Development of a Solar-Powered Wildfire Detector System for Remote Locations with XBee and GSM Capabilities

BRALLAN ALVARES, ERIC PEREZ, JOSHUA TRIGUEROS, JERRY HO, ERIC LY, HA THU LE

Department of Electrical and Computer Engineering
California State Polytechnic University, Pomona
Pomona city, California 91768
UNITED STATES OF AMERICA

Abstract — In the United States wildfires are rampant every year, taking lives, damaging properties and causing huge economic losses. This project designs a wildfire detector system using a Many-to-One communication method with XBee/Zigbee and GSM technologies. Testing of the prototypes has shown the system advantageous features, namely low-power, long-lasting, compact, scalable and communication-effective. The maximum power consumption of a Xbee fire detector and a GSM detector is 14W and 27W, respectively. In detection mode, the XBee detector consumes only 1.29W. The fire detectors are powered by solar panels and Ni-MH battery packs. A fully charged battery pack can sustain a detector up to around 19.3 hours in detection mode, and up to about 4.5 hours in alarm mode. The system has a high potential to be used for wide-area outdoor fire monitoring and detection. The covered area can be flexibly adjusted by varying the number of detectors. Early fire detection and alert provided by the system will enable timely responses that save human lives, as well as minimize property damages and other economic losses.

Keywords — Fire alarm, GSM, solar PV, wildfire detector, XBee, Zigbee.

Received: March 26, 2021. Revised: August 7, 2021. Accepted: August 21, 2021. Published: August 31, 2021.

1. Introduction

The destruction of property and livelihoods caused by forest fires is becoming an alarming problem in the United States. According to the National Interagency Fire Center (NIFC), there were 58,083 wildfires in 2018 and 71,499 wildfires in 2017. About 8.8 million acres were burned in 2018 and 10 million acres were destroyed by fire in 2017 [1]. Whether the fault lies in climate change, outdated infrastructure, or poor management, solutions to the wildfire situations are urgently needed. Unfortunately, so far few solutions are proposed. Until recently, the market has fire detection systems that are overly saturated with unnecessary features, such as optical camera sensors and image processing, resulting in high power devices that are impractical for use in remote areas such as forests where wildfires typically occur without detection [2, 3]. It follows that wildfire detectors of low power consumption are desirable.

Another method to deal with wildfires effectively is to detect them early. Outdated and aging infrastructure such as overhead power transmission lines often cause forest fires. Since these power lines often run through isolated areas, these fires are mostly not detected until they become big enough for people to see from miles away. Dealing with these large-scale wildfires is very difficult and costly.

We propose a way to detect wildfires early. That is to improve upon deployed fire sensor networks that already exist. Implemented forest fire monitoring systems include EYEFi (Australia), FireWatch (Germany), ForestWatch (South Africa), and FIRESENSE (European Union). A review in [2] describes how these fire detection systems perform. The major downfall of these systems is that they rely on optical sensors and image processing as the main method of detection. They consume a moderate amount of power. The wildfire detector that we propose in this project is stripped of any optical detection to conserve power while aiming to reduce its cost and maintenance.

To supply power to the wildfire detector, a solar PV module is used. Solar PV is an efficient way to supply power in various applications [4-7]. A battery pack is utilized to store power for use at night or when sunlight is low during cloudy days.

Low power, wireless sensor networks have been deemed as reliable and cost-efficient [8]. Flame detection algorithms are straightforward to implement for infrared sensors as their output voltages vary based on sensed amount of light/heat radiation [9]. After connecting the sensors to a microcontroller, limits defining flame detection can be set [10]. Since our wildfire detector is to be deployed in remote areas such as forests, a digital communication subsystem is integrated for ease of access. The Internet of Things (IoT) [11] provides an interface to monitor each device state, sensor data, and apply software updates.

To monitor large areas, we propose to integrate multiple wildfire detectors into a fire alert system (network). IoT can be used to enable a client to control the system effortlessly through an agreeable graphic user interface over the Internet [12]. Zigbee network, a low power Personal Area Network (PAN), is used to link all the detectors together. A temperature monitoring system using ZigBee and LabView can be used as a graphical interface [13]. However, a Zigbee network itself has no way of connecting to the Internet. Therefore, our wildfire detection system includes a mixture of both Zigbee nodes (for local data transmission), and a central GSM (Global System for Mobile Communications) node for communication to farther locations and the IoT.

Our proposed communication model for the fire alert system includes a GSM central node and associated sensor nodes. All sensor nodes will be running on the XBee/Zigbee network since XBee devices operate at lower power than Arduino boards required by the GSM node. Both XBee and GSM devices are meshed based on [14]. Using Application Programming Interface Mode, XBee devices can transmit serial data to a central point. Our central node will have access to the IoT using a GSM communications module. The GSM module (a SIM card) is equipped onto Arduino MKR GSM 1400 board. When a fire is detected, the sensor nodes will relay location data to the central GSM node, which, in turn, will alert authorities (e.g. local fire departments) of the fire within seconds via text messages.

Overall, the objectives of the project are:

1) To design a low-power non-optical sensor-based detector for discovering fire in remote locations (e.g. wildfires, forest fires).
2) To design communication functions for the fire detectors using Xbee/Zigbee and GSM technologies.
3) To integrate multiple wildfire detectors into a fire alert system that can communicate detected fire information to relevant authorities using Xbee/Zigbee and GSM networks.

The fire alert system can detect wildfires early to enable timely responses that save human lives and minimize property damages. The fire detection and alert process is performed automatically. The system is solar-powered, self-sustaining with minimal maintenance to provide fire monitoring and detection service around the clock.

2. Wildfire detector design

2.1 Theoretical design

When it comes to electrical wiring and electronic equipment, professional engineers refer to the National Electronic Code (NEC). In our case, we adhere to the requirements set forth by Article 760 - Fire Alarm Systems, and Article 800 - Communication Systems. Based on the NEC requirements, our wildfire detector must be weather-proof and low-power (<600V), and must not be a fire hazard to the surrounding environment. As shown later, all of our components consume a low amount of power so our detector easily meets the NEC low-power requirement. Hence, we focus more on meeting the safety standards, such as using Type FPLP power-limited fire-alarm cable, which is listed by the NEC as being fire-resistant and suitable for use in environmental air [15]. Rigorous testing of a prototype will be done to ensure that our fire detection system meets safety requirements.

Fire detection techniques

Each detector aims to detect fire within a radius of about 10 feet (3.048 meters). Our detector uses infrared sensors for flame detection. In addition, the device uses carbon monoxide (CO) sensors to detect smoke as a secondary method for fire detection. The detection angle of the infrared sensors is limited to 180^0 so the smoke detection is a simple method to increase the detection efficiency. After detection of fire, the device sets off an alarm and/or a light beacon, depending on whether it is nighttime or daytime.

Power supply

The self-sustaining fire detector is equipped with a 10-W solar panel connected to a charge controller and a battery pack. A speaker and a light beacon are connected to the charge controller and an Arduino board with relays. Excluding the solar panel, all the components are housed within a weather-proof case.

Communication techniques

A fire detector is equipped with Xbee/Zigbee capability if it is intended to be used as a sensor node in a fire alert network. It is equipped with GSM capability to function as a central node. The central GSM node receives the fire location coordinates from the sensor nodes running on the Zigbee network. Then, it transmits the coordinates via text messages (SMS) to a local fire department using GSM. When using appropriate routing techniques, over 1000 sensor nodes can be paired to one central GSM node. The 1000 sensor nodes (i.e. 1000 fire detectors) can monitor a vast area. Zigbee, which is based on IEEE standard 802.15.4 for high-level communication of personal area networks, and GSM meet market communication standards. The schematic diagram of Xbee node and GSM node is shown in Fig. 1. The detector component list and power consumption are provided in Table 1.

2.2 Infrared and CO sensors

The flame sensors used are lower cost versions of the KY-026 flame sensor. There is limited data given for its fire detection range. Testing shows that the sensor can detect a lighter's flame from 80-cm distance (2.62 ft). The larger the flame, the farther the detection range. Since forest fires spread and get large very quickly, the sensor is bound to pick up the fire in a short time.

To detect the fire as early as possible, three sensors are connected to a detector. This connection gives the detector a detection angle of 180^0, given that each sensor has a detection angle of 60^0. When being tested for detection range with a small bonfire, the range was about 5 feet. Although fire detection range increases with the size of the fire, we have not tried to test the maximum range of the sensors due to lack of proper safety facilities.

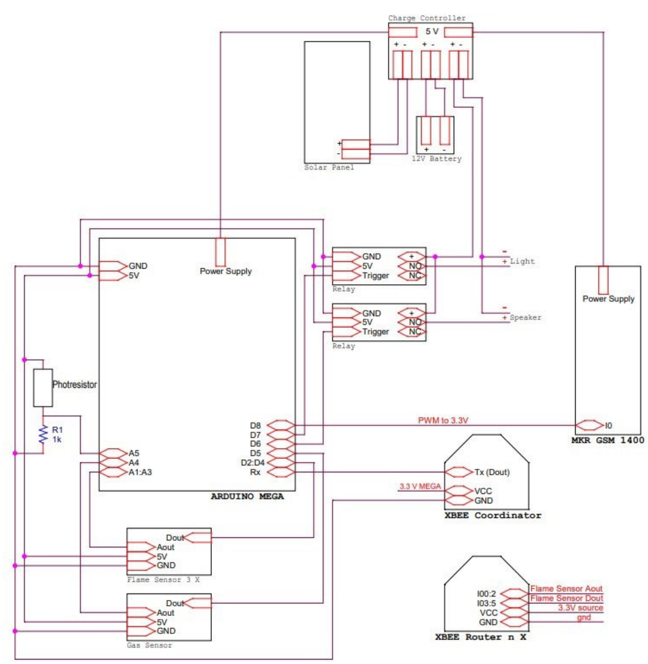

Fig. 1 Fire detector system schematic diagram (GSM node on left, XBee node on bottom right)

Table 1 Component list and power requirement

XBee node power consumption			
Part	**Current [A]**	**Voltage [V]**	**Power per unit [W]**
Flame Sensor (3 per device)	0.004	3.3	0.0132 x 3
MQ7 CO Sensor	0.160	5.0	0.800
Photoresistor	0	0	0
XBEE 3	0.135	3.3	0.446
Speaker (120dB)	0.350	12.0	4.200
LED Fog Light	0.708	12.0	8.5
Total:			13.9856 [W]
Rated:			**14 [W]**
Added components for GSM node – Power consumption			
Arduino Mega	0.3	9.0	2.700
MKR GSM 1400	2.0	5	10
Total:			26.6856 [W]
Rated:			**27 [W]**

An MQ-7 Carbon Monoxide Sensor for smoke detection, which detects concentrations between 10-10000 ppm, is used for fire detection by smoke. The range of the smoke detector is variable on wind direction. Although it is sufficiently sensitive to detect small amounts of smoke in a closed room, it is less sensitive in outdoor environments. However, large amounts of CO from forest fires should be enough to set off detection, although testing this event is impossible given the limitation of our lab facilities.

2.3 Control schemes

The logic flow diagram in Fig. 2 depicts the continuous detection loop for the detector to discover fire and smoke. Photoresistors connected to the devices determine whether it is sunny, overcast, or nighttime.

During the daytime, when a fire is detected, only the speaker will be sounding an alarm, as a light beacon would not be visible during the daytime. During nighttime, both the light and the speaker would turn on to alert people in the surrounding area. During cloudy weather, the devices will run in low power mode to extend battery life.

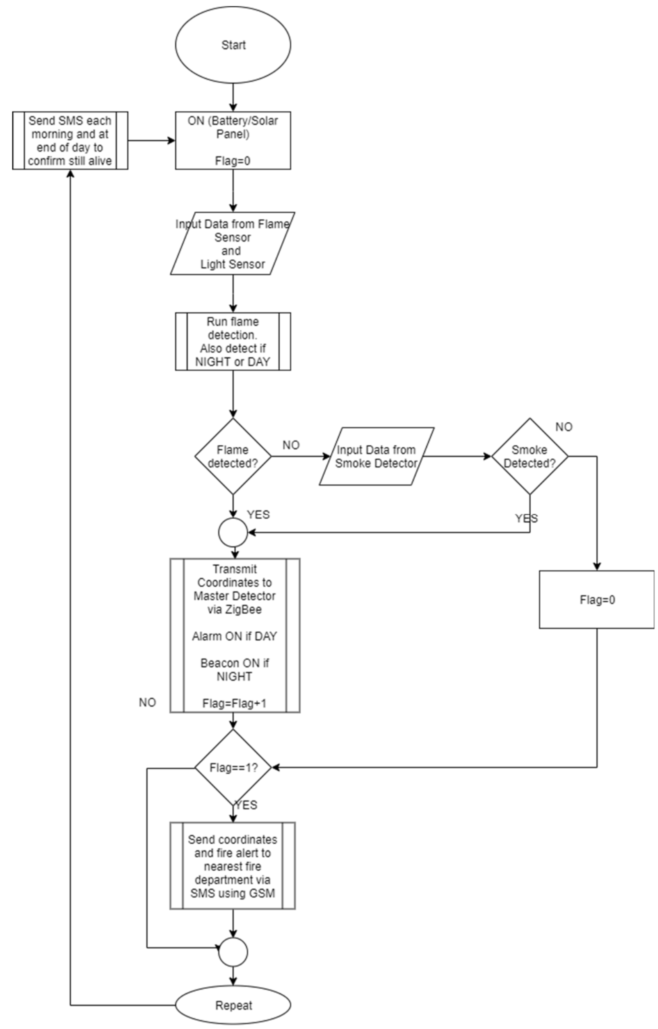

Fig. 2 Logic flow chart for day and night operation

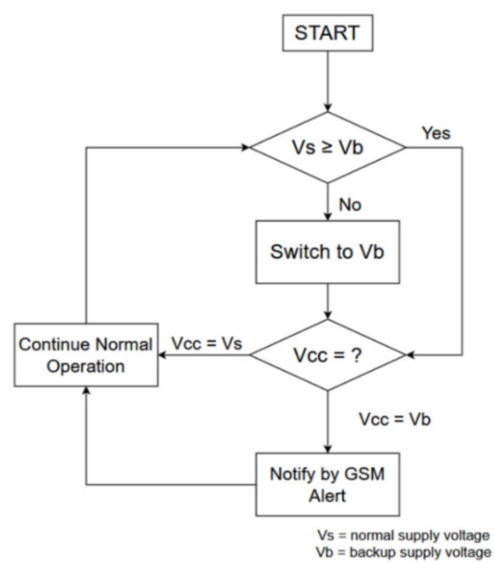

Fig. 3 Power loss detection flow chart

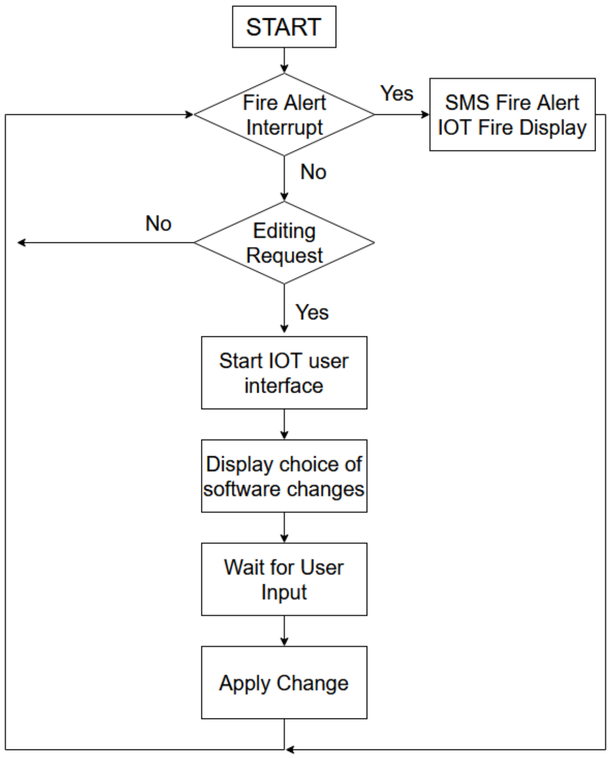

Fig. 4 GSM MKR 1400 flow chart

If a detector in the fire alert system detects fire or smoke, the location coordinates are sent to the GSM central node. The GSM node then sends an SMS alert containing the coordinate information to a designated local fire department. It can also display the information in an IoT interface (e.g. on a website).

To prevent false alarms, we simply run the detection loop on a 10-bit counter. For example, a detection loop with a minimum of 5/10 positives can define a confirmed fire. Anything below the threshold is considered a false fire event.

Every morning, a *"Good Morning"* message with coordinate information will be sent to confirm the detection device is functional. A *"Good Night"* message with coordinate information will be sent at the end of the day. Times of 8am and 4pm will be used to simulate a typical workday at the National Forestry offices. This is important since the purpose of these devices is safety. If these devices are used in a workplace, they must follow the Occupational Safety and Health Administration's guidelines, which state in standard 1910.164 for fire detection systems that they must be maintained in operable condition [15] [16]. If a detector fails to send a *"Good Morning"* or *"Good Night"* message, the fire detection device is not operating correctly and needs immediate maintenance.

The flowchart in Fig. 3 shows the operation procedure in case of power loss. This logic would take place within the Arduino board, comparing the nominal supply voltage from the charge controller with a secondary backup voltage using a step-down circuit directly from the battery pack, or using a smaller emergency battery. Power confirmation messages and fire alert messages will be distinct and different, so there will not be any confusion between them. However, to limit the number of components and complexity, only the logic of Fig. 1 is implemented in our prototypes.

Figure 4 shows the MKR 1400s operation of checking if there is a fire or a request from the user via an IoT website. When the Arduino Mega has detected a fire, it will send a high signal to an interrupt on the MKR. The MKR will immediately pause its current process and send the Alert. A more accurate scheme would have every block point back to the top fire alert interrupt condition because any instruction will get interrupted if that decision block goes high.

The MKR accesses the Arduino IoT cloud website to check if there is a user editing request. If yes, it will begin its user interface. The interface works by displaying a string IoT monitor every modification. Therefore, the MKR changes the string *IoT_monitor* to display on the IoT website. The MKR will then wait for the user to enter their response by allowing them to change a different string named *user_input*. Once the MKR sees that the user has changed the value of *user_input*, it will make its own software changes based on what the request commanded. This function allows users to make certain modifications (e.g. designated fire department SMS number) to the device control program remotely.

2.4 Battery selection and sizing

When being in detection mode, the XBee node operates at 1.29W, which is the total of the Xbee module and flame sensor power demands. Hence, 8 nickel metal hydride (Ni-MH) Energizer batteries rated at 1.5V and 2300mAh/Cell are used in series connection to power the system at 12-V nominal voltage and 2.3-Ah capacity, or 27.6Wh (12V x 2.3Ah

= 27.6 Wh). This is enough power to run the Xbee node for about 19.3 hours in detection mode, using 90% of the Ni-MH battery pack energy (27.6Wh x 0.9 = 24.84Wh / 1.29W = 19.3h). Note that the Ni-MH battery may be discharged up to 90% of its energy while preserving its lifespan.

When a fire is detected, the new power consumption of the active loads becomes 14W, as shown in Table 1. With a fully charged battery pack, the fully loaded XBee node would be sustained in the alarm mode for about 1.8 hours. However, the fully loaded device is only a nighttime event. During daytime, the LED fog light is not used, hence reducing the detector power consumption to 5.5W. It follows that the XBee node can operate for about 4.5 hours in the alarm mode. For the XBee nodes, the alarm mode will be programmed to run for a duration of 5 minutes, but the duration refreshes if fire/smoke keeps being detected.

Our GSM node, which acts as the central receiver for the fire alert system, has a higher power consumption due to the added Arduino boards and the power needed for GSM transmission. In detection mode, the central device consumes 4W, thereby can last on the battery supply for about 6.2 hours. Nighttime alarm mode consumes 27W, so the device can operate on this mode for around 55 minutes. Daytime alarm mode consumes 18.5W, so the device can operate on this mode for about 1.3 hours.

Different kinds of batteries with 12V and 2300mAh ratings are available, but the most suitable batteries for our purposes are Ni-MH batteries. Since the design of the wildfire detector requires weather-proof enclosures, using a lead acid battery would pose a fire hazard. Continuous use of a lead acid battery leads to gassing, which, if not properly ventilated, can ignite because the gases leaked out by the battery are oxygen and hydrogen. Compared to lead acid batteries, the Ni-MH batteries have longer lifespans and are more durable than other batteries in hot climates, thus more suitable for regions with high forest fire risks.

2.5 Solar panel selection and sizing

The wildfire detector is powered by a monocrystalline solar panel. It is chosen because it has less internal losses than polycrystalline panels. Monocrystalline panels are also rated for operation at higher temperatures and have a longer lifespan. However, for implementing the detector prototype, a polycrystalline solar panel is used as it is cheaper. The solar panel size is 10W, which provides sufficient power to the fire detector under various weather conditions while allowing the battery to charge.

The solar panel size for the wildfire detector is determined as follows. The battery size is calculated to be 27.6Wh (Section 2.4). The solar panel has a maximum power voltage V_{max} = 17V, maximum power current I_{mp} = 0.58A, and a power output of 9.86W. Hence, the battery would be fully charged if the solar panel produces the maximum power under sufficient irradiance for 3.1 hours (27.6Wh / (9.86W x 0.9) = 3.1 hours). The charging loss is assumed to be 10% (i.e. the charging efficiency is 90%).

In California [17], the average sun hours is around 5.5 hours. It follows that the maximum daily output of the solar panel is 54.23Wh. The battery is not designed to store 100% of the daily energy output of the solar panel. It only stores 50.9% of the average energy by the solar panel per day (27.6Wh / 54.23Wh = 50.9%). The discharged energy to loads is replenished by the solar panel. To prevent overcharging of the battery, we utilize a charge controller to regulate the charging process. Using the charging loss of 10%, the average daily energy stored by the battery would be 54.23Wh x 0.9 efficiency = 48.81Wh.

During non-ideal days where the sun hours is less than 5.5 hours, the 10-W solar panel can still charge the battery pack fully. The solar panel size is, therefore, sufficient for both ideal and non-ideal irradiance situations.

3. Implementation of wildfire detector system and testing

3.1 Detector prototypes and testing

Two detector prototypes, an XBee node and a GSM node, are built to test the fire detection range and communication capabilities. Their images are shown in Fig. 6 and Fig. 7. The solar-battery system diagram is shown in Fig. 5. Note that the size of our detectors will be much smaller than their layouts in the pictures since most components (except the solar panel) will be placed inside the enclosure shown in Fig. 8. The enclosure dimensions are 6.73in x 4.76in x 2.17in. The list of used components and cost of the prototypes is shown in Table 2.

The maximum range of fire detection, when tested with a small outdoor bonfire, is about 5 feet. The maximum communication range for Xbee detectors is 2.0 miles based on manufacturer specifications for the communication module. The communication functions of the Xbee and GSM prototypes are satisfactory. Testing also shows that the GSM prototype can survive a night with a fully charged 12-V, 2300-mAh battery (a lead acid battery was used for testing).

Table 2 Cost of GSM and Xbee detector prototypes

Part	GSM Node	XBee Node
	Cost Before Tax	**Cost Before Tax**
Arduino Mega	$40.00	N/A
3 Pack Flame Sensor IR	$6.99	$6.99
MQ7 CO Sensor	$6.99	$6.99
XBEE 3 – PCB Antenna	$29.95	$29.95
Speaker (120dB)	$8.80	$8.80
MKR GSM 1400 Module	$69.99	N/A
LED Fog Light	$9.00	$9.00
5V Relay Module	$5.50	$5.50
Battery (2300mA / 12V)	$23.88	$23.88
Charge Controller (30A)	$9.80	$9.80
UL Listed NEMA 3 Enclosure	$22.51	$22.51
Solar Panel	$20.73	$20.73
Total	**$254.14**	**$144.15**

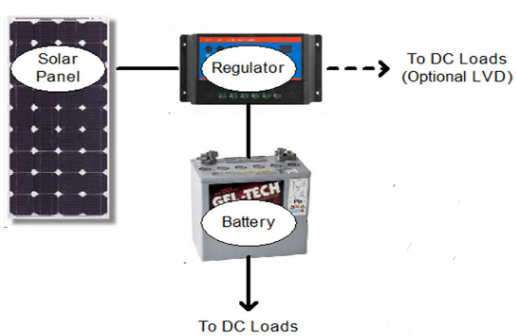

Fig. 5 Solar-battery system diagram

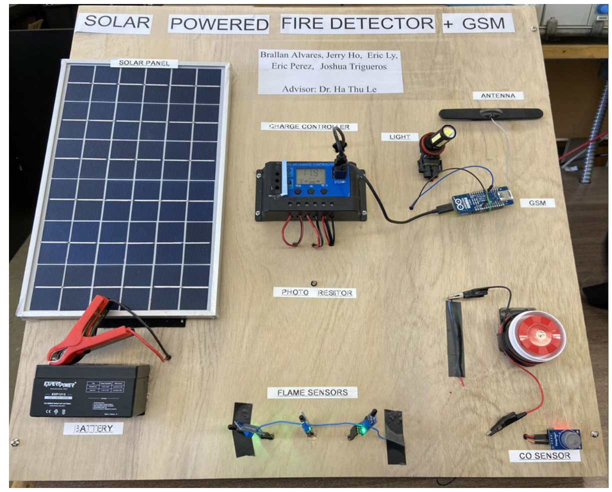

Fig. 6 GSM detector/node prototype
(Powered by a 12-V 2300-mAh lead acid battery)

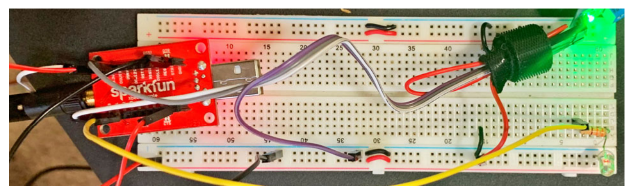

Fig. 7 XBee detector/node prototype
(Powered by a 5-V 1500-mA source)

Fig. 8 NEMA 3 UL listed enclosure
(6.73in x 4.76in x 2.17in)

3.2 Integration of multiple detectors into a fire alert system and communication model

To monitor and detect fire in large areas, we propose to integrate multiple wildfire detectors into a fire alert system (network) as shown in Fig. 9. It is called Many-to-One fire detector/alert system. The XBee nodes are

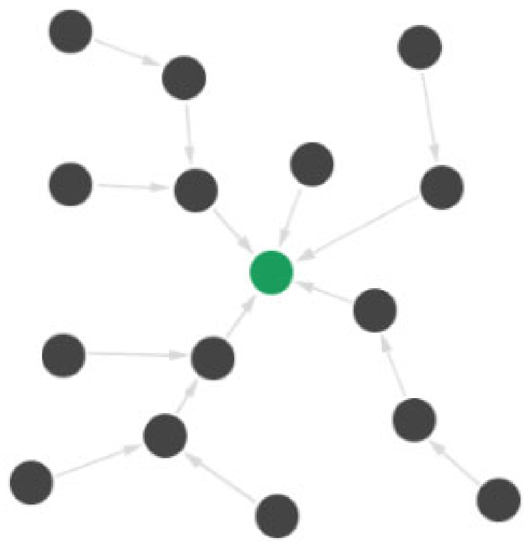

Fig. 9 Many-to-One routing: GSM node is green dot, XBee nodes are black dots.

the main devices used for fire detection i.e. they function as sensing devices and routers that lead to the GSM node. The GSM node is the central point of the fire alert system which receives fire-detected signals from the Xbee nodes and transmits the signals to a designated fire department via text messages. It must be placed within a GSM tower range to have a connection to the Internet and other GSM services.

Figure 9 shows how a many-to-one routing method works to relay the fire-detected signals from the Xbee nodes to the GSM node when being deployed in a large area. This method of cluster deployment is well suited for monitoring large high-risk areas of the forest.

One advantage of the Many-to-One fire alert model is that the area that may be monitored is flexible because the model is scalable by varying the number of nodes. Recall that the maximum communication range of XBee nodes is 2 miles and over 1000 Xbee nodes may be paired to one GSM node. Another advantage of the Many-to-One model is that the cost of the entire system may be reduced as most nodes are lower-cost XBee nodes (Please see Table 2 for the prototype cost)

Although the GSM node has fire detection capabilities, its main function is to act as a receiver for the lower power XBee nodes. Therefore, placement of the GSM node must prioritize cellular reception. Placement of the XBee node must prioritize fire/smoke detection. When placing either kind of node, exposure to sunlight is another crucial requirement since sunlight is necessary for the nodes' batteries to maintain a charge.

We have tested the Many-to-One model using three XBee nodes and one GSM central node. The results show that the system worked properly. The GSM node successfully received the fire-detected signal from the XBee nodes then transmitted it to a cellphone number via a text message. Due to time limitation, testing of communication using IoT was not performed and left as a future work.

4. Conclusion

This project designs wildfire detectors and a fire alert system using Many-to-One routing method with XBee/Zigbee and GSM technologies. Testing of the prototypes has shown that the system has the following beneficial features:

1) *Low power:* The maximum power consumption of a XBee detector is 14W while an GSM detector consumes at most 27W. In detection mode, the XBee detector consumes only 1.29W.

2) *Self-sustaining and long-lasting:* The fire detectors are powered by solar panels and Ni-MH battery packs. A fully charged battery pack can support a detector up to around 19.3 hours in detection mode, and up to about 4.5 hours in alarm mode.

3) *Compact and portable:* Most components of a fire detector are housed in a small enclosure.

4) *Flexible and scalable:* The Many-to-One fire alert system can be used to monitor large areas by using a sufficient number of detectors. The size of the monitored area can be flexibly adjusted by varying the number of nodes.

5) *Effective communication:* The wildfire detector system uses XBee/Zigbee and GSM networks to relay and transmit fire-detected signals successfully.

In terms of future work, we aim to improve the system capability to allow programing of the detectors through IoT. It is also desirable to test the Many-to-One system with more nodes, as well as testing weather-proofing ability of the detector enclosure and finding the maximum detection range of the infrared sensors. In terms of broader impact, the developed wildfire detector system has a high potential to be used for wide-area outdoor fire monitoring and detection. Early fire detection will enable timely responses that save human lives, as well as reduce property damages and other economic losses.

Acknowledgment

The student authors gratefully acknowledge the contributions of Dr. Ha Thu Le for guiding the team throughout this project, as well as for verifying our design and prototype implementation.

References

[1] "Facts + Statistics: Wildfires," *Insurance Information Institute,* 2019. [Online]. Available: https://www.iii.org/fact-statistic/facts-statistics-wildfires.

[2] A. A. A. Alkhatib, "A Review on Forest Fire Detection Techniques," *International Journal of Distributed Sensor Networks,* vol. 10, no. 3, p. 597368, 2014, doi: 10.1155/2014/597368.

[3] A. Molina-Pico, D. Cuesta-Frau, A. Araujo, J. Alejandre, and A. Rozas, "Forest Monitoring and Wildland Early Fire Detection by a Hierarchical Wireless Sensor Network," *Journal of Sensors,* vol. 2016, p. 8325845, 2016/02/14 2016, doi: 10.1155/2016/8325845.

[4] Anh-Huy Le, A. Giourdjian, A. Frankyan, V. Mandany, and H. T. Le, "Design, Sizing and Operation of a Hybrid Renewable Energy System for Farming," in *IEEE PES Innovative Smart Grid Technologies Conference*, 2016: IEEE, pp. 1-5.

[5] H. Cao, J. Gonzales, N. Dimetry, J. Cate, R. Huynh, and H. T. Le, "A solar-based Versatile Charging Station for Consumer AC-DC Portable Devices," *International Journal of Power Systems,* vol. 4, pp. 115-131, 2019.

[6] B. Postovoit, D. Susoeff, D. Daghbas, J. Holt, and H. T. Le, "A Solar-Based Stand-Alone Family House for Energy Independence and Efficiency," in *IEEE Conference on Technologies for Sustainability (SusTech)*, 2020: IEEE, pp. 1-6.

[7] D. Cardwell. "AT&T to Introduce Solar-Powered Charging Stations." The New York Times. https://www.nytimes.com/2013/06/18/technology/att-to-introduce-solar-powered-charging-stations.html (accessed 12 July 2018.

[8] A. Alkhatib, "Wireless Sensor Networks for Forest Fire Detection System -Seminar," 2012.

[9] L. Yuanyuan, "Design and implementation of recognition algorithm based on four-band infrared flame detector," in *2018 Chinese Control And Decision Conference (CCDC)*, 9-11 June 2018 2018, pp. 5639-5643, doi: 10.1109/CCDC.2018.8408115.

[10] Noorinder, J. Singh, and E. Sidhu, "Raspberry pi based smart fire management system employing sensor based automatic water sprinkler," in *2017 International Conference on Power and Embedded Drive Control (ICPEDC)*, 16-18 March 2017 2017, pp. 102-106, doi: 10.1109/ICPEDC.2017.8081068.

[11] F. S. Perilla, G. R. Villanueva, N. M. Cacanindin, and T. D. Palaoag, "Fire Safety and Alert System Using Arduino Sensors with IoT Integration," presented at the Proceedings of the 2018 7th International Conference on Software and Computer Applications, Kuantan, Malaysia, 2018. [Online]. Available: https://doi.org/10.1145/3185089.3185121.

[12] Aditya, M. Sharma, and S. C. Gupta, "An Internet of Things Based Smart Surveillance and Monitoring System using Arduino," in *2018 International Conference on Advances in Computing and Communication Engineering (ICACCE)*, 22-23 June 2018 2018, pp. 428-433, doi: 10.1109/ICACCE.2018.8441725.

[13] A. Rerkratn and A. Kaewpoonsuk, "ZigBee based wireless temperature monitoring system for shrimp farm," in *2015 15th International Conference on Control, Automation and Systems (ICCAS)*, 13-16 Oct. 2015 2015, pp. 428-431, doi: 10.1109/ICCAS.2015.7364953.

[14] M. M. S and E. S. Ustun, "Safety Based Smart Parking Guidance System Using GSM and Zigbee," in *2019 3rd International Symposium on Multidisciplinary Studies and Innovative Technologies (ISMSIT)*, 11-13 Oct. 2019 2019, pp. 1-5, doi: 10.1109/ISMSIT.2019.8932730.

[15] *Fire detection systems - Occupational Safety and Health Standards*, U. D. o. Labor. [Online]. Available: https://www.osha.gov/laws-regs/regulations/standardnumber/1910/1910.164

[16] C. B. Pepino, G. Dias, and D. F. Pigatto, "Pocket Guard– IoT-ready, Low-cost Personal Belongings Monitoring," in *2018 IEEE Symposium on Computers and Communications (ISCC)*, Natal, Brazil 2018: IEEE, doi: 10.1109/ISCC.2018.8538746.

[17] "Sun Hours/Day Zone Solar Insolation Map." Wholesale Solar. https://www.wholesalesolar.com/solar-information/sun-hours-us-map (accessed.