GuidingAll: A Smart Proactive iBeacon System with Crowdsourced Sensing Based on IoT Technologies

Lien-Wu Chen, Jun-Xian Liu, and Wei-Chu Huang
Department of Information Engineering and Computer Science, Feng Chia University, Taichung 407, Taiwan
Email: lwuchen@fcu.edu.tw; jxl.wood@gmail.com; g085785@gmail.com

***Abstract*—This paper designs and implements a smart proactive iBeacon system, called GuidingAll, using smartphones to detect abnormal events, guide mobile users, and find moving targets through Internet of Things (IoT) technologies. The GuidingAll system consists of the smartphone APP, guiding server, fixed iBeacon, and our designed smart iBeacon. The smartphone APP is used for real-time guiding and crowdsourced sensing through fixed iBeacons and nearby smartphones. The guiding server is employed for fastest path planning and moving target localization based on the sensing data reported by participating smartphones. The fixed iBeacons are deployed to provide indoor positioning information to smartphones with Bluetooth Low Energy (BLE) scanning, whereas the smart iBeacon is designed to enable proactive event detection and target BLE broadcasting through integrated sensors and associated iBeacon, respectively. In particular, mobile users with smartphones can form crowdsourced sensing networks in places with fixed iBeacons, and GuidingAll can continuously monitor and cooperatively find a specific moving target equipped with the smart iBeacon. An Android-based prototype with fixed and smart iBeacons is implemented to verify the feasibility and correctness of our GuidingAll system.**

Keywords: Event Recognition; iBeacon; Internet of Things; Crowdsourced Sensing; Mobile Device.

I. Introduction

The penetration of smartphones/tablets, the popularity of mobile communications/networks, and the development of embedded devices/sensors have made *crowdsourced sensing networks (CSNs)* possible. The widespread mobility of smartphone/tablet users, the event detection capability of embedded devices/sensors, and instant communications between embedded devices/sensors and nearby smartphones/tablets can be explored through CSNs to achieve large-scale, high-accuracy, and low-cost sensing results. Through the collection and distribution of individual status and environmental information in CSNs, living quality (e.g, air quality detection/surrounding noise measurement), physical safety (e.g., child/elder behavior monitoring), and mobility efficiency (e.g., traveling/queuing time estimation) can be further improved [1].

On the other hand, Internet of Things (IoT) localization devices (e.g., iBeacon devices [2], RFID tags/readers [3], etc.) have been adopted for time-efficient indoor navigation and evacuation [4]. In particular, through the cooperation of iBeacon devices (with BLE broadcasting) and crowdsourced smartphones (with BLE scanning), a moving target with the associated mobile iBeacon can be cooperatively tracked based on the periodic reported locations of smartphone users. Crowdsourced applications and systems, such as Fine-Grained Monitoring of Air Quality [5], Unobtrusive Recommendation of Privacy Permission [6], and Real-Time Estimation of Queue Time [7], have been developed based on CSNs.

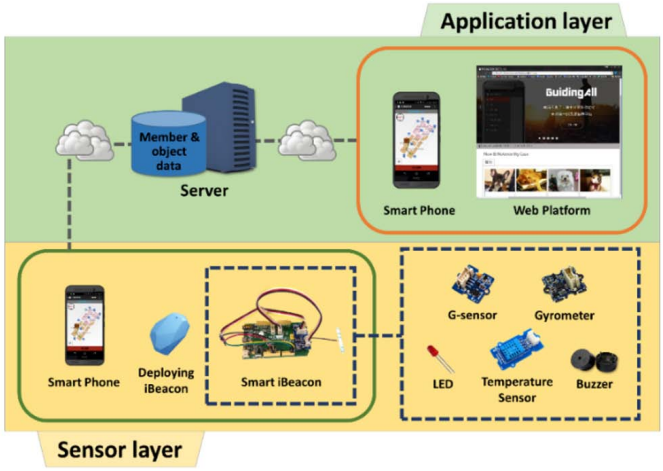

Fig. 1. System architecture of GuidingAll.

In this work, we design and implement a smart proactive iBeacon system, called GuidingAll, using embedded devices/sensors to actively detect abnormal events and employing nearby smartphones to cooperatively find moving targets through IoT localization technologies. The GuidingAll system consists of the smartphone APP, guiding server, fixed iBeacon, and our designed smart iBeacon. The smartphone APP uses fixed iBeacons and nearby smartphones to perform real-time guiding and crowdsourced sensing. The guiding server employs the sensing data reported by participating smartphones to localize moving targets and plan the fastest paths to the localized targets. Indoor positioning information is provided to smartphones with BLE scanning through fixed iBeacons, whereas proactive event detection and target BLE broadcasting are enabled through our designed smart iBeacon with integrated sensors and associated iBeacon, respectively.

In particular, mobile users with smartphones can form CSNs in places with fixed iBeacons, and moving targets can be monitored and localized with the smart iBeacon in CSNs. GuidingAll can cooperatively find and track a specific moving target equipped with the smart iBeacon. The convolutional neural network based behavior recognition method is designed to improve the recognition success rate and false alarm rate of the smart iBeacon for precisely detecting abnormal events. To verify the feasibility and correctness of our GuidingAll system, an Android-based prototype with fixed iBeacons (for indoor positioning) and smart iBeacons (for event detection and target localization) is implemented.

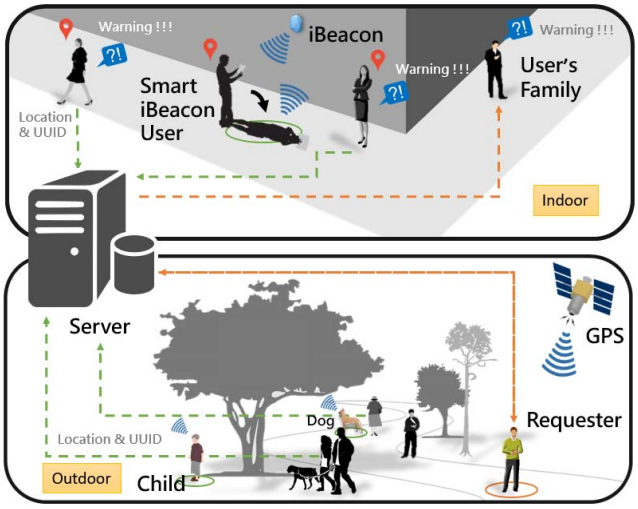

Fig. 2. Application scenarios using GuidingAll.

II. System Design

Fig. 1 shows the system architecture of GuidingAll. Fixed and smart iBeacons are deployed in the indoor space for positioning and equipped on the moving target for sensing, respectively. The guiding server stores and maintains the member information of GuidingAll users and the registered smart iBeacon UUIDs of moving targets. The crowdsourced sensing data of user positions and moving targets are reported by participating smartphones with BLE scanning to fixed and smart iBeacons through the Internet, respectively. The collected user and target positions are used to plan the guiding paths to the destination places/target locations. In the application layer, a smartphone or tablet can be used to monitor the current status of moving targets, receive the warning messages form smart iBeacons, and show the crowdsourced trajectories of tracked targets on the touchscreen. In addition, a Web platform is provided to post target finding announcement with awarded prices (provided by guardians/owners) and display up-to-date locations of moving targets reported by participating smartphones (only for guardians/owners).

In the sensor layer, the smart iBeacon consisting of the associated iBeacon and integrated sensors (e.g., 3-axis accelerometer, gyrometer, thermometer, etc.) is equipped on the moving target (e.g., child, elder, pet, etc.) to actively detect the abnormal events occurred at targets, instantly send the warning messages of detected events to guardians/owners, and continuously broadcast the UUID signals of the smart iBeacon to nearby smartphones for crowdsourced sensing. As shown in Fig. 2, application scenarios of GuidingAll include using the smart iBeacon to detect the unexpected holding up for a child, fall-over accident for an elder, and unusual breathing/tempature for a pet and to notify their guardians/owners with those abnormal events for immediate help/rescue as necessary. In addition, when target children, elders, or pets are lost/stolen, they can be cooperatively found by nearby smartphones through the broadcasting UUIDs of their associated smart iBeacons.

Fig. 3 shows the operation flow of GuidingAll for abnormal event detection, moving target localization, and diverse

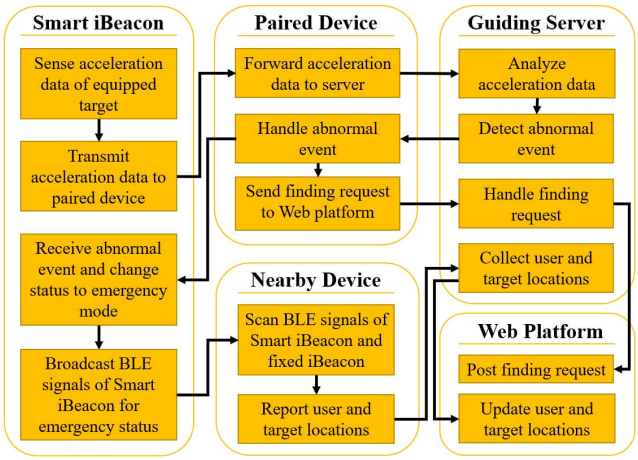

Fig. 3. Operation flow of GuidingAll.

destination guiding. Through fixed iBeacon deployment, the strongest iBeacon signal received by smartphones can be used to determine the current positions of mobile users by mapping the iBeacon UUID to the deployed position. For moving target localization and diverse destination guiding, the guiding server keeps collecting the mapped positions of mobile users. Through smart iBeacon equipment, the behaviors of the smart-iBeacon-equipped target can be kept sensing and recognizing to detect abnormal events and to warn its guardians/owners in a real-time manner. Moreover, the smart-iBeacon-equipped target can be detected and tracked through the associated UUID signals received by nearby target-detecting smartphones and reported to the guiding server with the mapped fixed iBeacon locations when the target is lost/stolen. The guardians/owners of the missing target can be properly guided to its up-to-date location through crowdsourced sensing networks formed by mobile users with smartphones, indoor places with fixed iBeacons, and moving targets with smart iBeacons.

In GuidingAll, the total moving and escaping times of mobile users can be minimized through planning the fastest guiding path and escaping route based on our previous work [4] for time-efficient indoor navigation and evacuation, respectively. In addition, the smart iBeacon is further designed to actively recognize abnormal behaviors using the integrated inertial sensors and cooperatively find moving targets using the associated mobile iBeacon. For dynamic crowdsourced sensing environments, the moving target can be precisely localized with different numbers of participating smartphones [8]. In particular, instead of fixed iBeacon positions, GPS locations can be used in GuidingAll for destination guiding and target sensing when fixed iBeacons signals are unavailable in outdoor spaces.

III. System Implementation

We have developed an Android-based GuidingAll system consisting of iBeacon iB07-C2450 nodes (i.e., fixed iBeacons), smartphones (i.e., user/guardian devices), a notebook computer (i.e., guiding server/Web platform), and an Arduino UNO R3 development board [9] with ADXL345 3-axis accelerometer and HM-10 mobile iBeacon modules (i.e., smart iBeacon). The fixed iBeacons (iB07-C2450 with TI CC2541 [10] Bluetooth 4.0 chip) are deployed in the field trial space and powered

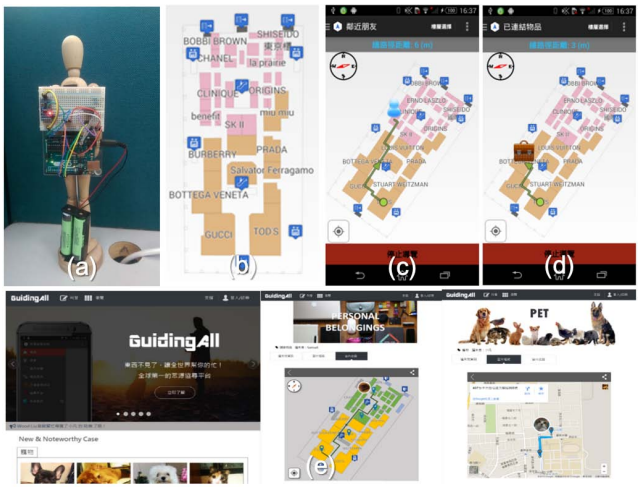

Fig. 4. Smart iBeacon, APP interfaces, and Web platform.

by a CR2450 coin battery, whereas the smart iBeacon is equipped on the target individual/object and powered by two AA batteries, as shown in Fig. 4(a).

The blueprint of a famous department store in Taiwan is adopted to draw the vector-typed and rotatable map using the SAILS SDK [11] for implementing diverse destination guiding and moving target localization, as shown in Fig. 4(b). For diverse destination guiding, the GuidingAll App displays the department store map that is around the nearest fixed iBeacon (with the strongest BLE signal). Moreover, the fastest guiding path to a destination place, friend location, or emergency exit can be provided to mobile users on the smartphone, as shown in Fig. 4(c).

Moving target localization can be manually requested by guardians/owners (as necessary) and automatically triggered by the smart iBeacon (as detecting abnormal events). The mapped fixed iBeacon positions are periodically sent by the smartphones of mobile users and the sensed smart iBeacon UUIDs of moving targets are continuously reported to the guiding server. Thus, the fastest guiding path from the requesting/notified user's location to the reported position of the target individual/object can be planned and replied by the guiding server, as shown in Fig. 4(d). In particular, the guardians/owners can further post target finding announcement with awarded prices on the Web platform of GuidingAll to provide the incentive and motivation of participating crowd-sourced sensing (for increasing the finding success probability) when their target individuals/objects are lost/stolen, as shown in Fig. 4(e).

For limited-space desktop demonstration (i.e., in a small space only with a table), numbers of smartphones and a wooden doll equipped with the smart iBeacon are used to demonstrate our GuidingAll system by simulating crowd-sourced target sensing and abnormal event detection in the department store, as shown in Fig. 5(a). In addition, several iBeacon iB07-C2450 devices, each powered by a coin battery and used as a fixed iBeacon, are placed on the large-size printed map of the department store for providing the location mapping. During the system demonstration, as shown

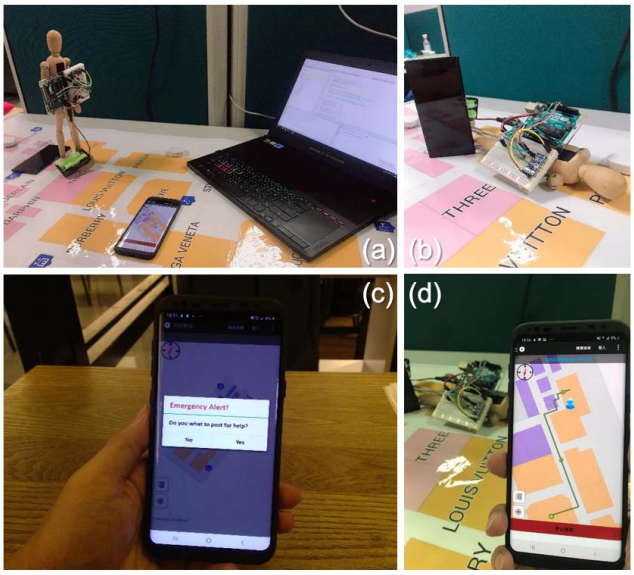

Fig. 5. System demonstration of GuidingAll.

in Fig. 5(b), the fall-over event for an elder is sensed and recognized using our designed smart iBeacon and developed convolutional neural network based recognition method (with the training data from the MobiFall dataset [12]), respectively. For verifying the correctness of fixed iBeacon positioning, fall-over event detection, smart iBeacon tracking, and fastest route planning results, the mapped, reported, and tracked positions can be checked on the notebook computer, and the recognized fall-over event can be notified for help/rescue on the smartphone, as shown in Fig. 5(c). In particular, the fastest guiding path from the current location to the tracked target can be sent to the guardian's/owner's smartphone after the fall-over event is detected, as shown in Fig. 5(d).

IV. Acknowledgments

This research is supported in part by MOST under Grant No. 106-2221-E-035-019-MY3.

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