Wildfire Detection using Wireless Mesh Network

Gokay Saldamli
Computer Engineering Department
San Jose State University
San Jose, CA 95192, USA
gokay.saldamli@sjsu.edu

Sumedh Deshpande
Computer Engineering Department
San Jose State University
San Jose, CA 95192, USA

Kaustubh Jawalekar
Computer Engineering Department
San Jose State University
San Jose, CA 95192, USA

Pritam Gholap
Computer Engineering Department
San Jose State University
San Jose, CA 95192, USA

Loai Tawalbeh
Department of Computing and Cyber Security
Texas A&M University - San Antonio
San Antonio, TX 78224, USA

Levent Ertaul
Department of Computer Science
California State University East Bay
Hayward, CA 94542, USA

***Abstract*—Forests are one of the prime protectors of earths ecological balance. Unfortunately, the forest fire is typically only discovered when it has already spread over a massive area, making its manage and stoppage onerous and even impossible at times. The end result is devastating loss and irreparable damage to the environment and atmosphere. Among other terrible penalties of forest fires are long-term disastrous outcomes such as impacts on local weather patterns, global warming, and extinction of rare species of the flora and fauna. Millions of hectares of forest are destroyed by means of fire each and every year. Areas destroyed through these fires are massive and trigger greater carbon monoxide than the average automobile traffic. Monitoring of the plausible threat areas and an early detection of fire can substantially shorten the reaction time and also minimize the potential damage as well as the cost of firefighting. Economic fire alarm structures are quintessential in imparting an early warning in the event of fire. They help to save lives and protect property whilst additionally satisfying the needs of insurance groups and government departments. The proposed system is capable of detecting smoke, different flammable gases and fire and notifying any hazardous situation using an Iot Dashboard. This wildfire smoke detection system with IoT framework provides a smart and cost efficient solution that saves lot of flora, fauna and human lives.**

***Index Terms*—Smoke detection, wireless sensor network, IoT, Raspberry Pi**

I. Introduction

Numerous individuals do not have fire alert frameworks introduced in their homes. Many accept that they can smell smoke when they are snoozing and wake up so as to escape if there will be an occurrence of a fire crisis. Indeed, this isnt valid in any way. Studies have been directed and it has been demonstrated that individuals sleep is disrupted when there is sound or commotion, yet it isnt the situation with smell. Our feeling of smell is lost when we are sleeping, and we wont wake up regardless of how solid the smell of smoke is. Many people do not take fireplace alarms seriously, and masses of do not test their alarm systems often. The exceptional element that could provide you and your family with a warning, from a fire is the sound of a properly set up and maintained alarm device. fire alarms are vital because of the truth they are able to come up with an early sign to some element that might be tragic essentially saving your lives.

A fire alarm alerts you when you are sleeping or working. You can immediately take some action before any damage is caused, therefore saving you and the cost of belongings loss. It is easy to get trapped within the start of a fire. An early detection can get you out of a situation that could potentially emerge as a tragedy. ensure to moreover alert your circle of relatives and buddies are the significance of putting in fire alarm systems.

Another thing to pay attention is that the way humans are interfering in earth's ecological balance with a lot of deforestation for development of cities and industries. This artificial development has caused adverse effects on ecosystem and proportion of natural calamities is increasing. According to national climate report published in May 2018 [1], number of storms and floods in years 2017-18 is significantly more than that of previous years. The same is happening with fires and earthquakes. According to Cal fire incidents and events report [2], about 3,513 fires burn 199,983 acres of forest totaling $657,630,136 damage on a five year average in State of California.

In November 2018, California witnessed a deadly wildfire that caused civilian fatalities, injuries, and destruction of property. The firestorm started in Concow and spread through the densely populated town of Paradise. The fire was contained after seventeen days of firefighting and recovery efforts. The fire has killed 85 people and affected 18,804 structures listed as the most destructive and deadliest wildfire in the history of California [3]. These losses and many others due to fire have a major impact on forest ecosystem their by indirectly affecting the natures ecosystem.

All of these reports show that wildfire is now a major catastrophe risk that must be rigorously managed with the best technology since an early detection of fire can substantially shorten the response time and minimize the potential damage people's lives. We propose a cost efficient and easy to implement solution. The proposed system contains a carbon monoxide and nitrogen oxide gas detection sensor node deployed on

978-1-7281-1796-6/19/$31.00 ©2019 IEEE

a high tree with a communication interface integrated with it. The node feeds an early detection backend where the data is processed and in case of an emergency create emergency signal. The rest of the paper follows the following organization with background in Section II, proposed system architecture in Section III, System components in Section IV, implementation details in Section V, results in Section VI and conclusion in Section VII.

II. Background

There is substantial work in detecting, controlling and managing forest fires using technological advances [4]–[9], [18]–[24]. Some of these works require quite complicated hardware and software stacks but in here we will briefly go through the most interesting works that related to our construction. Y. Liu et. al. [10] proposed a wireless sensor network (WSN) [11] for monitoring and detecting forest fire. They used temperature, humidity, light and smoke sensors on single device. This device is deployed in the forest with maximum communication range of 100m. After detecting the fire, each node will send data through cluster head by using a classifier of data aggregation technique. The proposed system is not actually deployed and have some flaws based on area coverage and deployment.

Mohapatra and Khilar [12] proposed a solution to detect fire using fuzzy logic. Also, faulty node in WSN is detected to validate the data received at cluster head. The experiment is carried out inside a room. This is helpful in wireless mesh networks as faulty node can be detected and diagnosed remotely.

G.Hristov et. al. [13] suggested two different methods to detect fire in the forest as early as possible. First method provides insights about past and current techniques of aerial assistance. As unmanned aerial vehicles (UAVs) have constraints of power, the cameras deployed in forest (ground cameras) will first detect the anomaly. If fire is detected using dual camera lens along with infrared imaging, then UAVs will be sent to confirm the situation. There are disadvantages with the solution like deploying cameras in national parks, flight time of drones (can hover only for 35 to 40 mins) and it is a costly affair. The second method introduces LoRaWAN sensor network and devices. Currently available LoRa gateway is integrated with Raspberry pi 3 model B and use to send the data to central hub or server. Model is costly and still needs improvement as these nodes are not equipped with sensors to detect fire.

The work in [14] proposes the idea of using satellite images to identify and differentiate the forest area which is prone to fire. They have used modified fuzzy c-means clustering approach to extract region of forest fire. This method will help in the deployment of wireless mesh network in fire prone forest areas and more precaution can be taken. In another paper [15], authors have introduced an idea of detecting the fire forest focused on Edge computing and using the concept of Mobile Hubs (M-Hubs). This method used sensor tag and Bluetooth powered hand-held devices carried by visitors and guards. The sensor values are forwarded through mobile devices to smart forest servers and then after processing data, each device will receive notification. There are certain drawbacks in this solution like longer response time and reliability. Also, if there is no mobile device near to sensor then the data may not be forwarded to server.

He et. al. [16] have used smoke detector to detect fire along with temperature sensor just to ensure the validity. They have used GPRS to communicate with PC or server using AT commands (TCP/IP protocol). Last to mention, [17] describes the use of UAVs and unmanned ground vehicles (UGVs) in forest monitoring and fire detection. As UAVs have less flight time, UGVs will carry UAVs from base station to search area assigned to each UAVs and then deployed. This helps reducing overhead flight time and also UGVs will be equipped with high computing power so that when UAV detects fire it will send that data to UGV for processing. Some of the issues with this idea is high cost for creating autonomous vehicle and coordinating both UGV and UAV is difficult and time consuming.

III. Proposed System

The solution this paper proposes is mainly cost efficient and relatively easy to implement than using complex hardware and firmware logic for cameras and image recognition. As seen in Fig. 1, the proposed system has a sensor node deployed on a high tree with a communication interface integrated with it. This node sends data to a PHP dashboard application to which firefighters can access.

The sensor node uses Carbon Monoxide and Nitrogen oxide gas detection sensor. It will capture increased level of CO and NO in air and if temperature sensor integrated with the node records significant temperature increase, it will transmit a signal that fire is detected. This data will be sent to a team of firefighters on dashboard along with node Id. These node IDs will be specific with location and firefighters have locations of each nodes in database. They can take immediate action depending upon how many nodes generate indications and how rapidly the fire is spreading. The sensor nodes are connected to each other to form a wireless sensor (mesh) network and a sensor node is connected to Raspberry Pi which acts as a gateway to the internet. Hence the innermost node in the forest, through the nodes (since connected in mesh network)in between, sends data to Raspberry Pi and then Pi, through internet, sends the data to firefighter's dashboard.

IV. System Components

The System proposed is divided into 3 main parts. Each division consists of some Hardware or Software components, tools or utilities to work with each other. The divisions and tools needed to integrate the system are researched and proposed as follows.

A. Hardware mesh network

Hardware part consists of carbon monoxide and nitrogen oxide sensor, a temperature sensor and a micro controller to

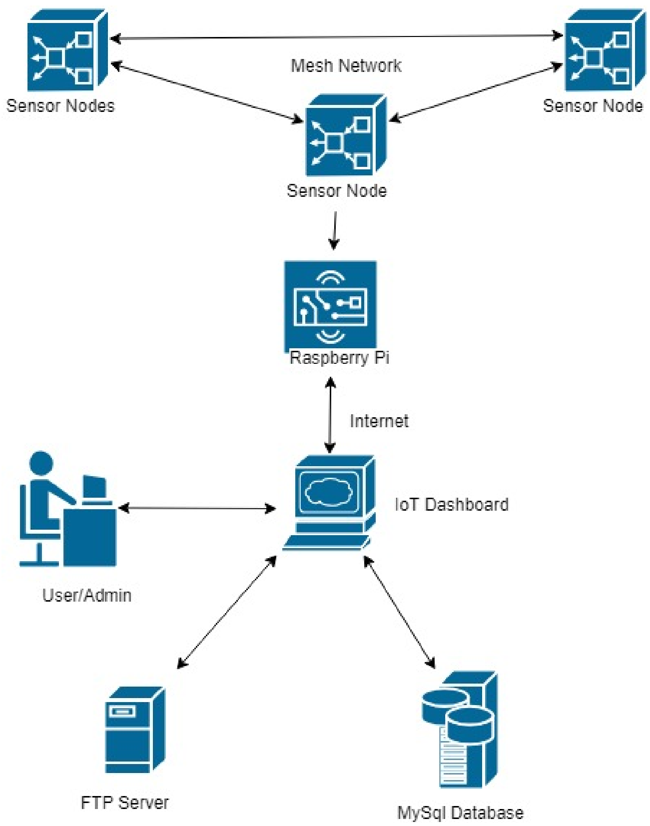

Fig. 1. System Block Diagram

interface these sensors with wireless communication module. There are several criterion to select specific sensors, specific micro controllers and wireless modules.Sensor nodes can be powered using Polymer Li-Ion Cell: 3.7V 5000 mAh (100 cells 16.15 dollar's each) [**?**]Sensors require 5V supply consuming 120mWh (current = 24mAh). Battery suggested can be used for 200 hours. Solar cell can be used. After configuring LoRa for medium range, it was tested for 3 straight hours in university campus and it consumed 198mAh that is 66mAh power consumption. So, if suggested battery is connected then it should power LoRa for 76 hours. But if event driven code is used, i.e., LoRa will be on only when sensors senses changes in air. Otherwise, LoRa will be kept in sleep mode where it consumes 2uAh. So, battery life can be extended using this trick. Also, there are solar powered cells available in the market like AMX3d Micro mini Solar cells) which provide 5V and 30mA. These cells stashed in parallel can provide required current for the module.

- **CO and NO sensor:** This sensor is most important in the whole system since, it will be sensing smoke from longer distance. The sensor must be effective for longer range as well as cheaper because, it has to be used in huge quantity. There are several options available such as grove MQ-2, grove Mq-7 or MiCS-4514. MQ-2 and MQ-7 are cheaper options than that of MiCS; however, MiCS senses the smoke from longer range and hence can be populated in longer distances.
- **Temperature Sensors:** Number of temperature sensors are available in the market. The one which enables long distance sensing should be selected. After considering these criterion LM35 temperature sensor can be chosen to integrate on sensor node.
- **Microcontroller:** ARM Cortex M3 based LPC1758 micro controller can be used for the sensor nodes since it is 32 bit and provides high computational power required for interfacing 2 sensors and sending the values with wireless mesh network modules.
- **Wireless Communication Module:** This is most important sensor node component since, this is to be used for communication between 2 sensor nodes, form a mesh network and send the smoke sensed indication to Gateway. LoRA 1276 SX wireless communication module provides Longer communication distance up to 500 meters and is cheaper than other modules of same range. LoRa configured for medium range (freq. = 434Mhz, 13dBm, BW = 125kHz, Cr =4/5, Sf = 128 chips/symbol, 5cm short SMA antenna placed at 50cm above ground) requires 3.3V and works flawlessly for 500m range (According to datasheet the module can actually send data over 2km of distance through dense forest.) Messages of 40 Bytes (GPS location) sent over 500m distance were received within 2 seconds. This lag can be due to data processed by GPS takes longer time than transmission rate and hence unless data packet was not ready data was not sent. [25]For mesh networking thread networking protocol (OpenThread) was used. [26]

B. Gateway Interface

Gateway interface is nothing but a bridge that connects sensor nodes to internet. Raspberry Pi is one of the great processor that has inbuilt network connection. The data received from sensor nodes is communicated over the internet to firefighters' dashboard.

C. Dashboard

In order to have rapid development we choose a modern software stack in designing the dashboard of the system. We pick PHP as the server-side scripting language because of its built-in capabilities. MySql and Javascript are the other technologies we deployed. The following gives the minimum the server and a database requirements to design a web based firefighters' dashboard application.

- **Backend:** PHP is a server-side scripting language designed for web development but also used as a general-purpose programming language. It stands for PHP: Hypertext Pre-processor, a recursive acronym. PHP has a rich functionality with codes written for specific tasks which makes coding easy unlike JSP which is too much descriptive and object-oriented code.
  MySql provides an open database environment that runs on a wide variety of computing platforms. A MySql database can grow from a small single-user application to

a large multi-user system. Using SQL, users can obtain data simultaneously from MySql and other databases. MySql includes a range of application development and management tools.

- **Frontend:** JavaScript is a client-side object oriented computer programming language used for interacting and performing validations on user data.
  Hypertext Markup Language, is used to design front end that is user interface of web application. It contains various tags to help user know what task to do.(CSS). Cascading Style Sheet, is used for decorating the web site.

V. Implementation

The implementation of the system is really simple and efficient. As soon as any part of the forest, where sensor nodes are deployed (500 meters away from each other) to form a mesh network, catches fire, one of the sensors in mesh network will sense the smoke. Firefighters will get an alert on their dashboard. They can find the location of the node using location database they have. If the fire spreads in any of the direction, another node will notice it and dashboard will get a signal. Thus, firefighters will know location of the fire and in which direction and how fast the fire is spreading. The following reveals our implementation details:

A. Hardware Mesh Network

Interface of sensors to Controller: Selected CO-NO detection sensor i.e. MiCS-4514 can be interfaced with LPC1758 micro controller using ADC interface. The sensor provides high resistance values if levels of the harmful gases, which are usually present in large amount in fire smoke, increase in the atmosphere and the above threshold values will indicate possibility of fire nearby. Temperature sensor LM35 is also interfaced using ADC since, it provides actual temperature value in analog form which is needed to be converted in digital form and processed.

Interface of LoRa module: LoRa 1276 SX module consists an SPI interface facility with the micro controller. Hence, This module can be interfaced with the controller with just 4 wires and very high speed 24MHz. The communication between 2 LoRa transceivers take place over 868MHz. This enables deployment of sensor nodes over the radius of 500 meters. These nodes communicate with each other and find a shortest path to reach to the gateway using mesh network.

B. Gateway Interface

Raspberry Pi is also interfaced with LoRa 1276 SX with SPI interface. It is costly to deploy in larger quantities. Thus, Raspberry Pi is placed at only one corner of the mesh network to which all the nearby sensor nodes are connected. Due to mesh network the nodes which are at longer distance from Raspberry Pi and can not connect to LoRa connected to Raspberry Pi, are connected to the nodes in between farther nodes and Raspberry Pi. Thus, packet forwarding takes place whenever innermost node needs to send the data to gateway and effectively to Dashboard.

Raspberry Pi due to its inbuilt Internet connection, sends the indication coming from any of the nodes to Dashboard. This data includes node id and smoke sense indication string. The backend simply captures this string, parses it and place the sensor data to the database. Although we implemented quite simple functions for data analytics, more complicated analysis models could also be deployed. However, our main goal here is analyze the hardware cost.

C. Dashboard

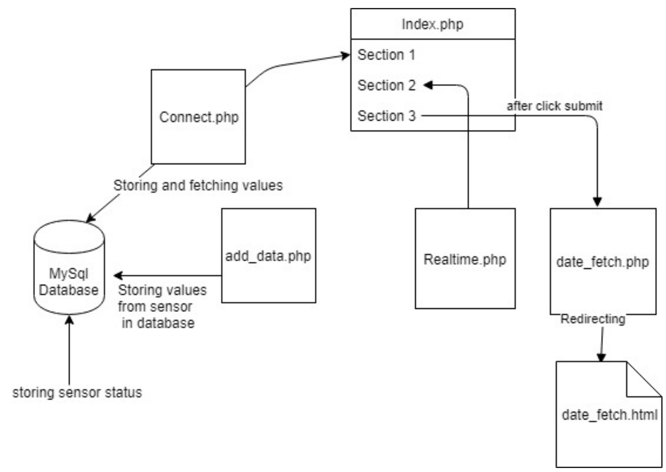

Fig. 2. Dashboard Components

An IoT dashboard as seen Fig. 2 will be developed for taking readings from the sensors and displaying it in graphical form. The languages used will be HTML, CSS, JavaScript for front end. PHP and MySQL for backend. All the sensors will send readings on the php page. The readings are embedded in the url (for example is used to select the time zone and date('Y-m-d', time()) is used to get the current date. PHP script will return data sent by sensor in JSON format to the javascript file to plot the real time graph. It will also add data in the MySql Database. To access the dashboard, the user will enter the url for the dashboard, an index/home page of a dashboard will open.

The index page will consist of three sections first one contains table with columns Device id, Date, Region where the sensor is placed and readings from Sensor. The user will be able to see latest 10 readings send by sensor. The second section consist of line graph of latest 100 readings from sensor. Chart.js library of JavaScript will be used to plot the graph. If two sensors are connected and sending readings simultaneously two lines will be plotted each representing reading from respective sensors. In case the readings from the sensor passes the threshold value a warning message will be displayed on the screen of fire department. Someone from the authority will confirm about the situation. If the situation is under control action will be taken else an alert message will be sent and the authorities will be informed.

The last section consists of date field which will provide user ability to check the readings of sensors plotted in graphical format between any two dates. When user selects two dates and click on submit button, the graph will be displayed for those dates. This feature will enable end user to perform the analysis on the collected data.

VI. Results

The proposed idea was experimented in a controlled environment using CC2650 sensorTag BLE SoC as sensor nodes along with MiCS-4514. The experiment resulted in immediate smoke detection and alert generation on dashboard. Drawback of the experiment was communication range (10 meters) and usage of LoRa wireless Communication module (500 meters) overcomes the drawback. Tables I and II show the cost of a single sensor and the overall system targeting $25km^2$ area respectively. At a cost less than $5K$, the proposed system may cover a decent area against forest fires.

TABLE I
The cost of a single sensor node

Component	Quantity	Cost (USD)
LPC1758 (ARM Cortex-M3 32-bit microcontroller)	1	10.62
Adafruit RFM95W LoRa Radio Transceiver	1	19.95
Mouser MICS-4514 (Air Quality Sensors)	1	15.96
Microchip MCP9700-E/TO Temperature Sensor	1	0.28
Total Sensor Cost	1	46.81

TABLE II
Overall system cost

Component	Quantity	Cost (USD)
Adafruit Raspberry Pi as a Gateway	1	35.00
Sensor cost covering 25 km^2 Area ($\sim$6,200 Acres)	100	4681
Total cost (100 sensor nodes + 1 Gateway)	1	4716

The following summarizes the features and results of this study obtained on implementation of our solution:

1. An alert message will be sent by sensor nodes which are in proximity of fire. The message is forwarded to Raspberry Pi through other sensor nodes. Raspberry Pi will check the reliability by checking the status of each node. If the status of nodes are active and getting similar alert messages from different sensor nodes, the fire alert will be considered valid.
2. Then Raspberry Pi, which is connected to Internet using Wifi at base stations, will send an alert signal to Web UI (Dashboard) using MQTT protocol.
3. The dashboard will use a MySQL database in the backend and stores readings coming from Raspberry Pi in the table. UI also displays the real time values in a tabular format.
4. The real time values are plotted in graph which is simpler visualization feature for user.
5. The dashboard offers to view the data of particular date and time when selected. This helps user to analyze the readings.
6. The dashboard can also be connected to number of devices and can display multiple devices data.
7. HTTP is slower than MQTT and hence, the system will use MQTT to send the data.

VII. Conclusion

In this work we design a smart and cost efficient technique for wildfire detection using smoke detectors and IoT framework. A web based IoT dashboard is implemented where the dashboard serves for the purpose of monitoring the device readings. The web technologies used are Python, JavaScript, PHP, MySql database.

LORA mesh network is implemented to connect multiple devices at a time using Raspberry Pi as edge router gateway. The proposed system could help to have a early detection solution for major catastrophic forest fire risk. It would substantially decrease the minimize the potential damage peoples lives at a fairly low cost.

References

[1] NOAA National Centers for Environmental Information, State of the Climate: National Climate Report for May 2018, published online June 2018, retrieved on March 6, 2019 from https://www.ncdc.noaa.gov/sotc/national/201805.

[2] Cal fire, Jurisdiction Fires, Acres, Dollar Damage, and Structures Destroyed, retrieved on March 6, 2019 from http://cdfdata.fire.ca.gov/pub/cdf/images/incidentstatsevents_270.pdf

[3] Cal fire, Top 20 most destructive California wildfires, retrieved on March 6, 2019 from http://www.fire.ca.gov/communications/downloads/fact_sheets/Top20_Destruction.pdf

[4] K. Muheden, E. Erdem and S. Vanin, "Design and implementation of the mobile fire alarm system using wireless sensor networks," 2016 IEEE 17th International Symposium on Computational Intelligence and Informatics (CINTI), Budapest, 2016, pp. 000243-000246.

[5] K. Deve, G. Hancke and B. Silva, "Design of a smart fire detection system," IECON 2016 - 42nd Annual Conference of the IEEE Industrial Electronics Society, Florence, 2016, pp. 6205-6210.

[6] Antonio Molina-Pico, David Cuesta-Frau, Alvaro Araujo, "Forest Monitoring and Wildland Early Fire Detection by a Hierarchical Wireless Sensor Network", Journal of Sensors, pp. 1-8, 2016.

[7] AAA Ahmad, "Wireless Sensor Network for Forest Fire Detection and Decision Making", International Journal of Advances in Engineering Science and Technology, pp. 299-309, 2015.

[8] A. Qandour, D. Habibi and I. Ahmad, "Wireless sensor networks for fire emergency and gas detection," Proceedings of 2012 9th IEEE International Conference on Networking, Sensing and Control, Beijing, 2012, pp. 250-255.

[9] N. Sabri, S. A. Aljunid, B. Ahmad, A. Yahya, R. Kamaruddin, M. S. Salim, "Wireless sensor actor network based on fuzzy inference system for greenhouse climate control", Journal of Applied Sciences, vol. 11, no. 17, pp. 3104-3116, 2011.

[10] Y. Liu, Y. Liu, H. Xu and K. L. Teo, ”Forest fire monitoring, detection and decision making systems by wireless sensor network,” 2018 Chinese Control And Decision Conference (CCDC), Shenyang, 2018, pp. 5482-5486.
[11] V. Potdar, A. Sharif and E. Chang, ”Wireless Sensor Networks: A Survey,” 2009 International Conference on Advanced Information Networking and Applications Workshops, Bradford, 2009, pp. 636-641.
[12] S. Mohapatra and P. M. Khilar, Forest fire monitoring and detection of faulty nodes using wireless sensor network, 2016 IEEE Region 10 Conference (TENCON), 2016.
[13] G. Hristov, J. Raychev, D. Kinaneva, and P. Zahariev, Emerging Methods for Early Detection of Forest Fires Using Unmanned Aerial Vehicles and Lorawan Sensor Networks, 2018 28th EAEEIE Annual Conference (EAEEIE), 2018.
[14] P. Ganesan, B. S. Sathish, and G. Sajiv, A comparative approach of identification and segmentation of forest fire region in high resolution satellite images, 2016 World Conference on Futuristic Trends in Research and Innovation for Social Welfare (Startup Conclave), 2016.
[15] G. B. Neumann, V. P. D. Almeida, and M. Endler, Smart Forests: fire detection service, 2018 IEEE Symposium on Computers and Communications (ISCC), 2018.
[16] Z. He, Y. Fang, N. Sun, and X. Liang, Wireless communication-based smoke detection system design for forest fire monitoring, 2016 31st Youth Academic Annual Conference of Chinese Association of Automation (YAC), 2016.
[17] K. A. Ghamry, M. A. Kamel, and Y. Zhang, Cooperative forest monitoring and fire detection using a team of UAVs-UGVs, 2016 International Conference on Unmanned Aircraft Systems (ICUAS), 2016.
[18] Molla Shahadat Hossain Lipu, Tahia Fahrin Karim, Md. Lushanur Rahman and F. Sultana, ”Wireless security control system and sensor network for smoke and fire detection,” 2010 IEEE International Conference on Advanced Management Science(ICAMS 2010), Chengdu, 2010, pp. 153-157.
[19] J. Lloret, M. Garcia, D. Bri, S. Sendra, ”A wireless sensor network deployment for rural and forest fire detection and verification”, Sensors, vol. 9, no. 11, pp. 8722-8747, 2009.
[20] J. Zhang, W. Li, Z. Yin, S. Liu and X. Guo, ”Forest fire detection system based on wireless sensor network,” 2009 4th IEEE Conference on Industrial Electronics and Applications, Xi’an, 2009, pp. 520-523.
[21] G. Boggia, P. Camarda, L. A. Grieco and M. R. Palattella, ”Fire Detection using Wireless Sensor Networks: An Approach Based on Statistical Data Modeling,” 2008 New Technologies, Mobility and Security, Tangier, 2008, pp. 1-5.
[22] L. zhen-ya, W. Zhen-dong, C. Rong, ”Intelligent Residential Security Alarm and Remote Control System Based on Single Chip Computer”, Nanchang Hangkong China, pp. 159-161, 2008.
[23] Li Guang-Hui, Zhao Jun and Wang Zhi, ”Research on Forest Fire Detection Based on Wireless Sensor Network,” 2006 6th World Congress on Intelligent Control and Automation, Dalian, 2006, pp. 275-279.
[24] Liyang Yu, Neng Wang and Xiaoqiao Meng, ”Real-time forest fire detection with wireless sensor networks,” Proceedings. 2005 International Conference on Wireless Communications, Networking and Mobile Computing, 2005., Wuhan, China, 2005, pp. 1214-1217.
[25] https://www.threadgroup.org/What-is-Thread.
[26] https://olddocs.pycom.io/v/development_release/tutorials-and-examples/lora/lora-mesh.