Using iBeacon for Intelligent In-Room Presence Detection

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***Abstract*—iBeacon, a novel technique for proximity estimation, is utilized in our work to establish an intelligent in-room presence detection system. iBeacon is a kind of beacon device introduced in 2014 by Apple Inc. based on Bluetooth Low Energy (BLE) technology. The beacon signal can be broadcasted every certain interval. We collected data for line-of-sight (LOS) situation in in-room environment, and then recognize in-room presence according to path-loss readings. Data in other situations and environments such as obstructed-line-of-sight (OLOS) and outdoor scenario has been also considered to guarantee the in-room presence detection accuracy. Based on the empirical measurement results, we deeply investigate the system performance in terms of error detection possibility. This system is specifically promising for some particular purposes such as graduate seminar check-in, security system, in-and-out counting.**

I. Introduction

iBeacon is a class of Bluetooth Low Energy (BLE) devices that broadcast unique information to the nearby receivable devices. When these iBeacons are detected, the receivers can estimate the proximity as a reaction. Compared with traditional Bluetooth technology, iBeacon with BLE signal is intended to have similar coverage area yet less power consumption. Most of the smart phones, such as iPhone, Android and Blackberry, are compatible with BLE technology which indicates that they can perform collaborative operations with iBeacon. It is also expected to apply BLE on Windows Phones soon.

IBeacon has many location-based applications. It can be used to develop indoor positioning systems [1][2]. It can be used to build an indoor proximity estimation system to detect the number of moving objects in a room, and even gather the patterns of their movement [3]. Moreover, iBeacons can be also used as launching APPs on remote devices [4]. The interest of industry for iBeacon is increasing as well. Not only Apple but enterprises such as Qualcomm, PayPal, and SKT carry forward related businesses by partnering with a variety of companies [5].

The hardware basis of this work is the iBeacon transmitters from Estimote [6], cooperating with the most recent iPhone 5s, 6/6Plus and 6s/6sPlus. We develop our intelligent in-room presence detection system using existing APIs which provide received signal strength indicator (RSSI) and the motion information. Most importantly, we managed to manipulate empirical data and decide whether a person is in-room or not.

In this paper, we assume that the entrance door automatically shuts after an individual goes into or out of the room. When the individual opens and gets through the door with our APP properly launched, our APP receives the beacon signal and sends the beacon RSSI to the server. The server archives the RSSI and decides the presence status of that individual according to computational result of our algorithm. We first and foremost focus on the system implementation with two iBeacons, one of them attached to the outside of door while another mirroring at the inside. Such implementation provides adequate understanding on the physical phenomenon. After that, we move on to single iBeacon implementation, for which our system still performs well enough, but works with less expenses and more convenience.

With the help of our iBeacon based intelligent in-room presence detection system, the attendance registration of large rallies like courses and seminars can be completed automatically and the system can be used for any meeting places without frequent charging. Moreover, the system can also be integrated into indoor localization systems, which will lead us to more applications.

The rest of the paper is organized as follows. In section II, we introduce the existing literature of presence detection applications and general iBeacon based applications. We also analyze the differences between existing marketable iBeacon APPs and our own APP. In section III, we explain the experimental setup for both two iBeacons and one iBeacon scenarios. Apart from that, we also present the details of our algorithms and systems in this section. After that, in section IV, we focus on system performance and validation. Finally, in section V, we draw our conclusions and discuss future works.

II. Background

A. iBeacon and In-room Presence Detection

Presence detection is a common application for smart homes, which may contribute to energy-efficient intellegent lighting control, smart heating and air-conditioning, home scurity system and etc. In public area, the in-room presence detection technologies can be also used to count the registration and check-in of a event. Existing literature introduces two major technical trends to implement in-room presence detection systems. At the beginning stage, the research community mounts various sensors to the room ceiling and tries to cover the room as much as possible. Sujin et. al [7], proposed a digital camera and image processing based presence detection system using intensity average variation to detect moving

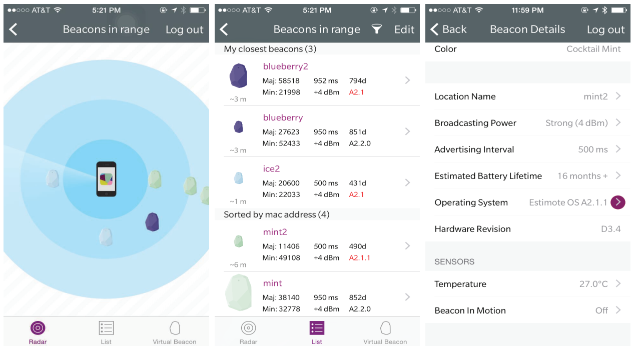

Fig. 1: Typical screenshot of APP provided by Estimote.

objects; Neubiberg et. al [8], presents a 360^o rotational camera based approach to enhance the camera coverage. Visible light sensing technique has been also employed in such systems and it has been even commercialized as products [9].

The above mentioned first technical trend suffers from certain disadvantages. First and foremost, the pre-deployment of the infrastructure is not unified. Take the $thePrema^{\text{TM}}$ in [9] as an example, only single sensor is required to cover a squared room but multiple sensors are necessary for an irregularly shaped room. As a consequence, the infrastructure cost is site-specific and it can goes exponentially high. To address that issue, the second trend locates sensors only to the entrance of the room. Motion sensors [10] and infrared sensors [11][12] are attached to the room entrance to count either entering or leaving of the individuals. Such techniques successfully cut down the cost but it still suffer the lack of ability to identify the presenced individuals.

IBeacon based system in this work is a potentially good choice without all above imperfections. With highly limited cost and long enough battery life, iBeacon is able to perform proximity estimation and at the same time identify the adjacent individuals. It also carries various other additional functionalities such as smart advertizing. Considering the advantages of iBeacon, we propose to used iBeacon for presence detection in this work.

B. Existing Marketable iBeacon APP

The manufacturer of iBeacon, Estimote company, provides their own iBeacon APP, which serves as a proximity estimator. The APP presents a graphic user interface (GUI) to display the geometric relationship between the iPhone and surrounding iBeacons. It also provides iBeacon ID, iBeacon status, distance between iBeacon and iPhone, iBeacon sensor reading and other information.

Typical screenshot of this Estimote APP has been depicted in Figure. 1. It is very obvious that the Estimote APP has two major disadvantages considering the purpose of this paper. (1) Originally the APP is *not* designed to perform presence detection; (2) The APP fails to explicitly provide the RSSI reading. Given those disadvantages, it is necessary to design our own APP to achieve intelligent in-room presence detection.

C. Our Self-designed iBeacon APP

To achieve in-room presence detection, we have to design our own APP. Since intuitively we know that the geometric relationship between the iBeacon and iPhone can be reflected by the RSSI fluctuation of beacon signal, we employ necessary APIs to get the RSSI reading directly from iPhone sensors. The APP encapsulates three essential information into each record, including the iBeacon ID, RSSI reading and Time stamp. Considering the scalability of the system, iBeacon ID has been partitioned into Universally Unique Identifier (UUID), Major field, and Minor field. In that sense, for large scale deployment, we may configure building number as iBeacon UUID, floor number as iBeacon Major and the iBeacon indicator as iBeacon Minor. The structure of each record can be given as

$$\{\text{UUID, Major, Minor, RSSI, Time stamp}\}$$

Typical screenshot of our own APP has been depicted in Figure. 2, in which we explicitly display Major, Minor and RSSI fields but implicitly record the UUID and Time stamp for privacy concerns.

III. Methodology

Our self-designed APP is written in Objective-C and has been tested with iPhone 5s and all newer versions. The APP firstly collects iBeacon RSSI readings upon activation and then sends the records to a remote server over wireless connection. Throughout the experiments, a Macbook has been employed to provide server side calculation and count the number of presences. The server side functionalities are implemented in Python.

A. Double iBeacons Approach

In order to implement the double iBeacons in-room presence detection system, it is necessary to clarify three distinguished movements of the Mobile Holder[1] (MH). The first type of movement is represented by yellow arrows in Figure. 3. The MH is walking pass the entrance of the room without opening

[1]Mobile holder denotes the individual holding iPhone, with our APP properly launched.

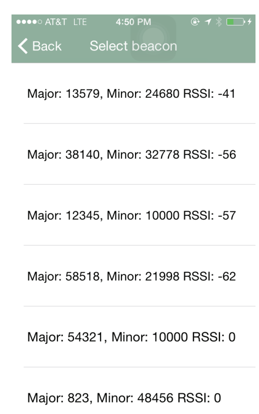

Fig. 2: Typical screenshot of our self-designed APP.

the door or entering. This is the most frequently appeared situation. The second type of movement is depicted by blue arrows, for which the MH is walking into the room. The third type of movement is represented by red arrows, for which the MH is going out of the room. The goal of your approach is to distinguish those three types of movements and properly adjusts the counter whenever there is a MH going into or out of the room.

The RSSI recording process is initiated by the motion sensor reading from iBeacon whenever the door is open. Any MH in the iBeacon coverage will be triggered to start data recording at a sample rate of 10Hz until it gets terminated by another iBeacon motion sensor reading showing that the door is closed again. When the recording process finishes, the APP uploads recorded data to the server in a binary file. The detailed logic for the self-designed APP has been shown in Algorithm 1.

Since we attach one of the the iBeacon to a specific side of the door and another iBeacon to the same position on the other side, the pathloss between each iBeacon and the iPhone is supposed to be different. Such pathloss difference is caused by the wooden/metalic door (and surrounding walls), which is lossy medium for radio propagation. We denote RSSI reading of the two iBeacons as RSSI_{out} for outside iBeacon and RSSI_{in} for inside iBeacon, so that the server side can easily determine the MH movements by the logic shown in Algorithm 2. The performance of double iBeacon approach will be investigated in the following sections.

B. Single iBeacon Approach

Even though iBeacons are considerably cheap, less iBeacons still guarantee lower cost and more convenience. We believe it is reasonable to take efforts and improve our system to the single iBeacon implementation. As is mentioned in previous sections, that scenario requires the assumption that the entrance door will be kept closed, that is, an individual will always shut the door no matter he/she goes into or out of the room. That assumption most frequently holds when the door automatically shuts. Given the assumption of this work, we know that the individual needs to be near the door and

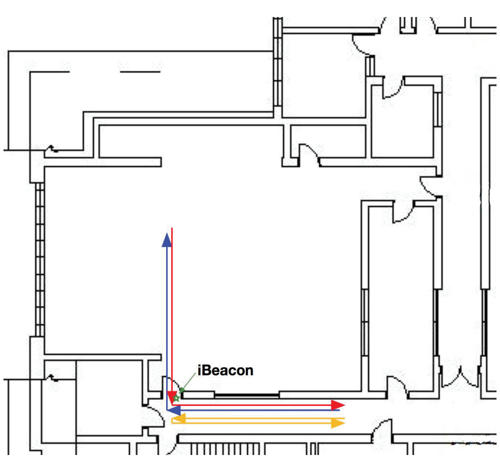

Fig. 3: Experimental environment and three different types of movements.

Algorithm 1 Logic for the self-designed APP

Initialize motion sensor **status** as “closed”;
while (**status**==“closed”)
    Monitor and update motion sensor **status**;
    while (**status**==“open”);
        Record RSSI_{out} and RSSI_{in};
        Monitor and update motion sensor **status**;
        if (**status**==“closed”)
            Send RSSI records to server;
        end
    end
end

Algorithm 2 Logic for the server

foreach iBeacon ID, **do**
    Acquire RSSI info from file;
    $\textbf{label}_{\textbf{out}}$ = false; //Initialization
    $\textbf{label}_{\textbf{in}}$ = false;
    origin = ($\text{RSSI}_{\text{out},t=1} > \text{RSSI}_{\text{in},t=1}$)?true:false;
    for t = 1 to N, **do**; // Traverse by time stamp
        if ($\text{RSSI}_{\text{out},t}$ - $\text{RSSI}_{\text{in},t} \geq 3$) //3dB RSSI threshold
            $\textbf{label}_{\textbf{out}}$ = true; //MH has appeared outside room
        end
        if ($\text{RSSI}_{\text{out},t}$ - $\text{RSSI}_{\text{in},t} \leq -3$)
            $\textbf{label}_{\textbf{in}}$ = true; //MH has appeared inside room
        end
    end
    if ($\textbf{label}_{\textbf{out}} \cap \textbf{label}_{\textbf{in}}$) //MH goes through the door
        type $=$ (**origin**)?-1:1; // 1 for enter, -1 for leave
        counter $=$ **counter** $+$ **type**; // # people in-room
    end
end

touch the knob to have it open, which results in a spike of RSSI reading. In that sense, the presence detection can be regarded as a RSSI value peak detection with properly setting thresholds. Based on that idea, we propose the single iBeacon system block diagram in Figure. 4. Note that for single iBeacon approach, the iBeacon is attached to the outside of the entrance door near the knob.

The logic for APP side is almost identical to the double iBeacons approach except for the fact that we only record and upload the RSSI information of the only single iBeacon. At the server side, we still use the iBeacon motion sensor status as the trigger and terminator of RSSI recording process. Within the activative sampling period, the server first and foremost performs a pick detection and then uses -60dB RSSI as the threshold to determine whether the MH is leaving or entering the room. For the case with maximum RSSI greater than -60dB, the MH is entering the room, otherwise, the MH is leaving the room. The selection of -60dB threshold comes from the analysis of empirical data and the threshold only works for the scenarios that iBeacon is attached to the outside of the entrance door.

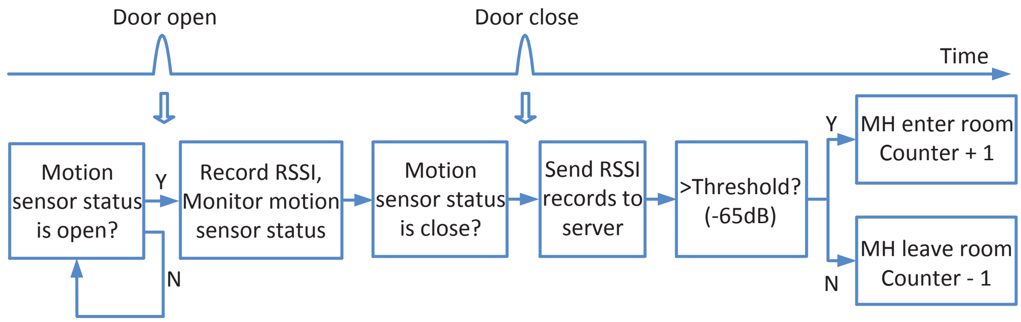

Fig. 4: System block diagram for single iBeacon approach.

IV. Performance Evaluation

In this section we validate the proposed systems. Each previously mentioned movement has been repeated for over 500 times and the RSSI of iBeacons has been measured. By investigating the RSSI samples, we show the validity of our approach using physical observation. Apart from that, the system performance has been also recorded to help the performance comparison between double and single iBeacon approaches.

A. Double iBeacons Approach

The RSSI samples for typical entering movement have been plotted in Figure. 5. As shown in the figure, when the MH opens the door, iBeacon 1 (on outside door) provides -54dB RSSI while iBeacon 2 (on inside door) has only -61dB. With the time going, when MH goes through the door at $t = 2.5s$, both iBeacons show approximately 63.5dB RSSI. After that, when the MH gets into the room, the two RSSI curves flip over and iBeacon 2 dwells on top of iBeacon 1. As for typical leaving movement, the opposite trend can be found, which still shows that the double iBeacons approach can provide successful detection. One thing worthes mentioning that we also investigated the situation that a MH came, open the door and then closed it without entering or leaving the room. The RSSI curve for that movement has been plotted in Figure. 6. As can be seen from the figure, even though there is period that two curves join each other, but they do not flip over at the end. In addition, with the 3dB threshold requirement, the double iBeacons approach can successfully recognize that situation and avoid mistakenly setting the counter. That observation also shows the robustness of tha double iBeacons approach.

B. Single iBeacon Approach

Given that the double iBeacons approach performs well, we move on to the validation of single iBeacon approach. Among our 1536 sets of empirical data, the typical cases for entering and leaving the room have been plotted in Figure. 7. It is clear that entering the room results in higher RSSI peak due to the fact that the single iBeacon is attached to the outside of the door. When the MH is in the room, even thought he/she could be close to the iBeacon, but the door lies between iBeacon and iPhone can create extra pathloss. The choice of -60dB RSSI shreshold comes from the regression fitting of our empirical data, that is, we find the best fit curves for both entering and leaving movements and notice that -60dB threshold provides satisfactory detection rate of different movements. To guarantee the robustness of the single

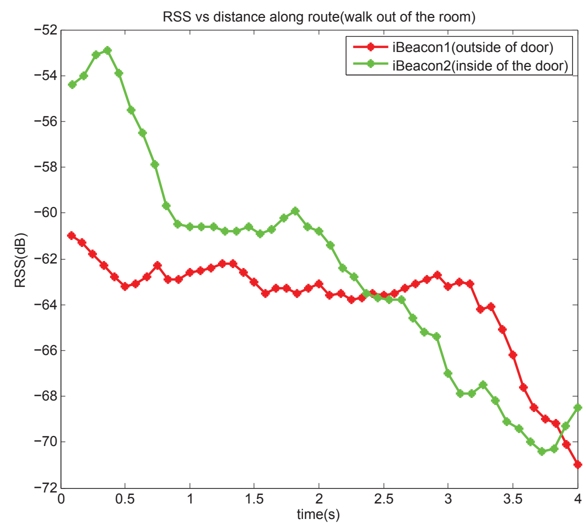

Fig. 5: RSSI plot for double iBeacon implementation, for the MH entering movement.

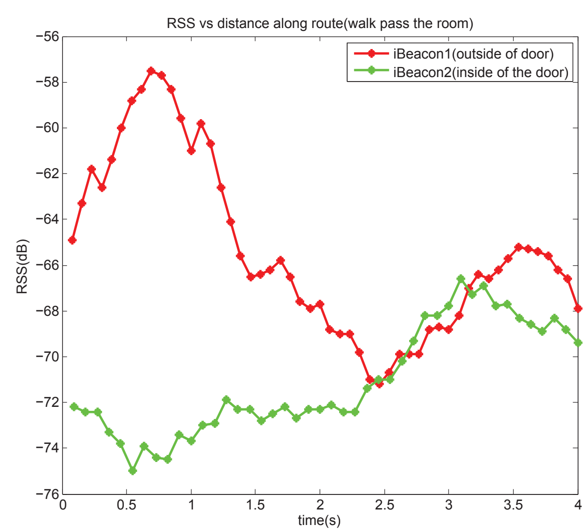

Fig. 6: RSSI plot for double iBeacon implementation, for the MH opening the door without entering/leaving.

iBeacon approach, we also conduct experiments with the iPhone located at various positions. In hand, pant pocket and shirt pocket have been selected as candidate locations of the iPhone and the best fit RSSI curves have been plotted in Figure. 7, respectively. Clearly we know that -60dB threshold works for all those iPhone positions.

It is worth mentioning that the single iBeacon approach is not able to detect the situation that the MH opens the door but neither entering nor leaving the room. Such reality shows that the single iBeacon is cost effective compared with double iBeacons approach, but is less robust against outliers.

C. Comparison

At the end of this paper, we would like to discuss the detection rates of the proposed systems. For the double iBeacons approach, we performed 521 measurements with the MH holding iPhone in hand, 500 measurements with the MH putting iPhone in pant pocket and another 500 measurements with iPhone in shirt pocket. For all these measurements, the double iBeacons approach is able to correctly detect the in-room presence. As for single iBeacon approach, we have 536 measurements with the MH holding iPhone in hand, 500 measurements with the MH putting iPhone in pant pocket and another 500 measurements with iPhone in shirt pocket. For the pant pocket iPhone position we have 2 mis-detections, while for in hand and shirt pocket cases the detection rates are all 100%. With such experimental results, we would like to claim that both approaches work well.

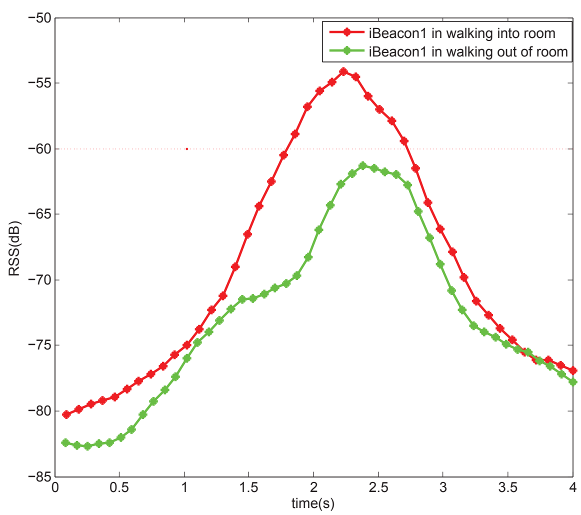

Fig. 7: RSSI plot for single iBeacon implementation.

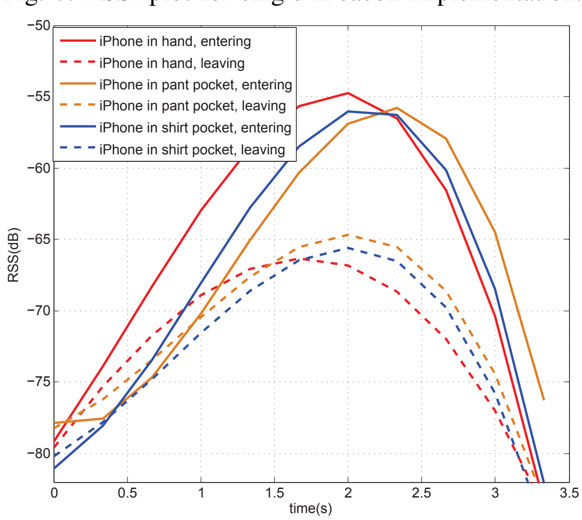

Fig. 8: RSSI plot for various iPhone position.

TABLE I: Performance of proposed in-room presence detection approaches.

Implementation approaches	**iPhone position**	**Detection rate**	**Detection rate (%)**
Double iBeacon	any	1521/1521	100%
Single iBeacon	in hand	500/500	100%
	pant pocket	534/536	99.63%
	shirt pocket	500/500	100%

V. Conclusion

In this paper, we investigated and developed an iBeacon based intelligent in-room presence detection system to record the users in a room. We collected the RSSI data of iBeacon for LOS situation in a typical indoor office environment and we implement both single beacon and double beacons based approach. We also analyzed the probability density function, error detection rate and other metrics using the empirical measurement results. The optimal performance of our approach can be as high as 100%.

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