Beacon-Based IoT System for Use in the Office : Monitor User's Location and Alert an Emergency

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***Abstract*— With the development of the network environment and the spread of smart devices, the Internet of Things (IoT) technology in which people and things interact has emerged. This technology can be used to troubleshoot the current system. A fire accident, for example, takes only a few minutes to become large enough to cause casualties. To reduce the damage, it is important to effectively control personnel and deliver accurate information in a short time, but the existing fire alarm systems cannot do this properly. In this paper, a fire monitoring system, using beacons, that identifies the real-time location of the user and sends a fire evacuation message to the app user when a fire is detected is proposed. This system can be divided into a data transmission module and a sensor module. The data transmission module sends data to the server by communicating periodically between the beacon and the user. At this time, the token value is generated by the application and used to identify individual data. The sensor module detects fire with two sensors connected in parallel to the Raspberry Pi. When the sensor module detects a fire, it sends fire detection information to the database, receives the user's token value from the server, and uses it to compose a disaster message and send a message request to the server. The system can solve problems such as bottlenecks at the exit by providing differentiated escape route information to each occupant and can support lifesaving work by continuously updating the number of people in the building. This system can be used not only in offices, but also in places where many people gather. Later, to improve system problems, data can be encrypted to enhance security, or other sensors can be added to detect disasters other than fire.**

Keywords—Bluetooth beacon, fire monitoring system, real-time location, token value, data transmitting module, sensor module, Raspberry Pi.

I. INTRODUCTION

A. Purpose of the Project

A Bluetooth beacon is a small wireless device that works based on Bluetooth Low Energy [1]. The beacon repeatedly transmits a signal so that a device can receive a signal when it is near the beacon. There are two important characteristics of a beacon: that it can be used for a long time with little power and that it can communicate in a long distance. Compared with NFC technology, which can communicate only when touched within 10cm, beacons can communicate without contact in a wider area, making it easier and faster to communicate with users. These two properties mean that beacons are a key technology needed for IoT implementations.

Beacon can provide information tailored to the user's situation. It can be utilized in various places such as hospitals, department stores, and sports facilities. In this paper, how beacons are used in office buildings will be discussed. As technology advances and the purposes required for facilities become more complex, the demand for high-rise buildings is gradually increasing. Because high-rise buildings are made up of more rooms, factors that can cause fires in each space are more widespread. Moreover, if the building structure is large and complex, it will be more difficult to escape in an emergency. As shown in Figure 1, it only takes a few minutes for the flame to become a big fire [2]. This can result in enormous human casualties, so it is important to evacuate quickly and accurately. Therefore, to reduce the risk of accidents by efficiently controlling many people without panicking in an emergency, a system that continuously checks and controls the situation is needed.

By using Bluetooth beacons, this project aims to build a system that collects real-time location information of users and provides evacuation routes to occupants when a fire is detected. Under normal circumstances, the server determines the real-time location of the user. When app users approach the beacon area, The application receives RSSI(Received Signal Strength Indicator) from beacons. The RSSI value is used to calculate the user's floor location information [3]. In the process of writing this data to the server, the app creates a token value that identifies each individual and stores the information separately for each token value. Due to this system, the server can manage

where each individual is located in the building. When the sensors attached to Raspberry Pi detect a fire, the Raspberry pi configures an evacuation notification message. This includes the number of people on each floor and an image showing the evacuation route from each person's current location. After that, all users receive a message from the server.

Fig. 1. Fire spreading procedure. (a) Fire ignited. [2]

Fig. 1. (Continued.) Fire spreading procedure. (b) 2 minuites later. [2]

B. *Related Works*

Recently, many studies have been conducted to measure the indoor location of a person using the RSSI value between the beacon and the user. According to [4], the paper corrects the user's position measured using iBeacon. And, demonstrated in [5], there is a study that presents a technique for efficiently placing beacons using triangulation. Although these studies have the advantage of increasing the accuracy of the user's location data, there is a problem that an expensive system is required.

There are studies that suggests a system that guides a user to a destination indoors by using several beacons installed in a building. According to [6], the paper proposes a method to search the route between the user and the destination from the server and send it to the client. And, demonstrated in [7], there is a study that proposes a system that guides the escape route through a beacon by executing a route guidance system based on Dijkstra's algorithm. Since these studies use a large number of beacons, there is a problem that a user cannot receive a proper signal because signal interference occurs between each beacon.

There are also studies that suggest how to design a fire detection system using Raspberry Pi. According to [8], the paper proposes a method of sending a fire alarm message to the user's smartphone when a fire is detected. And, demonstrated in [9], there is a study using a flame sensor and a gas sensor together to increase the accuracy of fire detection.

II. System Design

A. *System Configuration*

In this project, a fire monitoring system consisting of a sensor module and a data transmission module is proposed. The system structure is shown in Figure 2.

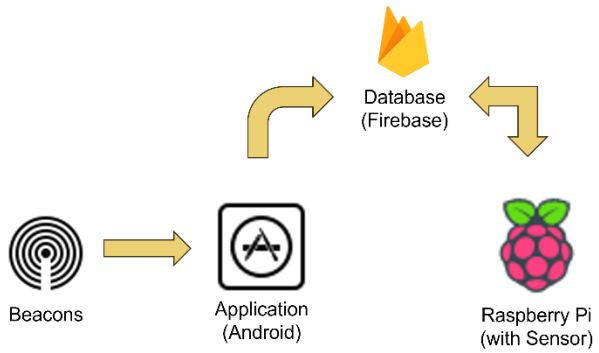

Fig. 2. System structure.

The data transmission module provides real-time location information through an app installed on a personal device. This data is updated at regular intervals in the server so that the location of the occupant can always be checked.

The sensor module detects disasters such as fire. When a sensor attached to the Raspberry Pi detects a fire, the Raspberry Pi constructs an evacuation message containing an image showing the number of people on each floor and an evacuation route for each person's current location.

B. *Tools*

The beacon used in this project is the ibeacon E7 from Hyunseung Korea. It is supported on iOS 7.0 or later and Android 4.3 or later, and can recognize up to 80m [10]. These beacons are installed one per floor so that when communicating with a user near the beacon, the location of that person can be identified.

Fig. 3. ibeacon E7.

Raspberry Pi model 3B was used as a platform that recognizes fire, notifies the server of the location of the fire, creates an emergency evacuation message, and transmits it to the server.

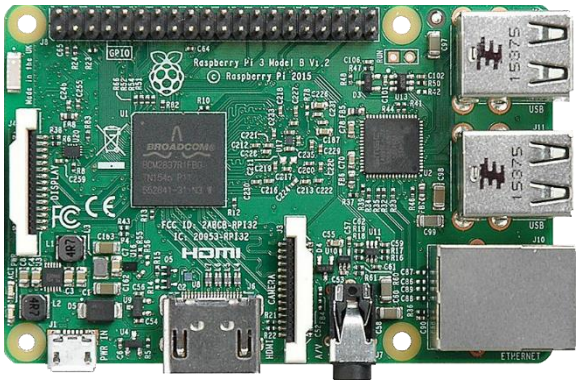

Fig. 4. Raspberry Pi model 3B.

A flame sensor and a gas sensor are connected to Raspberry Pi model 3B and used together to detect fire. The flame sensor detects infrared rays with a wavelength of 700 to 1100 nm to determine whether a fire has occurred [11]. The flame sensor uses the TTL level output method, which is normally in a high-level state and changes to a low-level state when a flame is recognized. The MQ-2 gas sensor recognizes gases such as CO and smoke, and outputs the value according to the concentration of the gas in the analog form [12]. To utilize the MQ-2 gas sensor, an ADC converter that converts analog signals to digital is additionally required.

Fig. 5. Flame sensor and MQ-2 gas sensor.

The database that stores the user's location information is implemented through Firebase. When the app and the beacon communicate and the user's location information is received by the server, it is stored in the form of a document. This information is used to create an emergency evacuation message on the Raspberry Pi.

C. Data Transmission Module

There are two ways a beacon can determine a user's location through communication. The first way is to place beacon receivers in each location and communicate with the beacons people are holding. Although this method can accurately track the location of the beacon, there is a limitation that it can be used only when all users have a beacon. The second way is for the beacons installed in each location to communicate with the user's mobile phone (beacon receiver). This method can reduce the number of beacons required because people use their cell phones, but there is a disadvantage that communication is possible only when the Bluetooth function of the cell phone is always on, and the recognition accuracy of beacons is lowered. In this project, the second method is decided to use, which can be configured at a low cost when applied to an actual system.

The data transmission module uses the service provided as an open-source by utilizing the Android development environment. When a user installs an app, a token is generated individually by firing onNewToken callback, and this token is automatically stored in the smartphone's internal storage [13]. It is also stored periodically in the database so that it can identify the user's identity. The reason for storing the token in the internal storage is to quickly and accurately update the data value associated with the token. Tokens created with the onNewToken callback usually do not change in value [13], so it is more efficient to store the token in the smartphone's internal storage and use it whenever needed. And although the database platform provides a function to get a token, it is slow to execute and runs asynchronously, which increases the probability that it will not store data properly.

The Bluetooth beacon continuously interacts with the device on which the app is installed and detects the app user's entrance and location change signals. In case of fire, Firebase Clouding Message (FCM) service is used to send emergency evacuation messages to app users. To use this service, messages must be written in a server environment that supports the FCM server protocol or the Firebase Admin SDK [14]. In this project, the Raspberry Pi composes a message and sends a message request to the FCM backend by code written in Python. When the FCM backend receives a message request, it generates a message ID and other metadata and sends it to the app user. This process is shown in Figure 6.

Fig. 6. Process of the data transfer module.

To implement message transfer, the HTTP protocol POST method is used to pass data in JSON format. The reason for transmitting data in this way is that it is similar to the existing text transmission method, it is good to send relatively large data, and it is easy to add other data because of its good scalability [15].

D. Sensor Module

The sensor module was designed to increase the accuracy of fire detection by configuring the carbon monoxide sensor and the infrared sensor in parallel. This module can detect fire in the range of 1~2m. If a sensor module is configured with only a single sensor, the probability of the module malfunctioning increases. For example, when cooking indoors or when a sensor is damaged and thus does not receive a correct measurement value, it can be recognized that a fire has occurred even if there is no fire. Therefore, using a multi-thread method, the system was configured to accurately recognize the situation. After the fire detection system is executed, the signal finally determined that a fire has occurred is transmitted to the central server. Then, the evacuation route guidance system is being executed based

on the location information of the occupants. The overall process of this module is described in a flowchart in Figure 7.

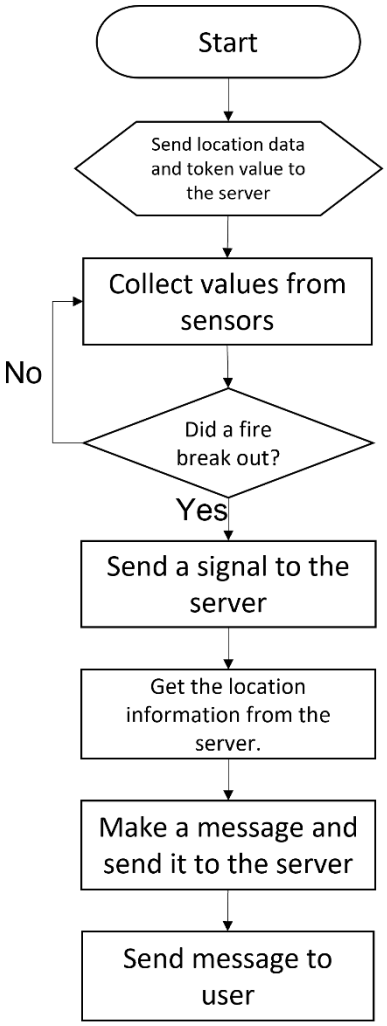

Fig. 7. Flowchart of the sensor module.

When the Raspberry Pi recognizes a fire through the sensor, it accesses the Firebase and receives token value information corresponding to which users are on each floor. Since the content of the message to be sent is different for each location, Raspberry Pi uses this information to create a message to be sent for each token value. These messages are sent from Raspberry Pi to Firebase.

III. Result And Discussion

A. Application Configuration

When a user enters a building and installs an application for the first time, the application requests a phone number, location, and background execution permission from the user to obtain the user's phone number and real-time location information. This process is shown in Figure 8.

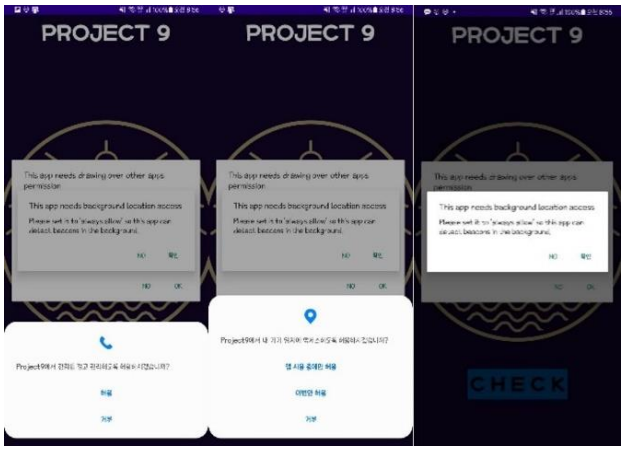

Fig. 8. Requesting permission from user.

After the user grants permission and launches the app, it goes to a screen that provides two pieces of information. When the user presses the 'MAP' button, information is provided indicating the location of the safety facility in the building and the evacuation route to the emergency exit. The app screen is like Figure 9.

Fig. 9. Main screen and “MAP”, “OURCOMPANY” execution screen.

When this notification message is pressed, the application does not go to the main screen, but to a screen that displays images of (1) fire location, (2) fire time, and (3) evacuation route to emergency exits. The app layout at this time is shown in Figure 10.

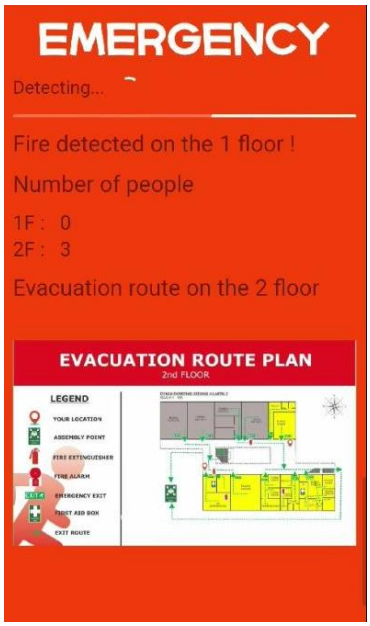

Fig. 10. App screen in a fire situation.

B. *System Operation Process*

When the mobile phone installed with the application enters the communication area of the Bluetooth beacon, the application receives the floor information from the beacon and sends it to the Firebase. In Firebase, a document is created with the mobile phone number, whether the building is inside/outside, the current number of floors, and whether it is inside/outside. And another document is created with the floor location as the title and the token value within the floor area as the content. The format of the generated document is shown in Figure 11.

Fig. 11. Documents in the database. (a) user information.

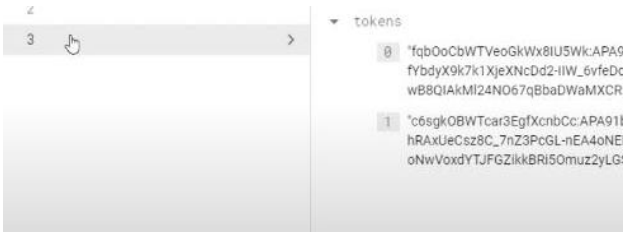

Fig. 11. (Continued.) Documents in the database. (b) location information.

The application normally runs in the background, and when the sensor module detects a fire, a different message is sent to the application for each floor. The process of sending a message to the phone is shown in figure 12.

Fig. 12. App operation process. (a) normal state.

Fig. 12. (Continued.) App operation process. (b) fire detected.

The message continues to show the number of people in the building, so app users can easily determine how many people have not yet escaped from which floor. A picture depicting this situation is shown in Figure 13.

Fig. 13. App behavior in a case of fire. (a) fire ignited.

Fig. 13. (Continued.) App behavior in a case of fire. (b) person left inside the building.

IV. Challenges

A. Beacon Signal Detection

Beacon products on the market have different detection signal strength and detection distance depending on the type and version. After several trials and errors, the beacon was arranged to correctly receive the signal by estimating the appropriate distance at which the signal of a specific beacon was received. If multiple signals are detected, updates are not performed except for the first received signal. As a result, it was possible to significantly reduce the probability of a malfunction with overlapping personnel information or fire detection signals.

V. Conclusion

A. Reinterpretation of Result

In this paper, a system in which the server receives the user's location information with high accuracy using a Bluetooth beacon is proposed. Based on the location information, this system can provide useful information that varies according to each location of users in normal times.

In addition, using sensors that detect flame and smoke respectively, a system that sends a fire emergency message to users in a fire situation was proposed. This system provides an appropriate emergency escape route to each user based on the location information of the users stored in the database.

B. Utilization of the System

The system is expected to be applicable in a variety of areas depending on its purpose. It can also be used to identify behavioral patterns of facility users by using location-related information in large indoor spaces such as museums and large shopping malls. When a fire occurs in large-scale indoor spaces, schools, dormitories, companies, etc., it will be useful when dealing with fire situations by providing information on fire occurrence and an evacuation route optimized for each user's location.

C. Supplement Point

This system has a problem that personal information can be easily leaked due to weak security, which is a problem with Beacon itself [16]. In addition, this system has limitations in that it can only detect fire situations and cannot respond to other disaster situations such as earthquakes and building collapses.

D. Improvements

Various methods can be used to compensate for the above-mentioned problems of the system. To prevent personal information from being easily leaked, the security problem can be solved by encrypting the data stored in the database. And more sensors can be added to the sensor module to detect other disasters. Through these improvements, it is expected that the system's capabilities will be improved and used more widely.

References

[1] "*What is a Beacon? The Complete Guide to Bluetooth Beacons,"* Kontakt.io, Accessed on: Aug. 19, 2021. [Online]. Available: https://kontakt.io/what-is-a-beacon/

[2] Amy Holibaugh. *How Quickly Fire Spreads: National Fire Protection Association Test Burn*, Mar. 6, 2015. Accessed on: Aug. 19, 2021. [Video file]. Available: https://youtu.be/zzbQ4k35-JU.

[3] U. M. Qureshi, Z. Umair, Y. Duan and G. P. Hancke, "Analysis of bluetooth low energy (BLE) based indoor localization system with multiple transmission power levels," *2018 IEEE 27th International Symposium on Industrial Electronics (ISIE)*, 2018, pp. 1302-1307, doi: 10.1109/ISIE.2018.8433787.

[4] H. Nam-Gung, I.-K. Lim, and J.-K. Lee, "Location estimation method of positioning system utilizing the iBeacon," *Journal of the Korea Institute of Information and Communication Engineering*, vol. 19, no. 4, pp. 925–932, 2015.

[5] H.-C. Lee and D.-M. Lee, "A study on localization system using 3D triangulation algorithm based on dynamic allocation of beacon node," *The Journal of Korean Institute of Communications and Information Sciences*, vol. 36, no. 4, pp. 1564-1566, 2011.

[6] D.-H. Kim, S.-Y. Kim, J.-H. Youn, and C.-H. Ban, "The design and implementation of an indoor navigation system using beacon signal" *The Journal of Korean Institute of Communications and Information Sciences*, vol. 12, no. 1, pp. 31–38, 2017.

[7] K. Shimizu and D. Kushida, "Evacuation guidance system using beacon information and Dijkstra's algorithm," *2021 IEEE 3rd Global Conf. on Life Sci. and Technol. (LifeTech)*, 2021, pp. 319-323, doi: 10.1109/LifeTech52111.2021.9391946.

[8] M. Sheth, A. Trivedi, K. Suchak, K. Parmar and D. Jetpariya, "Inventive fire detection utilizing raspberry pi for new age home of smart cities," *2020 Third International Conference on Smart Systems and Inventive Technology (ICSSIT)*, 2020, pp. 724-728, doi: 10.1109/ICSSIT48917.2020.9214108.

[9] S. Jamadagni, P. Sankpal, S. Patil, N. Chougule and S. Gurav, "Gas leakage and fire detection using raspberry pi," *2019 3rd International Conference on Computing Methodologies and Communication (ICCMC)*, 2019, pp. 495-497, doi: 10.1109/ICCMC.2019.8819678.

[10] *"All about Beacons,"* Hyunseung Korea, Accessed on: Aug. 19, 2021. [Online]. Available: http://www.beafon.co.kr/beafon/#feature

[11] *"Flame Sensor Module,"* Proto Supplies, Accessed on: Aug. 19, 2021. [Online]. Available: https://protosupplies.com/product/flame-sensor-module/

[12] *"How MQ2 Gas/Smoke Sensor Works? & Interface it with Arduino,"* Last Minute Engineers, Accessed on: Aug. 19, 2021. [Online]. Available: https://lastminuteengineers.com/mq2-gas-senser-arduino-tutorial/

[13] *"Set Up a Firebase Cloud Messaging Client App on Android,"* Google Developers, Accessed on: Aug. 19, 2021. [Online]. Available: https://firebase.google.com/docs/cloud-messaging/android/client#java_2

[14] *"FCM architectural overview,"* Google Developers, Accessed on: Aug. 19, 2021. [Online]. Available: https://firebase.google.com/docs/cloud-messaging/fcm-architecture

[15] R. Sharma, *JSON - its advantages and disadvantages*, Ezeelive Technologies, Nov. 21, 2014. Accessed on: Aug. 19, 2021. [Online]. Available: https://ezeelive.com/json-advantages-disadvantages/

[16] H.-S. Hwang, J.-T. Park, J.-S. Yun, G.-S. Phyo, I.-Y. Moon, and J.-S. Lee, "Beacon-based Internet of Things(IoT) analysis of the case study," *The Journal of The Korean Institute of Communication Sciences*, vol.35, pp.977-980, 2015.