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Drone-Based Technology for Monitoring and Detection of Fire in Nigerian Forest Reserves

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ABSTRACT

The recent reports on forest fire from different countries of the world including Nigeria have been very disturbing. The effect of these fires calls for an urgent approach to tame the scourge of its occurrences as it is the main threat to human productivity and the sustainability of forests. Many infrastructures such as telecommunication equipment, electricity, oil pipeline, and water pipes are also located in the forest. Wireless sensors networks will be deployed in the forest to gather relevant dataset about the condition of the forest which will be transmitted in real-time to the drone and invariably to the control server, the control server with machine learning capability will be able to predict and alert the forest management administrators about illegal activities, intrusion and unfavorable state of the forest in real-time. The system when developed will provide a communication tool for real-time monitoring and surveillance of our forest reserves. This will assist forest management decision-makers greatly in taking timely actions that will assist in preserving our forest from intrusion, illegal activities, and other unfavorable situations such as fire outbreaks.

KEYWORDS: Wireless sensor, Surveillance, Forest, Drone, Microcontroller.

I. INTRODUCTION

Fire can be a natural occurrence in some forest ecosystems and inversely, a forest fire can pose a huge threat to public safety, property, wildlife, and forest resources. Forest fire is an uncontrolled fire occurring in vegetation more than 6 feet (1.8 m) in height. It can reach the proportions of a major conflagration and is sometimes begun by combustion and heat from surface and ground fires. Forest fires are often long-lived, widely spread, and disastrous. The resultant ash is carried away by winds and has devastating effects on air quality by considerably increasing particulate matter of air [1]. Such fires are a constant occurrence in the savannahs of Africa, Australia, and the steppes and grasslands of North America, Europe, and Asia, and the specter of global warming and changing weather patterns have intensified this problem of forest fire [2].Drones technology has achieved significant growth both at the elementary and the advanced stages which led to cutting-edge research and development. According to [3], drones are unmanned aerial vehicles (UAVs) that were designed around the early century and after the 1950s, drones are mainly used in the military field for reconnaissance or surveillance. [4], explained that over the last decade drones have been of different sizes, shapes and have the tendency to grow rapidly. Their applications are civilian, precision agriculture, forestry, biodiversity, meteorology, emergency management, wildlife research, land management, traffic monitoring, and many others. Drone technology offers a platform that can increase the impact of development and serve as a way forward to organizational growth and improve operational efficiency.The risk of fire during the dry season in Nigeria forest and other temperate regions of the world is relatively high. There has been a diverse occurrence of wide fire in Mediterranean zone countries which has destroyed thousands of hectares of forest, causing the loss of valuables lives and valuable properties. The forest destruction has also resulted in disastrous environmental degradation and a constant decline in the ozone layer, causing uncontrollable global warming. As stated by the International Forest Fire News (IFFN), the landmass use pattern in Nigeria is about thirty-three percent (33%)arable land, forty-four (44%) permanent pasture, twelve percent (12%) forest and woodland, three percent(3%) permanent crops and eight percent (8%) for other land-use patterns (IFFN, 2006).

Unreliability of traditional forest fire monitoring systems involves human observation towers and the limitation of fire lookout personnel have led to the demand for the development of technological systems to effectively monitor various activities on the forest, most especially monitoring against the attack by wide fire. Spread features of forest fires show that to put out forest fire without making any permanent damage, the firefighter Centre or rescue team should be aware of the threat in at most six (6) minutes after the start of the fire [5].Tools such as Charge-Coupled device (CCD) cameras and Infrared detectors have been employed in the monitoring forest fire. Charge-Coupled Device (CCD) cameras and Infrared detectors work like the traditional human observation tower. High definition cameras are used to replace the activities of humans on the towers, with sensors spread across the forest area. The system is limited by its accuracy which is influenced by weather conditions and the topography of the forest. The drone technology equipped with sensors with night vision will be able to overcome the challenge of weather conditions and topography.

Satellite-based forest fire detection systems use the data gathered by two satellites. Advanced Very High-Resolution Radiometer (AVHRR) and Moderate Resolution Imaging Spectrometer (MODIS) [6]. However, the limitation of this system is that it provides the complete information of the earth every 1 to 2 days. This negates the fact that the firefighter center should be aware of the threat in at most six (6) minutes after the start of the fire [5]. The comprehensive information provided by the satellite is therefore not usable in rescuing forests from permanent damage if a fire occurs. For a satellite system to be successful in detecting and monitoring forests, the satellite has to focus on a single forest and provide prompt information at almost every six (6) minutes which is currently impracticable in current satellite design due to the high cost of satellite set up.Research has proved that the use of drones and Wireless Sensor Network (WSN) are a promising alternative in gathering information about our natural environment, and provide robust tools for monitoring and maintaining them [7]. Wireless Sensor Network is a successful architecture for the deployment of the sensors used for fire detection. Wireless sensor nodes are deployed to various locations in a forest to collect temperature, humidity, barometric pressure values and deliver this data to the sink without requiring manual control. WSN consist of many small devices called sensors which measure physical parameters from the environment, it introduced a low-cost, low-power featured hardware consisting of rich micro-controllers, storage memory, power supply, single-chip radio transceivers, one or more sensors, and in some cases an actuator [7].

We depend on the forest for survival, from the air we breathe to the wood we use. Forest provides habitats for animals and livelihood for humans. It offers watershed protection, prevents soil erosion, and mitigates climate change. Despite our dependencies on the forest, the disaster faced by the forest cannot be tamed. Forest provides us with shelter, water, food, and fuel security, some of which are easy to figure out, such as; fruits, paper, and wood from trees, and others less obvious, such as by-products that go into everyday items like medicines, cosmetics, and detergents. Forest is the world’s largest storehouse of carbon. It provides ecosystem services that are critical to human welfare. It helps in absorbing harmful greenhouse gasses that cause climate change. There is a constant loss of these forest resources yearly due to fire attacks. Therefore, there is a need for a real-time communication tool that will alert necessary authorities about the occurrence of any unfavorable occurrence in our forest. [8], applied deterministic (regular sensory node) deployment scheme, where the distance between sensory nodes are relatively even, hence time to detect fire between neighboring sensory node is relatively constant and more reduced compare to random sensory deployment scheme. Regular communication among cluster heads was used without the use of a gateway or router which is relatively difficult to achieve in real-life implementation due to the distance between cluster heads. Information gathered in a cluster is sent to the cluster head which communicates to the sink node through other cluster heads. If a cluster is down, the whole cluster is down since the cluster head is the only node communicating to the sink node. Also, communication among cluster heads is done using a predefined pattern, when a cluster head is down, it may be difficult to communicate to the sink node. Hence, the system implements a low level of fault tolerance which is crucial in a system that is to be deployed in harsh environmental conditions.

One of the sustainable development goals of the United Nations is sustainable forest management because it is the major source of dependency for human existence. Forest management is bedeviled with various challenges such as emergencies, natural disasters, illegal deforestation, climate change, and natural disasters that pose threat to its sustainability. Effective and efficient real-time communication medium in the management of our forest will reduce the threat posed by the challenges faced in the management of the forest. In this research, a drone technology with WSN that will be used to detect forest fire, curb illegal deforestation, and monitor the health of forests with the changing environmental conditions was proposed. This work introduces the use of innovative technology; drone technology, wireless sensor networks, and machine learning to develop a communication tool that can be used in forest monitoring and management. A network topology that will improve fault tolerance that allows both component redundancy and transmission redundancy was proposed.

II. II.LITERATURE REVIEW

The use of wireless sensors and drone technology (Unmanned Aerial Vehicles) have emerged as a useful platform for acquiring remotely sensed data of vegetation that offers the ability to collect imagery with high spatial and temporal resolution [9]. According to Padua et al., (2017), the use of professional civilian UAVs for forestry surveys is increasing around the world, and it is expected to expand in years to come. The main factors supporting this growth are related to the low-cost systems, user-friendly controls, and the technological advancements of components [9]. The awareness of the benefits that this technology offers to forestry and natural resources management is increasing all over the world. The working mode of the sensor nodes may be either continuous or event-driven. Global Positioning System (GPS) and local positioning algorithms can be used to obtain location and positioning information. Wireless sensor devices can be equipped with actuators to "act" upon certain conditions. These networks are sometimes more specifically referred to as Wireless Sensor and Actuator Networks as described in [10].[11] analyzed remote sensing of tropical forest environments towards the monitoring of environmental resources for sustainable development. The research analyzes the indicators that can cover the conditions and type of tropical forest environment. It includes the mapping of forest cover, estimation of biomass, and biodiversity which will bring the impacts of extreme drought on the forest. Emphasis was placed on the need to increase the level of potential of information extraction beyond what is derived with conventional approaches to have more usefully informed sustainable development practices. Wireless sensor networks (WSNs) enable new applications and require non-conventional paradigms for protocol design due to several constraints. Owing to the requirement for low device complexity together with low energy consumption (i.e. long network lifetime), a proper balance between communication and signal/data processing capabilities must be found. This motivates a huge effort in research activities, standardization process, and industrial investments in this field since the last decade.

[5] proposed a real-time forest fire detection using a wireless sensor network paradigm. The major goal is to design a model for data collection and processing in wireless sensor networks for real-time forest fire detection using neural networks and data processing. The network takes the measured data (temperature, relative humidity) as input to produce a weather index, which reduces the likelihood of the weather causing a fire. Cluster headers will send weather indexes to a manager node via the sink. The manager nodes in this work are randomly deployed sensors that deduce the forest fire danger rate based on received weather indexes and some other factors. The methodology involves the Neural Network data aggregation method to determine what data is sent from the cluster head to the sink node. The work is limited as sensor nodes were randomly distributed without a regular pattern, making it difficult to have a proper alignment for the management of the system nodes.[12], proposed a Forest Fire Surveillance System (FFSS) in South Korea. A dynamic minimum cost path forwarding protocol is applied within WSNs. FFSS consists of WSNs, middleware programs, and web applications to analyse and transform the collected data into precise information. The sink node makes several deductions based on the input data and produces a forest risk level. The objective incorporates detection of forest fire earlier and alerts people to extinguish the fire properly to prevent economic and environmental damage. Minimum Cost path Forwarding (MCF) routing protocol was used to route packets among sensor nodes. The architecture does not contain a power management scheme because the system depends on the internet connection to communicate data between the site and the central system.

[13], proposed a multi-tiered portable wireless system for monitoring environmental conditions. The system was integrated with a web-based system that gives real-time data from enabled surveillance cameras with wireless sensor nodes. Sensor networks were deployed to different parts of a forest and the communication between the networks was provided by powerful wireless devices that can send data up to 150km to communicate information from the deployment areas to a central server called incident command. The study concentrated on determining the behavior of fire rather than its detection. Requirements regarding weather data, elevation gradient of terrain were formulated as a model to drive the design of the system. The system relays data from many points of interest to the central server through an area with no internet connectivity or even electricity. It was reported that the system exhibited packet loss averaging 50% which reduced the effectiveness of the system. Packets were resented multiple times which improved the success rate to nearly 80% but increased the overall power consumption due to overhead. [14], proposed a multi-sensor node with IP cameras in a mesh network to detect and verify fire occurrence. When the fire is detected by a wireless multi-sensor node, the sensor alarm is propagated through the wireless network to a central server on which a software application runs. Real-time images from the zone are captured through wireless IP cameras. The system can verify the exact location of the fire outbreak and capture real images of the affected location. A model to calculate the total number of cameras, access points, and sensory nodes needed to effectively cover a forest is proposed. The methodology optimized wireless IP multi-sensor network to detect forest fire and verify it employing images from cameras. The wireless multi-sensors are connected wirelessly using IEEE 802.11g or optic fiber (IEEE 802.3u). Since data is transferred from the access

point to the central server over a wireless communication network hence, the effectiveness of the system depends on the strength of the communication link. [15], proposed a proactive routing method for WSNs called EMA (Environmental Monitoring Aware) to be used in disaster detection. The method adapts routing tables based on the possible failure threat due to the sensed phenomenon. EMA also attempts to be power efficient; it proactively avoids route breaks caused by disaster-induced node failures and thus increasing network reliability. The methodology employed consists of an algorithm, the Received Signal Strength Indicator (RSSI), and the hop count of the respective route as parameters. The sink node sends out data packets called beacons which contain information about the sink's health and a hop count of 0 to the sensor nodes that initiate the transactions. The work focuses on routing protocol leaving out the other essentials of a wireless sensor network.

[16], proposed a design for a wireless sensor network for the early detection of forest fires. The WSN was based on the fire weather index (FWI) system which is one of the most comprehensive forest fire danger rating systems in the USA. The proposed system determines the risk of propagation of a fire according to several index parameters. The forest fire detection problem was modeled as a k-coverage ($k\geq1$) in wireless sensor networks while an approximation algorithm was designed to solve the node k-coverage problem. Although the system was designed with localization protocol without the use of GPS devices to save cost, the protocols-imposed communication and computation overheads on sensors will increase energy consumption in the overall system and chances of node failure. [17] explored the application of wireless sensors for environmental monitoring. The research described the limitations in hardware, software, and network design and stressed the understanding of the natural and agricultural environment to be the key in deploying workable sensor networks. The architecture consists of a Reduced Instruction Set (RISC) Micro-Controller with a small program and data memory. External storage media was used with the microcontroller to increase the secondary storage space. The sensors were attached to the micro-controller board through an expansion bus. The micro-controller device contains an I/O controller that can accept more than one sensor. The hardware specification includes an ATMEGA 128 processor, 128kb flash memory, 4Kb RAM, and a stream-based Nordic nRF903 radio transceiver of 433MHZ, providing 72kb/s channel and a range of 500m using a quarter-wave antenna. The routing and network topology were not considered in the design, so also the power management. The storage capacity of the system is low and therefore cannot manage large volumes of data. While various techniques used in the detection and management of forest fire have been identified, it has been established that there are so many limitations to these techniques. The deployment of unmanned aerial vehicles with remote sensing techniques will add value to pre-existing methods. These will increase operational efficiency, improve risk assessment and enhance data gathering and processing. In addition, UAVs can operate remotely which makes them safe in hazardous environments that cannot be reached by humans and the materials are available to suit the Nigerian domain.

III. PROPOSED SYSTEM

The proposed research aims at eradicating the challenges faced by the Nigeria Forest Reserves. This will help to increase the productivity and sustainability of the environment. It is motivated by the need to take a giant step towards having a safe Forest Reserve as it is practiced in other developed nations of the world. The proposed model will take advantage of the existing technologies such as drone technology, WSNs, and communication technology to develop a communication tool for managing forests in Nigeria.

Study Area: Akure forest reserve will be used as a case study, the system will be scalable to other forest reserves in Nigeria. Akure forest reserve is geographically located in a humid rainforest zone of Akure South Local government area of Ondo State, Nigeria. It covers an area of 66 km2 (25 sq. mi) lies between latitudes7o16′ and 7o18′ N of the Equator and longitudes 5o 9′ and 5o11′E of the Greenwich Meridian. It was constituted as a reserve in 1936 and the total land area covered is 69.93 km2. Politically, it lies in Ondo State in Southwestern Nigeria and shares border with Osun State in the Northeast, surrounded by five Local Government Areas in Ondo State namely: Ile Oluji, Oke-Igbo, Ifedore, Akure South, Idanre, and Ondo East. The trees were planted with fixed row spacing.

Proposed Architecture: This section provides a brief description of the system architecture describing the solution to the problems identified. Foremost the terrain is divided into a finite set of disjoint spatial objects that outline boundaries of the areas. The framework involves the design of four main parts: drone with embedded sensors deployment scheme, cloud as a platform for service, a clustered network architecture, and communication protocol (intra-cluster and an inter-cluster). It comprises the functions of detecting a potential fire and monitoring the future evolution of the fire based on real-time conditions. These functions will be done by using either a single drone or multiples. The objectives are to use drones to predict fires or the occurrence and provide timely real-time information to firefighters for the management of the scenarios.

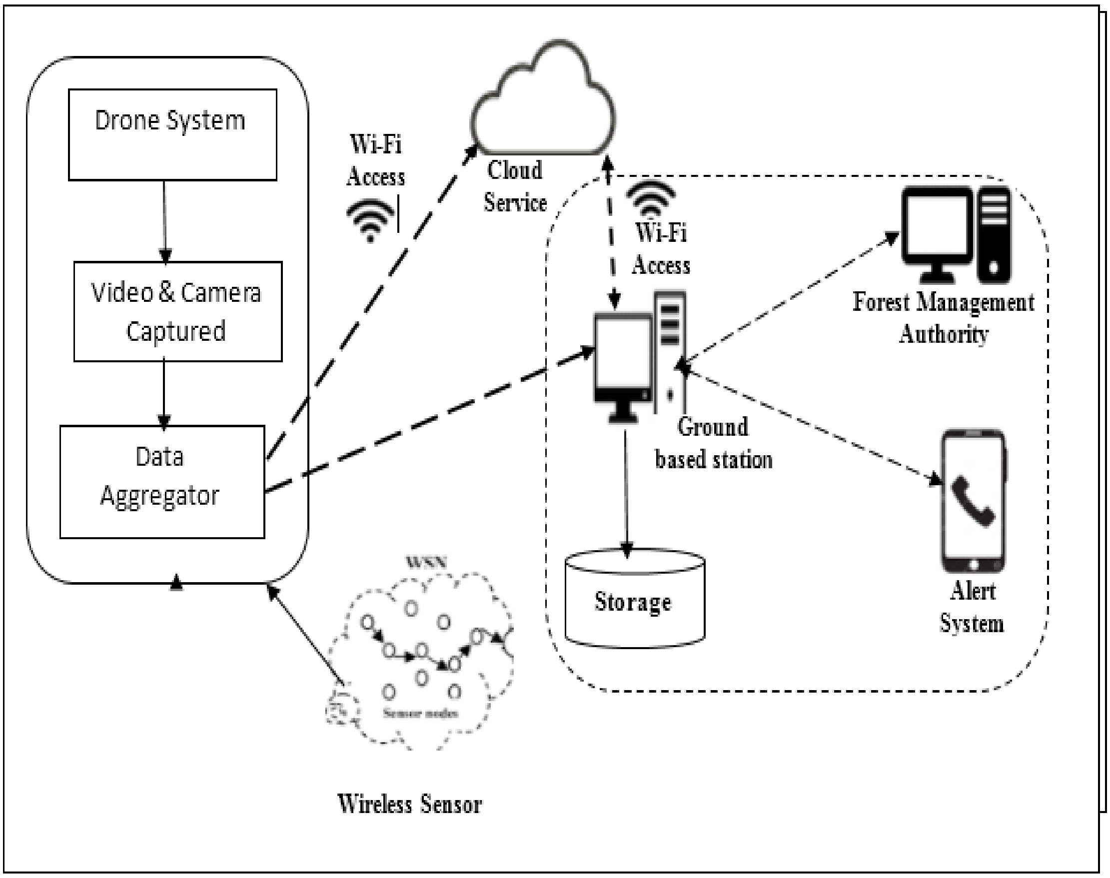

Fig. 1: Architecture of the Proposed System.

This research aims to develop a forest fire detection and monitoring system in real-time using an Unmanned Aerial Vehicle (UAV). The configuration setup is depicted in Fig. 1. The UAV with embedded sensors (temperature, humidity, rainfall, smoke, and GPS), a mini processor Raspberry Pi and Arduino ATMEGA. Five types of sensors will be used in this system. The first is a temperature sensor that measures the temperature in the monitored forest area. The temperature sensor uses a Non-Contact Infra-Red Sensor, while other sensors are embedded in the Arduino. A barometer will be attached to the drone with an inertial measurement compass. The GPS and compass are used as the navigation system to estimate the vehicle's position. The data from both the temperature sensor and GPS are processed by the Raspberry Pi, which serves as a mini processor. The data transmission uses the Transmission Control Protocol (TCP) system and data are sent through the Raspberry to the webserver which makes it available to be accessible online

Mathematical Model : The modeling is divided into two: the monitoring through the sensors and the image processing through the cameras. The numbers of the sample will be taken from each sensor. Several samples will be taken to avoid potential errors due to different environmental conditions in reading data from sensors. We define a random variable R to be the reading of sensors which is assumed to be a normal distribution due to ranges in factors above. They are stochastic. We denote the mean and standard deviation of R as µR and σR, respectively. The estimated mean µR, also known as the sample mean, is given by:

$$\hat{\mu}R = \frac{1}{k}\sum_{i=1}^{k} r_i \qquad (1)$$

Bayesian theorem and statistics will be used to calculate the probability of each instance. The training data contain attributes x_i and are split into two classes C_k for (Fire, None), 1≤ k ≤2. The learning of the Gaussian algorithm relies on the computation of the mean and the variance of each attribute x_i in each class C_k. To find the probability of a new sensing instance $I\ (x_1, x_2 \ldots . x_m)$ to belong to a specific class$C_{k,}$ equation 2 applied;

$$P\ (C_k \mid x_1, x_2 \ldots . x_m)\ = \frac{P(C_k)\prod_{i=1}^{m} P(x_1 \mid C_k)}{evidence} \qquad (2)$$

Where evidence is given as:

$$\prod_{i=1}^{m} P\ (x_1 | Fire) + \prod_{i=1}^{m} P(x_1\ | None) \qquad (3)$$

Therefore, fire is detected if the probability of the Fire class $P\ (Fire \mid x_1, x_2 \ldots .\, x_m)$ is greater than the probability of the None Fire class$P\ (None \mid x_1, x_2 \ldots .\, x_m)$. The required maximum time it will take the drone to detect fire in the distance value is also considered. This includes the initial energy of the drone and the required lifetime. To determine the distance of the drone:

$$\Delta D = \frac{n_i(E * T)}{(N * I)2} \qquad (4)$$

Where: ΔD $o$optimum distance of the drone in flight (in meters), $n_i = Normalization\ value,$
T = required maximum fire detection time (in seconds),
N = required network lifetime (in seconds),
E = Initial energy of the drone regular sensor node (in Joules), and I = the vulnerability of the forest area. To avoid the risk factor in monitoring and fire detection, the temperature change is needed to be considered. The increment in temperature and any other weather condition like a lightning can be a risk factor in monitoring the forest reserves. Therefore, to check the temperature rise of the forest region equation 5 applies;

$$r_i = \frac{Td - t_i}{\Delta t_i} * e_i \qquad (5)$$

where: r_i is the risk level, Td is the optimum temperature, t_i is the current temperature, Δt_i is the change in the ratio of the temperature, e_i is the current energy of the drone.

The System Flowchart : To collect information from the drones a website will be developed using the forest fire information PHP: Hypertext Preprocessor (PHP), Cascading Style Sheets (CSS) and MySQL database will be used to save the information. The information system will include the numbers of the hotspot, the temperature, humidity, and the exact coordinates of the location. Google Maps will be integrated into the website to locate the spot easily. The flowchart of the system is represented in figure 2 below.

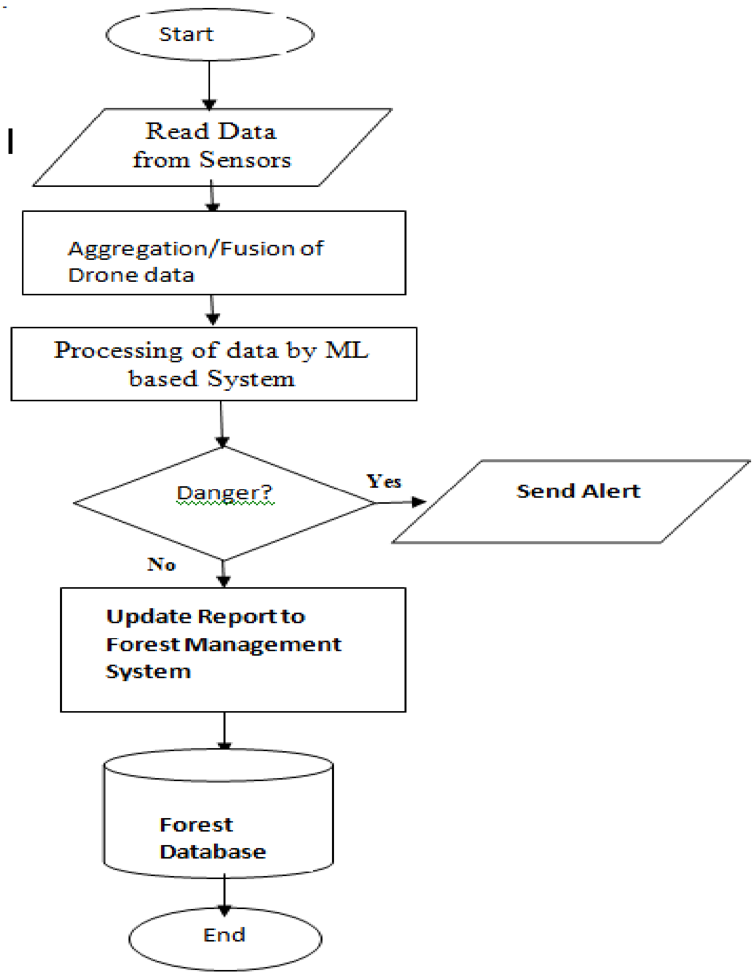

Fig. 2: Flowchart of the Proposed System

IV.CONCLUSION

This paper presents a novel design architecture for monitoring and detection of forest fire using drone-based technology. It is expected that full implementation of the design will help prevent the occurrence of fire in our forests.

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