A novel architecture using iBeacons for localization and tracking of people within healthcare environment

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***Abstract*—Internet of Things (IoT) can help healthcare facilities to transform the experience for both the staff and patients. IoT can facilitate novel solutions for a classic problem, which is the real-time tracking of patients and staff. In this work, an architecture for real-time tracking using Bluetooth Low Energy (BLE) and iBeacons in hospitals is proposed. The proposed system is to locate not only humans but also other facilities such as medicines. It consists of four different frameworks: server communication, user interaction, cross-platform communication and indoor localization. A wearable BLE-enabled device or any smartphone can be used in our system. The first stage of the tracking system is setting up and calibrating the BLE iBeacons for initialization. Then the Received Signal Strength is collected from the BLE-enabled devices carried by users. These data are analyzed and calculated using our improved Least Square Estimation approach to estimate the actual location of users. Experimental results show that in a crowded environment, our tracking system achieves resolutions of the order of 12cm. This will be further integrated with other sensors such as accelerometer or heart rate monitor to improve the real-time healthcare monitoring experience.**

***Keywords*— IoT; Healthcare; Indoor localization; Bluetooth Low Energy; iBeacon.**

I. INTRODUCTION

The wide adoption of networks in which billions of mobile devices and sensors are connected has been witnessed in the last decade. It is called Internet of Things (IoT), which is a mega trending concept currently. The idea of IoT is to connect and share data among any objects, any devices, any users at any time and in any place. According to Gartner [1], it is estimated that by 2020, there will be 20.6 billion connected devices in the IoT. They are expected to transmit and collect data in real-time, which will allow a comprehensive observation on different aspects of human life. The data from IoT can be processed and organized by organizations into valuable information that will redefine how people live, how machine and human, machine and machine interact. Thus, the IoT offers broad range of applications, which can be classified into these domains:

- Transportation: smart vehicles, assisted driving etc.
- Environment: traffic control, water quality, air polluted etc.
- Retail: automated checkout, smart marketing etc.
- Industrial: flow monitoring, smart manufacturing, quality control etc.
- Smart home and smart city
- Personal: example, healthcare.

Healthcare is one of the most popular and exciting applications that IoT can fit well. The steadily increasing population and the related demands for the healthcare standard brings with it a huge pressure on patient care and treatment. Fortunately, with the rapid deployment of IoT, the integration of this advanced technology is bringing some significant developments in the medical sector such as remote health and monitoring. However, there is another aspect that should be considered in order to improve the healthcare safety and the efficiency of healthcare facilities. It is the ability to track patients, staff and inventory in busy facilities. The healthcare facilities are looking to implement a relatively low-cost system that automatically provide real-time data tracking to manage all the resources as well as improve the workflows and enhanced the staff and patient satisfaction. There are some application examples for locating and tracking systems, such as:

- Monitoring patients in and out of the doors or through the building.
- Medical asset tracking to monitor and manage beds, rooms, medicines and equipment.
- Aiding and guiding patients, staff and guests through buildings.

The ability to locate and track people or objects is called positioning. At present, the well-established positioning systems, such as Global Navigation Satellite System (GNSS) including the famous Global Positioning System (GPS) provides an exceptional solution for outdoor environment. However, inside a building, the signal from satellites is blocked by walls, people and other obstacles. Therefore, this signal is very weak or even non-existent. Also, the usual acceptable error range for outdoor environment is larger than it is in the indoor environment, especially in the healthcare sector. This means that we need to implement new technologies and system for the indoor positioning. There are several challenges an indoor positioning system needs to address: accuracy, complexity, cost, scalability, power consumption, noise and interference [2-3].

There are several well-known technologies currently available for Indoor Positioning such as Wi-Fi, Bluetooth Low Energy (BLE), Radio Frequency Identification (RDIF) or using mobile sensitivity sensor. We have chosen BLE [4] as the main technology for our research work due to its several advantages over other techniques. BLE is the new standard of Bluetooth since 2010. It offers a simple communication process based on master/slave model with low cost and low energy consumption [4].

In this paper, an asset tracking and real-time location system architecture for hospitals from RSSI based estimation using BLE is proposed. Our system requires two types of devices: beacons (anchors) which are pre-installed in a pre-known position and tracking nodes, which might be smartphones, BLE-enabled smart tag or BLE-enabled bracelet for patients. The tracking nodes will collect the received signal strength indicator (RSSI) data from anchors. This data will be processed in the server and the position of nodes can be estimated. This system is integrated with other sensors on the node such as gyroscopes, sensitivity sensor and accelerometer to detect falls and enhanced the real-time tracking.

The rest of this paper is organized as follows: section II will introduce the literature review and related studies; section III highlights the research questions for this paper and; section IV presents the proposed architecture; section V discusses our initial experiment and results and section VI is the conclusion and future work.

II. RELATED WORK

A. *Overview of indoor positioning technologies*

Currently, Wi-Fi is being used commonly for indoor positioning [5]. One of the main advantages of this technology is that Wi-Fi access points are widely deployed in almost all hospital venues at present. The method called "Fingerprinting" is one of the most effective approaches for Wi-Fi signal to locate indoor objects and devices [5]. However, recent research [6-7] has shown that in order to resolve the positioning within 5 metres, too many access points need to be installed. This is an overkill because the Wi-Fi access point originally was designed to broadcast Wi-Fi signal rather than for locating users. In this light, the density of pre-installed access points in a usual hospital might not be enough to resolve the resolution of the position estimation under 5 meters. Furthermore, noise/interference due to the wide distance between access points and receivers, and as well as energy consumption are big drawbacks in using the Wi-Fi technology for indoor localization in large scale hospitals.

Using BLE for indoor positioning has been on the rise due to its advantages in cost, durability, simplicity and accuracy. BLE and beacon devices provide a portable solution for indoor localization [8] A lot of research is being carried out on this topic. In [9], the authors proposed a BLE based approach with up to 1-meter accuracy and the positioning delays of about 1-2 sec [9]. They had demonstrated that the accuracy of the approach increases with the number of beacons used per unit area, up to a threshold of 6 to 8 beacons.

Passive Radio Frequency Identification (RFID) is another favorable alternative technology to BLE for indoor positioning [10]. It consists of two simple devices: a tag and a reader. A passive RFID localization system can achieve the mean error down to 0.31m [10]. However, in order to achieve high accuracy, a single location estimation will require many readers in the RFID system, which is a major drawback in terms of the cost. Moreover, unlike BLE, the passive RFID system cannot provide real time tracking or navigation. The RFID is more suitable for objective identification application and is often combined with other technologies for the localization. In the context of this paper, our focus is on high-resolution patient locating and tracking.

Table I gives the summary of existing candidates for our proposed system.

TABLE I. INDOOR POSITIONING TECHNOLOGY

Tech	Accuracy	Advantage	Disadvantage
WiFi	**5 – 15m**	**High coverage High availability High range**	**Large training database required High energy consumption**
BLE	**1 – 5 m**	**Low cost Low energy consumption High availability Simple and flexible**	**Attenuation Only medium accuracy Additional hardware required**
RFID	**Up to 5 cm**	**High accuracy Medium Security High coverage**	**Can be high cost Static location Short range**

B. *Overview of localization using BLE and RSSI-based technique*

Several researchers have tried to tackle this topic since the arrival of BLE. RSSI describes the relationship between transmitter, i.e. beacons, and the receiver, i.e. devices. Different conditions will affect the RSSI value: transceiver direction, battery level, obstacles etc. Hence, RSSI needs to be smoothed and corrected. In [11], methods were proposed to smooth RSSI value by removing the outlier RSSI. In [12], the authors estimate the position based on processed RSSI using trilateration method, whereas in [13], centroid and Least Square Estimation were presented as the position calculation techniques. However, according to these authors, the RSSI smoothing still needs a great deal of attention, especially when the environment and power factor are considered. Also, there is room for improvement in achieving high accuracy by the position estimation approaches. In addition, the practical maximum distance between the anchor and devices is claimed to be under 10 meters [14].

III. RESEARCH OBJECTIVES

We have considered the following research objectives to present our results in high-resolution localization and tracking system for patients and staff in healthcare systems.
RO1: To design a system architecture for achieving indoor localization with high accuracy.
RO2: To demonstrate the system's ability to integrate with other IoT application for healthcare.
RO3: To demonstrate the suitability of the design for healthcare environment.

IV. PROPOSED SYSTEM

A. System overview

The patient tracking system is designed to be used in the indoor environment, i.e. hospitals, in an IoT network. Fig. 1 presents our system architecture overview. There are two main tasks which are: collecting and exchanging data with operator and users and applying different technologies and algorithms to provide location tracking and health monitoring based on data collected. It consists of four main interfaces:

- Interface 1: data collection and exchange data with the database within the IoT network of operators.
- Interface 2: application to interact with users: users' input or automatically collect required data.
- Interface 3: enable communicate between different platforms, various type of devices which suitable for the hospital's environment.
- Interface 4: applying suitable technology and calculation to analyze data to provided tracking results as well as other required health monitoring.

In this paper, out proposed architecture is focusing on the interface 4 which will identify the location of patients and staff, with time stamps of their movement, in indoor environment.

B. System Architecture and implementation

This section provides an insight into the architecture for the interface 4, of our proposed tracking system. Fig. 2 describes the system model and work flows. There are three main stages:

- Modelling and collecting data: beacons are pre-installed in appropriate positions (as identified in our earlier work) [15]. Their positions and the reference RSSI value will be collected, measured and calibrated. Users with BLE-enabled devices/tags will communicate with these beacons. Useful information such as RSSI, timestamp, height, etc. are collected and will be analyzed in the next stage.
- Data processing and position calculation: the RSSI value collected in the previous stage is filtered and processed through a set of improved LSE calculations [15] in order to estimate the actual position of devices. Other integrated health data will be analyzed in this stage.
- Output: the position is provided after achieving satisfactory error correction. Real-time tracking in a grid map, 2D map or 3D map is presented. Other metrics such as fall detection, heart rate, etc. will be communicated to appropriate staff.

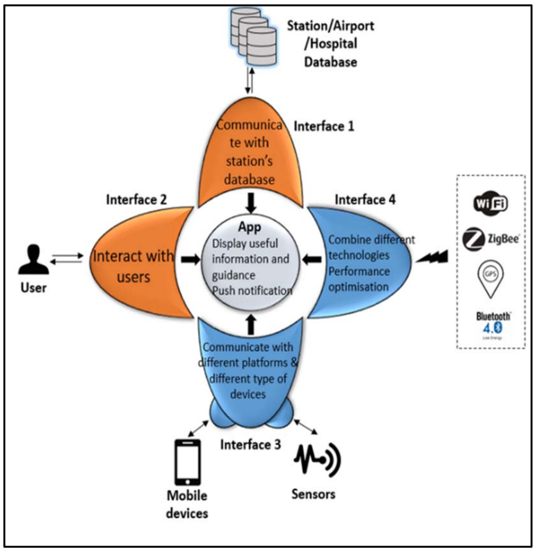

Fig. 1. System architecture overview

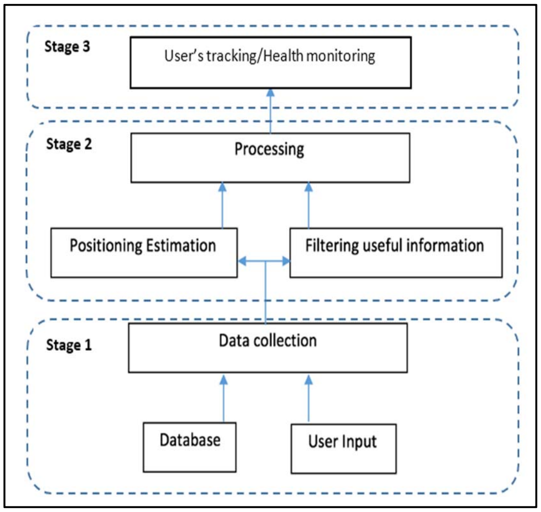

Fig. 2. Patients/Staffs Positioning working flow

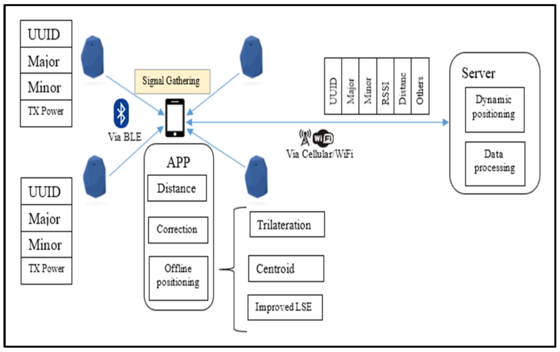

Fig. 3. BLE Positioning system

As mentioned earlier, we chose BLE as our main technology for the tracking system due to its advanced technical capability compared to other competitors available on the market. Fig. 3 illustrates the schematic of our implementation. The BLE-enabled beacons are used as anchors. They advertise their identity and transmission power periodically. This advertisement will be picked up by user's device when they enter within the range of a beacon. On receiving the data from beacons, the APP in the user's device will process the data and calculate the distance between itself and the beacons. If the device is offline, i.e. there is no internet connection, the Offline Positioning module in the APP should estimate the position of device and display it in the offline map. The tracking/navigation and any guidance will be based on this offline data. If there is internet connection, all collected and calculated data will be transferred to a server. This server will execute the localization and other data processing in real-time. A comparison process between estimated positions in the server will be made in order to select the most satisfied result based on the actual application. The positioning techniques used at this stage of research is our hybrid Centroid-Least Square Estimation [15].

C. *Implementation*

1) Beacon

This is the anchor which plays an important role in the system design. The anchor must be low-cost, low energy consumption and easy to be installed. We have chosen BLE and iBeacon [16] in order to implement the demonstration system due to its compatibility to various platforms. The iBeacon is manufactured by Estimote [17] as Fig. 4. The formfactor of this device is quite small which can be stuck on a convenient place, and it is powered by coin batteries. Depending on the settings, it can last up to 2 years.

2) Mobile nodes

The mobile node can be either a smartphone or any BLE-enabled devices. In the hospital's environment, patients and staff might not be allowed to carry smartphone all the time, so we suggest using a BLE-enabled bracelet worn by users in those circumstances. This bracelet can be integrated with other sensors such as proximity, accelerometer, heart rate sensor or alarm in order to improve the tracking and healthcare monitoring. The automatic alarm is triggered when the system detects anomalies in the metrics, for example heart rate, fall detection, etc. The bracelet should be designed using a small formfactor, with no sharp edges and ideally water/splash proof. In the context of this paper, we use a tablet for our testing purpose.

Fig. 4. Estimote iBeacon [17]

3) Server system

The server system consists of a mother server, a data centre and beacon managers. These act as a central data hub in order to process all the data. These data are managed and integrated with other information collected in the IoT network. For simplicity and convenience, a web-based tool should be designed to manage and tracking location, calibrate characteristic and managing beacon and server. In addition, in a large and busy hospitals, there might be several sub-centre hubs to manage each area. These should be connected, and the data must be processed effectively. This particular implementation can be done in the future research.

D. *The system workflow*

This section will summarize and describe the work-flow steps of our system:

1. Collect RSSI values from beacons at pre-defined positions; and the central hub calibrates the process.
2. Measure RSSI value from beacons to device; Transmit to the central hub and do the position calculation process.
3. Other values such as acceleration, height, heart rate is collected and transmitted to the central hub
4. Clinical staff or carer will monitor data and provide appropriate management.

V. EXPERIMENTATION

A test bed environment for locating device were built for the tracking experimentation. Fig. 5 and Table III demonstrate our experimentation environment and the corresponding results. Four iBeacons were placed at fixed positions in the form of a parallelogram. The experiment was carried during the peak time within the LJMU building. There were about 10-12 people, 16 computers, 32 chairs and tables and 02 active Wi-Fi routers within the area of the parallelogram. The user carried an iPad moving within the beacon area. The RSSI from each beacon to the iPad were collected. This data was processed by smoothing filters and processed in real time using our optimized Least Square Estimation approach [18]. The result is compared to that achieved using classic LSE method in Table III.

Table II lists the devices used in our experimentation for measurements. There are several assumptions made for this experimentation as listed below:

- All the antennae are omnidirectional.
- All the devices are at the same height of 1.2m.
- The area of the parallelogram is about $20m^2$.
- Radio interference comes from the Wi-Fi routers and computers.

The results as seen in Table III, show that our tracking system provides a promising result. As can be seen, it achieves better resolution than the classic LSE. The mean error of the classic LSE approach is 0.675m whereas that of our improved LSE method is only 0.125m. This means our approach is able to place the object within 12cm of resolution. The maximum error of the classic LSE is also higher than the max error of our approach. This level of accuracy should be sufficient enough to perform the medicine/item tracking in hospitals. This particular experiment will be studied in the next step of our research.

VI. FUTURE WORK AND CONCLUSION

In this paper, a novel architecture for tracking patients and staff in hospitals was proposed using BLE based technology. The system design follows the structure of IoT. The application of this system could provide significant benefits in healthcare environment. It can provide a real-time positioning solution in order to improve the healthcare work flow and enhanced customer satisfaction. Furthermore, it can be integrated with other equipment in the IoT network to transform the patient experience such as remote health monitoring.

An experimentation had been carried out to demonstrate the ability to track objects in real time. We have shown that our positioning approach can achieve very promising results for tracking of not only patient/staff but also of drugs and equipment. Experimental results also show that the improved LSE method outperforms the competitor with a high accuracy of about 0.125 - 0.37m. As a next step in our research, the medicine and small object tracking application using our approach will be investigated. Also, a complete solution for the server sides of the system will be developed. The demonstration could be done in a real-life healthcare environment.

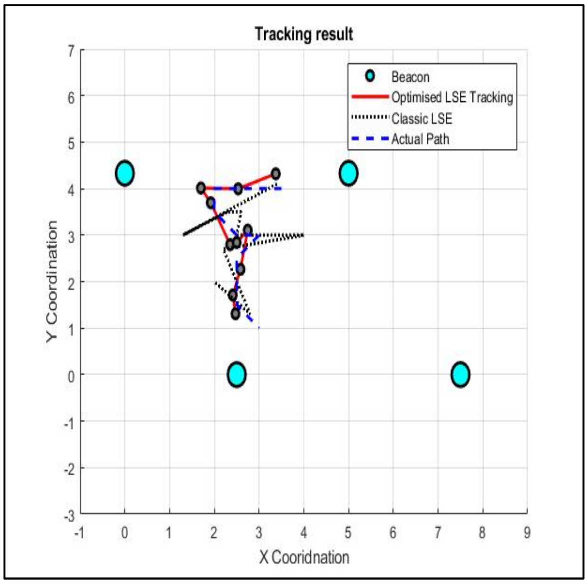

Fig. 5. Tracking result

TABLE II. DEVICES

Items	Details	
	Manufacturer	***Settings***
iBeacon	Estimote [17]	Transmit power: 4 dBm Advertising interval: 400ms
iPad 2	Apple	iOS 10.2.1 Wi-Fi: On - Bluetooth: On

TABLE III. POSITIONING ACCURACY

Method	**Average error**	**Maximum error**
LSE	0.675 m	0.7 m
Improved LSE	0.125 m	0.37 m

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