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An efficient and low cost realization of LoRa based real-time forest protection system

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ABSTRACT

The forest is a natural habitat for a variety of fauna and flora, and helps to maintain the ecosystem equilibrium. However, wildfire incidents and deforestation lead to forest degradation. Moreover, most of the existing methods, to preserve the forest resources, are ineffective due to their large establishment cost, more power consumption, and poor coverage. This paper brings out a sustainable solution by developing a forest protection system (FPS) that uses internet of things (IoT) technology together with long range (LoRa) communication. The work focuses on the development of an IoT framework for the detection of any intrusion into the forest as well as the detection of fire incidents in the vicinity of the equipment. Powering the equipment through solar energy makes the system cost-effective. The system is examined in terms of acquisition of data from sensor nodes pertaining to forest protection, relaying the same to the cloud using LoRa wide area network (LoRaWAN) technology and analyzing using cloud based visualization tools. The developed system has been deployed at Eturnagaram Wildlife Sanctuary, Mulugu district, Telangana, India for validation in the forest environment. The obtained results have shown that the system has an accuracy of 97.14% for intrusion detection and 100% for fire detection.

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1. INTRODUCTION

The forest, is a hub of biodiversity including different kinds of trees/plants, animals, and micro-organisms; and is greatly responsible for maintaining the ecological balance. However, deforestation, forest fire incidents, illicit felling, forestry mining (timber harvesting for meeting domestic needs and urbanization), illegal transport of precious forest resources, and poaching, cause an imbalance in the ecosystem. Balancing the ecosystem, for the forthcoming generations, is becoming essential and is the most challenging task. Forest management is a system that defines regulatory actions for supplying different products and services to society, and preserving forest resources including wildlife, soil, and water. Though various laws and acts for an effective forest management system are being enforced by the government/concerned authority from time to time, forests are still vulnerable to illegal activities by humans.

Monitoring the forest from a distant control station against the aforementioned activities is the challenging task due to: i) large geographical coverage area, ii) lack of reliable communication link, and iii) high power requirements of communication link. This work outlines the development of a scalable forest protection system (FPS) that protects the forest from intruders and equipment nearby fire accidents. For communication, to mitigate the high power needs of cellular technology and less coverage problems of short range communication technologies, this work utilizes the long range wide area network (LoRaWAN) technology. Moreover, to make it eco-friendly, the system is designed to run on solar power. This paper is organized into five sections. Section 2 outlines the works being carried out in the area of forest monitoring/protection. Proposed FPS and its implementation in a LoRaWAN environment have been described in section 3. A case study for testing and validation of the developed system is presented in section 4. Section 5 presents the obtained results and its comparison with previous works. Finally, the conclusion of this work is presented in section 6.

2. LITERATURE SURVEY

In the literature, it is found that a lot of works are being carried out to incorporate technology in forest protection. Works that are focused on forest protection are outlined in this section. Most of the works are on fire detection/alerting on forest fires while no significant work has been found in the direction of intrusion detection.

2.1. Forest monitoring, wildfire detection and prevention

A startup called, Treevia has developed a system called SmartForest [1] in 2014 in Brazil to monitor the forest growth by building internet of trees. The system collects the data from the sensors mounted on tree belts and the images from satellites to have a end-to-end forest coverage. The system proposed in [2] utilizes fire, rain, temperature, and smoke sensors integrated with global system for mobile (GSM) technology to detect wild fires and take swift actions against them. Jayaram *et al.* [3], a system that is capable of early detecting the forest fire and sending the global positioning system (GPS) location to authorized personnel has been proposed. In this work, satellite-based remote sensing technology and geographic information system (GIS) tools have been used. Forest protection works utilizing various technologies include: cloud-assisted green internet of things (IoT) framework [4], artificial neural network [5], wildfire prediction system using deep neural network to predict the intensity of wildfire based on the various environmental parameters such as temperature, humidity, soil moisture, and pressure [6], Remote sensing technology [7], temperature and humidity sensors integrated with Zigbee communication technology [8], a forest fire detection and monitoring system enabled with Wi-Fi [9], Raspberry Pi based IoT system with GSM [10], and fire detection using sensors, satellite system and unmanned arial vehicles (UAVs) using wireless routing algorithm [11]. The development of wireless sensor network (WSN) based intruder detection system using a magnetometer, accelerometer, and geophone sensors has been discussed in [12]. This system detects the arrival and location of vehicles to prevent timber thefts to a larger extent. Kadir *et al.* [13] discuss the development of WSNs to collect environmental data for the detection of forest fire hotspots and presents a mathematical analysis to model the number of sensor nodes required to cover a given forest area.

The IoT-based forest fire warning and monitoring system has been proposed in [14]. Major components of the system include (i) sensing unit consisting of gas sensor, temperature and humidity sensor, wind speed and direction sensor; (ii) information transmission using public communication network; and (iii) application layer. An IoT based sea forest environment monitoring system using Raspberry Pi computer and sensors has been demonstrated in [15]. The increase in carbon monoxide (CO) gas and temperature has been correlated to detect wildfire. The chainsaw sound analysis algorithm which relies on mel-frequency cepstral coefficients (MFCCs) has been proposed to differentiate vehicle or forest noise. Rumee [16], has discussed the development of a cost-effective IoT prototype utilizing remote sensing using satellites, UAVs and various sensors has been developed to monitor the mangrove forest. The simulated test results have shown that alert notifications are received if any emergency event occurs. An IoT based forest safety and conservation system has been proposed in [17]. The system performs data collection from various sensors, data processing, analyzing and decision making, alerting the concerned through short message service (SMS) with location information, thereby supporting the e-governance in the forestry. The smart forest alert monitoring system developed in [18] is using various wireless sensors for early detection of wildfires. Data from these sensors is transmitted to a cloud server using 4G/LTE link and automated fire extinguishment and deforestation action is initiated to control the forest hazards. Singh *et al.* [19] outlines different available technologies for the digitization of various services like environmental parameter monitoring, fire tracking and monitoring, forest fire detection and prediction, and flora analysis in the forest. However, from the aforementioned works it is found that the power consumption and coverage area are the major constraints for a system designed and deployed for forest applications. Hence, the LoRaWAN technology seems to be an alternative solution considering its ability to provide long-range communication with low power requirements.

2.2. Leveraging LoRaWAN technology for IoT applications

Augustin *et al.* [20] and Noreen *et al.* [21] have discussed the exploration of LoRa technology as an alternative solution to cellular, GSM, Wi-Fi, and Zigbee to establish Internet connectivity for IoT applications in the forest cover. Zhou*et al.* [22] presents the design and implementation of a flexible private LoRa network for the IoT applications such as smart city, environmental monitoring, smart healthcare, and smart farming. Ayoub *et al.* [23] and Rawat *et al.* [24] focus on the strategies of constituting low power wide area networks (LPWANs) wherein all the smart things are connected to the Internet and can transmit a few bytes of data over a long distance. The most widely available LPWAN technologies that support mobility of the things include LoRaWAN, DASH7, and narrowband-IoT (NB-IoT). Out of these technologies, the LoRaWAN technology is best suited for rural areas and low-power applications.

Gaitan and Hojbota [25] has proposed a LoRaWAN technology based IoT system using a LoPy development board from Pycom and Arduino board. With the flame detector interfaced with the Arduino, the system detects the early fire and sends information regarding the possible fire to the control room. Batalha *et al.* [26] outline the detailed measurement model for signal propagation, path loss (PL), signal-to-noise ratio (SNR), and received signal strength indicator (RSSI) during uplink and downlink of messages using LoRa technology. The authors have taken the test case of LoRaWAN technology operating at 915 MHz, a spreading factor of 12, and a signal bandwidth of 125 kHz. The other parameters evaluated in the work include the positioning of the gateway, channel efficiency, quality of service (QoS) network planning, and propagation models. Kamal *et al.* [27] have brought out the in-depth analysis of the requirements in implementation and the offerings of LoRa technology in various industries and sectors. The major challenges in using the LoRa technology are network performance issues, and deployment costs.

3. PROPOSED METHOD

In this section, an FPS which is capable of detecting the intrusion (through the periphery) and fire accidents (in the vicinity of the equipment), is designed. The IoT framework of the proposed FPS is shown in Figure 1. The data from each of the sensor node is forwarded to the network server via the LoRaWAN gateway and then pushed into the IoT cloud. The data from the IoT cloud is accessed into the application dashboard for analytics and visualization. The following subsections describe the procedural steps followed to implement the proposed FPS.

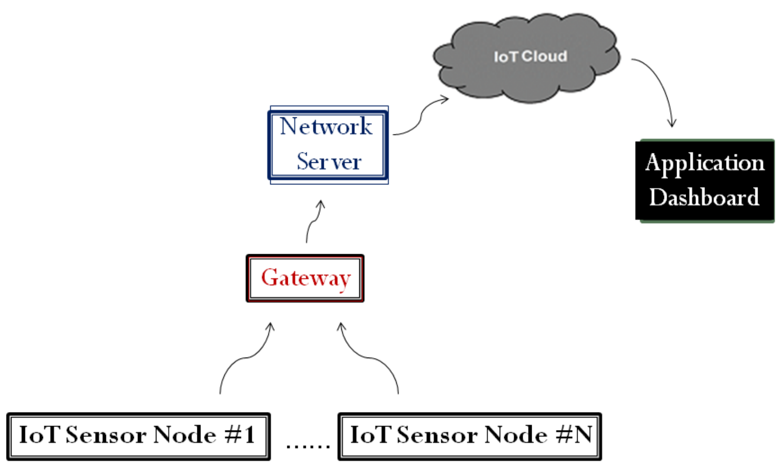

Figure 1. IoT framework of the FPS

3.1. Development of an IoT sensor node

The system illustrated in Figure 2 is designed with three poles (Pole A, Pole B and Pole C) in which LASER beam sensors have been installed at the height of 4 feet and 1 feet, that guarantees the intrusion detection. Since each pole contains different sensors that are interfaced with the micro-controller board (illustrated in Figure 3), here onwards called IoT sensor node. As per the specifications of the considered LASER beam sensor, the poles are placed 100 meter apart. If an unauthorized object attempts to gain an entry, it breaks the communication between the transmitter and receiver modules of LASER beam sensor which triggers the microcontroller board to generate a notification. However, to allow the entry of authorized personnel, an radio frequency identification (RFID) technology based authentication system has been integrated. Further, temperature and flame sensors are incorporated to detect any nearby fire. Moreover, passive infra red (PIR) sensors have also been included in the system to ensure the protection of the equipment from deliberate tampering. At each pole, all the sensors and a LoRa module (SX1276) are interfaced with the Arduino Nano board.

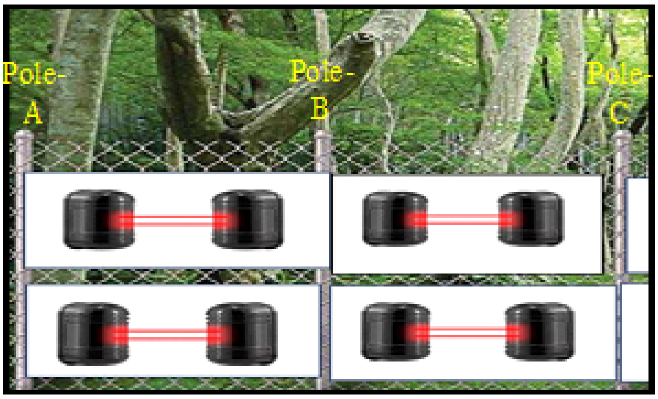

Figure 2. The conceptual idea of the proposed FPS

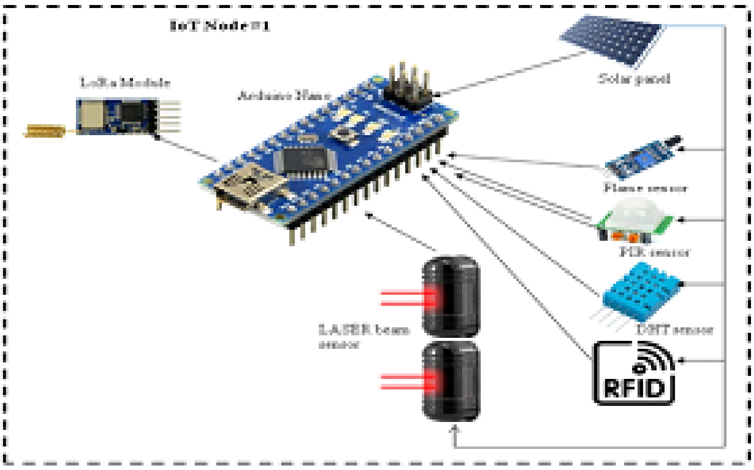

Figure 3. IoT sensor node with various sensors and circuit elements

3.2. Configuration of LoRaWAN gateway

The LoRa technology has been used to establish the data communication between the IoT sensor node and the LoRaWAN gateway (Pygate). The gateway has been configured (by registering the gateway and IoT sensor nodes with the things network (TTN) server) to receive the data from IoT nodes and forward the same to TTN server. The gateway and TTN server are connected through the Internet. The LoRaWAN gateway has been established with the configuration shown in Table 1 using WiPy3.0 development board and Atom

IDE to build the communication between IoT node and TTN server. The TTN console is used to visualize the messages from IoT sensor nodes (uplink). The authentication and integrity of data packets from end-to-end are achieved through two-level cryptography using 128-bit network session key and 128-bit application session key.

Table 1. Configuration details of LoRaWAN gateway

Parameter	Value/setting
Type	SX1257
LoRaWAN band ID	IN_865_867
RSSI offset	-166 dBm
Max. transmitting frequency	870 MHz
Min. transmitting frequency	863 MHz
Spreading factor	7
Bandwidth	125 KHz
Adaptive data rate (ADR)	Dynamic mode
ADR margin	15 dB
LoRaWAN activation mode	ABP (activation by personalization)

3.3. Customization of ThingSpeak application dashboard

The ThingSpeak provides a cloud platform into which the TTN server pushes the sensor data. The IoT sensor data forwarded by the LoRaWAN gateway to the TTN server is uploaded to the ThingSpeak IoT cloud. This data can be accessed from the cloud via the application dashboard at the control station to monitor the forest at its periphery level for any intrusion or fire flames. Various Widgets and Gauges are created on ThingSpeak for data visualization and to generate notifications, accordingly. The complete functionality of the system has been illustrated by the action flow chart shown in Figure 4.

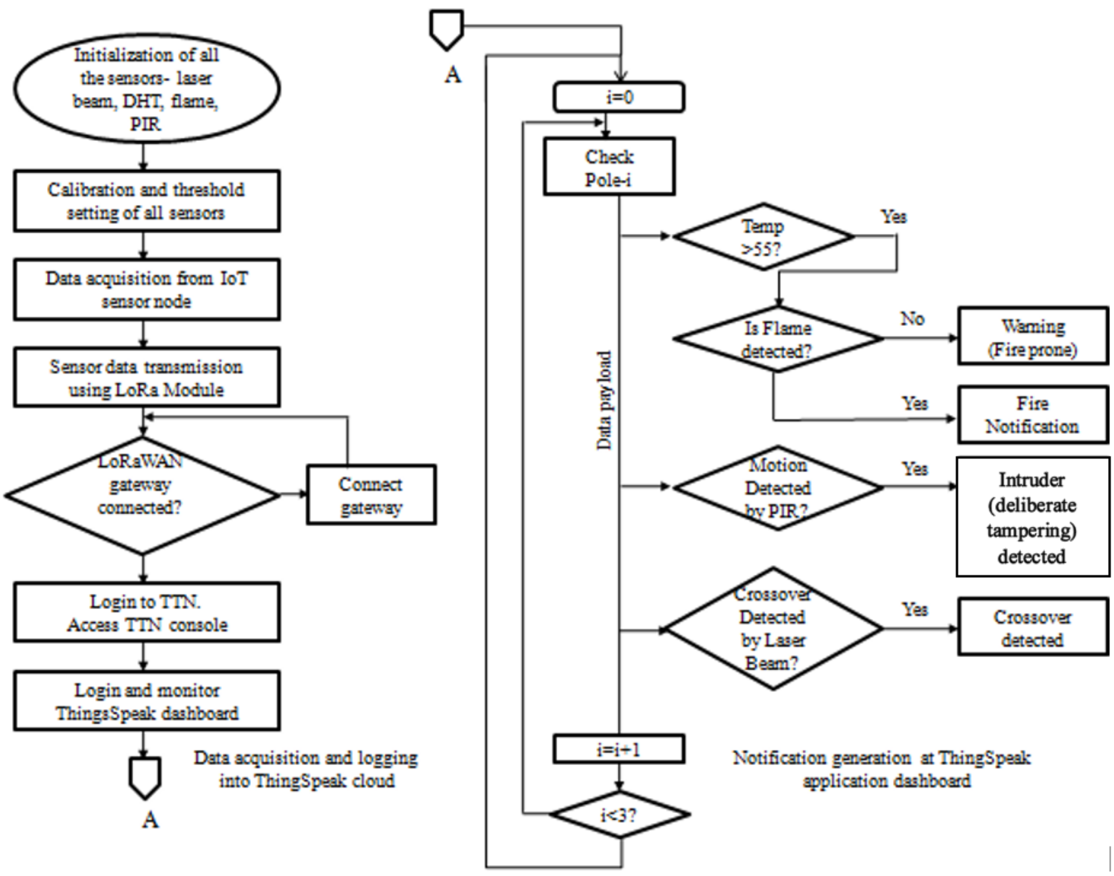

Figure 4. Action flowchart of the proposed FPS

4. CASE STUDY

In this section, a case study that was conducted at Eturnagaram wildlife sanctuary, Mulugu District, Telangana, India after the successful validation of the FPS at Sreenidhi Institute of Science and Technology, Hyderabad, Telangana, India has been discussed. A peripheral distance of 250 m was fenced with the three poles. Each pole equipped with two LASER beam sensors (one transmitter section and one receiver section), temperature sensor, flame sensor, PIR sensor and LoRa module; all interfaced to the Arduino Nano board, and solar power source with a lithium-ion solar battery for power back up. All the electronics (PCB) is placed in a weather-proof metallic box with proper insulation, and fixed on each pole. Since the poles are stationary, the assigned Pole IDs provide the exact location of the incident and hence this system does not require any GPS support. Figure 5 shows the deployed FPS. The information collected from the sensor nodes is transferred to a central application server (ThingSpeak cloud) via LoRaWAN gateway and TTN server. The widgets are created to visualize notifications related to crossover, flame and deliberate equipment tampering detections, whereas the Gauges are created to visualize the temperature and humidity at the location under observation.

Figure 5. Deployment of the developed FPS at Eturnagaram Wildlife Sanctuary, Mulugu District, Telangana

4.1. Testing of the developed FPS

The field test revealed that the distance of communication between IoT nodes as well as the LoRaWAN gateway has been 5 Km. Out of 2,343 samples taken during the test, 99 intense samples have been considered for evaluation, and to plot the graphs. Figure 6 is a plot of physical parameters obtained from the sensor nodes. Crossover detection, flame and equipment tampering detection are indicated as 1 (activity detected) or 0 (no activity detected). Figure 6 shows the plots of six parameters: Figure 6(a) shows the crossover detection using upper LASER beam sensor, Figure 6(b) shows the crossover detection using lower LASER beam sensor, Figure 6(c) shows the temperature, Figure 6(d) shows the humidity, Figure 6(e) shows the flame detection, and Figure 6(f) shows the equipment tampering detection using PIR sensor. Widgets and Gauges created in ThingSpeak are shown in Figure 7, to visualize the activities: Figure 7(a) show authorised entry detected by RFID, Figure 7(b) show equipment tampering warning detected by PIR sensor, Figure 7(c) show crossover detected by upper LASER beam sensor, Figure 7(d) show no crossover detected by lower LASER beam sensor, Figure 7(e) show Gauges indicating temperature, Figure 7(f) show Gauges indicating humidity, Figure 7(g) show graph indicating temperature, and Figure 7(h) show graph indicating humidity. The tests are carried out under simulated environmental conditions: temperature range of 0.4 C to 74.8 C and humidity range of 14% rh to 94% rh. During the test, it is observed that each pair of LASER beam sensors detect intrusion/crossover within a distance of 120 m. Moreover, at the application server, the parameters received from the sensor node are compared with the actual values for validation and it has resulted in an accuracy of 98.43%. The corresponding alert messages are generated at the application server under the following conditions: i) detection of crossover between the poles detected by LASER beam sensors; ii) detection of motion for equipment tampering near the poles by PIR sensor; and iii) detection of fire using DHT and flame sensors. The test results are summarized in Table 2. Since the sensor data will be updated at the ThingSpeak cloud for every 15 seconds, necessary actions including alerting the local personnel can be initiated from the control room against the intrusion into the forest and the nearby fire incidents.

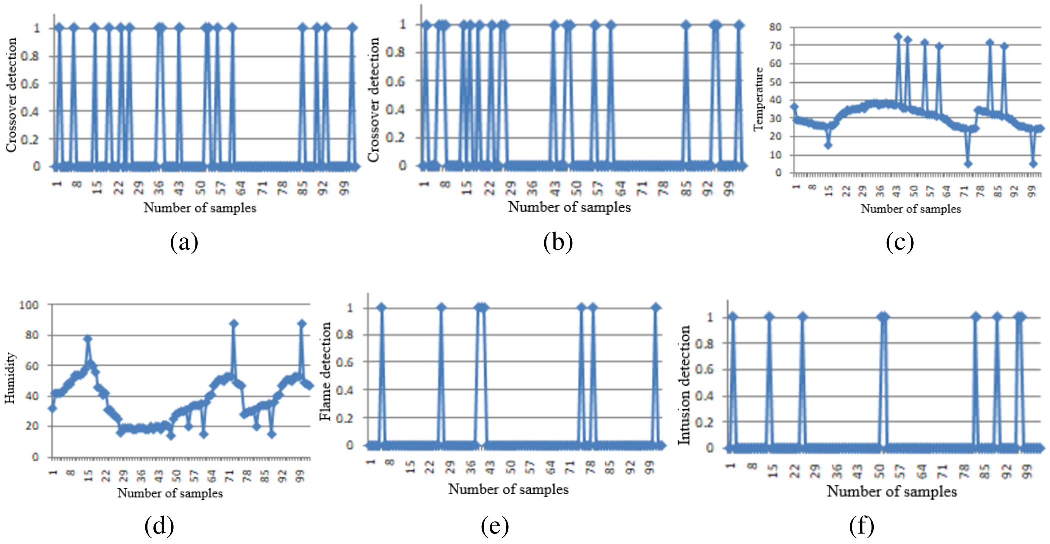

Figure 6. A plot demonstrating the design parameters: (a) crossover detection using upper LASER beam sensor, (b) crossover detection using lower LASER beam sensor, (c) temperature, (d) humidity, (e) flame detection, and (f) equipment tampering detection using PIR sensor

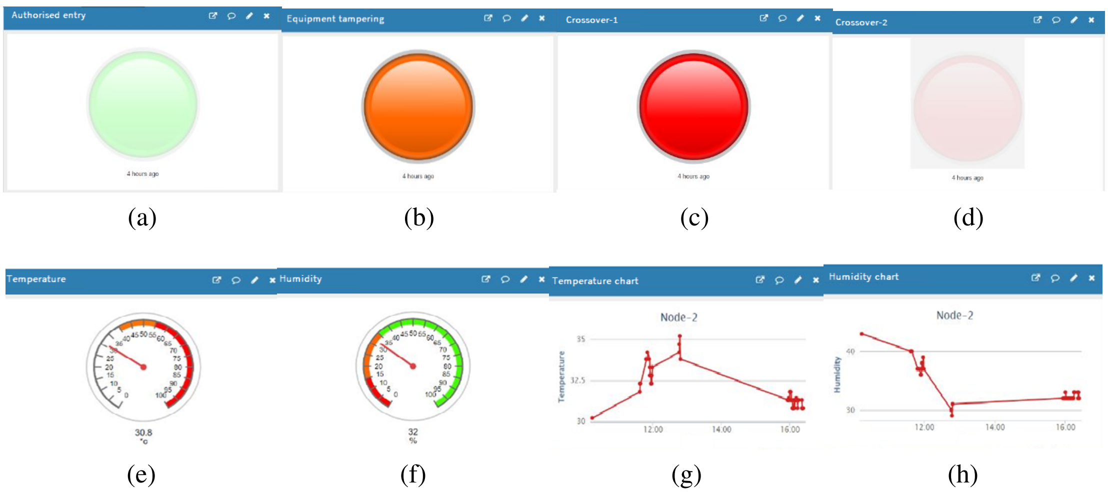

Figure 7. Widgets indicating the cases of: (a) authorised entry detected by RFID, (b) equipment tampering warning detected by PIR sensor, (c) crossover detected by upper LASER beam sensor, (d) no crossover detected by lower LASER beam sensor, (e) Gauges indicating temperature, (f) Gauges indicating humidity, and (g) graph indicating temperature, and (h) graph indicating humidity

5. RESULTS AND DISCUSSION

The screenshot in Figure 8 illustrates the TTN console (gateways tab) depicting device address (DevAddr), data rate, spreading factor (SF), SNR, and RSSI. Figure 9 depicts TTN console (applications tab) showing the format of payload received from the node 1. The proposed FPS has the ability to predict the forest activity without any false alarms. Because of its high level data accuracy, the concerned authority can take timely actions to minimize the loss. This work has explored the efficiency of integrating the fire detection with a reliable and low cost solution for intrusion detection using LASER beam sensors. The exploration of LoRa technology with cloud computing has resulted the system a more energy efficient and cost-effective. Table 3 illustrates a brief performance comparison of some of the earlier works with the proposed one.

Table 2. Summary of the test results

Forest activity/parameter	Detected by	Number of tests conducted	Correctly notified	Falsely notified	% of accuracy
Human crossing (by walk)	LASER beam sensor	23	23	0	100*
Human crossing (by crawling)	LASER beam sensor	22	22	0	100*
Dogs crossing	LASER beam sensor	7	6	1	85.71*
Flame detection	Flame sensor	12	12	0	100**
Equipment tampering detection	PIR sensor	17	17	0	100**

*obtained within a distance of 120 m, ** obtained within a distance of 2 m

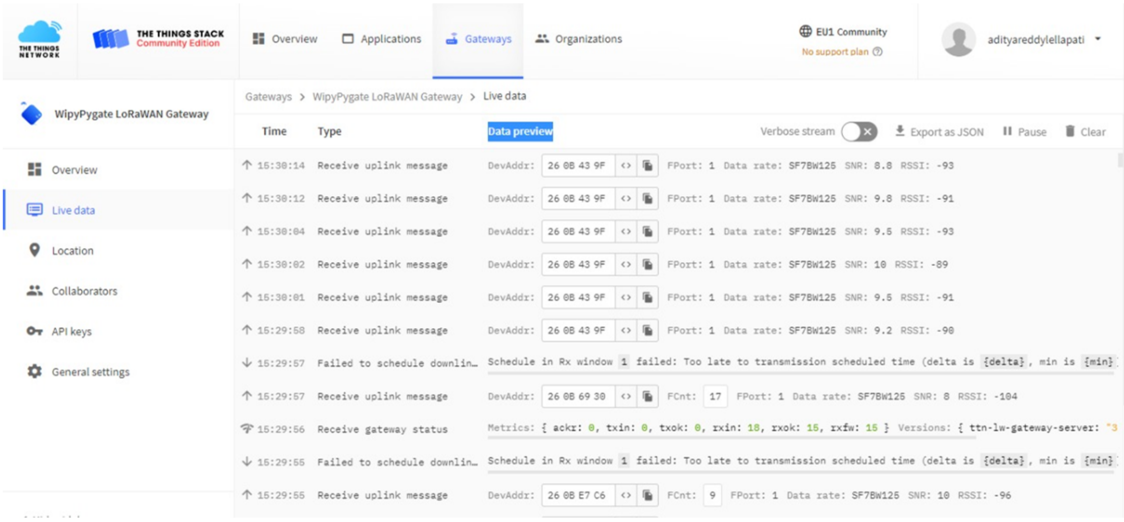

Figure 8. TTN console showing the connectivity between gateway and the IoT nodes

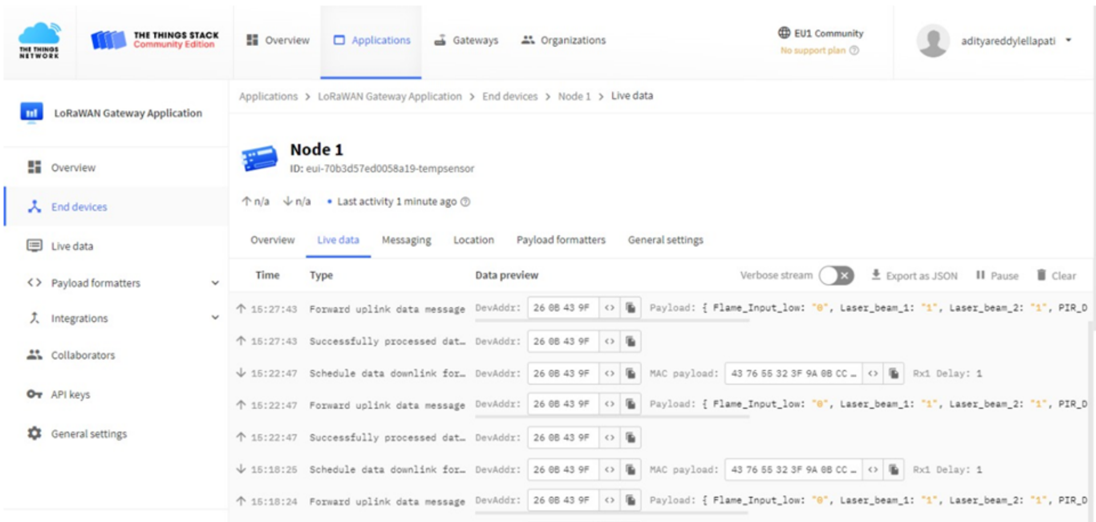

Figure 9. TTN console showing the decoded payload received from application node (node 1)

Table 3. Performance comparisons among the notable research works

Methodology	Detection capability	Notification delay	Distance coverage	Communication technology	Power requirement	Cost of deployment
Forest fire detection and alerting [2]	Forest fire	High	NA	GSM	High	High
Cloud-based wildfire monitoring [4]	Forest fire	Low	NA	Satellite communication and GIS	High	High
Artificial Neural Network for wildfire prediction [5]	Forest fire	High	NA	GSM	High	High
WSN-based IoT system for wildfire detection [8]	Forest fire	Moderate	NA	3G communication	Moderate	Moderate
WSN-based Intruder Detection System [12]	Intrusion	Moderate	NA	GPRS	Moderate	Moderate
Proposed FPS	Intrusion & nearby fire	Low	10-15 Km (suburban)	LoRa	Low	Low

NA- not available

6. CONCLUSION

A forest protection system consisting of LASER beam sensors, temperature sensor, flame sensor, PIR sensor, RFID card, Arduino Nano boards, lithium-ion solar battery, LoRa module, and some electronics has been developed and deployed at Eturnagaram wildlife sanctuary, Mulugu district, Telangana, India. The developed system mainly targets on intrusion detection, and nearby fire detection. For the taken 2,343 data samples, received from IoT sensor nodes during the test, an accuracy of 97.14% for intrusion detection, and an accuracy of 100% for fire detection is recorded, within the given conditions. Hence, the designed system could be very much effective and useful to safeguard the forest resources without causing any hazardous effects on the wildlife and environment. The deployment of dense sensor nodes can further improve the performance/accuracy of the developed system. Designing a scalable robust communication is the another area to be considered for future work for it's widespread deployment.

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REFERENCES

[1] S. Tunes, "IoT technology for remote forest monitoring," *FAPESP Research for Innovation*, 2018. https://pesquisaparainovacao.fapesp.br/iot_technology_for_remote_forest_monitoring/741 (accessed Feb. 5, 2024).

[2] R. Niranjana and T. HemaLatha, "An autonomous IoT infrastructure for forest fire detection and alerting system," *International Journal of Pure and Applied Sciences*, vol. 119, no. 12, pp. 16295–16304, 2018.

[3] K. Jayaram, K. Janani, R. Jeyaguru, R. Kumaresh, and N. Muralidharan, "Forest fire alerting system with GPS co-ordinates using IoT," in *2019 5th International Conference on Advanced Computing & Communication Systems (ICACCS)*, Mar. 2019, pp. 488–491, doi: 10.1109/ICACCS.2019.8728383.

[4] H. Kaur, S. K. Sood, and M. Bhatia, "Cloud-assisted green IoT-enabled comprehensive framework for wildfire monitoring," *Cluster Computing*, vol. 23, no. 2, pp. 1149–1162, 2020, doi: 10.1007/s10586-019-02981-7.

[5] V. Dubey, P. Kumar, and N. Chauhan, "Forest fire detection system using IoT and artificial neural network," *Lecture Notes in Networks and Systems*, vol. 55, pp. 323–337, 2019, doi: 10.1007/978-981-13-2324-9_33.

[6] V. Zope, T. Dadlani, A. Matai, P. Tembhurnikar, and R. Kalani, "IoT sensor and deep neural network based wildfire prediction system," in *2020 4th International Conference on Intelligent Computing and Control Systems (ICICCS)*, May 2020, pp. 205–208, doi: 10.1109/ICICCS48265.2020.9120949.

[7] S. Sannigrahi *et al.*, "Examining the effects of forest fire on terrestrial carbon emission and ecosystem production in India using remote sensing approaches," *Science of The Total Environment*, vol. 725, p. 138331, Jul. 2020, doi: 10.1016/j.scitotenv.2020.138331.

[8] A. Tsipis, A. Papamichail, I. Angelis, G. Koufoudakis, G. Tsoumanis, and K. Oikonomou, "An alertness-adjustable cloud/fog IoT solution for timely environmental monitoring based on wildfire risk forecasting," *Energies*, vol. 13, no. 14, 2020, doi: 10.3390/en13143693.

[9] H. D. Ahlawat and R. P. Chauhan, "Detection and monitoring of forest fire using serial communication and Wi-Fi wireless sensor network," *Advances in Intelligent Systems and Computing*, vol. 1132, pp. 464–492, 2020, doi: 10.1007/978-3-030-40305-8_23.

[10] A. Vidya, P. Malini, and S. Sathiya, "IOT based forest fire detection and early warning system using Raspberrry Pi And GSM," *International Journal of Future Generation Communication and Networking*, vol. 13, no. 1, pp. 1–6, 2020.

[11] V. R. Karumanchi, S. H. Raju, S. Kavitha, V. Lakshmi Lalitha, and S. Vijaya Krishna, "Fully smart fire detection and prevention in the authorized forests," in *Proceedings - International Conference on Artificial Intelligence and Smart Systems, ICAIS 2021*, 2021, pp. 573–579, doi: 10.1109/ICAIS50930.2021.9395969.
[12] B. Koszteczky, G. Vakulya, and G. Simon, "Forest intrusion detection system with sensor network," *Conference Record - IEEE Instrumentation and Measurement Technology Conference*, vol. 2015-July, pp. 1672–1676, 2015, doi: 10.1109/I2MTC.2015.7151531.
[13] E. A. Kadir, H. Irie, and S. L. Rosa, "Modeling of wireless sensor networks for detection land and forest fire hotspot," in *ICEIC 2019 - International Conference on Electronics, Information, and Communication*, 2019, pp. 1–5, doi: 10.23919/ELINFOCOM.2019.8706364.
[14] J. Han, "Application of internet of things technology in forest fire warning of Jizhou district," *Journal of Physics: Conference Series*, vol. 1732, no. 1, p. 012004, 2021, doi: 10.1088/1742-6596/1732/1/012004.
[15] A.-E. Marcu, G. Suciu, E. Olteanu, D. Miu, A. Drosu, and I. Marcu, "IoT system for forest monitoring," in *2019 42nd International Conference on Telecommunications and Signal Processing (TSP)*, Jul. 2019, pp. 629–632, doi: 10.1109/TSP.2019.8768835.
[16] A. R. Rumee, "IoT system for remote monitoring of the mangrove forests of Sundarbans," *Journal of Computer Sciences Institute*, vol. 20, pp. 254–258, 2021.
[17] P. R. Patil and V. T. Patil, "Smart forest: an IoT based forest safety and conservation system," *International Journal of Scientific & Technology*, vol. 9, no. 3, 2020.
[18] M. Krishnamoorthy, M. Asif, P. P. Kumar, R. S. S. Nuvvula, B. Khan, and I. Colak, "A design and development of the smart forest alert monitoring system using IoT," *Journal of Sensors*, vol. 2023, 2023, doi: 10.1155/2023/8063524.
[19] R. Singh, A. Gehlot, S. Vaseem Akram, A. Kumar Thakur, D. Buddhi, and P. Kumar Das, "Forest 4.0: digitalization of forest using the internet of things (IoT)," *Journal of King Saud University - Computer and Information Sciences*, vol. 34, no. 8, pp. 5587–5601, 2022, doi: 10.1016/j.jksuci.2021.02.009.
[20] A. Augustin, J. Yi, T. Clausen, and W. M. Townsley, "A study of Lora: long range & low power networks for the internet of things," *Sensors (Switzerland)*, vol. 16, no. 9, 2016, doi: 10.3390/s16091466.
[21] U. Noreen, A. Bounceur, and L. Clavier, "A study of LoRa low power and wide area network technology," in *Proceedings of the 2020 International Conference on Advanced Technologies for Signal and Image Processing (ATSIP)*, 2020, pp. 1–6.
[22] Q. Zhou, K. Zheng, L. Hou, J. Xing, and R. Xu, "Design and implementation of open LoRa for IoT," *IEEE Access*, vol. 7, pp. 100649–100657, 2019, doi: 10.1109/ACCESS.2019.2930243.
[23] W. Ayoub, A. E. Samhat, F. Nouvel, M. Mroue, and J. C. Prévotet, "Internet of mobile things: overview of LoRaWAN, DASH7, and NB-IoT in LPWANs standards and supported mobility," *IEEE Communications Surveys and Tutorials*, vol. 21, no. 2, pp. 1561–1581, 2019, doi: 10.1109/COMST.2018.2877382.
[24] A. S. Rawat, J. Rajendran, H. Ramiah, and A. Rana, "LORA (long range) and LORAWAN technology for IoT applications in Covid-19 pandemic," in *Proceedings - 2020 International Conference on Advances in Computing, Communication and Materials, ICACCM 2020*, 2020, vol. 2020-Augus, pp. 419–422, doi: 10.1109/ICACCM50413.2020.9213067.
[25] N. C. Gaitan and P. Hojbota, "Forest fire detection system using lora technology," *International Journal of Advanced Computer Science and Applications*, vol. 11, no. 5, pp. 18–21, 2020, doi: 10.14569/IJACSA.2020.0110503.
[26] I. D. S. Batalha *et al.*, "Large-scale modeling and analysis of Uplink and Downlink channels for LoRa technology in suburban environments," *IEEE Internet of Things Journal*, vol. 9, no. 23, pp. 24477–24491, 2022, doi: 10.1109/JIOT.2022.3191639.
[27] M. A. Kamal, M. M. Alam, A. A. B. Sajak, and M. Mohd Su'ud, "Requirements, deployments, and challenges of LoRa technology: a survey," *Computational Intelligence and Neuroscience*, vol. 2023, 2023, doi: 10.1155/2023/5183062.

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