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An Indoor Guidance System Combining Near Field Communication and Bluetooth Low Energy Beacon Technologies

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***Abstract*—**Users rely increasingly on Location-Based Services (LBS) and automated navigation/guidance systems nowadays. However, while such services are easily implemented in outdoor environments using Global Positioning System (GPS) technology, a requirement still exists for accurate localization and guidance schemes in indoor settings. Accordingly, the present study presents a methodology based on GPS, Bluetooth Low Energy (BLE) beacons, and Near Field Communication (NFC) technology. Through establishing graphic information and the design of algorithm, this study develops a guidance system for indoor and outdoor on smartphones, with aim to provide users a smart life through this system. The presented system is implemented on a smartphone and evaluated on a student campus environment. The experimental results confirm the ability of the presented app to switch automatically from an outdoor mode to an indoor mode and to guide the user to the requested target destination via the shortest possible route.

***Keywords*—**Beacon, BLE, Dijkstra algorithm, indoor, GPS, near field communication technology.

I. Introduction

ACCORDING to statistics published by the International Telecommunication Union (ITU), the number of mobile devices in the world reached 6.835 billion at the end of 2013 [1]. Furthermore, the number of devices is still growing. As wireless technology continues to improve, and wireless networks are ever more extensively deployed, the feasibility of developing LBS has attracted growing interest [2]. LBS have many advantages from a user perspective, including convenience, efficiency and fun. As a result, they are now widely applied in social networks, traffic and geographic search systems, and even public safety [3], [4]. Of the many functions offered by LBS, those of positioning localization and guidance are some of the most useful. According to previous research, adults spend around 86.9% of their time indoors, 5.5% in vehicles and 7.6% outdoors [5]. Thus, in realizing seamless LBS applications, it is necessary to develop localization and guidance schemes capable of working in both indoor and outdoor environments, and switching between the two modes automatically as required.

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GPS technology is used widely in the navigation, tourism, measurement, and engineering fields. However, the success of GPS depends on a strong signal between the user and the navigational satellite. Thus, while GPS functions well in open outdoor environments, its performance suffers dramatically in mountainous areas or build-up urban areas. Furthermore, the signals are unable to penetrate through building structures, and hence GPS is of only limited use in indoor environments.

The literature thus contains various alternative proposals for performing indoor localization. For example, in [6], [7], the user position is estimated using a wireless communication signal, while in [8], a visible light communication system is used. The authors in [9] performed indoor positioning using radio-frequency identification (RFID) tags. In [10], user positioning was performed by mapping the activities of the user to the positions in the indoor environment at which these activities were known to be performed. Finally, in [11], multiple indoor positioning technologies were combined in order to improve the localization accuracy.

Although mobile devices are invaluable in daily life nowadays, their usefulness is limited by their short battery lives, which prompts the need for frequent recharging. To address this problem, many mobile devices use BLE technology to realize wireless communication connections. BLE has many advantages as a connection technology, including a stable signal, an ease of distribution, a low cost, and widespread compatibility with existing wireless devices. Furthermore, BLE beacons have an operating life of several months using only a simple button cell battery [12]. As a result, BLE has significant potential as an enabling technology for indoor LBS applications.

Owing to indoor environment is a complicated space. The spreading of wireless or GPS signals are easily affected by the interior structure of the building, therefore, it urgently needs precise technologies and a lot of spherical auxiliary electronic devices, leading to the difficulty in indoor precise positioning. Thus, for many years, these well-known positioning technologies such as GPS positioning system or Google map services are usually applied in public construction fundamental facilities, road or outdoor large area; however, along with the urbanization of living environment, there are more and larger complex buildings, increasing the need for indoor positioning. NFC is a short-range wireless connectivity standard which enables communications to be achieved between devices simply by touching them together or bringing them into very close proximity of one another (typically, less than 10 cm).

NFC has found widespread use nowadays for such applications as loyalty schemes, home healthcare, public transport payment, ticketing, mobile workforce management, and so on. With the ability it provides to infer the user position with an ultra-high degree of precision, NFC also has significant potential for indoor localization purposes. Thus, to enhance the application of the positioning system and enable smartphones to become a key equipment of augmented humanity which can effectively enhance the convenience, this study is based on short-distance wireless communication technology, combining NFC, BLE Beacon and GPS technology to develop a positioning guidance system which is suitable for indoor buildings. This study combines GPS, BLE and NFC technologies to realize a seamless indoor-outdoor user localization and guidance app suitable for implementation on a smart mobile device. In the proposed scheme, user localization is performed using conventional GPS technology in the outdoor environment. However, when the user enters an indoor space, the app switches automatically to an indoor mode, and user positioning is performed by means of BLE beacons and NFC tags. The positioning information obtained via the various technologies is combined with map information (outdoor and indoor) to realize a guidance system capable of leading the user to the requested target destination via the shortest available route.

The design of the system includes "storage data design", "positioning method design", "algorithm design" and "graphic design." In between, for indoor map establishment, this study designs a method which can assist in establishing positioning point storage function through wireless signal exploration (indoor space area as unit positioning base). Outdoor maps use GPS as positioning base to obtain the location information, using route maps to display the guidance results. When users are outdoors, this app will automatically adopt "outdoor mode" to obtain GPS positioning to provide users with guidance information.

The remainder of this paper is organized as follows. Section II reviews the GPS, BLE and NFC technologies used for localization purposes in this study and introduces the path-finding algorithm used to realize the indoor guidance system. Section III describes the system framework and implementation. Section IV presents and discusses the experimental evaluation results. Finally, Section V provides some brief concluding remarks.

II. Background Knowledge

This section commences by describing the GPS, BLE beacon and NFC technologies used in the present study to develop the proposed positioning and guidance system. The shortest-path algorithm used to accomplish indoor guidance is then briefly introduced.

A. GPS

GPS is a middle-distance global tracking satellite guidance system with a coverage area of more than 98% of the earth's surface. GPS can be used by any enabled device capable of receiving its signals and has the advantage of anonymity in that the user's position is not recorded as part of the communication process. However, GPS relies on the availability of a clear Line of Sight (LOS) between the user device and the satellite system. As a result, it provides only a limited positioning capability in indoor environments.

B. BLE

BLE is a communication standard designed to enable short-range wireless devices to operate for months or even years on a single coin cell battery. When combined with beacon technology, BLE provides a highly effective method for estimating the position of the user relative to certain predefined monitoring spots. BLE operates over a distance of up to 50 m and provides the means to customize the LBS offered to the user based on their physical location. For example, certain advertisements can be pushed to the user device as the user approaches a particular sales counter in a store. Similarly, the user may be presented with different notification messages and application events as he or she moves across the boundary separating one monitored area from another.

The literature contains various proposals for integrating the BLE standard with beacon technology in order to support user localization, including iBeacon, Gimbal, and AltBeacon. The beacons used in such systems periodically broadcast a wireless radio signal advertising their presence. As described above, BLE operates over a range of up to 50 m. Hence, in the event that the signal is detected (sighted) by a proximity-enabled user device, the user position can be inferred with an error of no more than 50 m. As a result, BLE/beacon technology provides a low-cost and energy-efficient solution for performing user localization with a medium degree of accuracy. The localization system proposed in the present study utilizes the Gimbal Series 10 beacon produced by Qualcomm.

C. NFC

NFC is an ultra-short distance wireless communication technology based on RFID. NFC utilizes signal attenuation technology to enable devices to conduct non-contact point-to-point data transmissions over distances of up to approximately 10 cm (3.9 inches). NFC is currently used for such applications as automated payment, ticketing, loyalty schemes, and so forth. However, with its high bandwidth and low energy consumption, NFC also has significant potential for highly-precise indoor positioning. As with the Gimbal beacon, each NFC chip has a unique ID number assigned to it by the manufacturer. Thus, by associating the ID with a physical location, and storing this information in a database, the position of the user can be inferred with an extremely high degree of precision each time a sensing event occurs.

D. Shortest-Path Algorithm

Determining the shortest route between a start point and a target end point given the availability of multiple paths between them is a common problem in many walks of life [13]. The guidance system proposed in this study utilizes the algorithm proposed by Dijkstra [14] since, of the various algorithms available, it has the advantages of being a concise algorithm and the optimal solution can be obtained.

III. System Framework and Implementation

The app proposed in this study provides the user with a seamless positioning and guidance service as he or she moves from an outdoor environment to a target destination in an indoor environment or vice versa. In other words, the app switches automatically not only from an outdoor mode to an indoor mode, but also from an indoor mode to an outdoor mode. As described in the Introduction section, positioning in the outdoor environment is performed using conventional GPS technology, while in the indoor environment it is performed using BLE beacon and NFC technologies. For both environments, the guidance function is achieved using map information stored in a remote server and downloaded to the user device as required. For illustration purposes, the present study considers the localization / guidance problem for the case of a student campus environment containing many buildings scattered over a wide geographic area with many floors and rooms within each building. As described in the following sections, the system framework comprises four design components, namely (1) storage data design, (2) positioning method design, (3) shortest-path algorithm design, and (4) map structure design.

A. Positioning Method Design

To simplify the data storage and management task, four different data structures are used to support the different functionalities of the system, namely an outdoor map structure, an indoor map structure, a Beacon positioning data structure, and an NFC positioning data structure. The localization / guidance app proposed in this study resides by default in the "outdoor mode" and uses conventional GPS technology to locate the position of the user. More specifically, the system acquires the current latitude and longitude information from the GPS system and uploads this information together with the Device ID to a remote server. On receiving this information, the server interrogates the coordinate information and returns the appropriate outdoor map to the user device using the JavaScript Object Notation (JSON) format, as shown in Fig. 1.

The JSON message sent back includes the name, address, latitude and longitude and building introduction of the destination whose format is shown in Fig. 1.

When the user moves from the outdoor environment to an indoor environment, the app switches automatically to an "indoor mode" and launches an indoor positioning routine. If the user is within wireless range of a Beacon, a sighting event occurs and the device uploads both its own ID and that of the beacon to the server. Utilizing the Factor ID as a key, the server retrieves the approximate location of the user and returns this information to the user device. When the user's smartphone approaches an NFC tag, the user can send tag ID along with the Device ID back to the server after the mobile reads the set NFC tag. The server will conduct indexing from the NFC data list and send the index results back the app to obtain the user's location and conduct indoor positioning.

```
{
  "id": 1,
  "name": "School",
  "address": "No.195, Kunda Rd.,",
  "latitude": "22.996175",
  "longitude": "120.252970",
  "info": "Kun Shan University"
  }
```

Fig. 1 JSON data format

B. Shortest-Path Algorithm Design

After obtaining the user location, the app downloads the map from the server. Specifically, the app informs the server of the Device ID and the required map ID and the server searches its database for the corresponding map and returns it to the user device.

Let G = (V, E) denote an indoor map, where V is the set of nodes in the map and E is the set of connecting edges (paths). In constructing the map, the server hosts a database with four columns, namely ID (primary index key), node ID, adjacent node ID and Distance Between Adjacent Nodes. Taking Node 2 in Fig. 2 as an example, let the nodes adjacent to Node 2 be denoted as Node 0, Node 1, Node 3 and Node 4, respectively. Furthermore, let the distances of these nodes from Node 0 be equal to 4, 2, 9 and 2, respectively.

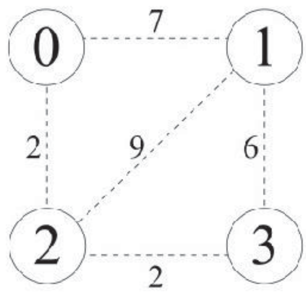


Fig. 2 Node layout scheme

The information provided in the JSON message, provides the app with the relevant indoor Shortest-path map However, the Dijkstra shortest-path algorithm requires the input information to be presented in the form of a matrix. Therefore, in implementing the indoor guidance function, the JSON map information must first be converted into a matrix form. For example, the illustrative layout in Fig. 2 contains five nodes, and should therefore be converted to a 5 × 5 matrix of the form shown in Table I.

TABLE I
Dijkstra Adjacent Matrix

Node	0	1	2	3
0	0	7	2	INF
1	7	0	9	6
2	2	9	0	2
3	INF	6	2	0

Accordingly, in the app proposed in this study, the matrix construction task is performed automatically using the function shown in (1), in which i is the number of the current node, v is the number of the adjacent node, and e is the cost of the path between them. When presented with the node map (constructed manually by the system developer), the matrix construction algorithm takes the current node and adjacent node information as an input and uses (1) to automatically generate the corresponding $n\times n$ adjacent matrix with a time complexity of O(n)).

$$\text{graph[i].adjacentEdge(v, e)} \tag{1}$$

For example, taking Node 2 in Fig. 2 for illustration purposes once again, the relation between Node 2 and its adjacent nodes has the form shown in (2). Taking the i, v and e information given in (2), the algorithm automatically constructs the matrix shown in Fig. 4.

$$\begin{aligned}&\text{graph[2].adjacentEdge(0, 4)}\\&\text{graph[2].adjacentEdge(1, 2)}\\&\text{graph[2].adjacentEdge(3, 9)}\\&\text{graph[2].adjacentEdge(4, 2)}\end{aligned} \tag{2}$$

C. Map Structure Design

In general, the success of any app is determined to a large extent by the appearance and intuitiveness of its graphical user interface (GUI). For a guidance system such as that is proposed in the present study, a pictorial map with too much detailed information will serve simply to confuse the user. Consequently, in the proposed app, the indoor and outdoor maps are presented in the form of metro-like maps, in which the key locations (e.g., buildings, offices, classrooms, toilets, and so on) are represented as nodes and the distances between them are indicated by numerals placed alongside the corresponding paths (see Fig. 3).

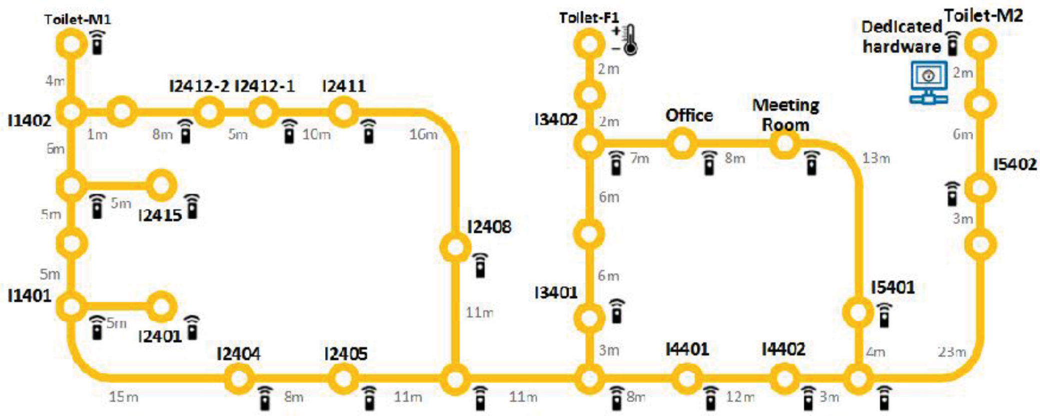


Fig. 3 Map representation

As discussed above, having determined the user's current location, the app requests the appropriate map from the server and then stores the received map in the device. Notably, the map is downloaded in its entirety, and hence the need for repeated download events is avoided. Having downloaded the map, the user then selects the target destination (i.e., node) for which they require routing information. To ensure smooth node selection, the app stores an acceptable touch range error in addition to the coordinates of each node center.

When the user touches the screen to select a particular destination node, the app determines the intended node in accordance with (3), in which X1 and Y1 are the stored coordinates of the node center, X2 and Y2 are the coordinates of the point at which the user touches the screen, and r is the allowable touch range error.

$$|X_1 - X_2|^2 + |Y_1 - Y_2|^2 < r^2 \tag{3}$$

Having established the user's present location, and his or her intended destination, the app invokes Dijkstra's shortest-path algorithm and marks the suggested route pictorially on the node map.

IV. Implementation Results

A. System Implementation and Function Display

Performance evaluation trials were performed on a university campus in Taiwan, with the aim being to guide the user to a specific target in the building shown in Fig. 4. As shown, seven beacons and 31 NFC tags were placed at appropriate points throughout the experimental field, e.g., on the doors of the main rooms in the building, at the entrances to staircases, at forks or corners in the corridors, and so on. Due to their lower cost, the NFC tags greatly outnumbered the beacons, and were placed with an approximate spacing of 2 ~ 15 m.

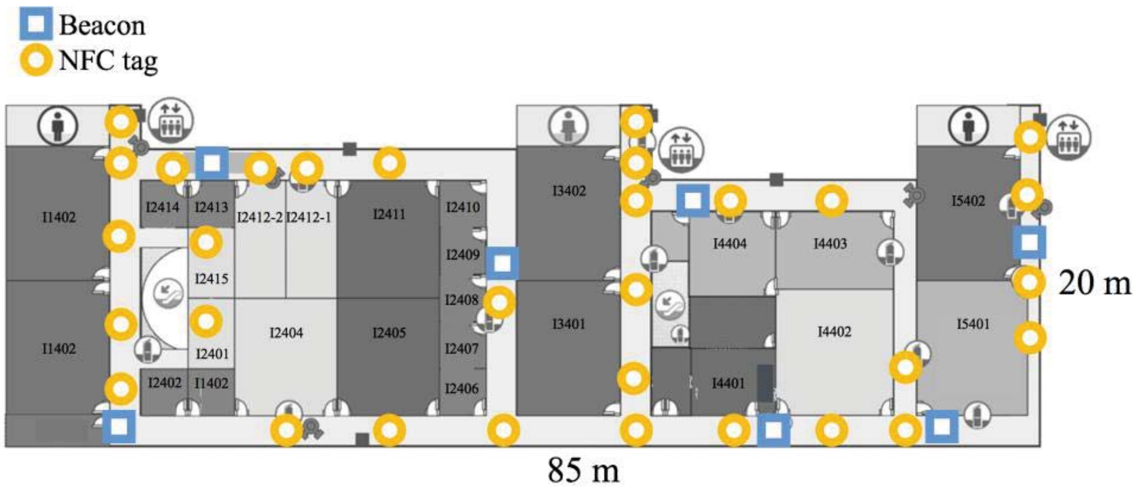
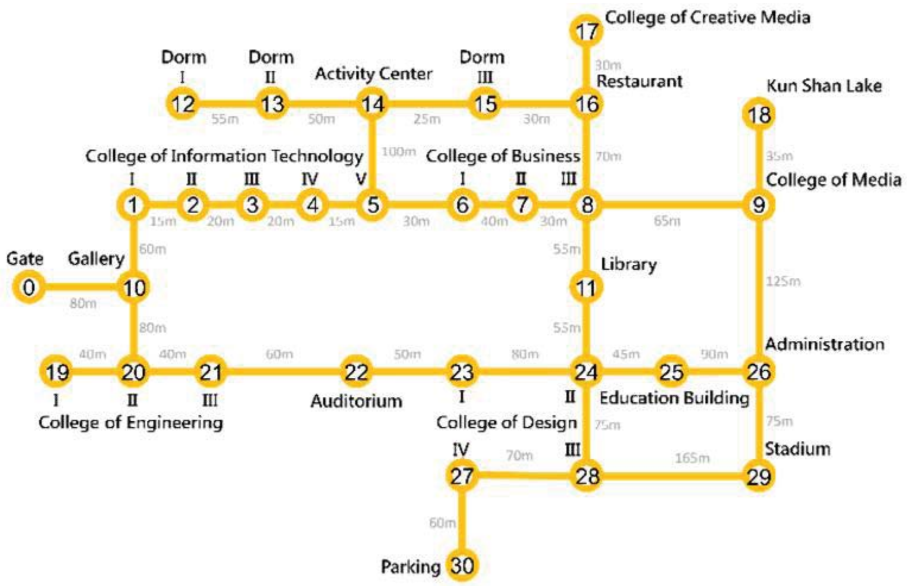


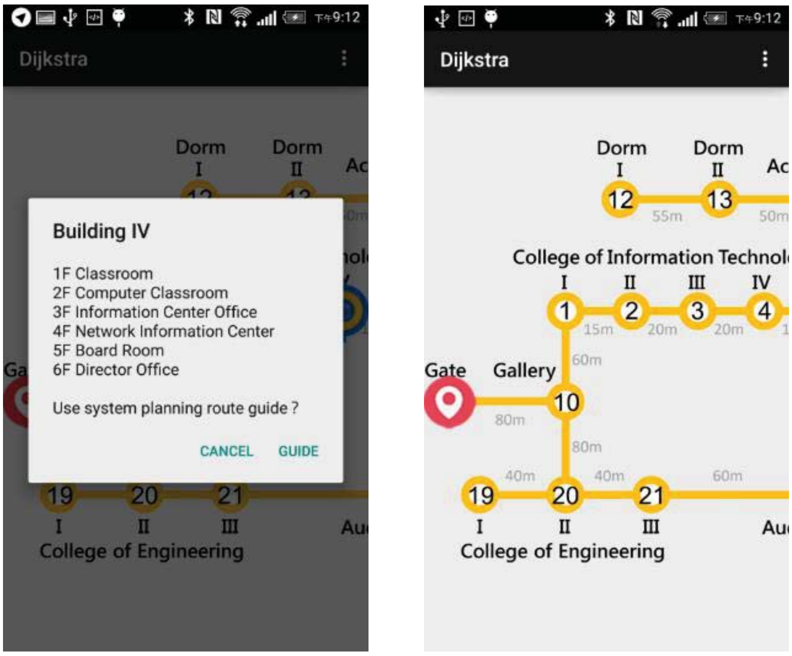
Fig. 4 IoT Building in Department of Computing and Communication at Kun Shan University, Taiwan

When the app is launched, the system first checks the status of the communication services of the user device and issues a notification message if required. The system then performs a localization routine to establish the user position. If the app senses a GPS signal, it loads the outdoor map and marks the user location accordingly. By contrast, if the app detects a Beacon or NFC signal, it loads the appropriate indoor map and again marks the user location as appropriate. Having received the map (indoor or outdoor), the user selects the destination node (e.g., a campus building or a room within the present building), and the app launches the shortest-path route discovery routine and marks the identified route on the map accordingly.

As shown in Fig. 5 (a), if the user is outdoors, the app automatically lists the main destinations within the closest building (Fig. 5 (b)) and indicates the user's location on the map (Fig. 5 (c)). The app then asks the user if a guidance function is required (Fig. 6). If the user requests guidance, the app searches for the shortest-path to the selected destination and then plots the route on the map (Fig. 7).



(a) Outdoor map overview



(b) Nearby building information (c) Position of user

Fig. 5 User located outside

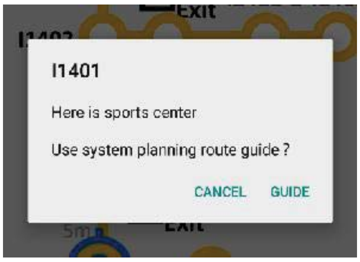
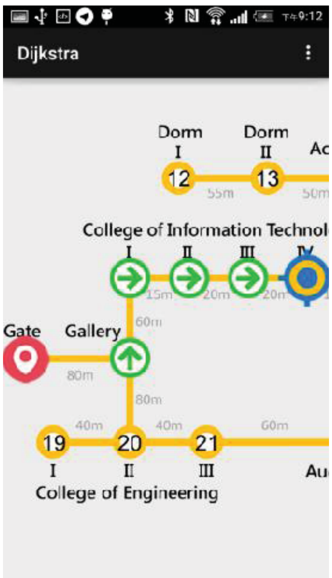
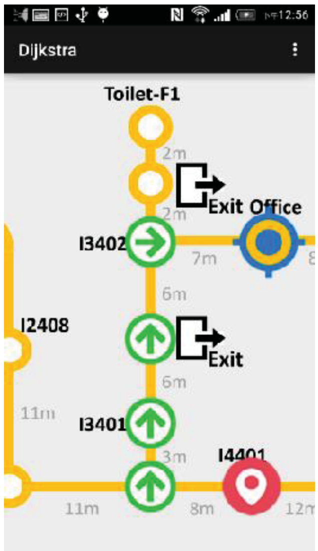


Fig. 6 Guidance notification



(a) Outdoor navigation aid



(b) Indoor navigation aid

Fig. 7 Navigation aid

B. Experimental Design and Results

The performance of the proposed app was evaluated by comparing the time spent by four users in finding their way from the main campus entrance to a particular classroom within a certain building with and without the assistance of the localization / guidance system, respectively. In performing the experiments, the process of navigating to the classroom was separated into six steps, namely (1) looking for campus map; (2) find the target building; (3) search for indoor floor layout;

(4) reach the floor; and, (5) reach the destination. Thus, we record the spent time in various steps as reference. As shown in Figs. 16 and 17, the total time spent by each user in reaching the target was divided into four separate times, namely the time taken in moving from the main campus gate to the first destination sign at Spot A; the time spent in moving from Spot A to the target building (Spot B); the time spent in walking from Spot B to the destination sign located in the building at Spot C; and the time taken in moving from Spot C to the target classroom at No I4401.

Tables II-A and II-B show the timing results obtained for the four users. Note that Users 1 and 2 performed the search process in a non-assisted manner, while Users 3 and 4 both used the app. As shown, Users 1 and 2 completed the search process in 281.7 s and 333.9 s, respectively (i.e., an average search time of 307.8 s). Since Users 3 and 4 used the guidance app, they did not need to locate the direction signs at Spots A and C, respectively. Consequently, the total search times for the two users were just 206.48 s and 202.3 s, respectively (i.e., an average search time of 204.39 seconds). In other words, the mean time of the assisted users was 33.59% shorter than that of the two non-assisted users.

TABLE II-A
TIMES SPENT BY FOUR USERS IN COMPLETING EACH STAGE OF SEARCH PROCESS: SEARCH TIMES OF FOUR USERS (UNIT: S)

Name	Spot A	Spot B	Spot C	Spot D
Subject 1	43.87	113.93	118.97	4.93
Subject 2	23.4	153.6	128	28
Subject 3	N/A	109.43	N/A	97.05
Subject 4	N/A	129.9	N/A	72.4

TABLE II-B
TIMES SPENT BY FOUR USERS IN COMPLETING EACH STAGE OF SEARCH PROCESS:(B) TOTAL SEARCH TIMES OF FOUR USERS AND AVERAGE SAVED TIME (UNIT: S)

Name	Total	Percentage of Time Saving
Subject 1	281.7	0%
Subject 2	333.9	-18.53%
Subject 3	206.48	26.8%
Subject 4	202.3	28.18%

V. CONCLUSION

With the emergence of LBS, the need to locate the position of the user with a high degree of accuracy has emerged as an important concern. Accordingly, this study has proposed an app based on GPS, Bluetooth Beacon and NFC technology for providing both a user localization service and an automatic guidance function. Importantly, the app functions in both outdoor and indoor environments, and thus provides a seamless localization / guidance function as the user moves from one environment to the other. The feasibility of the proposed system has been demonstrated by means of localization and guidance tests on a typical student campus building.

VI. CONCLUSION

A conclusion section is not required. Although a conclusion may review the main points of the paper, do not replicate the abstract as the conclusion. A conclusion might elaborate on the importance of the work or suggest applications and extensions.

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