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Research Article

LoED: LoRa and Edge Computing based System Architecture for Sustainable Forest Monitoring

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Abstract *- Sustainable Forest monitoring is significant for monitoring the forest with advanced digital technologies. The rise of population, pollution emissions from industry and agriculture, loss of productivity, and soil fertility in pure planted forests, diseases of complex etiology are the issues in reducing forest cover. Motivated by these aspects, this article proposed LoRa and edge computing inspired hybrid architecture for real-time monitoring of the health and growth of the trees by monitoring the quality of soil, water, and the climate. In this study, the sensor mote is deployed at trees and monitored the soil moisture content, humidity, temperature, and air pressure. The monitored sensor values are recorded in the cloud server (ThingSpeak server) through 433 MHz LoRa and ESP 8266 Wi-Fi controller.*

Keywords *- Forest monitoring, edge computing, 433MHz LoRa, Wi-Fi, cloud server.*

1. Introduction

The forest lies at the heart of the planet's terrestrial biodiversity, where it minimizes carbon emissions and climate variability, supports livelihoods and promotes long-term food supply [1]. Environmental sustainability and climate change are also intertwined concerns supporting sustainable forestry and managing natural sources. According to a World Bank report 2020 [2], forest covers around 30.7% of the earth's land globally and has reduced their cover from 31.6% (1990), as shown in Fig. 1. The rise of the population has increased the huge consumption of resources, which shows a significant effect on forests, as one-third of the forest is lost due to the wide extension of agricultural land for food demand [3]. Along with this, other factors include pollution from industry and agriculture, loss of productivity,/or soil fertility in pure planted forests, and diseases of complex etiology [4]. Technology advancement has gained wide importance to enhance forest growth and monitor the forest to decline the causes of deforestation [5].

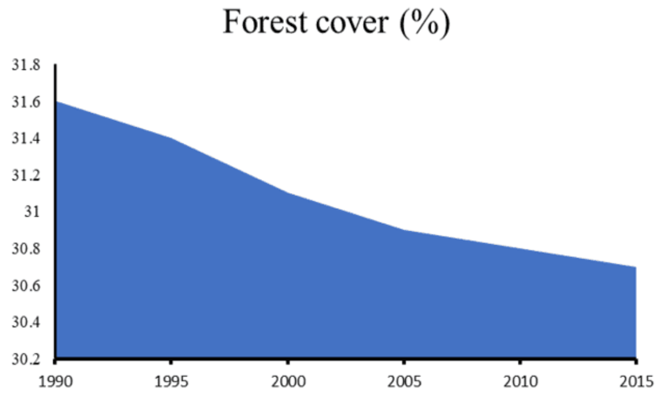


Fig. 1 Global Forest cover by world bank [2]

High-performance LiDAR remote sensing technology has proved to be an effective tool used in applications in the field of forestry [6] with the application of photography, aerial ground remote sensing, synthetic aperture radar (SAR) data, multi-temporal, multi-spectral, satellite data, hyperspectral data, and LiDAR data, etc. [7]. The implementation of LiDAR and remote sensing technology requires high-end infrastructure and high computing to process the data.

To overcome this challenge, The Internet of Forest Things (IoFT) and Internet of Trees (IoTr) are new technologies that help manage forest sustainability and safeguard the forest from threats by deploying smart sensors to collect data streams while monitoring and detecting floods, fires, and storms [8] [9]. Moreover, the advancement in sensors and communication technology has empowered to wide implementation of IoT devices for real-time monitoring [26]. Furthermore, edge computing and fog computing enable the processing, analysis, and prediction of sensing data at the edge network level, improving latency and response time [10], [11].

Generally, in implementing an IoT-based system, wireless communication also plays a crucial role in transmitting data from a remote location to an internet availability location [12] [30]. The wireless communication protocol selection is significant in connecting the device to an internet availability location. Long-range transmission and low-power consumption are the communication protocol requirements that are to be integrated into the IoT system [13] [27]. The evolution of long-range (LoRa) meets the requirements of IoT systems in real-time monitoring [14].

With the motivation of these aspects, this article proposed edge computing and LoRa [15] inspired architecture for real-time monitoring of trees in the forest through IoT and advanced wireless communication protocol. The contribution of the study is as follows:

- Proposed an edge and LoRa-inspired computing-based architecture for supervising a forest.
- Implementation of hardware in real-time for obtaining the sensor data of trees.
- Visualized the real-time of the sensor node on the cloud server through a gateway.

The organization of the article is as follows: Section 2 covers the review of literature; section 3 covers the proposed architecture; section 4 covers real-time implementation, and section 5 provides the conclusion.

2. Related Studies

In this section, the previous studies implemented different methodologies and approaches for forest monitoring. A low-cost LoRa-based system is proposed to assess fire danger and the presence of a forest fire using relative humidity, temperature, $CO_{2,}$ and wind speed levels [16]. The monitoring systems are interconnected with the global system for mobile communication (GSM)/general packet for radio service (GPRS) module, Grove Sensors, DHT11 sensor, Arduino microcontroller, and Thing-Speak platform for the implementation of IoT based environmental monitoring of urban trees plantation and growth [17] [28]. Unmanned aerial vehicles (UAVs) for forest monitoring, and fire/flood detection, in which location path is determined corresponding to the fire propagate model to generate an elliptical fire perimeter [18].

A study used time series of the Enhanced Vegetation Index (EVI), Modified Soil-Adjusted Vegetation Index (MSAVI), Normalized Difference Moisture Index (NDMI), and Normalized Difference Vegetation Index (NDVI) to assess the mangrove health of Rabigh Lagoon while and after road building [19]. Forest genetic monitoring (FGM) allows for early detection of potentially hazardous variations in forest adaptation before they manifest at greater biodiversity ranges, enhancing the sustainability of existing forest management approaches and guiding future studies [20]. Spectrograms and Object-Based image analysis are implemented to develop more and more gardens/parks in the urban areas to boost the urban forest biodiversity and Diversity Monitoring of Coexisting Birds [21]. An IoT system utilizes security algorithms such as a block cypher and an advanced authentication method to supervise environmental parameters, such as CO_2 and CO [22]. [22]. In the sensor node region, a fire warning system with a primary concern communication mechanism [23] has been implemented. All implanted sensor devices communicate automatically to the base station utilizing Dijkstra's algorithm for the route. An effective IoT framework backed by cloud [29] and fog technologies is built by merging cloud storage, fire prediction, and management levels for predicting forest fires [24].

3. Proposed Architecture

Currently, forest monitoring has gained attention to achieve environmental sustainability for a sustainable future to combat drastic climate changes. The technology advancement and wide availability of digital technologies have empowered different areas to meet the goal of sustainability. To implement digital technologies like IoT, wireless communication plays a key role, as delay in transmission and high transmission power limit the reliability and effectiveness of the system. This study proposes a hybrid-based architecture that integrates three layers for forest monitoring. The proposed architecture captures real-time and communicates to the data processing and analytics layer to identify and detect anomalies in the forest in a real scenario. The data acquisition layer, data processing & analytic layer, and data visualization layer are three layers of the proposed architecture. The data acquisition layer is the primary layer of the architecture for acquiring the environmental parameters of the trees and forest. This layer is specifically dedicated to continuous monitoring of environmental parameters, including water moisture, temperature, humidity, light intensity, and rain level.

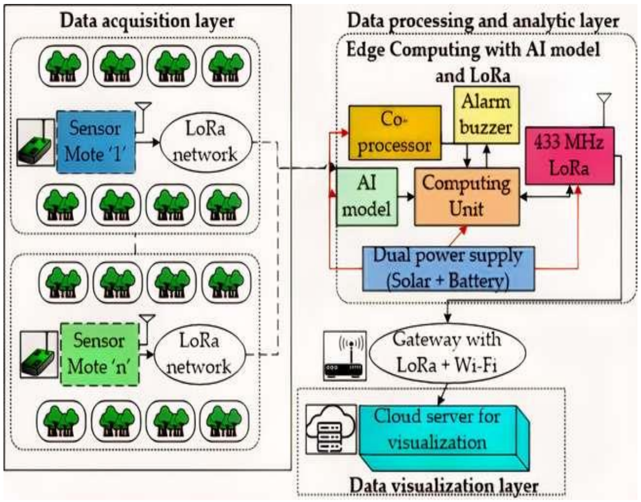


Fig. 2 Proposed architecture

IoT sensors are attached to the sensor mote and transmit it through 433 MHz LoRa communication protocol. The functioning of the sensor mote is described in Fig. 2, where it comprises of sensing unit, processing unit, and transceiver unit. The sensing unit comprises different sensors embedded in the sensor mote for sensing different parameters of forests and trees. The sensing unit forwards the data to the processing layer, where the computing unit process the analog data and convert it into digital. Based on instruction embedded in the computing unit, the computing unit transmits the data through a transceiver unit, i.e., wireless communication protocol.

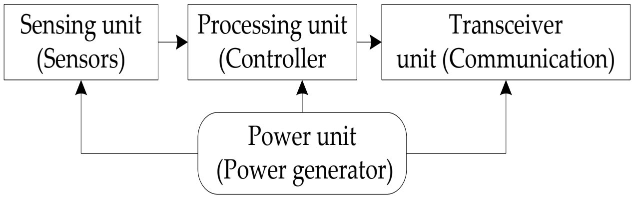


Fig. 3 Sensor mote

Data processing and analytics layer placed nearby the location of sensor mote to process the sensed data. 433 MHz LoRa enables this layer to receive the data from the sensor mote and communicate the outcome from the received data to the cloud server through the gateway. This layer is driven by an edge computing-based device, which leverages computing, and co-processors, to detect changes in ambient conditions that affect tree growth, as shown in Fig. 4. This layer is provided with a dual power supply to power the computing unit and other components during the computational process. An alarm buzzer is placed in this layer to generate an alert in an emergency.

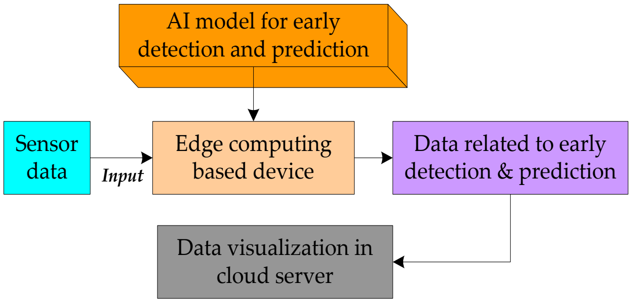


Fig. 4 Process flow of sensor data

The data visualization layer in the proposed architecture assists the authorities/user in visualizing the real-time status of the forest growth and trees. The outcome of data analytics from the data processing and analytics layer is connected to the data visualization layer through the gateway. The gateway integrates multiple communication protocols like LoRa as a receiver unit to receive data on 433 MHz frequency. The IEEE 802.11Wi-Fi module assists in converting the radio frequency (RF) packets into Internet protocol (IP) packets for logging the data on the cloud server through internet connectivity.

4. Real-Time Implementation

The proposed system is implemented in real-time in the location of Dehradun (Uttarakhand, India) with a latitude of 30.3410° N and a longitude of 77.9544° (Fig. 5). A customized sensor mote based on 433 MHz frequency LoRa is utilized for the data transmission of sensors incorporated into it. The sensor mote is embedded with the ATMega 328 P controller and multiple power pins (+12V, +5V, +3.3V). The firmware development of sensor mote is programmed with multiple unique features like node mapping and symmetric encryption. Node mapping enables the sensor mote to minimize the data redundancy; symmetric encryption in the sensor mote enables the secure sending of the sensor data. The sensor mote is connected to the edge computing-based device and gateway through a 433MHz LoRa module as per the proposed architecture. The edge computing-based device based on 433MHz LoRa assists in filtering the data that is required to be sent to the gateway. The integration of ATMega 328P controller, 433MHz LoRa(receiver), and ESP8266 Wi-Fi controller in gateway hardware enables the receiver and register the sensor information on the cloud.

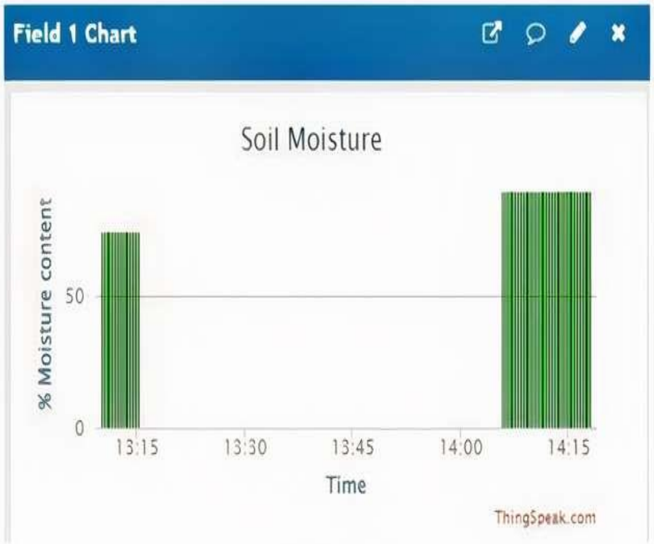
In this study, the temperature sensor, humidity sensor, soil moisture sensor, and air pressure sensor are integrated into respective analog and digital sensors of sensor mote to monitor the temperature, humidity, soil moisture content, and air pressure for the tree monitoring the forest. The calibration of the sensors is implemented in this study before implementation for error-free sensor values. A frequency agility-based interference avoidance algorithm is used in the gateway to detect interference and transfer it to a safe channel with minimal energy usage and latency while dealing with interference.

Fig. 5 Deployment of sensor mote at the tree

ThingSpeak server was employed in this study to visualize sensor value on the cloud server through an edge computing-based device and gateway. An application programming interface key (API) of the ThingSpeak server loaded in the ESP 8266 Wi-Fi controller enables authentication and interfacing with hardware as the hardware's sensor calibration and firmware development are completed.

The system is deployed in real-time, as shown in Fig. 5. Based on the system's deployment, the sensor directs the sensing analog data to the ATMega 328P controller unit, and the ADC converts the analog sensor value into digital. The sensor values like soil moisture content, temperature, humidity level, and air pressure around the trees are processed in the sensor mote and transmitted to the gateway through an edge computing-based device through 433MHz LoRa.

The sensor values of the sensor mote are logged on the ThingSpeak server, and they are visualized in Fig. 6 and Fig. 7. Fig. 6 of the ThingSpeak server dashboard visualizes the soil moisture content and temperature of the particular location at two different time intervals. At 13:15, the soil moisture content recorded on the server is 52%, and again the moisture sensor value recorded in the server is 55% at 14:15. As discussed earlier, the sensor mote is embedded with a node mapping feature, where it matches the present value and previous sensor value.

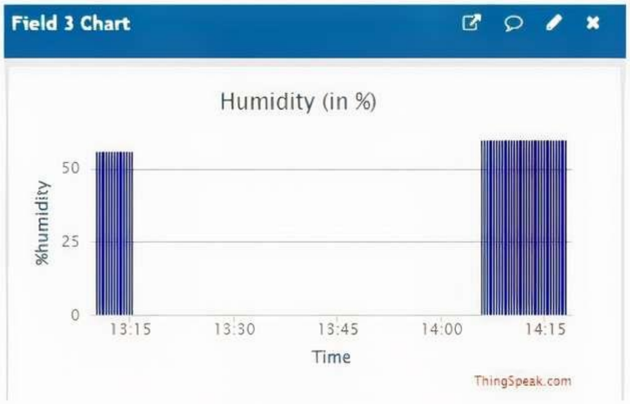


(a) Soil Moisture

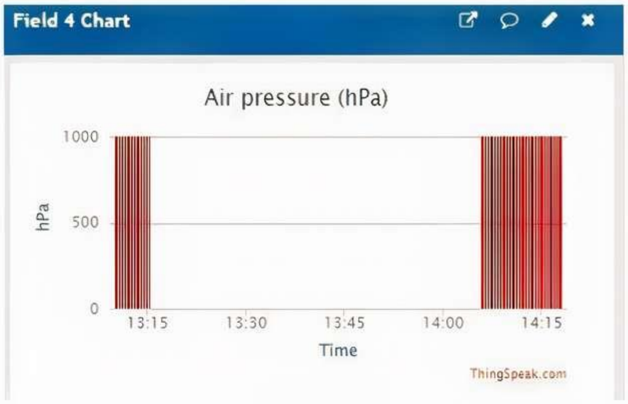
(b) Temperature of air

Fig. 6 Moisture and Temperature of the air sensor value

If the present value is the same, it will not send the senor value and vice-versa. Here the sensor value between 13:15 and 14:15 are the same, so that is the reason behind no sensor value visualization in the server. Similarly, the temperature value recorded at 13:15 is 22°C and at 14:15 is 24°C. Fig. 7 illustrates the sensor value of humidity and air pressure, where the humidity varies from 51% to 53% between 13:15 and 14:15. Similarly, the air pressure varied has remained constant, i.e., 1000 hPa.



(c) Humidity



(d) Air pressure

Fig. 7 Humidity and air temperature sensor value

This study implemented a LoRa network and cloud server-based architecture for monitoring the forest in real-time. In previous studies, it has been concluded that the LoRa network is utilized for forest fire monitoring. However, limited studies have implemented hardware with the LoRa network for environment parameters monitoring the forest. This study also logged the sensor value of the hardware on the cloud server through the internet connectivity.

5. Conclusion

Real-time monitoring and edge computing-based devices have significantly impacted different applications. Integrating these technologies in the forest is highly required for monitoring the forest in real-time based on a sensor. This article proposes LoRa and edge computing-based architecture and system for real-time monitoring of forests and trees. To realize the system in real-time, the sensor mote integrated with multiple sensors is deployed at trees and monitors the temperature, humidity, soil moisture content, and air pressure. The monitored sensor values are recorded on the cloud server. The deployed sensor mote is empowered with node mapping and symmetric encryption for minimizing data redundancy and secure transmission.

Conflicts of Interest

The author(s) declare(s) that there is no conflict of interest regarding the publication of this paper.

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