A Route Guidance System for Car Finding in Indoor Parking Garages

Pei-Chun Lee, Sheng-Shih Wang

***Abstract*—**This paper presents a route guidance system for car owners to find their cars in parking garages. The presents system comprises a positioning-assisting subsystem and a car-finding mobile app. The positioning-assisting subsystem mainly uses the iBeacon technology for indoor positioning. The car-finding mobile app guides car owners to their cars based on a non-map navigation strategy. This study also designs a virtual coordinate system to support identifying the locations of parking spaces and iBeacon devices. We use Arduino and Android as the platforms to implement the proposed positioning-assisting subsystem and car-finding mobile app, respectively. We have also deployed the system in a parking garage in our campus for testing. Experimental results verify that our system can efficiently and correctly guide car owners to the parking spaces of their cars.

***Keywords*—**Guidance, iBeacon, mobile app, navigation.

I. Introduction

PARKING management is one of the important services of intelligent transportation systems because of the largely growing number of cars worldwide. In parking management, the Parking Guidance and Information System (PGIS) has already been accepted as a significant service [1]; however, another noteworthy service is the car finding service. It is fairly common for people to forget where they have parked their cars, especially in parking garages or structures. Therefore, finding a parked car is a great challenge for many people, especially in the case of massive parking garages.

The key factors to realize car finding services in the indoor environment are localization mechanisms and guidance information presentation. Global Positioning System (GPS) has become a widely used localization scheme for outdoor environments, but it is not applicable for indoor environments because of inaccurate positioning caused by environmental limitations. A more suitable indoor localization technology is the micro-location technique based on iBeacon technology. The iBeacon technology operates over Bluetooth Low Energy (BLE) which is power-saving and low-cost, and is already being deployed in various environments [2], [3]. Hence, the iBeacon technology can be a very appropriate solution for localization in indoor parking environments, such as parking garages. On the other hand, guidance information presentation also plays an important role in car finding services. Since the use of smartphones and mobile apps are prevalent nowadays, it is quite suitable to present guidance information via smartphones with guidance mobile apps [8]-[14]. It is feasible to provide users with precise, real-time car-finding guidance information.

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This study develops a car-finding guidance system for indoor parking garages. The proposed system is based on iBeacon technology and aims to provide users with correct and effective guidance information. Users can precisely pinpoint the location of their car via their own smartphones with our car-finding app. In order to determine each parking space and iBeacon device, a virtual coordinate system and a car-finding algorithm based on the proposed virtual coordinate system was designed. Furthermore, the proposed system adopts a Turn-by-Turn guidance strategy [4], [5]; that is, the system simply provides an indication about the walking direction at the next junction without detailed map information, and only when the user enters the target aisle (the aisle in the parking module or bay [6], [7] where the user parked his/her car), does the system show the detailed map information of the target parking module (consisting of the target aisle and the parking spaces beside the target aisle) with the destination (the parking space where he/she parked the car).

The rest of this paper is organized as follows. Section II describes the model and assumptions of the proposed system. Section III presents our route guidance system in detail. Section IV explains the system implementation and experimental results. Finally, Section V concludes this paper.

II. System Model and Assumptions

For simplicity, the parking garage in this research exemplifies a rectangular-shaped parking site with 90-degree parking (perpendicular parking spaces) [15] as in Fig. 1. The pedestrian access is in the bottom left corner. Every parking space has a unique number. Every aisle has an iBeacon device deployed in the middle (the triangles in Fig. 1) to assist in user localization. We use the power control mechanism to adjust the transmission power of each iBeacon device so that every user's smartphone only receives the iBeacon signal transmitted by the iBeacon device deployed on the aisle in which the user is located.

This paper considers the following assumptions:

1) Users enter or exit the parking garage only via the pedestrian access;
2) Users do not randomly walk but only walk alongside the aisles;
3) Users' smartphones have built-in Bluetooth modules, and have already had our car-finding app installed;
4) Users follow the routing guidance advised by the proposed

system;

5) Users' orientation always conforms to the routing guidance direction indicated by the proposed system.

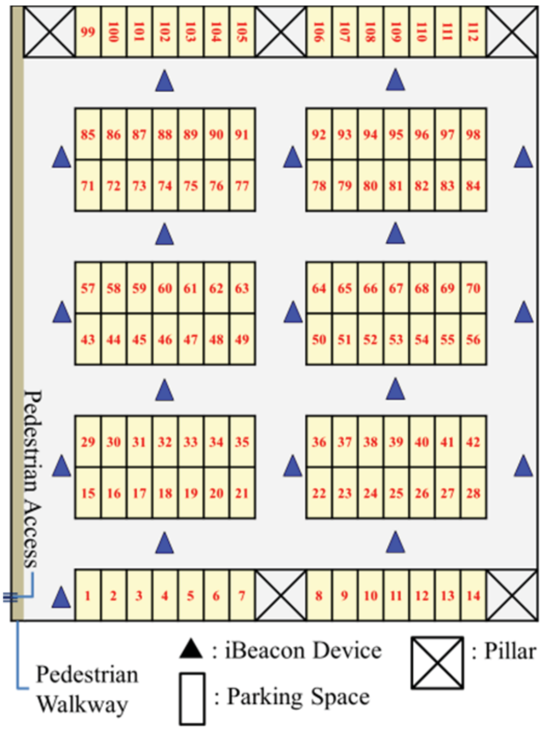

Fig. 1 Parking layout exemplified in this research

III. Proposed Route Guidance System

A. Guidance Strategies

The presents system adopts two guidance strategies:

1) Non-map navigation strategy (Turn-by-turn guidance strategy): if the user has not entered the target aisle, the proposed system only provides an indication about the walking direction (walk straight, turn right, or turn left) at the next junction. Only when the user enters the target aisle, the system shows the detailed map information of the target parking module with the destination (the parking space where he/she parked the car) emphasized. By this strategy, users need only to pay minimal attention to necessary and useful guidance information (i.e., the walking direction at the next junction), being relieved from pressure and confusion caused by unnecessary, complicated entire-map information.

2) Walk-straight-first strategy: this strategy aims to provide the user with the route which has the minimum number of changing directions (turning left or right) at junctions, further reducing the pressure for users to reach their cars. Fig. 2 elaborates this strategy as follows: Assume that the destination (parking location) is the parking space with number *X*. Spot ① indicates the entry to the target parking space *X*. If a user needs to move from the pedestrian access to the destination entry ①, there are actually three possible routes with same distance: A, B, and C. Route A requires only one turn at ②, whereas routes B and C both require three turns at ③-④-⑤ and ⑥-⑦-⑤, respectively. Because route A requires the least number of direction changes, the proposed system will suggest the turn-by-turn non-map guidance along route A to the user based on the walk-straight-first strategy.

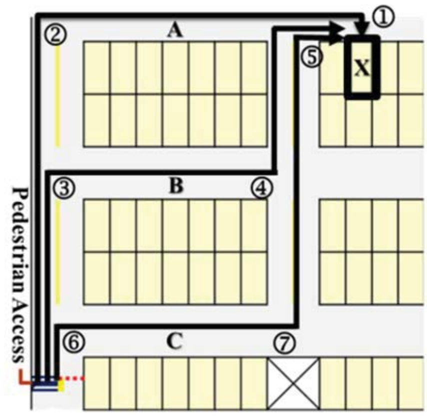

Fig. 2 Illustration of walk-straight-first strategy

B. Virtual Coordinate System

Recall that the proposed system adopts iBeacon technology to assist in indoor positioning. Without the help of the longitude and latitude coordinates used in outdoor environments, this research proposes a virtual coordinate system for parking garages to assist in the localization of each parking space and iBeacon device. The proposed virtual coordinate system is a two-dimensional coordinate system. The units of the horizontal axis (*x*-axis) and vertical axis (*y*-axis) are both the same length as the stall width (the width of a parking space).

Fig. 3 illustrates the concept of the proposed virtual coordinate system by demonstrating how we design a virtual coordinate system for the parking layout exemplified in Fig. 1. The coordinates of the pedestrian access are (0, 1). Each parking space and iBeacon device has unique coordinates. For example, the coordinates of the iBeacon device nearest to the pedestrian access are (2, 1); the coordinates of parking space A are (12, 7); the coordinates of parking space B are (14, 11); the coordinates of the iBeacon device located on the aisle between parking spaces A and B are (15, 9).

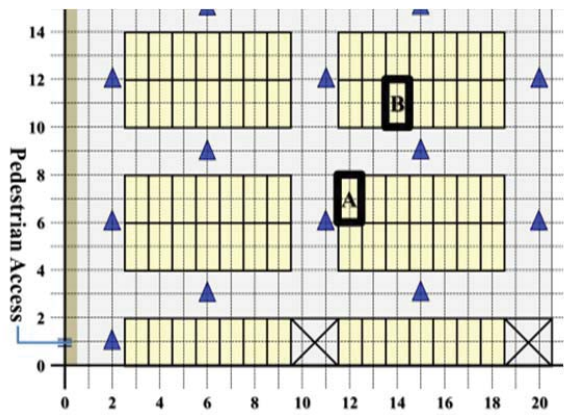

Fig. 3 Concept of the proposed virtual coordinate system

In our system, when users want to find parking locations, they can provide the target parking space number to the car-finding app, and the app is able to translate the parking space number to its corresponding virtual coordinates. The proposed system considers the dynamic mapping method to correlate the parking space numbers and the virtual coordinates. That is, we use a conversion formula to calculate the virtual coordinates of a parking space from the parking space number. This kind of mapping does not require any storage of pairs of parking space numbers and virtual coordinates in the database, but only converts the target parking space number to its corresponding virtual coordinates when necessary.

Fig. 4 illustrates the notations which we use to develop the dynamic mapping conversion formula for the parking layout in Fig. 1. Let (x_m, y_m) be the corresponding virtual coordinates of parking space number m, W be the width of the parking garage with the unit of stall width (e.g., $W = 20.5$ in Fig. 4), N^H be the total number of parking spaces on one side of a parking module (bay) (e.g., $N^H = 7$ in Fig. 4), N^B be the total number of parking modules in a single horizontal line (e.g., $N^B = 2$ in Fig. 4). Then, we can derive N^B as:

$$N^B = \frac{W-2.5}{N^H+2}. \qquad (1)$$

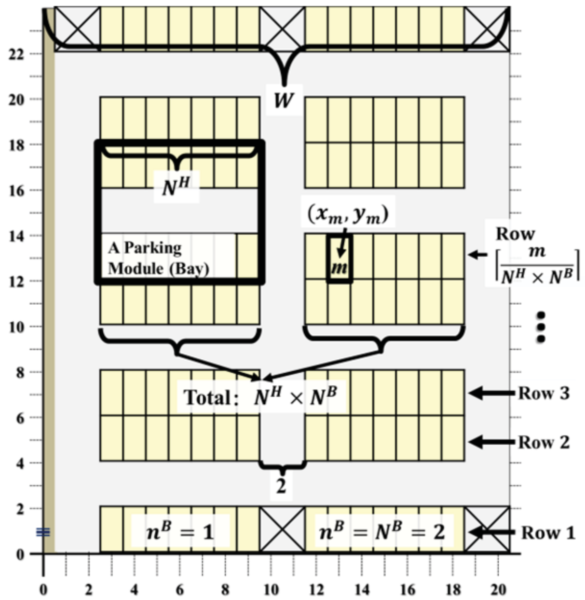

Fig. 4 Illustration of notations in the conversion formula

Let n^B be the serial number of the parking modules in a single horizontal line ($n^B = 1, 2, \ldots, N^B$ from left to right). Then n^B can be derived from:

$$n^B = \begin{cases} \left\lceil \frac{m}{N^H} \right\rceil \% \, N^B, & \text{if} \left\lceil \frac{m}{N^H} \right\rceil \% \, N^B \neq 0; \\ N^B, & \text{otherwise.} \end{cases} \qquad (2)$$

By (1) and (2), we have:

$$x_m = \begin{cases} m\%(N^H \cdot N^B) + 2 \cdot (n^B - 1) + 2, & \text{if } m\%(N^H \cdot N^B) \neq 0; \\ N^H \cdot N^B + 2 \cdot (n^B - 1) + 2, & \text{otherwise.} \end{cases} \qquad (3)$$

$$y_m = \begin{cases} 3 \cdot \left(\left\lceil \frac{m}{N^H \cdot N^B} \right\rceil - 1 \right) + 1, & \text{if } \left\lceil \frac{m}{N^H \cdot N^B} \right\rceil \%2 \neq 0; \\ 3 \cdot \left\lceil \frac{m}{N^H \cdot N^B} \right\rceil - 1, & \text{otherwise.} \end{cases} \qquad (4)$$

C. Positioning-Assisting Subsystem

The positioning-assisting subsystem is composed of the iBeacon devices. These iBeacon devices are deployed in the parking garage, where each iBeacon device periodically broadcasts location frames (containing the virtual coordinates of each iBeacon device) to assist in the self-localization of users' smartphones. When the proposed car-finding app is activated and the user's smartphone receives a location frame, the proposed car-finding app will proceed with self-localization and generate car-finding guidance information. Because the iBeacon devices have to broadcast their virtual coordinates, we modify the original iBeacon frame format by writing the *x* coordinate and *y* coordinate of the iBeacon device into the Major field and Minor field, respectively, as shown in Fig. 5.

Octets : 1	4	2	6	31	3
Preamble	Access Address	Header	MAC Address	Data	CRC

Octets : 9	16	2	2	2
iBeacon prefix	Proximity UUID	**Major**	**Minor**	TX power

Fig. 5 Format of the location frame in the proposed system

D. Car-Finding App

To provide the route guidance function, the proposed car-finding app has to locate where the user is positioned within the parking garage. Even so, this app does not need to diagnose the exact position of the user, but only needs to know *in which aisle* the user is located according to the information in the iBeacon location frame received. On the other hand, as for the route guidance strategy, the proposed app adopts the turn-by-turn non-map navigation strategy and walk-straight-first strategy, which are elaborated as follows.

First, when the proposed app receives an iBeacon location frame from some iBeacon device, it will derive the next expectant iBeacon device coordinates going to be received. If later the user's smartphone does receive the expectant iBeacon location frame, the proposed app will keep directing the user with the same guidance strategy. However, once the user's smartphone receives an unexpected iBeacon location frame, the proposed app will find that the user has not followed the guidance provided by the proposed system, and indicates the user go back to the previous junction and follow the advised path directions. Then, because the pedestrian access is located in the bottom left corner of the parking garage in this research (see Fig. 3), the target parking space is always located on the right or upper right side of the pedestrian access. Therefore, we can infer two rules for the proposed app to derive correct route guidance information.

1) Under the condition that an iBeacon location frame received is sent by the iBeacon device located on a vertical aisle, if a right turn should be made at the junction ahead,

then the proposed app shall indicate a right turn; otherwise, the app shall indicate to walk straight at the junction ahead.

2) Under the condition that an iBeacon location frame received is sent by the iBeacon device located on a horizontal aisle, if this iBeacon device is located on the target aisle, the proposed app shall know that the user has arrived at the target parking module; otherwise, the app shall indicate to walk straight at the junction ahead.

Following these two rules, Fig. 6 illustrates the proposed car-finding algorithm which is activated when the car-finding app receives an iBeacon location frame.

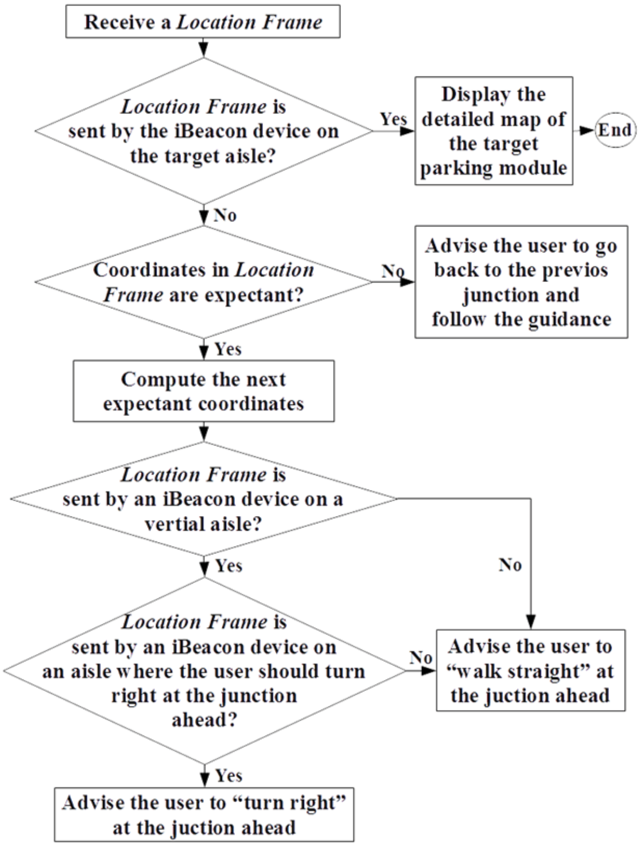

Fig. 6 Flow chart of the proposed car-finding algorithm

IV. System Implementation and Experimental Results

A. System Implementation

The proposed system consists of the positioning-assisting subsystem and the car-finding app. The positioning-assisting subsystem provides localization information to the car-finding app via iBeacon location frames. The car-finding app takes care of target parking space setup, route guidance planning, and guidance information presentation. Fig. 7 shows the main hardware and software function blocks of the proposed system.

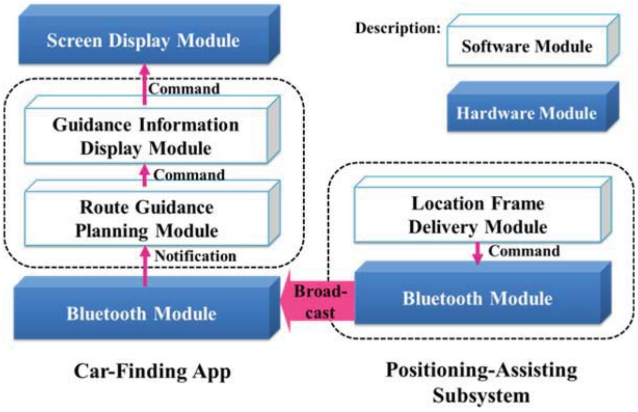

Fig. 7 Function blocks of the proposed system

In the proposed system, the car-finding app is implemented using Java with Eclipse IDE and installed on an Android smartphone. Besides the functions of target parking space setup, route guidance planning, and guidance information presentation, a subroutine to receive the iBeacon location frames is also written in the car-finding app. On the other hand, the positioning-assisting subsystem is implemented using the DFRobot Bluno module as the iBeacon device. DFRobot Bluno [16] integrates the BLE module into Arduino UNO and supports the iBeacon technology. A location frame delivery sketch is written and burnt to the DFRobot Bluno module to broadcast the iBeacon location frames periodically.

Lastly, the transmission and reception of the iBeacon location frames between the positioning-assisting subsystem and smartphones are performed by the Bluetooth modules on both sides.

B. Experimental Results

To verify the correctness and effectiveness of the proposed system, we deployed the positioning-assisting subsystem in the underground parking of the College of Management at Minghsin University of Science and Technology and tested the implemented prototyping system. Also, we installed the proposed car-finding app in our Android smartphone to conduct the following experiments.

First, we assumed that the car was parked at parking space number 23. We recorded the parking space number in the car-finding app before we left the parked car. Later, when we came back to the pedestrian access of the parking garage, we activated the car-finding app and entered the parking space number to start the route guidance function. Upon activating the route guidance function, the car-finding app started to guide us turn by turn with the non-map navigation strategy according to the iBeacon location frames received.

Fig. 8 shows the experimental result of route guidance. At first, the car-finding app indicated us to turn right at the first junction we were going to meet, as in Fig. 8 (a). Following the directions, we then walked onto the next aisle and noticed that the car-finding app advised to continue to walk straight at the second junction we were going to meet, as in Fig. 8 (b). Continuing on to the next aisle, the car-finding app displayed the map information of the target parking module and highlighted the target parking space on the map with the parking space number specified, as in Fig. 8 (c).

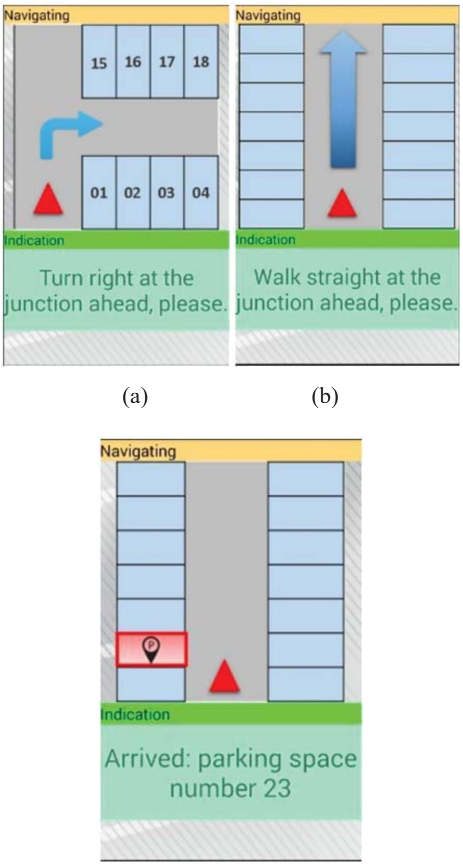

Fig. 8 Process of car-finding route guidance

It is worth highlighting that before the user arrives at the target parking aisle, the car-finding app only shows a simple indication about walking direction (turn right or walk straight) at the junction ahead, as in Figs. 8 (a) and (b). Only when the user has arrived at the target aisle does the car-finding app presents the map information of the target parking module and emphasizes the target parking space with the space number specified, as in Fig. 8 (c). These experimental results show that the proposed system did guide us back to parking space number 23 based on our design, and therefore verify the correctness and effectiveness of the proposed system.

V. Conclusion

This paper has proposed a car-finding route guidance system for indoor parking garages. The proposed system integrates iBeacon technology and a proposed virtual coordinate system concept to assist in the localization of parking spaces and iBeacon devices. The proposed system consists of the positioning-assisting subsystem and car-finding app. A novel car-finding algorithm is designed with the walk-straight-first and turn-by-turn non-map navigation strategies to eliminate the car-finding pressure or confusion caused by complicated, entire map and route information. The latter strategy provides users with non-map simple directions at each junction (walk straight or turn right) prior to the user reaching the target aisle. Only when the user arrives at the target aisle does the car-finding app show the map information of the target parking module and highlights the target parking space with the space number specified. The prototyping system is mainly implemented by the iBeacon technology, BLE, Arduino embedded system, and mobile app. The experimental results verify the correctness and effectiveness of the proposed system.

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