ESTEEM Academic Journal
Vol. 17, August 2021, 32-44

Internet of Things: The Use of Raspberry Pi, Sensor Devices and Geo-Fencing Technology in Fire Detection Monitoring System for A Home

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ARTICLE HISTORY

Received
31 May 2021

Accepted
5 July 2021

Available online
4 August 2021

ABSTRACT

Accidents caused by fire can result in serious injury and damage to personal property. Fire hazards are not always obvious in and around the home, so accidents involving fire are often unexpected and sudden. The main purpose of fire detection monitoring systems using Raspberry Pi is to provide an early warning for homeowners, to take immediate action to stop or eliminate fire effects as soon as possible. The system called Ifire provides a real time monitoring system, where they can receive push notification once the sensors are triggered. This system is a combination of technology using Internet of Things devices like temperature and humidity sensors (DHT11), infrared (IR) flame sensor, and mobile application. This system is an application that uses geo-fencing technology for homeowners, to find the nearest fire department to give a fast emergency response. Besides, it could help fire department staff to receive homeowner addresses and navigate directly to the location. The project was tested with functionality testing and network performance testing to make it work properly and successfully. The network performance testing shows the distance between Raspberry Pi and the access point will decrease when the distance increases. In addition, the response time testing result also shows the time during peak hour will decrease the performance. For future enhancements this Internet-based monitoring system will need security protection to prevent false fire information.

Keywords: *fire detection system; sensors; Raspberry Pi; geo-fencing; network performance testing.*

1. INTRODUCTION

We are living in a time that safety has become one of the necessary needs in all areas of life. There are several types of safety such as vehicle safety, safety in the workplace and home safety. One of the safety issues that need to be concerned about is the fire occurrence at home. These accidents can occur from faulty wiring, discarded cigarettes left on flammable materials and defective products. In case of fire, a few seconds could save many lives. Everyone should be aware of fire risks and take appropriate steps to prevent fires. The utilization of wireless sensor network technology can improve the anticipation of the occurrence of fire hazards in home. It can be done by replacing the human task in monitoring the situation around the home by using multiple sensors, which can directly interact with the environment. This study focuses on early fire detection systems. Sensors are used to detect the level of fire danger including temperature

p-ISSN 1675-7939; e-ISSN 2289-4934

and flame sensors. There are several devices that might be used to develop this project such as Raspberry Pi, a few sensors and smartphones. Raspberry Pi will act as a microcontroller to process all input from sensors. The main feature of the system is the ability to send push notifications when a fire is detected by sensors. Besides, this system also could help homeowners to supervise the condition of their house even when they are not at home.

2. LITERATURE REVIEW

2.1 Resident Fire Issue

Nowadays, fire safety is one of the important things to be concerned about. There are several issues that can lead to fires at residential areas. According to [1], the combination of home-building materials, synthetic materials used in furniture cause fires in modern-day homes to burn much faster. An interview had been done in March 2019 at Balai Bomba Merlimau to determine the process of the emergency call service, and to seek the problem regarding resident fire. Based on their Senior Officer, Mr. Selomon, there are several systems that have been developed to monitor any fire cases in Malaysia such as Computerized Monitoring System (CMS) and Sistem Pengawasan Kebakaran Automatik (SPKA). CMS is a system that was used before and because of too many fake calls or hoaxes, the system was upgraded to SPKA. Besides, some issues are identified based on the interviews, where both systems were implemented to monitor fire accidents or cases that only focused on registered premises like shopping centers, hotels and places that are visited by many people, while about 60 percent of the fires in Malaysia started at home [2].

Furthermore, residential fires can lead to loss of life, loss of valuable property and the loss of personal irreplaceable belongings. According to [3], Malaysia also has lost RM 5.2 billion from property destruction in 2017. On 26 February 2019, one fire case was reported in Kampung Tayor Tengah, Terengganu. According to three reports, the owner of the house was not at home and they have lost about RM 200,000 due to the fire accident. Rapid detection of fire and its control can save millions of dollars of property loss every year. Based on [1], it has shown that with today's modern furnishings, fires can spread much more rapidly when more natural materials are used. The major characteristics of fire are that it can spread rapidly. Hence, timely detection of fire is important. Several factors have been highlighted and different approaches are taken to ensure the effectiveness in terms of addressing this problem. Therefore, this project could be the alternative way for homeowners to take care of their safety and belongings.

2.2 Types of Dwelling and Placement

It is generally believed that smoke or fire detection cannot prevent fire from starting but it can detect fire at an early stage before it spreads rapidly. Thus, fire and smoke alarms are important things to implement at every home to avoid any enormous fire tragedy. Besides, the placement of the detectors also needs to be focused on. The placement of the detectors in the house plays a big role to show the effectiveness of the detectors. Furthermore, the physical location must be located where it is easily traced so that the maintenance can be handled properly [4].

There are three types of dwellings for residential building, which are Class 1, Class 2 and Class 3 [5]. Class 1 classifications include two categories; Class 1A and Class 1B. Types of dwellings are important because the number of detectors installed depends on the classification of the dwelling as shown in Table 1.

p-ISSN 1675-7939; e-ISSN 2289-4934

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Table 1: Type of dwellings

Type	Description
Class 1	Class 1A refers to a single dwelling house like terrace houses, single detached houses, or villa units where it is separated by a fire resisting wall. Class 1B refers to a hostel or guest house where not more than 12 people would be the resident and the total area of floors is not exceeding above 300m^2.
Class 2	A building contains two or more units such as apartments and flats.
Class 3	Class 4 refers to as a part of a residential unit within non-residential area

In this project, the Fire Detection System using Raspberry Pi will lay on Class 1. Besides, based on [1], the detectors should be installed at least 10 feet from cooking appliances and bathrooms to prevent any false alerts from the system.

2.3 Fire Detector Technology

Sensor-based are one of the technologies used for monitoring purposes, as they change the physical parameters to measure quantity of electricity [6]. This section will describe details about the detectors typically used for fire detection based on heat, gas, smoke and flame.

2.3.1 Heat Detector

Heat detector is designed to detect any temperature changes. It can be grouped into two classes according to their operation such as heat rate rise and fixed temperature. There are several detectors that are commonly used in fire detection such as LM35. LM35 is a very efficient and highly calibrated heat sensor. This sensor is used to detect temperature rise, and it may have attributes such as less heating and low linear impedance [7].

2.3.2 Gas and Smoke Detector

Smoke and gas are produced much earlier than other fire signatures during the stages of fire growth and development. The rapid detection of smoke at very low levels can maximize the probability for successful fire suppression, escape and survivability. Mass concentration, volume fraction and smoke distribution size are identified as the main parameters for smoke detection [8]. Smoke detectors must be able to respond to smoke from both burning and burning combustion, as smoke from this fire differs from structure and composition [9]. Various types of smoke sensors are available in the market such as MQ2 and MQ5.

The MQ2 sensor is highly sensitive to flammable gases like liquefied petroleum gas (LPG), propane and hydrogen. The principle of the MQ2 sensor is that when gas interacts with the sensor, it is first ionized into its constituent and then absorbed by the sensing element. This process creates a difference based on the element which is conveyed to the processor unit through output in the form of current [10].

2.3.3 Flame Detector

The fire is a radiation source and can be detected with the radiation recognition generated in the combustion zone. Flame detector is a sensor able to detect and respond to the presence of a

p-ISSN 1675-7939; e-ISSN 2289-4934

flame or fire. Infrared detectors and ultraviolet detectors are two different types based on the measurement of the range of flame radiation [9]. Infrared detectors (IR) detect fires when fire-producing elements are received, while ultraviolet detectors detect fires when ultraviolet radiation emitted by combustion is detected. Fire detectors are normally used for the protection of large areas and are rapidly reacting because of the lack of fire smoke or heat.

2.4 Microcontroller

Based on the Fire detector technologies specified in the previous part, it requires a microcontroller to process input. The microcontroller is simply a computer on a chip. It is one of the important developments in electronics since the invention of the microprocessor itself. It is essential for the operation of devices. Microcontrollers are usually designed for embedded applications and used in automatically controlled electronic devices such as mobile phones, washing machines and microwaves. Microcontrollers also are less expensive and use less power than microprocessors. There are several types of microcontroller boards used to develop fire detection systems for example Raspberry Pi, Arduino Uno and ESP8266.

Raspberry Pi-3 has higher performance in comparison with other boards like Arduino and ESP8266 in terms of its storage and computing speeds but at the cost of a higher price. Raspberry Pi equipped with in-built wifi and Bluetooth, serves as an easy means to connect to the internet and push the data to the cloud servers if required for further processing.

Whereas it is clearly visible from the comparison that boards like Arduino being equipped with inbuilt analog to digital conversion has a better means of sensing the analog data readily when there is a need to sense some continuous analog signals coming out of analog sensors.

ESP-8266 on the other hand stands out strongly when it comes to device level sensor networking abilities due to its small form factor and wireless connectivity. ESP-8266 being a low cost device is a first choice for implementing sensor networks in an Internet of Things (IoT) scenario.

2.5 Geo-fencing

Geo-fencing uses GPS coordinates to set a geographic area and retrieve the location of a mobile user using GPS to assess their nearest location. On the other hand, the important role in geo-fencing is Geo notification that is used to inform the mobile user whether they are inside or outside the specific area. As shown in Figure 1, geo-fencing is generally defined as boundaries to generate the location event when the users entering and exiting geo-fence [11].

In addition, the latitude and longitude are used to mark the location of interest while the radius is used to adjust the proximity of the location in the geo-fence area. In this modern area of technology, geo-fencing techniques has been used widely in various fields. Geo-fencing techniques have been implemented in many applications for several purposes such as for safety, security, agriculture, marketing and shopping tracker and disaster management [12].

p-ISSN 1675-7939; e-ISSN 2289-4934

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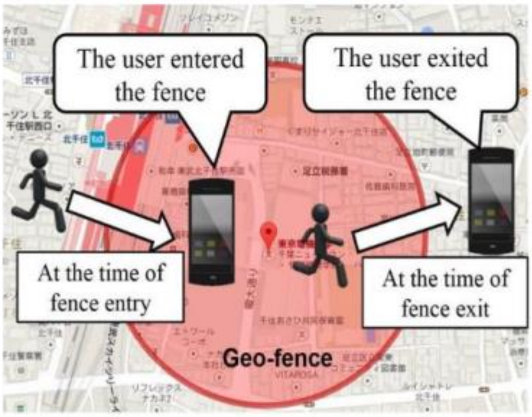

Figure 1: Geo-fencing Area

3. PROJECT METHOD

3.1 Information Gathering

Information gathering is the first phase to obtain all information regarding this project. This phase is important because it gives a better understanding regarding projects that will be worked on. It consists of many techniques that can be employed when gathering information such as interviews, questionnaires, observation and more. Interview is one of the techniques used in information gathering. It refers to a direct conversation that is created with a question-and-answer format. Purpose of the interview session is to collect data from expert people to gain knowledge and to understand the process of the system in their field. On 10 March 2019, an interview was conducted with Mr. Selomon. He is a Senior Officer II, who has served more than 10 years in this field and was willing to share some knowledge about fire accidents. From the interview, several problems have been found based on Mr. Selomon's explanation and opinion.

3.2 Requirement Analysis

Requirement Analysis is the second phase that is required to identify the hardware and software specification. Hardware and software requirements have been figured out, in order to choose suitable requirements for developing this project. Hardware that refers to as a physical device is one of the crucial things to develop this project successfully. Table 2 shows the list of hardware that will be used for this project.

Table 2: List of Hardware Requirement

List of Hardware	Function
Raspberry Pi	Act as a microprocessor to process data from sensors.
DHT11	To sense the environment temperature.
Infrared Flame Sensor	To detect and respond to the presence of a flame or fire

Table 3 shows the list of software requirements that will be used for this project. Both hardware and software components must be compatible for the application in order to produce higher performance in a mobile application development process.

p-ISSN 1675-7939; e-ISSN 2289-4934

Table 3: List of Software

List of Software	Function
Android Studio	To develop the application for mobile
Firebase console	To store data from raspberry pi
Idle	To programme Phyton code into Raspberry Pi
Magic Iperf	To test network performance of data transfer rate

3.3 Design

The purpose of the design phase is to give a better view about the flow of the system. It can be described as using use case diagrams, flowchart and system architecture. Use case diagrams represent interaction between the user and the system. By using the use case diagram, the relationship between the user and Raspberry Pi involved will be shown. Figure 2 shows the use case diagram.

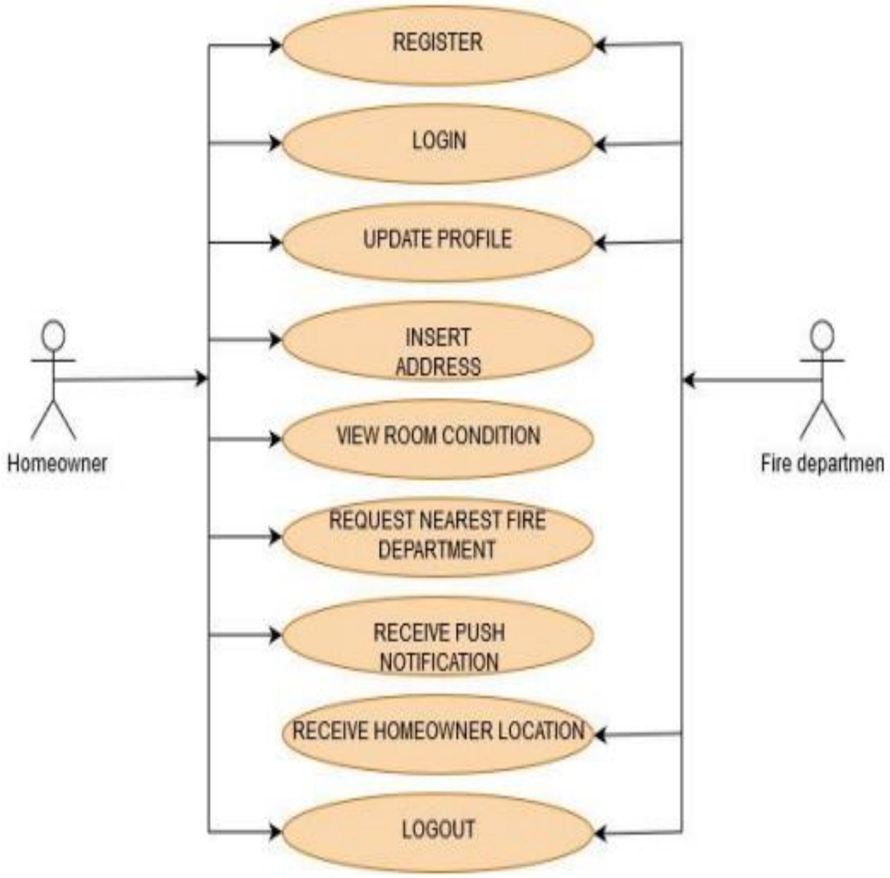

Figure 2: Use Case Diagram

System architecture is a conceptual model which defines the structure, behavior and more views of a system. It is also used for designing a logical model which describes the structure of a system. Figure 3 shows the system architecture of the Fire Detection Monitoring System using Raspberry Pi. Multiple microprocessors will be used to process data from different rooms. These multiple sensors will be used to detect flames and sense the current temperature of the room. All collected data will be stored into firebase online database.

p-ISSN 1675-7939; e-ISSN 2289-4934

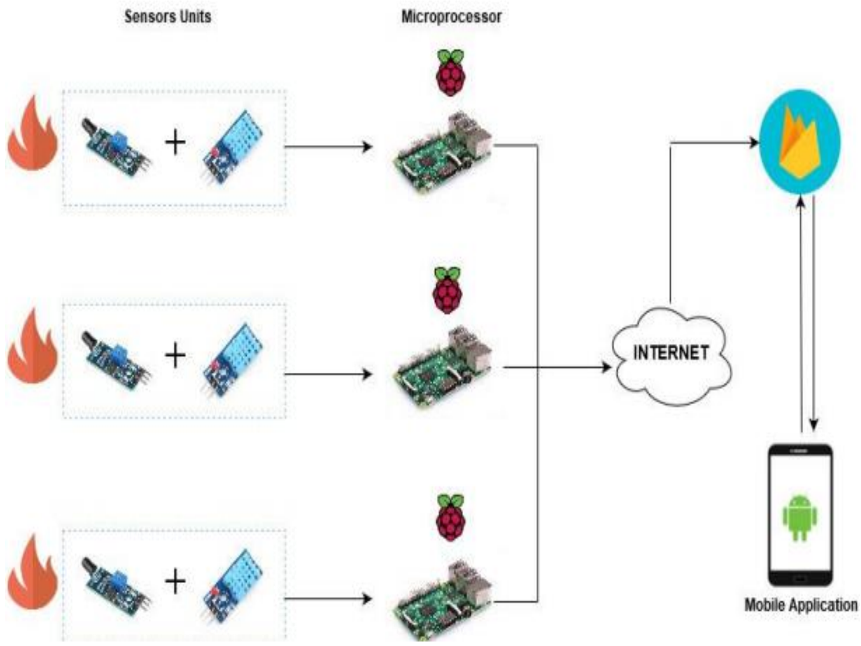

Figure 3: System Architecture

Flowchart is used to represent how the process in the project works. Figure 4 shows a flowchart diagram that represents the logical view of the application for homeowners.

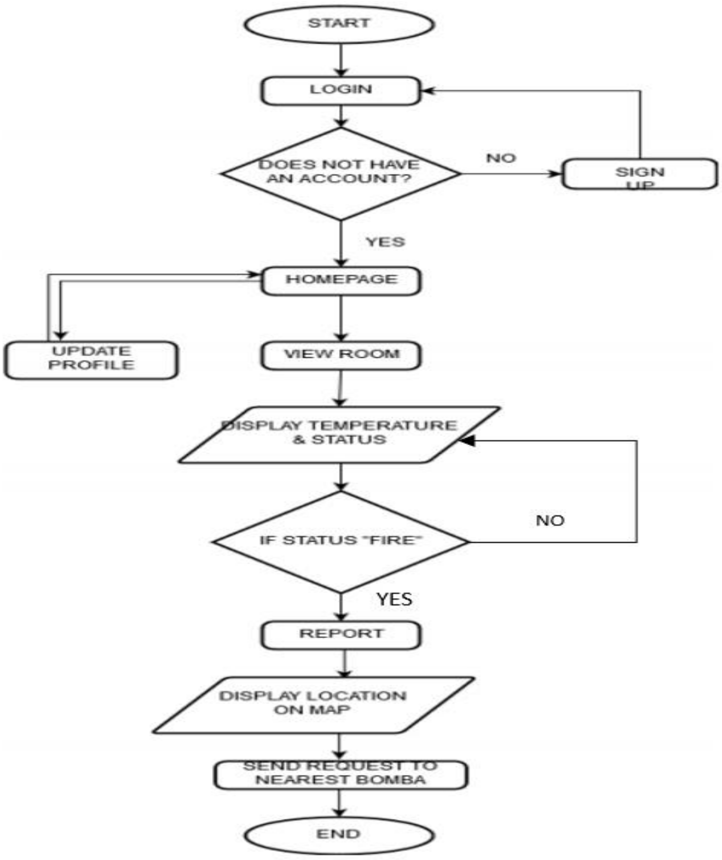

Figure 4: Flowchart of Application for Homeowner

p-ISSN 1675-7939; e-ISSN 2289-4934

Figure 5 shows a flowchart diagram for the fire department. Based on the flowchart, the fire department will receive notification from the homeowner. In that case, the fire department will be able to navigate to the location received from the homeowner.

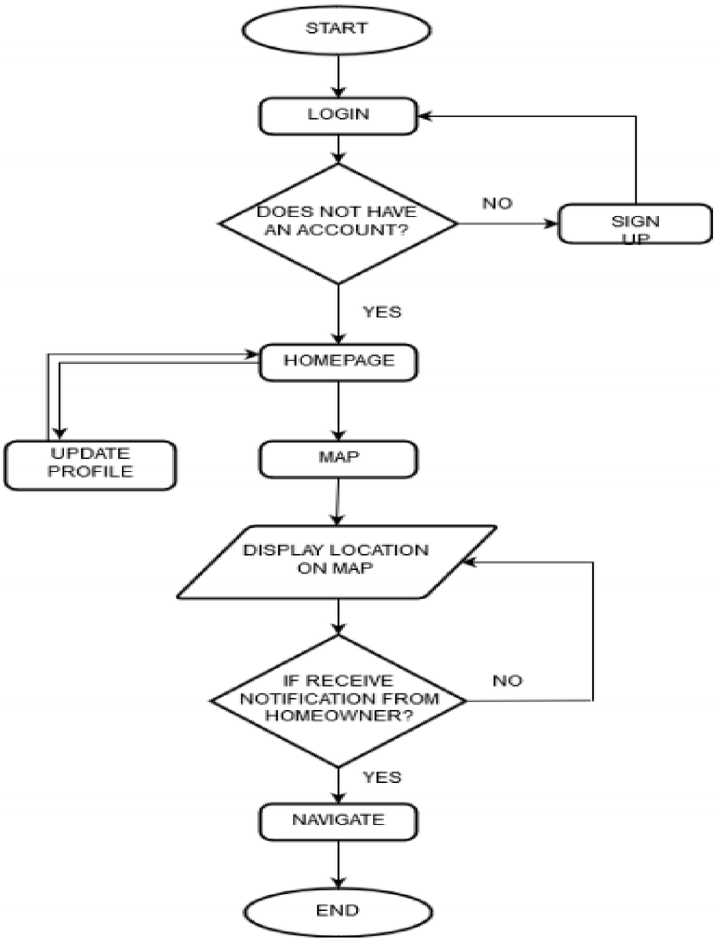

Figure 5: Flowchart of Application for Fire Department

3.4 Development

The development process of the fire detection monitoring system will include hardware installation, the connection with firebase online database and mobile programming. Raspberry Pi, IR flame sensor, DHT11 and a few jumpers should be installed correctly, to avoid compatibility problems with the microcontroller.

Firebase online database provides an online storage service where the data can be read and written. The system uses real-time database services from firebase, where it provides an API that allows application data to be synced across clients and stored in database cloud storage. In order to use an online database, the connection between android application and firebase must be set up first using dependencies.

The software used to design and develop the application is android studio. There are two parts required in developing mobile applications, which are interface design and programming. The application required two different users, homeowner and fire department as shown in Figure 6.

p-ISSN 1675-7939; e-ISSN 2289-4934

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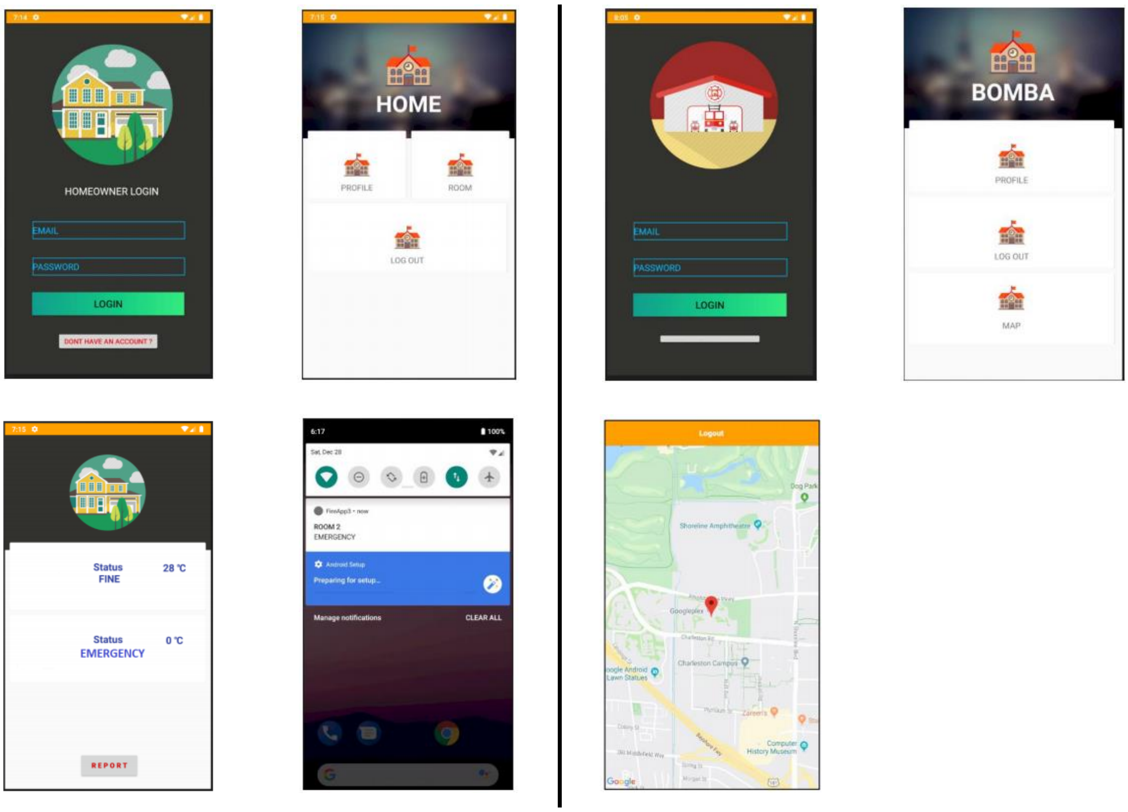

(i) Homeowner Interface (ii) Fire Department Interface

Figure 6: Interfaces of Application for (i) Homeowner and (ii) Fire Department

The application uses Pusher services which is Beams to send push notifications. Beams is an Application Programming Interface (API) for sending push notifications to iOS and Android apps. In this project, python script is created in Raspberry Pi for sending automated push notifications to users through an android application when the sensor detects any fire.

Geo-fencing method is used in the application for users to detect the nearest fire department locations. It is important to use this method in applications, especially when the user is not aware of the authority's phone number. Besides, the fire department will receive the homeowner's home location and details such as name and phone number. To use geo-fence in the application, *ACCESS_FINE_LOCATION* and *ACCESS_COARSE_LOCATION* permissions need to be added in manifest file as shown in Figure 7. These permissions provide locations and allow geo-fence methods to use the GPS function.

```
<manifest xmlns:android="http://schemas.android.com/apk/res/android" package="com.example.fireapp3">
<uses-permission android:name="android.permission.ACCESS_FINE_LOCATION" />
<uses-permission android:name="android.permission.ACCESS_COARSE_LOCATION" />
```

Figure 7: Screenshot Permission of Geocoding in Manifest File

p-ISSN 1675-7939; e-ISSN 2289-4934

Next, the application uses a geo-location library to store the location of the latitude and longitude of the homeowner based on the location of the Raspberry Pi. Figure 8 shows the geofire sample code to retrieve location of homeowner based on "*cust Id*" location.

```
CallBomba.setOnClickListener(new View.OnClickListener() {
    @Override
    public void onClick(View v) {

        GeoFire geoFire = new GeoFire(ref);
        geoFire.setLocation(custID, new GeoLocation(location.latitude, location.longitude), new GeoFire.CompletionListener() {
            @Override
            public void onComplete(String key, DatabaseError error) {
                if (error != null) {
                    System.err.println("There was an error saving the location to GeoFire: " + error);
                } else {
                    System.out.println("Location saved on server successfully!");
                }
            }
        });
```

Figure 8: Screenshot Sample code of Geofire declaration

Based on Figure 9, it shows a sample code of function in geo-fence to find the nearest fire department. There were five functions automatically created, which are *onKeyEntered(), onKeyExited(), onKeyMoved(), onGeoQueryReady(),* and *onGeoQueryError()*. These functions are added to what happens when a user enters or exits from a geo-fence area. Notifications are added for the fire department for a notice of emergency On the other hand, geo-fence radius is used to find specific geo-fence areas. In this project, locations that used geo-fence areas were set to a one (1) kilometer radius of a nearby fire department, and if within one kilometer the nearest fire department was not available, it would automatically add another one kilometer more.

```
private void GetClosestDriver() {
    GeoFire geoFire = new GeoFire(DriverAvailableRef);
    GeoQuery geoQuery = geoFire.queryAtLocation(new GeoLocation(location.latitude, location.longitude), radius);
    geoQuery.removeAllListeners();

    geoQuery.addGeoQueryEventListener(new GeoQueryEventListener() {
        @Override
        public void onKeyEntered(String key, GeoLocation location) {
            if(!driverFound){
                driverFound = true;
                driverFoundId = key;

                DriverRef = FirebaseDatabase.getInstance().getReference().child("Users").child("Fire Department").child(driverFoundId
                HashMap driverMap = new HashMap();
                driverMap.put("CustomerRideID",custID);
                DriverRef.updateChildren(driverMap);

                CallBomba.setText("Looking for nearby Bomba");

                getAssignedDriverInfo();
                relativeLayout.setVisibility(View.VISIBLE);
            }
        }
```

Figure 9: Screenshot Sample Code of Function in Geo-fence

p-ISSN 1675-7939; e-ISSN 2289-4934

4. NETWORK PERFORMANCE TESTING AND RESULT

4.1 Network Performance Testing on Data Transfer Rate

The purpose of this testing is to study the impact of distance on performance in data transfer rate between Raspberry Pi an access point. The testing has been conducted at home. During the testing, the distance will start at five (5) meters. Based on Table 4, it shows a result of network performance testing. Distances at five meter were recorded as the highest value, where it can transfer up to 20.7 Mbytes. After that, it is observed the data transfer rate is starting to decrease from 10 meters to 30 meters. The lowest data transfer rate that can be reached is 588KB at a distance of 30 meters.

Table 4: Data Transfer Rate Result Testing

Distance (m)	Result 1	Result 2	Result 3	Result 4	Result 5	Result 6	Result 7	Result 8	Result 9	Result 10	Total Data Transfer Rate
5	2.32 MB	2.17 MB	2.24 MB	1.99 MB	2.24 MB	1.99 MB	1.99 MB	1.99 MB	1.99 MB	1.99 MB	20.7 MB
10	2.12 MB	1.80 MB	1.74 MB	1.49 MB	1.99 MB	1.74 MB	1.49 MB	1.74 MB	1.74 MB	1.49 MB	17.1 MB
15	1.75 MB	1.93 MB	1.74 MB	1.49 MB	1.37 MB	1.49 MB	1.74 MB	1.74 MB	1.49 MB	1.24 MB	15.7 MB
20	1.42 MB	1.58 MB	2.24 MB	1.49 MB	1.24 MB	1.49 MB	0.00 KB	5.9 KB	0.00 KB	3.82 MB	9.86 MB
25	1.05 MB	772 KB	636 KB	382 KB	636 KB	891 KB	891 KB	1.13 MB	1.01 MB	1.24 MB	8.34 MB
30	100 KB	56.5 KB	0.00 KB	103 KB	100 KB	42.4 KB	52.3 KB	79.4 KB	0.00 KB	105 KB	588 KB

4.2 Network Performance Testing on Response Time

The testing for response time was obtained by running Android Profiler tools that have been provided in Android Studio. These tools provide real-time data on how applications use CPU, memory, network, and battery resources. The network performance analysis is taken at several rates of times, such as 11.00 am, 1.30 pm, 3.30 pm, 5.30 pm and 9.00 pm, to analyze between peak hour and normal hour. The experiment was conducted at home with Wi-Fi connection. During the testing in the morning session at 11.00 am, we can see in Table 5, the response time that can be achieved is 291 ms and started to be slower at 1.30 pm which is 592 ms. Figure 5 also shows the response time becomes more efficient at 3.30 pm, 391 ms than the testing before at 1.30 pm. When testing began at 5.30 pm, the response time performance slowly became inefficient, where the response time increased to 486 ms and reached until 664 ms at 9.00 pm.

Table 5: List of Software

Time	Response Time (ms)
11.00 am	291
01.30 pm	592
03.30 pm	391
05.30 pm	486
09.00 pm	664

p-ISSN 1675-7939; e-ISSN 2289-4934

4.3 Discussion of Network Performance Testing

The reason for conducting network performance testing is to analyze the influence of distance and time towards the performance. The purpose is to measure data transfer rate because it can show the amount of data that can be sent within 10 seconds. The measurement is conducted by transmitting data in different distances up to 30 meters, ignoring interference factors. Table 4 above shows how distance can affect the data transfer rate, that can be achieved by raspberry pi and access point. The result of data transfer rate shows as the distance increases, the total data that can be sent slowly decreases. It can be observed that each time the distance from the access point doubles, the performance is also reduced [13]. Besides, the quality of the data transmission depends on the distance and other factors. The further a device from its access point, the weaker the signal it can send and receive.

Based on Table 5, the data collected shows that the push notification network performance takes a certain amount of time to respond when the network is busy. Therefore, the user should be prepared with a high bandwidth internet connection to support good quality of response time. However, all the response time is just a little slightly different between each other because all the results are lower than one second. This testing on network performance has been carried out successfully. It meets the features that have been set.

5. CONCLUSION

The aim of this system is that homeowners will be provided with a real time monitoring system, able to sense and detect home temperature and flame through sensors. The system used multiple sensors to detect the occurrence of flame where the result will be more accurate. On top of that, it will help homeowners to monitor the condition of their house even when they are not at home. In addition, the system provides a feature, where the fire department can navigate directly to the location, once the homeowner requests for an emergency. The result of the network performance test shows that distance can affect the data transfer rate, and due to enormous connection in Wi-Fi can degrade the response time performance. On the other hand, fire detection devices currently are distributed in different rooms. It requires several microcontrollers to process the input from the sensor for transmission to online databases. Therefore, it requires higher cost for implementation. The improvement for the fire detection system is by using only a single microcontroller. The fire detection system located in a different room will be controlled from one microcontroller that will be placed in secure place. This will increase the efficiency and reduce costs for building management operations, more efficiently discriminate between fire and non-fire threats, and increase the time available for property and life protection. However, Internet-based monitoring will need security protection to prevent false fire information.

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p-ISSN 1675-7939; e-ISSN 2289-4934