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IoT-Based BLE Architecture for Interactive Information Sharing in Resource-Constrained Educational Environments

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Abstract

This study, based on the advancement of existing smart city convergence content, installed Low-power Bluetooth Beacon Sensors inside the campus of G University in Gyeonggi-do, South Korea, and built the IoT-based environment to build the infrastructure network where users can effectively share information within the campus in the form of interaction through short-range communication. Thus, it realized a future university infrastructure environment by super-connecting the university campus with Local Area Network to manage data and share important information generated on campus with members and users. In addition, it conducted the test-bed for the Integrated Information Sharing Platform of the Campus Environment built in this study and verified its excellence by analyzing the Efficiency, Stability, and Effectiveness of the Infrastructure Construction centered on users. The greatest strength of this Platform is that it can minimize infrastructure costs. If it is applied to universities in developing countries and underdeveloped regions overseas as well as domestically in the future, it is expected that a competitive campus environment can be established.

Keywords: *Bluetooth, Sharing Platform, IoT.*

Introduction

In various fields, including domestically and internationally, BLE Technology is being utilized to provide various services to users [1][2][3]. It is a type of short-range communication network that is evolving into the Beacon, and is the IoT-based ubiquitous technology that can detect the location of a client or transmit and share data [4]. Domestically, it is attempting to integrate technologies such as big data storage, management, and transmission using sensors based on smart cities into various fields [5][6]. Bluetooth Technology has been gradually accelerating its introduction domestically since the past, but it has not been applied to various fields and is mostly used as a part of wearable devices and equipment [7]. In this trend, research to expand services is gradually being conducted and is further being applied to building urban infrastructure. Therefore, in this study, it applied the previous studies to build the Integrated Information Sharing Platform that can efficiently transmit data based on BLE Sensors. It proceeded with the following procedures. First, based on previous studies, a large number of BLE Sensors were installed at a university in Korea. It proposed the model for adjusting the distance between sensors by controlling the scanning of the sensor and considering the terrain and distance. Second, it developed the client app that can be linked with sensors to flexibly share data, and built CMS that can efficiently manage data and resources. Third, it verified the platform and infrastructure construction through pilot operation and effectiveness analysis. Thus, it designed the effective infrastructure system that allows university visitors or members to share information by installing BLE Sensors in a campus environment, thereby building the infrastructure that allows busy generations who are sensitive to information sharing to effectively obtain specific information.

Related Work

Bluetooth Model

The Bluetooth Technology proposed in this study has several models. Initially developed Bluetooth Technology was released from version 1.0 to version 1.2, and at that time, the maximum transmission speed was not possible at 721kbps. Since then, with the introduction of version 2.0, the transmission speed has improved to 3 Mbps. However, due to overhead, etc., the actual maximum transmission

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speed is about 2.1 Mbps. Since then, version 3.0 has been released, providing the speed of 24 Mbps, which is about 8 times faster than before. However, if this is not supported by +HS (High Speed), it is significantly reduced. Starting with version 4.0, low-power Bluetooth was introduced, and the Protocol called BLE was added to the Classic Bluetooth and Bluetooth High Speed Protocols. The sensor used in this study also utilized the Beacon Sensor based on BLE [8]. BLE, a key feature of version 4.0, focuses on minimizing power consumption and extending battery life, but its transmission speed is relatively slower than other wireless transmission standards.

Domestic Study Cases

In the study of Transmission Control Method of Beacon Signal Based on Bluetooth of Lower Electric Power by AS-Oh (2016), the Beacon Device utilizing Acceleration Sensors and Hall Sensors was proposed. This enables control in specific situations through movement detection. In addition, it was mentioned that it can be applied to various factory environments such as convenient installation in a detachable form and optimized management linked with sensors. In the study “An Indoor Localization and Guidance System for the Visually Impaired Person Based on Bluetooth 4.0 (2016)”, it developed the indoor location estimation and guidance system that can provide the visually impaired with various information such as direction, distance, height, and obstacles to the destination via a smartphone using TTS (Text to Speech), a voice technology, Haptic, a tactile technology, and Beacon, a short-range wireless communication technology based on Bluetooth 4.0 [9][10].

a. Main UI

b. Sensor RISS Information Screen

c. Coupon Transmission Screen

Fig. 1. U-CITY Based Convergent Content System

In the study of JH-Seo, KH-Joo (2017) (our study) "Development of U-CITY Based Convergent Content System Using Bluetooth Low Energy Beacon Sensors", it developed content that provides product and coupon information to users using beacon sensors. In the study by KH-Joo and NH-Park (2023), the customized marketing system was developed that supports data transmission services through apps for hospitals and sports stadiums using Bluetooth Low-Energy Beacon Technology, and collects accumulated data from apps and uses it for statistics. This study aims to build the advanced infrastructure environment based on previous studies [11].

Proposed Method

System Design

The qualities of the alignment of ten data sets are listed in Table 1 (‘before’ treatment columns). These examinations reveal the qualitative differences between the data sets. The overall system configuration presented in this study is as shown in [Fig. 2] below. The client must install the app developed through this study on their smartphone, and the smartphone must be equipped with a Bluetooth connection function. The reason for developing the separate app for information sharing is to avoid random information transmission to clients who do not want to share information, as well as to provide a variety of functions, and to strengthen security based on the principle of privacy infringement.

When a client enters a random area where BLE Sensor is installed, data is shared through the Data Sharing Platform of the CMS (Content Management System). The type of data sharing can be in the form of an electronic document or a data link. Here, the client's personal unique information is stored on the main server through CMS by the app. The client's personal information stored on the main server is secondarily processed through data analysis and managed for sharing customized personal information.

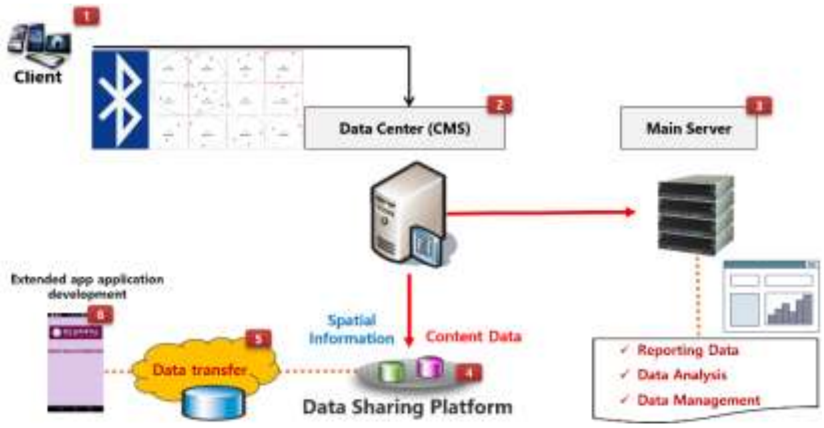

Fig. 2. Overall System Configuration Diagram of the Integrated Information Sharing Platform using BLE

The operation algorithm of this study proceeds through the following procedures based on objects and clients.

Table 1. Operation Algorithm between BLE Sensor and System

System Operation Algorithm	
Step 1.	Link BLE Sensors installed around the campus and the client's terminal to each other and collect data on the location visited by the client through CMS (At this time, the application must be logged in on the smartphone).
Step 2.	Share the desired information through the data sharing platform.
Step 3.	Store the client's personal information in the main server's DB. The information that can be collected here includes the client's affiliation, gender, and visit history.
Step 4.	Manage secondary processing and data analysis based on the client's personal information.
Step 5.	Use the analyzed data to share customized information during the second visit. Through the client's gender, it can share a map of the restrooms inside the building, and through the visit history, it can provide customized information through the time the client frequently appears at the location and the movement path within the campus.

Methodology and Infrastructure Design for BLE Sensor Installation on Campus

In this study, it built the campus infrastructure based on the installation and operation design of BLE Sensors with systematic procedures. It also developed the campus information sharing app to easily and quickly transmit information to clients, and established a login authentication and security system for sharing information on campus. It can get support for three procedures of security management: Pairing, Bonding, and Encryption Reset. In the case of an encryption reset, once the bonding procedure is completed, the keys must be stored on both sides of the connection, and once the encryption keys are stored, this procedure defines how these key values will be used to reestablish a secure and encrypted subsequent connection without having to go through the pairing procedure again. Control of information received from the network and information to be shared is managed and operated through CMS. It is the important system that can monitor the stability of the device and analyze the client's pattern information and equipment performance.

Selecting Environment for the Test Bed

In order to secure an effective testing space for infrastructure construction in this study, our research team selected the campus of G University in Gyeonggi-do, South Korea as the experimental site. G University operates two campuses, Campus 1 is located in Incheon City and Campus 2 is located in Anyang City, Gyeonggi-do. This experiment was conducted at Campus 2 located in Gyeonggi-do due to various factors, and was selected considering the following constraints.

First, Campus 1 has more buildings than Campus 2 and the buildings are extremely close together, so although the number of sensors that can be accommodated in the experiment is small, there may be various variables in the communication experiment.

Fig. 3. Structure of Campus 1 with Narrow Space between Buildings when BLE is installed

[Fig. 3] shows the map of the Incheon campus of G University. When BLE Sensors are installed, communication is possible in all areas because most buildings are densely packed together. However, communication-enabled areas overlap, causing competition between sensors in information transmission, and creating an environment where unnecessary communications occur even in areas with small floating populations.

Table 2. Expected Demand for BLE Sensors on Campus

Campus Name	No. of Building	Expected Demand for Sensor
Campus 1 (Incheon)	13	26
Campus 2 (Gyeonggi-do)	11	26

Second, Campus 1 has older buildings and more complex spaces than Campus 2, so there are some places where sensors cannot be installed. Also, the expected number of sensors required per building is the same.

Third, Campus 1 has more high ground than Campus 2. In this study, when installing sensors, the height of each floor of a high-rise building was not considered, and the sensors were installed on the first floor close to the ground. At this time, the installation location was on the exterior wall, not the ceiling inside the building, and was installed at a height of at least 1.5m to 1.7m. Therefore, Campus 2 located on flat ground, was selected as the optimal environment for the experiment.

Standard for Installation of BLE Sensors

When installing BLE Sensors, one thing to consider is reducing the cost of infrastructure construction. In this study, it designed the infrastructure construction environment that allows members within the campus to share a lot of information while being effective and minimizing the budget. [Fig. 4] below is a photo that can be used to identify the location of BLE installation and communication distance using the map. The photo on the left show basic information about the building's location, and the photo on the right is a satellite photo that shows the location and information about the terrain.

Fig. 4. Structure of Campus 1 with Narrow Space between Buildings

As it can see in the picture, Campus 2 of G University is not affected by any obstacles within 100m in front, is not located in an urban area, and although there are low-angle slopes, it is mostly flat, so experiments can be conducted in a desirable communication environment. The configuration for BLE Sensor Installation can be defined as follows. If it looks at the left picture in [Fig. 04], the part that forms an oval with the blue solid line is the area where BLE is installed. That is, it means the radius of communication distance of the area. The installation location of the BLE Sensor within the building section was selected by analyzing the building where students attend lectures and the floating population on campus, and the places where people stay for a longer period of time. The red dot points were intended to be BLE Sensor Installation Areas during the design phase, but were excluded from installation after confirming through floating population analysis that they were not areas frequented by many people. And for the green dot points, people do not stay in the same place for a long time, but they represent the areas where they pass by the most on foot based on their movement patterns. This is practically the area that is a candidate for BLE Installation. Lastly, the blue dot points represent unconnected areas where communication is not possible when the BLE Sensor is installed.

Defining Distance Adjustment Rule between BLE Sensors

In this study, the distance adjustment rule model between sensors was applied to build an effective infrastructure. In the case of Campus 2 of G University, if it looks at [Fig. 05 Right Side], unlike Campus 1, the gaps between buildings are not densely packed but rather widely distributed. Accordingly, since there is no overlap in the communication distance between sensors, the amount of sensor required can be minimized, but since communication is done with an elliptical radius, there are still unconnected points even if the range is adjusted. The installation location of the sensor should be based on the connection distance and should sufficiently consider the areas where communication is possible and areas where it is not possible. In addition, it is necessary to appropriately utilize the terrain information. The left side of [Fig. 05] below is the diagram that defines the Distance Adjustment Rule Model between Sensors.

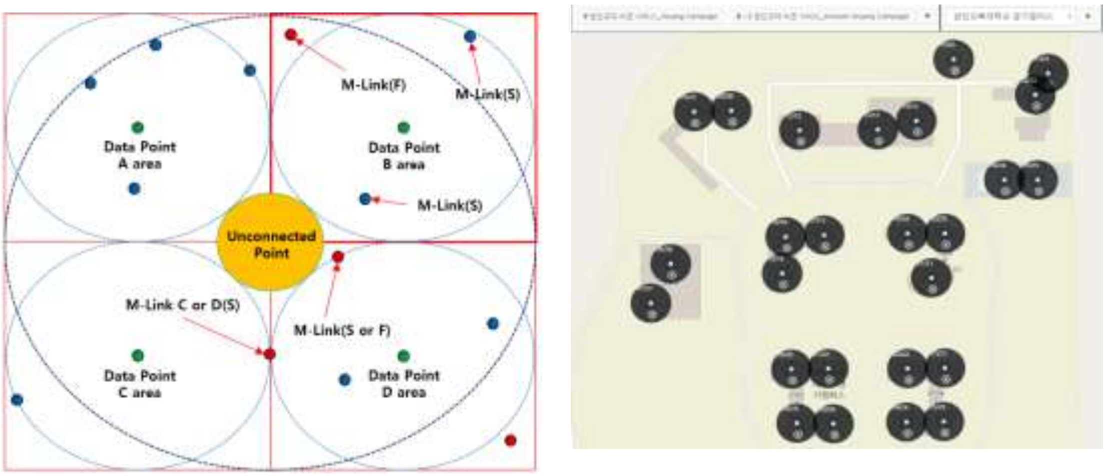

Fig. 5. Rule for Adjusting the Distance between Sensors

Table 3. Definition of Distance Adjustment Rule between Sensors

Distance Adjustment Rule between Sensors for building BLE Infrastructure
STEP 1. Set up 4 BLE Sensors in one section. The four sensors cannot be in locations where their communications overlap, and the radius within which each sensor can communicate is identified by the Area ID. STEP 2. BLE Sensors are stationary, but clients have mobility. STEP 3. When the client enters the BLE sensor radius range (data point area) while moving, it recognizes the connection and the communication is successful (S) state. STEP 4. If the client is not within the data point area range, the connection is disconnected, resulting in a deadlock and a failure (F) state. STEP 5. If a moving client is located at the border of two data point areas, it can share information with the sensor that is connected the fastest based on the priority of the task (determined by the number of clients that can be accommodated in each data point area). STEP 6. If the client enters the BLE sensor radius range boundary while moving, the connection is recognized and communication can success (S) or fail (F) in deadlock. STEP 7. If one data point is added to the center of the unconnected point, the range of short-distance communication will increase, but communication will be wasted in unnecessary areas, and the unconnected point will increase to 4 sections. Therefore, the location of the unconnected point is configured as an area where clients cannot move in the building (an area that is difficult to access) or an area with a small floating population.

Building and Experimenting with Campus Infrastructure

It discusses the development environment configuration and system implementation, as well as the effectiveness analysis for the test bed.

Hardware Configuration and Development Environment

The experimental equipment used in this study is ODROID, and was tested in Linux Kernel Environment. Since this app was developed based on Android, the test equipment was selected considering its compatibility, and separate experiments were conducted using clients with Android-based mobile phones.

			

Fig. 6. Experimental Equipment and Components

The Bluetooth module applied to ODROID uses the built-in CSR8510 A10. This module can perform experiments on classic Bluetooth (2.0), Bluetooth high-speed (3.0), and Bluetooth Low Energy (BLE 4.0).

Fig. 7. Experimental Hardware Setup and Scanning

Components and Scanning of BLE Sensor Device

The Bluetooth Module uses the Beacon Sensor based on Low-Power Energy 4.0. The BLE device installed for research has the advantage of being easy to install and manage due to its small size. However, since it recognizes space with a radius range of about 0 to 40 m, in order to increase the recognition range, additional sensors must be installed or enterprise-level sensors that can structurally increase the range must be considered.

When it enters the Token ID into the input window, it can confirm mutual communication by exchanging signals with the beacons set up in advance around it.

Fig. 8. Connecting to the Sensor

UUID is divided into Major and Minor, and the distance to the sensor is identified as ‘Near’, ‘Far’, ‘Unknown’ by Proximity. The main server used for R&D was developed in an environment with SuperMicro Server 1CPU/4Core, 8GB, 1TB.

Installation of BLE Sensor Device and Test Bed Operation

In this study, it applied the following additional rules through field surveys, including the criteria for the installation of BLE Sensors that it suggested and the definition of the Distance Adjustment Rule between BLE Sensors. First, it was placed based on the entrance on the first floor of each building in the flat layout. Considering that the typical reception range of BLE Sensors is 40~50m, the intersection area of the reception range between sensors was set not too wide. In the case of the dormitory building, considering that the entrance is a central passage, one sensor was placed. Second, for buildings with large usage areas, the required number of sensors was measured based on a maximum of four, and they were placed so that clients could contact them in four directions: east, west, south, and north. Third, for the efficiency of sensor placement, the bridge section of the building was excluded from the sensors. In the case of outdoor facilities, there are many technical limitations in terms of not only sensor installation but also future management, maintenance, and repair, so they were excluded. Fourth, considering that the sensors in areas with relatively high user contact frequency even after the experiment consume a large amount of battery, it placed sensor models with large battery capacities to prepare for the decrease in reception sensitivity due to continuous battery consumption. Finally, in the case of a square building plan, the distance was measured directly on site to reduce the sensor range and build it. It is to prevent excessive traffic from occurring due to the cross-connection of sensor signals caused by radio communication at the intersection between each sensor.

The details of the BLE Sensor finally constructed in this study are presented in [Table 04].

Table 4. Sensor Installation Location within the Campus

No.	View Image	Sensor Layout	Basic Information	Require
1			- Bldg. Name: Administrative Building - Bldg. Floor: 8F above ground (Main Building) - Purpose: School Administration & Office Work	1EA
2			- Bldg. Name: Teacher Training Center - Bldg. Floor: 4F above ground - Purpose: Faculty Training & Undergraduate Computer Education	3EA
3			- Bldg. Name: Student Hall - Bldg. Floor: 4F above ground - Purpose: Student Council & Student Club Activity Facilities	2EA
4			- Bldg. Name: Student Cultural Center - Bldg. Floor: 2F above ground - Purpose: Student Cafeteria & Welfare/Convenience Facilities	1EA
5			- Bldg. Name: Humanities and Social Sciences Building - Bldg. Floor: 5F above ground (Building A) / 6F above ground (Building B) - Purpose: Humanities and Social Sciences Curriculum Education	4EA
6			- Bldg. Name: Natural Science Building - Bldg. Floor: 6F above ground (Building A) / 5F above ground (Building B) - Purpose: Curriculum Education in the Life Sciences Field	4EA
7			- Bldg. Name: Music Hall - Bldg. Floor: 3F above ground - Purpose: Performance Music Education & Instrument Practice Room	2EA
8			- Bldg. Name: Yelim Dormitory - Bldg. Floor: 9F above ground (Building A) / 7F above ground (Building B) - Purpose: Student Accommodation & Living Facilities	1EA
9			- Bldg. Name: 2nd Yelim Dormitory - Bldg. Floor: 9F above ground - Purpose: Student Accommodation & Living Facilities	1EA

10			- Bldg. Name: Gym - Bldg. Floor: 3F above ground - Purpose: Student Accommodation & Living Facilities	1EA
11			- Bldg. Name: Library - Bldg. Floor: 3F above ground - Purpose: Student Accommodation & Living Facilities	1EA

Client-based Integrated Information Sharing APP

It developed the client-only App in this study. Beacon-based apps have been commercialized to some extent by foreign for-profit companies and domestic companies with low-power beacon content, but they have limitations in the use of functions and lack diversity, which makes it difficult to provide convenience to users. In this study, it recommended that each client use the APP by logging in after performing the authentication procedure.

a. Campus App Icon

b. Authentication Procedure Activity

c. Main Activity

Fig. 9. App Authentication and Main Screen

The MainActivity Class that was initially created is Java Class that is linked to the login activity. It is set so that when the ‘Login’ button is pressed if the email account and password are entered correctly, the intent is sent to the main menu, ContentsMenuActivity Class.

Content Management System

In this study, since it is important to check whether the developed APP and the BLE Sensor installed in the corresponding location are transmitting and receiving normally and to maintain the detection status, the linkage was performed through Onboarding in the CMS area. Onboarding is the process of configuring a single location for when it wants to install a beacon in a new area or create a campaign of content. In the Onboarding Configuration Table, input the country name and installation location, and enter the road name and postal code (zip code) address system for location information identification.

Table 5. BLE Sensor Use Case Table Sample

Corner	Teacher Training Center	Student Support
UUID	XXXXXXXX-XXXX-XXXX-XXXX-XXXXXXXXXXXX	
Major	1	2

Minor	1	30% off Computer Training	50% off On-Campus Study
	2	Department Announcement Document	N/A

The basic techniques of UUID, Major, and Minor, which are broadcasting techniques for identifying APPs, are utilized, and the universal unique identifier (UUID) is used as a key value that can identify the visit history of a user who has completed authentication. Major values specify a specific Sensor and Use Case, while Minor values set detailed quantitative subranges of the Use Case.

Fig. 10. Connection Status Information for Scan Completion

The Scanner can be started and stopped during runtime by calling "startScan() and stopScan()", and is possible to store information about the range of the content provider database and the monitored area. In order to adjust the power consumption of background scanning, the background scan frequency must be adjusted, and the concept of frequency presented here means the interval between two scans. The interval is measured in milliseconds (ex. 3s=3000) and can be defined by setting the code "setBackgroundBetweenScanPeriod(long interval)". [Fig. 10] above represents the desired operation of the sensor.

Data Sharing Module

In this study, information is provided through electronic documents or links to sites. When sharing information through BLE Sensors, it is difficult to exchange large amounts of data due to the limited data size.

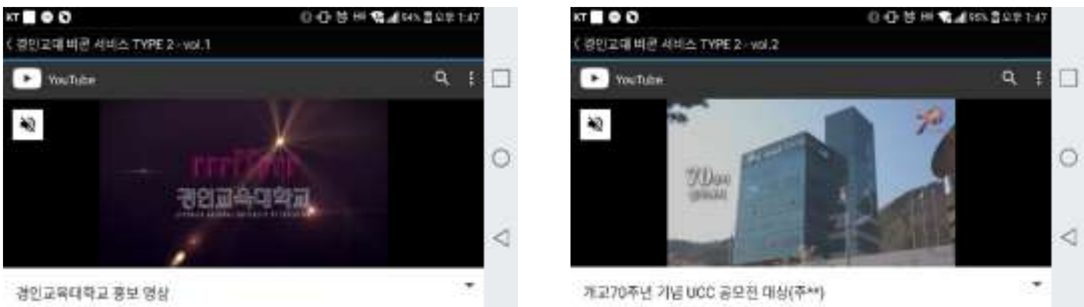

Fig. 11. Data Sharing Sample (Sharing Videos via 'url' Information)

It handles message events in case the connection is unstable. The warning message of the Bluetooth app is processed by two events, the action filter and the additional part. In the case of the action filter, it corresponds to the package setting of "app.package.name.scan" and in the additional part, it corresponds to the processing of "BeaconApplication.SCAN_EVENT". The events for this item are "Ambient Scan Event" and "Invalid RSSI Identification", and the Ambient Scan Event is triggered when the Bluetooth Scanner cannot find any BLE Sensors in the vicinity for a certain period of time. Cases like this occur due to a conflict in the Bluetooth stack.

Effectiveness Analysis for Reliability Verification

In order to verify the reliability of the integrated information sharing platform using BLE built in this study, an evaluation was conducted through the test-bed pilot operation and effectiveness analysis was derived. The test of this study was conducted as an open test for 113 campus visitors for one week, and data was collected and analyzed by investigating the functional aspects of the platform and the practicality of client use. The evaluation verification scale is as shown in [Table 06].

Table 6. Evaluation Verification Scale

Functional Part	
1	Is this providing the user with the right information?
2	Does the sensor operate smoothly and transmit information without interruption?
3	Is this satisfactory in terms of ease of installation?
4	Does information share interactive and reliable?
5	Will this system contribute to the IoT environment?
6	Is this system actually seem like it would be helpful?
UI & Usability Part	
1	Is this satisfied with the UI Use?
2	Does the device control method in good condition?
3	If it were built at another university, would it be usable?
4	Does the definitions of the menu and table correct?
5	Is this accessible?
6	Does the security well maintained?
7	Is this willing to use the actual system?

[Fig. 12] shows the functional part and presents a total of 6 items. The most positive response was to item 5, with 107 out of 113 respondents giving a positive response that the study would Contribute to IoT. On the other hand, the lowest item was item 2, and 76 people responded positively and 37 people responded negatively to the question, “Did the sensor transmit information smoothly without interruption?” It was confirmed that this was a case that occurred due to unstable elements between the server and the network rather than a case that occurred due to a sensor recognition error. Thus, the analysis results showed that a method to guarantee future data transmission rate and server stability was needed.

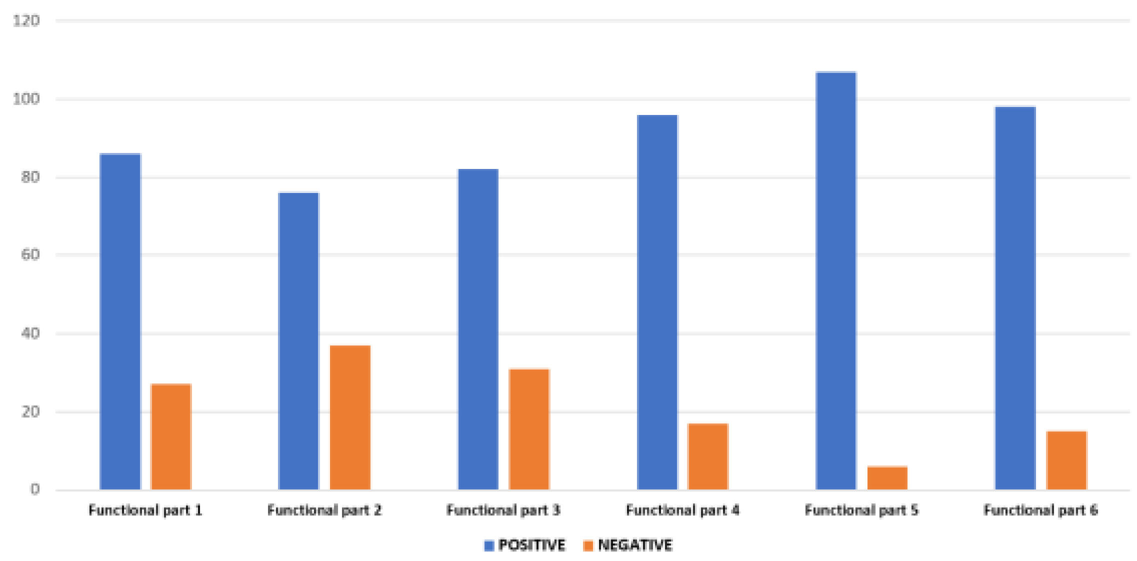

Fig. 12. Evaluation Results for the Functional Part

The functional part received the high positive response of 90.8 in the overall average index, which is interpreted to mean that the BLE Sensor Infrastructure Installation was effectively built. However, the fact that 27 out of 113 client respondents gave a negative response to the question “Is this provide appropriate information to users?” suggests that this is due to the inconvenience caused by indiscriminate sharing of unnecessary information.

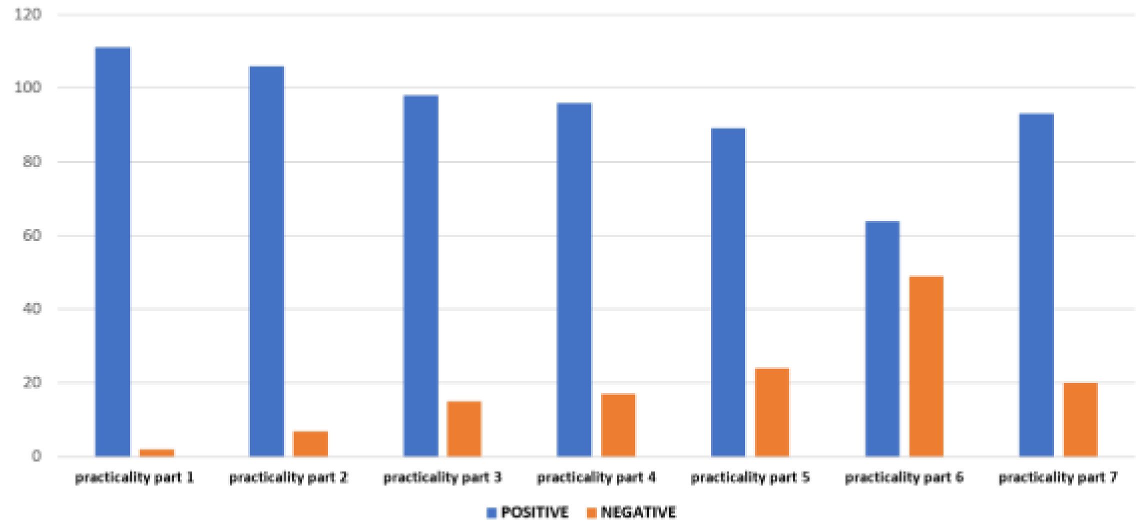

Fig. 13. Evaluation Results for Practicality

Then, the practicality part presented the scale with 7 items, as shown in [Fig. 13]. The most positive response was the satisfaction with UI Use. The most important consideration in this development was to compose the user-defined interface with an intuitive and simple screen regardless of age, and above all, the code was completed in compliance with Korean mobile accessibility. On the other hand, the negative item is the response to “Does the security well maintained?” In this item, 49 out of 113 clients responded negatively. The reason is that personal information exposure increases during the process of using the app, and the administrator can check the movement patterns of clients. However, overall, the total average index for system use was 93 points, which is a positive result. Therefore, it expects that this platform will become an even better platform if it is supplemented server stabilization, client security management, and customized information sharing.

Conclusion

In this study, it developed the platform that provides efficient information sharing by installing BLE Sensors on campus. In this research phase, it proposed the installation method considering the topographical environment and the sensor application distance, and applied it to an actual university campus through the overall system configuration. It also developed the dedicated application for clients to systematically share data and presented the stable data sharing model based on CMS. It is the system that can provide information quickly and easily by sharing information within the campus through sensor and smartphone linkage by applying existing prior research in general. It also verified the platform by conducting the effectiveness analysis through the pilot operation. Considering that O2O Services utilizing BLE Sensors are not widely used on domestic university campuses, it is expected to be an effective way to build campus infrastructure in the future in terms of convenience, efficiency, and reliability.

Acknowledgments

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