A Review on Forest Fire Detection Techniques: A Decadal Perspective

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Abstract

Forest fire disasters have always been mankind's constant and inconvenient companion since time immemorial. In the recent past years, managing crisis for example a large scale fire has become a very difficult and challenging task. Things that are common in most of the forest fire that occur at large scale are loss of life (human or animal), loss of vegetation, loss of flora and fauna, and communication failure (if any). Apart from causing a great loss to valuable natural resources of nature forest fire pose a greater risk not only to life of human being but also to the inhabitant's such as wild life living in the forest. As per National Fire Danger Rating System (NFDRS), if a fire is detected within 6 minutes of its occurrence then it can be easily disposed-off before it turns into a large scale fire. For this a network that can detect fire at a very early stage is required. There are numerous techniques to detect the occurrence of forest fire and this article is dedicated towards reviewing detection techniques present in the literature. This work will give a bird's eye view of the technologies used in automatic detection of forest fires and reviews almost all the detection techniques available in the literature. To the best of our knowledge this is the first time that almost all the techniques available in the literature are reviewed and considering almost all the parameters.

Keywords: Forest Fire, Networks, Techniques.

1. Introduction

Forests are the main ecological balance contributor to the nature. Unfortunately, this ecological balance is greatly disturbed by fire disaster that occur regularly every year in every forest of every country. Every year thousands of hectares of forest land are destroyed by incidences of fire. This will generate much more Carbon Monoxide (CO) when compared to CO released by overall vehicular traffic. A known rule as mentioned in [1] applies here i.e., if a fire continues to burn for a minute then it can be disposed-off by one cup of water (say 1 litre) and if the burning time is doubled then the amount of water required will be multiplied by ten times. Similarly, a fire with a burning time of 10minutes may need more than 1000 litres of water. The main causes of forest fire almost every time are natural and man-made of which man-made causes are always on rise. Natural causes include fire due to lighting and lava and man-made causes range from unattended campfires, cigarettes that are discarded negligently, uncontrolled burning of debris to intentionally setting the forest on fire, the causes that are mostly common. The sad part of forest fires is that it can only be detected once it has spread and covered a considerable area. Once a fire covers a considerable portion of forest it always becomes uncontrollable and disposing off these fires is out of reach. The occurrence of fire in forest can be classified into three types as shown in Fig.1.

Ground fire generally produces only heat without much flames. Therefore, to detect these type of fires high precision sensor is required which are sensitive to detect changes in temperature of even 1° C. Thermal and radiation sensors are sensitive to record changes as small as 1° C in temperature[2]. Also as given in [3] reptiles equipped with sensors can be used to detect ground fires. Surface fires generates smoke and will occur on the surface of the forest. There will not be much heat generated and neither flames are developed. Therefore, a smoke sensor will suffice the purpose of detecting surface fire. Crown fire generates heavy flames and is a result of surface fire going undetected. A surface fire if not disposed-off at its initial stage will take a shape of crown fire. No sensor will be able to withstand the high temperature generated by crown fire.

Rest of the paper is organised as follows

Section II gives the overview and comparison of different detection techniques available in the literature. Section III proposes architecture suitable for forest fire detection and section IV concludes the paper.

(a) Ground Fire

(b) Surface Fire

(c) Crown Fire
Fig. 1: Types of Forest Fire

Fig. 1a represents ground fire where the fire ignition happens below the ground and only smoke will be visible above the ground without any flames.

Fig. 1b is for surface fire where the ignition happens because of leaves spread on the surface of forest. In this case flames are visible and also some smoke. The height of the flame at the initial stages of fire will be minimum and as the fire progresses the height of flame increases and the smoke density reduces. If the fire is not controlled in its initial phase, then within no time it converts into a crown fire.

Fig 1c is crown fire where the complete forest is burnt and the height of flames is visible from distance. Here the fire becomes uncontrollable and can only be disposed-off naturally.

2. Forest Fire Detection Techniques

There are many techniques used by the authorities to detect forest fires, satellite detection being the common amongst authorities of across the globe. Few authorities use human observers as detectors and reporters of forest fires. This section is detected towards discussing the different detection techniques available in the literature and also highlights the differences among all the techniques. Table I highlights the differences amongst them. Table II divides the number of references into year wise and technique wise. This division is performed on the basis of techniques available in the literature and considering the techniques available in the last decade. Parameters considered for comparison are generalized ones such as implementation cost of the system, the practicality of the system in real time scenario, discussion of the system in literature, whether the detection device is stationary or mobile, the mechanism of providing power to the detection device/ recharging, whether the system is providing the fire behaviour i.e., the fire spread information, whether the system is suitable for detection in a specified/limited region or can it cover the entire forest, the delay between detecting the fire incident and reporting it to the central node or control centre, rate of false alarms i.e., whether the system is capable of differentiating the exact occurrence of fire from the symptoms of fire, the error between the exact location point of fire to the point given by the system. These techniques can also be divided into a category that differentiates between hardware computing techniques and soft computing techniques. In hardware computing techniques the fire detection network should have a real time data which has to be collected by deploying the network in close to real time situations. The data collected will be in real time and analysis performed will also be in real time. In soft computing techniques the data on which analysis will be performed will not be of real time and therefore will have certain assumptions which may not be true. Also there are many techniques which are dependent on data coming from satellite images and these techniques will have a waiting period that ranges from 12 to 48 hours.

Table 1: Comparison Amongst Different Forest Fire Detection Techniques

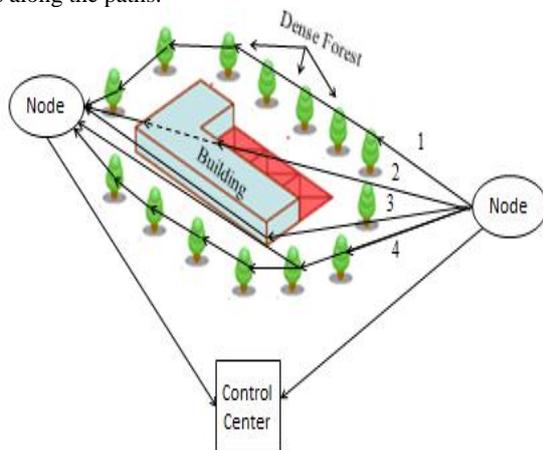| Comparison	Sensor Based Techniques (Wireless sensor Networks) [4-12]	Camera Based Techniques (Image and Video Processing) [13-27]	Neural Networks Based Techniques [28-33]	Satellite Based Techniques [34-37]	UAV/ Air borne Techniques [38-42]	Fuzzy Logic Based Techniques [43, 44]	Animals as mobile sensors [3, 45]	Radio-acoustic based techniques [46]
Cost	Low	High	Low	Very High	High	Low	High	Medium
Practicality	High	Medium	Low	Very High	High	Low	Very Low	Very Low
Frequency of use in literature	High	Medium	Rare	Very High	Medium	Rare	Very Rare	Very Rare
Detection device mobility	Fixed	Fixed	Fixed or mobile	Mobile	Mobile	Fixed or mobile	Mobile	Fixed
Battery power provided through	Rechargeable Devices	Rechargeable Devices	Rechargeable Devices	Solar	Rechargeable Devices	Rechargeable Devices	Rechargeable Devices	Rechargeable Devices
Information	Yes	No	Yes	Yes	Yes	Yes	Yes	No

on fire behaviour								
Region of Interest	Can be extended	Limited	Limited	Complete Forest	Can be extended	Limited	Limited	Limited
Detection to notification delay	Small	Long	Small	Very Long	Long	Small	Long	Small
False Alarm	Low	Medium	Medium	Very Low	Medium	Medium	High	High
Fire localization error	Low	High	Low	Very High	High	Low	High	High

Table 2: Year Wise and Category Wise References used in this Article

Year ⟹ Technique ⟱	2008-10	2011-13	2014-16	2017-18	Total References
WSN Based	4	4	1	--_	9
Camera Based	5	2	5	3	15
Neural Networks Based	2	1	2	1	6
Satellite Based	--	--	4	1	5
UAV Based	1	1	3	--	5
Fuzzy Logic Based		1	1	--	2
Animals as mobile sensors	1	--	1	--	2
Radio-acoustic system	1	--	--	--	1
Total References	14	9	17	5	45

3. 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. Fig 3a 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 [47]. 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.

Fig 3b describes an architecture of system that can detect incidences of fire in the complete forest. It is basically a cluster based network where a group of sensor node form a cluster and a central node will act as a cluster head. Sensor node will have limited range communication ability where as a cluster head i.e., central node can communicate directly with the control centre which can be either situated near to the forest under surveillance or it can also be situated remotely very far from the forest under surveillance.

The system proposed in the Fig. 3a and 3b consists of sensor nodes which can have

i) Sensors such as temperature, humidity, CO which are suitable for fire detection through Wireless Sensor Networks

(a) Detection of fire in Limited Region of Interest
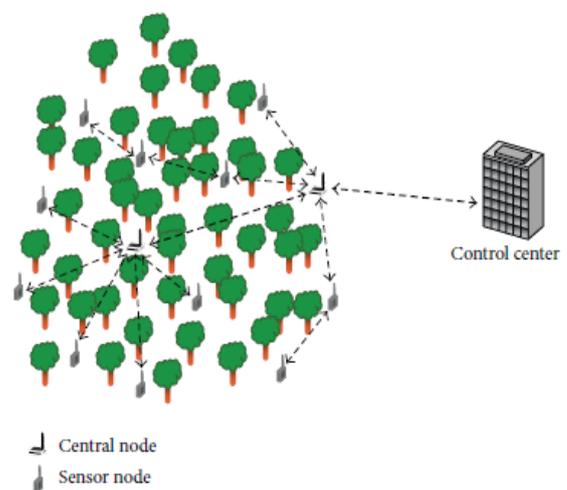
(b) Detection of fire in complete forest
Fig. 2: Proposed architectures of forest fire detection

Table 3: List of sensors with potential applications

Type of Sensor	Potential Applications
Temperature sensor	Detecting change in temperature with respect to change in humidity
Humidity sensor	Detecting change in humidity with respect to change in temperature
Smoke sensor	Detecting presence of smoke which typically indicates occurrence of fire
Carbon Monoxide(CO) sensor	Detecting CO gas released from fire
Infra-red(IR) sensor	IR sensor is used as a flame indicator
Barometric Pressure sensor	Detect the change in pressure in environment in case of fire
Passive Microwave Imaging sensor	Microwaves can easily penetrate dense smoke.

ii) Cameras interfaced with sensor nodes such that image processing and video processing techniques can be implemented

iii) Microprocessor and microcontroller along with sensor nodes to implement neural network and fuzzy logic based detection techniques.

iv) Unmanned Aerial Vehicle (UAV) embedded with sensors that can detect and monitor the incidences of fire.

v) Sensors as wearable devices capable of detecting fire incident and which can be placed on inhabitants of forest.

Communication between central node and sensor nodes can be through ZigBee transceiver, Radio Frequency transceiver, GSM transceiver through SMS. Likewise, communication between central node and control centre can be through ZigBee transceiver, Radio Frequency transceiver, GSM transceiver or else Internet of Things concept can be utilized. GSM communication allows a user to send alerts in the form of SMS (Short Message Service) or in the form of call to the firefighting services so that the rescue operations can be immediately carried without any delay. A ZigBee communication is desirable in scenarios where the amount of hardware required is limited and also the cost function is of prime importance.

4. Conclusion

In this article a details review of techniques available for forest fire detection from the literature has been performed with respect to generalized parameters that fits best to all the techniques. Finally, we propose a list of sensors that can be used in any technique and are readily available. Table III gives the list of sensors that can be used for forest fire detection with their potential applications. Out of the listed sensors one can easily conclude that the frequently used sensors for forest fire detection are temperature humidity smoke and CO sensor. The other sensors can be combined with aforementioned sensors in order to reduce the rate of false alarms and increase the detection probability. The similarity index of measurements among different sensors should be carried out in order to make sure that the combinations of sensors will not give false alarms. For example, when temperature, humidity and smoke sensors are used together than one can compare the readings of temperature with humidity and smoke so that false alarms can be reduced to negligible count. When fire occurs temperature increases and humidity decreases therefore combination reading reduces the rate of false alarms. Moreover, the network for forest fire detection should be an easy to implement network with a very little or no maintenance.

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