Smart Wireless Forest Fire Alerting System

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Abstract*: The forest coverage over 30% of the Earth's land surface assist to balance the water cycle as well as the natural conversion of O_2 and CO_2, which aids in organism respiration. Therefore, various research and studies have been paid attention to prevention of deforestation. Deforestation is mostly caused by forest fires, which can occur naturally or as a result of human negligence. Since a forest fire can be started by a single lightning strike, preventing them before they start is deemed impossible. However, early discovery and response can lower the frequency of occurrence. The study proposes a Wireless Sensor Network with smart sensor concept, which uses radio frequency communication as the communication technique and allows sensor nodes to connect with each other to verify the status of their neighbors. The base station or master node of the sensor network, which is located outside the forest cover, has been used to send out alerts using GSM technology. The communication network was built up with the help of HC-12 and NRF 24L01+ radio frequency transceivers, and the DHT-*
11 temperature and humidity sensor were utilized for detection. The accuracy was tested through a different testing strategy with a prototype of a distributed single sink wireless sensor network, and the results were evaluated. A comprehensive system with more components can be developed to expand the sensor network to cover a large forest area.

Keywords: *Forest Fire Detection and Alerting, Wireless Sensor Networks, Smart Sensors, Inter Sensor Communication, HC-12 Communication, NRF24L01+ Communication*

1. Introduction

According to the earth's mechanism, which was designed to persist, life has been constructed on trees, water, and air. These three factors work together to provide a healthy environment for all living beings on the earth. Trees are the most important of the three elements when it comes to maintaining the balance of the other two. Trees have a big impact on the water cycle and the composition of the atmosphere. Although the total area of the globe is 509 600 000 km^2, only 148 326 000 km^2 is land (“Earth Facts - Nations Online Project,” n.d.). From this land area over 30% is covered with forests. Forests are also an important part in the natural conversion of CO_2 to oxygen, which is the respiratory gas of almost all living things. Forests not only keep the planet's living conditions alive, but they also shelter the most species on the planet.

In Sri Lanka, forests cover more than 29.9% of the land area. The island of Sri Lanka is home to a diverse range of animals and plants. Depending on the weather, there may be 50 to 200 fires reported in Sri Lanka each year(“GLOBAL FOREST FIRE ASSESSMENT 1990-2000 - FRA WP 55,” n.d.). Additionally, a single fire in Sri Lanka often affects an area of 10 acres. 20% percent of all reported fires are in eucalyptus plantations, and nearly 55% of all reported fires occurred in Pinus plantations. For comparison, even though most of the countries have taken various kinds of measure to detect and reduce the damage caused by the forest fires, Sri Lanka doesn’t have a solution to this problem. Main reason for this one can be seen as the forest fires are neglected by not only public but also the authorities until it occurs and ends up with a huge damage to the forest cover and the biodiversity of Sri Lanka.

Forest fires can start in one of two ways: the natural way or the artificial way. The artificial method involves man-made conditions such as cigarette stubs, charcoal left behind from camping trips, and so on. The natural way is to spontaneously combust dry fuels like wood or dry leaves due to severe heat or a lightning strike. Even while the artificial way can be controlled by implementing strict laws, forest fires that occur spontaneously cannot be stopped. The only way to solve this problem is to detect them early and respond quickly to reduce the damage. Throughout the history of technology, people have invented a variety of solutions to this problem. Among these are satellite-based solutions, image processing approaches, and sensor-based solutions. As well as various forms of advantages, the disadvantages can also be recognized when revising them. The system aims to identify the methods used by the world to detect and alert the forest fires, identify the weakness of them and develop a novel and efficient system to mitigate. In order to achieve the above aim this paper proposes a system that uses Wireless Sensor Networks (WSNs), which are widely utilized in industrial automation

and large-scale agricultural fields, to detect and alarm forest fires early, and prevent the damage as soon as possible. The proposed system will be able to implement in anywhere in the world as it uses the radio frequency as the medium of communication where it can function alone even in a forest with no network coverages available and also power saving techniques have been used to maximize the efficiency with a new method added to have inter-sensor communication.

2. Literature Review

A. Types of Forest Fires and Detection Techniques

As mentioned earlier, when considered the forest fires all over the world, an origin of a fire can be named in to 2 categories as Naturally Occurred Fires and Man Made Fires. ("A Review on Forest Fire Detection Techniques - Ahmad A. A. Alkhatib, 2014," n.d.). Naturally occurred fires can be due to the extreme heat and the humidity conditions of the atmosphere which eventually begin to burn the dry leaves, twigs, lichens etc. Also, spontaneous strike of a lightning on to a dry tree or a log can give a head start to a forest fire. Man-made fires are due to the carelessness of the humankind when doing activities inside the forests. A burning trash of a cigarette, leftovers of a campfire which was not properly terminated are the common reasons for man-made fires. In countries like Sri Lanka, traditional farmers set fires to the part of a jungle to setup the land for their chena cultivations. These fires also can be spread through the forest and make a huge fire. Through this literature review, it was able to identify the earlier applied techniques and methodologies by other researchers to implement similar systems and advantages and drawbacks of them. According to the types of forest conditions the forest fires are categorized as Creeping fires, Crown fires and Ground fires(Drapalyuk et al., 2019).

Fire suppression is a difficult task as it spread in large areas within minutes. There is a known rule by fire fighters on suppression of forest fires: "1 minute – 1 cup of water, 2 minutes – 100 liters and 10 minutes 1000 liters"("A Review on Forest Fire Detection Techniques - Ahmad A. A. Alkhatib, 2014," n.d.). The first step of an effective fire suppression is to detect as soon as possible and alert the authorities. Most common fire suppression and detection techniques used by the authorities can be identifies as, controlling burning of a forest layer, fire weather forecasting and estimation of fuel and moisture, watch towers inside forest, optical smoke detection, lightning detectors by which the coordinates of the strike can be detected, infrared, spotter planes, water tankers, educating house owners through Fire Watch or similar schemes("A Review on Forest Fire Detection Techniques - Ahmad A. A. Alkhatib, 2014," n.d.).

With the evolution of the technology, the world identified the importance of forests and the importance of the reducing the damages of forest fires, the world began to search for new methods to detect and alert on forest fires.

B. Satellite based Systems

The satellites orbiting around tasked to observe and detect forest fires. Advanced Very High Resolution Radiometer (AVHRR) ("USGS EROS Archive - Advanced Very High Resolution Radiometer (AVHRR) - Sensor Characteristics | U.S. Geological Survey," n.d.), which launched in 1998 and Moderate Resolution Imaging Spectroradiometer (MODIS) ("MODIS Web," n.d.), which launched in 1999 are been used. The drawbacks of these are, they can provide the images of the regions Earth with a 2-day time interval and the resolution of the images can vary with the weather conditions ("A framework for use of wireless sensor networks in forest fire detection and monitoring," n.d.). Forest Survey of India under the ministry of Environment, Forest and Climate Change is using a satellite-based system using MODIS as Forest Fire Alert System 3.0 since 2017("Forest Fire Alerts System 3.0 | Forest Survey of India," n.d.) . Registered users will alert on the forest fires via SMS with the geo location of the fire and a weblink to open via browser.

Other than those, any geostationary (GEO) and Low Earth Orbit (LEO) satellite can be used. The optical and infrared radiations emitted by burning flames has to identified as early as possible by those satellites and should send back to Earth to alert authorities. LEO and GEO satellites are orbiting over 22,800 miles above the10 planet's surface. So, the intensity of radiation decreased. Also, a satellite is sent to perform various tasks like communication, remote sensing etc. A dedicated satellite for forest fire detection cannot be defined as a cost-effective method. So, they might not be equipped with all the relevant technical requirements like transponders, amplification receptions, antennas, a dedicated downlink transmission for forest fire detections etc ("A Review on Forest Fire Detection Techniques - Ahmad A. A. Alkhatib, 2014," n.d.).

C. Optical Sensor and Digital Camera

Present, two types of sensor networks are available for the forest fire detection. Wireless Sensor Networks and Camera Surveillance Networks. Development of the technology have given the world high performance hardware products like sensors, digital cameras, thermal imaging etc. When it integrated with software capabilities like image processing techniques, it will provide optical automated systems for early detection of forest fires. According to National Forest Centre of Slovak republic, there are few sensors which can be used to develop such kind of optical sensor systems such as, Video-

camera, Thermal and Infrared camera, IR spectrometer and Light Detection and Ranging Systems. (“Detection and monitoring of forest fires.pdf,” n.d.)

FireHawk is a risk management system used in South Africa to detect forest fires. This a camera-based system controlled by an operator. Cameras are placed on a tower which will cover around 6-7km of range (“FireHawk,” n.d.).

AlarmEye is a fire detection system with self-learning algorithms. The system is specially designed to detect forest fires with monochrome, IR, color, multi frequency sensors. Effective distance my differ with the selected camera. The system is implemented in Thailand (“Detection and monitoring of forest fires.pdf,” n.d.)

Nayana G H (G. H, 2018) proposed a system using color models to detect the forest fires. The images taken from digital camera are analyzed through matlab simulations and detect the fires. For this also it needs to be a clear image of a fire and also a large area should be covered with fire to detect using the software algorithms. Motions of the sun, moving clouds, shadows of trees also obstruct the sight of the cameras and may give errors. Also, the tower with these systems has to be located on a top of a hill in order to cover a maximum area of land. Hence forests with flat terrains and rich canopies will not provide effective results with these optical sensor towers. When integrated with image processing techniques also, give some false alarms due to the weather conditions like mist, heavy rains.

D. Wireless Sensor Networks

Wireless Sensor Networks are mostly used in industrial automations in the world. The line of sight and the early detection of the fire can be achieved through this technology. The sensors will gather the environmental parameters and it will be sent to the master nodes using a wireless communication protocol. When setting up a WSN, communication networks, routing protocols, power management are key areas which needed to be considered. The components of a sensor node should be defined in the design, and it may differ from the type of task it has to achieve. Also, the scale of the sensor network may vary with the type of the area and the operations (Lewis, n.d.).

Aslan (“A framework for use of wireless sensor networks in forest fire detection and monitoring,” n.d.) has proposed a fire detection framework using WSN with sensor deployment scheme, network architecture and intra cluster communication protocol. The architecture is based on finding the optimal distance between the sensor nodes to avoid collision and minimum number of sensors to maximize the coverage. However proposed system does not state about the power resources and the wireless communication protocol to be used.

Wenning et al (Wenning et al., 2010) present a successful disaster detection routing technique using wireless sensor networks. The protocol was created to be aware of a destruction of a node. And it can change the pathways if a sensor node fails. The method can also change the routing state based on the data it receives. A potential failure danger indicated by an observable phenomenon. When implementing in the forests the source of power and the wireless communication protocol has to be considered carefully as both the resources are limited inside the forests.

There are few wireless communication standards used in wireless sensor networks such as IEEE 802.15.4 , ZigBee, Wireless HART, IEEE 802.15.3, ISA100.11a and Wibree. (“iceeot.2016.7755194.pdf - International Conference on Electrical, Electronics, and Optimization Techniques (ICEEOT) - 2016 Forest Disaster management | Course Hero,” n.d.).

According to the study, the low cost and effective method of detecting and alerting forest fires can be defined as the use of Wireless17 Sensor Networks. The existing and the proposed systems also taken into consideration. In the next chapter we moved into the approaches based on Wireless Sensor Networks. And figure out the best approach to develop a system which can give a solution to the problem identified while fulfilling the objectives.

3. Design Framework and Methodology

The Smart Wireless Forest Fire Alerting System is based on Wireless Sensor Technology. The architecture of the proposed system consists of mainly 3 components.

- Sensor Node – The sensor node is responsible for taking the environmental parameters.
- Sink Node – Sink node takes the data from the sensor node and send it to the base station.
- Base Station - The base station sends the alerts to the authorities

- *A. Proposed Architecture*

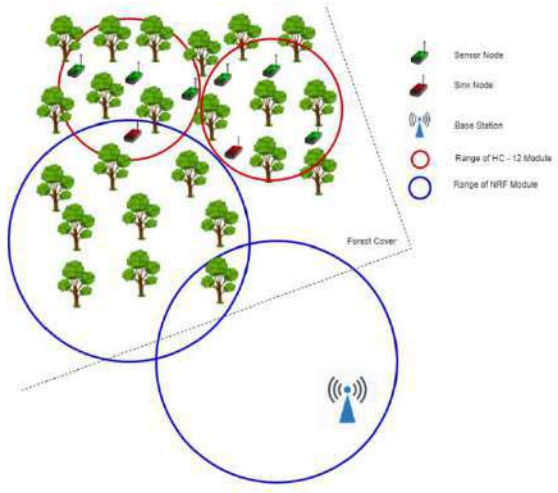

Figure 1: Proposed Architecture
Source: Author

The environment of the proposed system is forests. So, the harsh environment, power factor and the lack of communication coverage inside the forests has to be addressed when designing the system. Also, to acquire the scalability, distance of the components and the range of the communication protocols have to be decided. Inter sensor communication also should be taken into consideration.

The system will obey the basic rules of single sink distributed WSN. But because of the constraints in the theoretical approaches, the system will adapt the components in centralized formation technique also.

Usually, the sensor nodes will take the environmental parameters like temperature and humidity, it will send to the sink node to analyze. But, in proposed system sensor nodes are designed according to the smart sensor concept. Thus, inside the sensor node heat index will be calculated as increasing of the heat will not be accurate to detect fire. If the heat index is not exceeding the threshold level, sensor node will check for the status of the active. Else, the sensor node will alert the sink node on heat. And if the sensor node detects a failure of the neighbor node, it will also alert to the sink node. Sink nodes will get the analyzed data from the sensor nodes and send it to the base station. Base station which is placed outside the forest cover will send and SMS alert to the pre-defined authorities about the temperature increment.

According to the architecture of the proposed system, inputs and outputs will be specific to the component according to their role in the system. As the system is fully autonomous, all the inputs will be taken by each component itself. Sensor node will have two kinds of inputs. The main input to the system is the environmental temperature and humidity. Those will be taken from the temperature sensor which is integrated to the sensor node. The secondary input to the sensor node will be the signal from the neighbor node which will be received to check the status of the neighbor node. This will be received by the signal transceiver in the sensor node. Inputs to the sink node will be the two signals from sensor nodes on heat and the neighbor node failure. Both signals are acquired by the transceiver in the sink node. Inputs to the base station will be the signals from the sink node. Those are received by the long-range transceiver integrated in the base station.

The output of the system also differs with each component according to their role in the network. Sensor node will output the heat alert signal and neighbor node failure signal to the sink node. Sink node will output the two signals taken from sensor node to the base station. These signals will transmit one by one in different time intervals to avoid data loss. Output of the base station is the alert to the authorities through GSM technology. All the components in the system are designed to get the optimal power consumption as power is the critical resource inside the forest. All components are designed to get the power from solar panels separately.

B. Sensor Node

Sensor node is consisted with 2 components. Temperature sensor and the radio transceiver for the communication. Sensor nodes are made according to the smart sensor concept so the sensors will analyze the gathered data within the sensor, and it will decide what to be sent to the sink node for the alerting process. This will make the power consumption low. Taking the environmental parameters also done it time intervals. All the other times, the sensor is in idle state. Another feature of the sensor node is it will communicate with neighbor node to check the status of the node. Inter sensor communication has been establish in this system. If the neighbor node is in inactive stage, the sensor node will alert the sink node about the failure.

C. Sink Node

Sink node is act as the mediator between sensor node and the base station. It consisted with two transceivers. One will communicate with sink nodes and the other one will communicate with base station. This is done because of two reasons. As soon as a heat anomaly detected, the sensor node should send it to sink node and sink node should sent it to the base station. Because of this a transceiver will always in listening state. The other reason is the range of the transmission. Sink node will transmit the alert message to the base station which is outside the forest cover. This will need strong transmission power. So, a different frequency is used to do the communication.

D. Base Station

Base station is mainly responsible for sending a SMS to the authorities alerting the heat or the sensor failure. Sensor node and the sink node are placed inside the forest to take the environmental parameters. Since the forests do not have any network coverages, base station must be placed outside the forest cover where a network coverage is available. It will receive alert from the sink node and send the SMS to the relevant authorities via GSM technology.

E. Smart Sensor

This is the novel idea which has added to the system. As the radio frequency has used as the communication protocol in this system, there is not any method found to establish a sensor-to-sensor communication. Smart sensor means the sensor nodes will communicate with each other to check each other's status. This has achieved by exchanging signals through radio transceiver integrated in the node.

F. Development Methodology

1) Sensor Node: Sensor node was developed with DHT 11 sensor and HC – 12 radio frequency modules integrated to Arduino nano micro controller. Initially developed the circuit in bread board for the testing purposes before making a printed circuit board. Tx and Rx pins in the HC 12 modules also connected to the GPIO pins in the Arduino board. SoftwareSerial.h library is used in the coding to program the module. In the market, there are few HC radio frequency modules like HC 06, HC 05 and HC 12. The specialty of the HC 12 module is it has a SET pin. Using that pin the module can setup to different frequency channels to do the communication. This can be done within the code with AT commands. Checking the status of neighbor node will be done in a separate channel and when a sensor node has to communicate with sink node, sensor node will change the channel to the frequency channel which is used by sink node and sends the alert signal. DHT 11 was given a 5V and data pin was connected to the GPIO pins in Arduino board. Adafruit DHT.h library was used in programming the temperature and humidity sensor which will give the parameters to calculate the heat index. DHT – 11 will not measure extreme temperatures. So, when programming the sensor module, decided to take heat index as the variable data to get the threshold which will calculated with humidity.

$$\square\square at\ \square n\square\square x(\square\square) = \square 1 + \square 2T + \ \square 3R + \square 4TR + \square 5T2 +$$

$$\square 6R2 + \square 7T2R + \square 8TR2 + \ \square 9T2R2$$

2) Sink Node: Sink node is developed with two radio frequency modules namely HC 12 and NRF240L1+ module integrated to Arduino mega microcontroller. HC 12 will do the communication with the sensor nodes to get the alert. NRF module will send the alert signal to the base station which is outside the forest cover. Reliability, accuracy and efficiency is high for long range transmission with NRF module as it has few built-in features to enhance the performance and prevent data loss(Bento et al., 2019). Also, the ability to use 125 channels will give the system to scale easily. Same as the sensor node, SoftwareSerial.h library was used to do the programming in HC 12 module. Since NRF 24L01+ is a complex module 3 libraries have to use in addressing the module. SPI.h library handles the SPI communications and nRF24L01.h and RF24.h libraries to control the module. As soon as the sink node receives the alert using HC 12 module, NRF module will task to send the signal to the base station.

3) Base Station: The base station is placed outside the forest cover where it can have the mobile network coverage to send the alert via SMS. When doing the study, we considered on to implement the system in any forest cover. So, the main problem was lack of network coverages inside the forests. Because of this reason we have used 2.4 GHz radio frequency to do the communication inside the forests. System is automated so that without any human intervention, the system can run. Base station is the medium which the system connects with the outside world. Outside the forest cover a place where GSM coverage available has to be found to place the base station. Same as the sink node Arduino mega microcontroller was used to integrate NRF module and the GSM module.

4. Discussion

Everyone in Sri Lanka disregards the value of trees and their protection. Technology is rarely used to save forests. A vast amount of forest cover has been destroyed over the years as a result of forest fire negligence. To address this issue, a low-cost effective system for detecting and alerting forest fires has been proposed. The system was designed to produce a Smart Wireless Forest Fire Alerting System. The system was created using Wireless Sensor Network technology, allowing it to be implemented in any type of forest. The prototyped system is capable of covering more than 600 m2 of forest cover and is scalable as necessary.

The table below shows the test results obtained with range testing for each component separately. The tests were carried out in an open environment with trees and obstacles to simulate the environment found in forests. Started with the minimum distance specified in the specifications and ended when the signal failed.

Table 1: Range Test Results

Components	Distance	No. of Repetitions	Results (Number of successful nodes)	Percentage of Success
Two Sensor Nodes	1 m	10	10/10	100%
	10 m	10	10/10	100%
	50 m	10	10/10	100%
	100 m	10	8/10	80%
	500m	10	6/10	60%
	1 km	10	0/10	0%
Sensor Node and Sink Node	1 m	10	10/10	100%
	10 m	10	10/10	100%
	50 m	10	10/10	100%
	100 m	10	8/10	80%
	500m	10	6/10	60%
	1 km	10	0/10	0%
Sink Node and Base Station	2 m	10	10/10	100%
	50 m	10	10/10	100%
	100m	10	10/10	100%
	500m	10	10/10	100%
	1km	10	10/10	100%
	1.2 km	10	8/10	80%
	1.5 km	10	0/10	0%

Source: Author

Sensor to sensor range and the sensor node to sink node range give the same results as the same HC 12 modules were used. According to results the HC – 12 module is had issue when the transmission distance is greater than 50m. The Success rate is gradually decreasing and comes to zero at 1 km distance. So, by considering these results the maximum effective distance to place the sensor nodes and sink nodes can be decide as 50m. The placement of the sensor nodes can be explained as in the vertices of a regular polygon where the length of an edge is 50m and the sink node in the center.

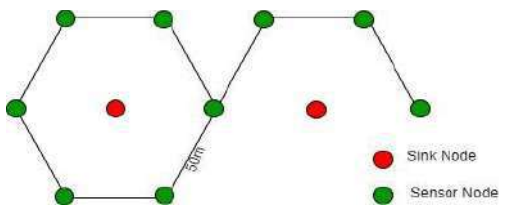

Figure 2: Ideal Sensor Placement
Source: Author

In the other scenario, the NRF module exhibits significantly greater transmission strength due to its Power Amplifier and Low Noise Amplifier features. It can successfully transmit over a distance of 1km. According to these results, the Sink node and the Base station should be placed as their ranges get intersected. In order to check the accuracy of the temperature measurements of the DHT 11 sensor, few types of fires according to the magnitude were introduced to the sensor and recorded the maximum distance where it stops the detection of the fire and increase the temperature up to 45°C. The maximum body temperature a human body can withstand is 42.2°C("Thieme Medical Publishers - What can a person survive? The borders of the human body," n.d.). 4 types of fires were introduced to do the test:

- Flame – A candle flame
- Small Fire – Fire made by burning of papers.
- Medium Fire – Burning of household trash
- Large Fire – A fire made using a pile of dry woods (To simulate a small campfire)

Other than a large fire mentioned in this cannot be made in an urban environment. By analyzing the results how the sensor is responding to the above fires we can predict the results to a fire than a large fire. Here the distance was rounded off to the nearest meter.

Table 2: Accuracy Test Results

Type of Fire	Repetitions of testing	Average Distance where the detection ends
Flame	10	1-2m
Small Fire	10	3-5m
Medium Fire	10	6-10m
Large Fire	10	10-15m

Source: Author

According to the results of this test, we can decide a fire larger than a small campfire made with pile of dry wood, will detect before 10m to the sensor node. To test the system's response rate, the time between exceeding the temperature threshold and receiving the SMS alert was measured. All of the above-mentioned fires were also used in this test, and all of the components were placed within the effective distances taken in range testing. The average time it took to receive the SMS after exceeding the temperature threshold was around 4.5 seconds. Based on the results of this testing, the proposed system's prototype can be implemented in a real-world scenario to detect and alert forest fires. Using the table 2 calculations, this prototype with two sensor nodes can cover more than 600 m2 of forest cover.

5. Conclusion and Future Works

In Sri Lanka, everyone is neglected the value of trees and protecting of the trees. The technology is hardly used in saving of forests. In the world, they always tried with their maximum to protect forests from forest fires. Even the foreign governments funding for the research regarding forest fire alerting systems. Vast amount of forest cover has been destroyed due to the negligence of forest fires throughout the years. To give a solution to this problem, the paper has proposed a low-cost effective system to detect and alert forest

fires in Sri Lanka. This study has focused on developing a Smart Wireless Forest Fire Alerting System. The system was developed in Wireless Sensor Network technology providing the ability to implement in any kind of forests. The prototyped system can cover more than 600 m2 forest cover and the system is scalable as needed. The limitations of this system are as only two sensor nodes were developed as the prototype, the coverage area is low, Base station has to be placed where a GSM coverage is available, Signal interferences may occur due to the animal behaviors inside the forests and once a node alert received, human resources should be available for maintenance. This system can be further improved with the technological enhancements such as adding the GPS sensor to the node to give the location, using machine learning technologies to analyze and predict the fires, and Beacon signal can send to air observers on the origin of the fires.

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