementioned methods, the WSN has left an everlasting impression on the early detection of forest fires as given in Table 1. The sensor nodes are cheap and readily available in the market to use for the harsh environment monitoring. The methods involving 'satellites' and 'optical sensor and digital cameras' have the following shortcomings over the WSN.

(a) There is comparatively larger delay in case of delivering critical information to the rescue team in case of employing satellites and digital cameras; however, WSN performs the same task by consuming very little of time.
(b) The methods employing WSNs are more robust as compared to the competitive methods.
(c) The most striking feature for using WSNs is the least cost incurred for fire detection in forest as compared to the other methods.

3 Management of Forest Fires

The management of forest fires is done in four ways [32]. These ways have been shown in Fig. 3. Firstly, the prevention of forest fires is done by taking control on the activities nearby to the forest prone areas. Secondly, there are different mitigation processes shown in Fig. 3, that are important to consider to control the number of forest fires. Thirdly, it is essential to create early warning for the forest fires occurring in the fire-prone areas. Lastly, the preparation needs to be intact to deal with the crown fires. It is the responsibility of every citizen to follows the laws laid down by the forest ministry. Moreover, it is also important to be aware of the mischievous activities that might bring havoc to the natural resources of any nation. Prevention of throwing

Table 2 Methods of forest fire detection in heterogeneous WSN

Study reference	Name of technique	Method used	Key findings	Research gap
Yu et al. (2005) [33]	Neural Network Method	• Collected data by CH is then forwarded to sink and hence to manager node • Data processing and network processing, neural network is applied in context of forest fires	• Average communication load is reduced on nodes with the proposed method • The threshold factor is varied for inspecting behavior of communication load at different values of threshold	• The selection of CH is inefficient as it only considers energy and node density factor • The approach is not suitable for large area network, as the hotspot problem will counter the network performance
Zhang et al. (2008) [34]	Zigbee-based WSN	• Employed Zigbee-based WSN • CC2430 chip is used to design the hardware circuitry	• Information regarding temperature and humidity can be collected from any part of the network at any given time	• The concern of energy consumption, location of nodes, and requirement of synchronization question the reliability of the proposed system
Hefeeda et al. (2009) [35]	Distributed k-Coverage algorithm	• It employs Fire Weather Index (FWI) to model the fire detection system by investigating its (FWI) different parameters	• Activate near-optimal number of sensors	• The selection of CH is done only based on remaining energy which can be improved further
Aslan et al. (2012) [23]	A general forest fire detection framework	• Develops its own custom simulator using C# and Microsoft Visual Studio 2008 development environment	• Focuses on efficient energy consumption along with the earliest detection of forest fire	• Remaining energy is considered for CH selection but the distance and node density factors are not taken into consideration

(continued)

Table 2 (continued)

Study reference	Name of technique	Method used	Key findings	Research gap
Koga et al. (2014) [36]	Improved Maximize Unsafe Path routing protocol (MUP)	• The priority fire detection data is selected, and thereafter parent election is done for a node to whom data is to be forwarded	• Improves MUP by decreasing dropped rate and end-to-end delay of high priority data	• Multi-hop transmission among nodes will exert burden on relaying nodes that eventually lead to energy-hole problem
MA et al. (2018) [37]	Sybil detection method	• RSSI-based and Residual energy-based Sybil attack detection techniques are used False negative alerts are avoided	• High stability period and network lifetime are achieved by the proposed technique as compared to LEACH, SEP, and PASCCC	• There is computational complexity in CH selection. Overheads are too many that lead to energy consumption

any inflammable material in the forest mitigating the dry leaves and helps the ruling government bodies to declare early warning timely are some of the important tasks that are to be valued.

4 Conclusion and Future Scope

Forest fires are one of the important concerns that every other country with significant forest resources is experiencing. In this paper, different scenarios of forest fires are briefly discussed while pointing out the reasons and the prevention measures to avoid the forest fires. Moreover, we have statistically discussed the forest fires prevailing in India and the role of WSN and different attempts made in WSN to detect forest fires are discussed. It is observed through the reported study that the forest fires still seek a lot of significant serious attention to avoid heavy damage to natural resources or human resources at big magnitude. In future, this study will be taken into consideration to frame an effective measure to avoid the forest fires and also the actions that should be taken to put control on fires before it spreads all across the lands. Moreover, in future, a framework can be generated that regulates the local body around the forest area, so as the forest resources could be saved from fire caused due to any reason.

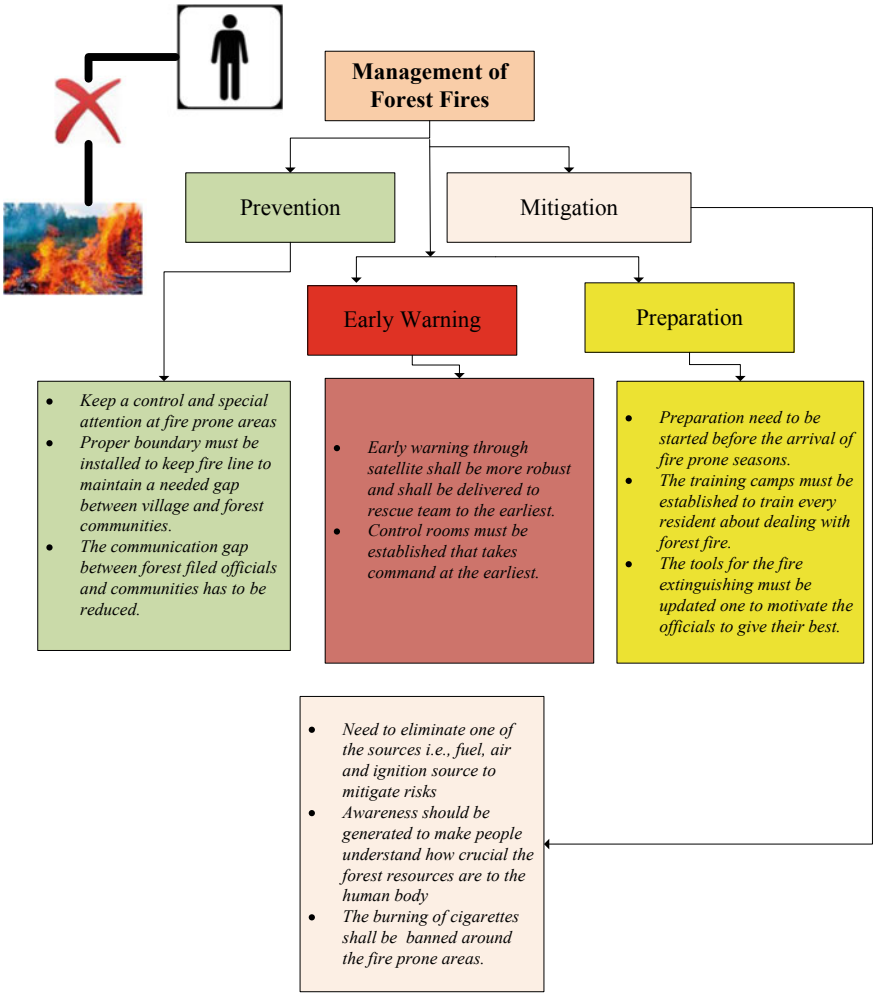

Fig. 3 Management of forest fires

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