Beacons for Indoor Positioning

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***Abstract*—This work aims to develop a system for the tracking and control of elderly or handicapped people in an indoor environment. We have developed both a special box using an Arduino board, and a mobile application on Android to determine the location of the target based on the Bluetooth Low Energy signals transmitted by special Beacons which are placed in the area of interest. Both systems are used to determine the position of the person and to monitor any event that would cause an alert. Those events can be a long stay in a fixed position, or the entry into pre-defined forbidden zones. The location data will be stored in a database for further processing. Alerts can trigger messages to be sent to local authorities and/or relatives of the people. Measurements and test results are discussed regarding their performance. It is clear that more research and development is necessary for obtaining reliable products.**

Keywords—indoor positioning; BLE; beacon; alert generation; mobile application; microcontroller board.

I. INTRODUCTION

Indoor localization using different types of wireless signals has been a hot research topic by many people employing a variety of techniques. Especially, after the release of Bluetooth Low Energy (BLE) protocol many companies carry out research work on indoor localization for the main themes of Internet of Things (IoT) technology, such as tracking people and devices to determine their location, making brand advertisements etc. BLE technology is a wireless personal area network which provides new applications in daily life such as security, healthcare, beacons etc. In comparison to Bluetooth Classic, BLE consumes less power, it is cheaper and allows higher speed. BLE has 40 channels and three channels (i.e., 37, 38, and 39) are used for broadcasting advertisement messages. The received signal strength indicator (RSSI) from these three channels can be used for estimating the target's location [1-3, 10]. Furthermore, some companies brought into market specialized devices called beacons which utilize BLE technology. Beacons transmit BLE signals to nearby devices. These beacons are named according to the protocols they use such as iBeacon developed by Apple, Eddystone developed by Google and AltBeacon developed by Radius Network. Those BLE beacons allow the development of important and big projects that can have huge impact in daily life due to their small size, light weight, low cost, low power consumption and their wide support by smart devices. BLE beacons use small lithium chip batteries and the battery life of the device is between 18 to 24 months. The battery life depends on signaling range, signaling power which can be configured according to the needs of the project. Many indoor positioning and tracking applications are created utilizing this technology such as tracking big and expensive devices in hospitals, sending offers to customer in the vicinity of stores, navigation support in large and complicated venues such as stadiums, airports etc. This work focuses on an important problem for the social life: tracking and control of elderly or handicapped people or patients of the family in the home environment. They cannot be tracked or controlled easily when they are alone at home. This work aims to solve this problem by providing an economical and reliable solution especially for elderly people suffering from mental problems e.g. loss in logical reasoning etc. Sometimes they leave the house and get lost, or they get fainted somewhere in the house. In this project, two alternative solutions are designed and implemented to track the target person and to send alerts generated for specific events (cases). The first one is based on specific hardware. A portable electronic box has been designed by using a microcontroller board (Arduino Mega), Bluetooth module and Light Emitting Diodes (LED). This box will be carried by the person to be tracked and it will be able to receive signals from beacons which are placed in a certain indoor or outdoor area. These signals will be processed to calculate the distance of the receiver to those beacons. Then, the position of the person will be calculated by utilizing the distances of the three devices providing the best signals, in the trilateration algorithm. Moreover, based on the position of the person and the unusual situation, called an event such as staying for a long time in a fixed position, the LEDs on the box will be light up in different colors to identify alerts. The second solution is based on software running in a smart phone operated by Android. There are two applications. The first one gets the position of the person and sends this data to a database and the second application gets the location of the person from the database and uses them for alert generation corresponding to the events. The rest of the paper is organized as follows: Section II describes the design of the hardware and software parts. Section III includes the experimental setting, the analysis for the calculations, and the algorithms for location estimation. In Section IV, results of measurements and alert tests will be displayed. Conclusions and future research topics will be summarized in Section V.

978-1-5386-1949-0/17/$31.00

II. Design and Implementation

The overall architecture of the proposed system is given in Fig. 1. The system employs beacons that are small and cheap devices transmitting signals according to the Bluetooth 4.0 Low Energy standard specification. Beacons repeatedly broadcast their Universally Unique Identifier (UUID), which can be received by BLE receivers including all sorts of smart devices. Those signals can be used to identify unique id, subgroups and individual ones in subgroups. In this work, iBeacon type beacons are used as they can easily be detected by both Android and iOS devices. The receivers used in our work are an Android smart phone and an Arduino Mega microcontroller board [4] equipped with a BLE receiver module. Both of them can be programmed to scan the available BLE signals "on the air" and the received signals contain the following pieces of information in a total package size of 60 bits: 8 bits for the factory ID, following 24 bits for the iBeacon UUID, 10 bits specify major and minor values, 2 bits for TX power, 12 bits specify MAC address and the last 4 bits specify RSSI value in dBm. Hence, the RSSI values can be used to determine the distance of the receiver to each of the beacons from which a BLE signal is received. Then, the location of the receiver can be estimated as the locations of the beacons are known (see the next section). As those location data are stored in the database, navigation of the receiver can also be tracked and alerts can be generated if certain rules are violated. Those rules can be based on positions (presence in a certain area), movements or excessively long stays in a position or area.

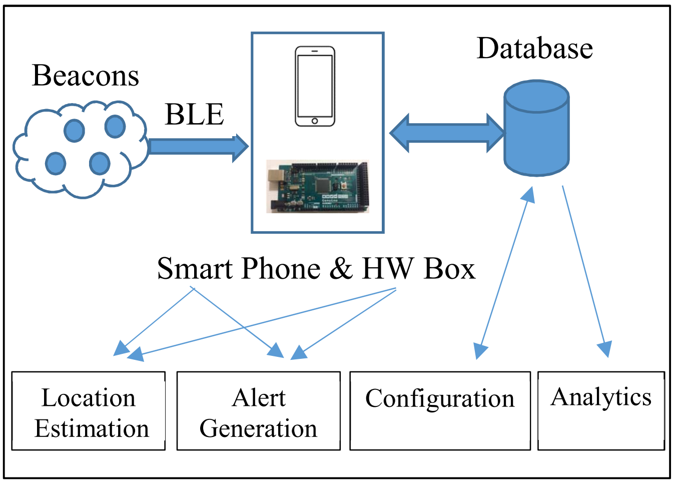

Figure 1. General architecture of the proposed system.

III. Experimental Setting and Algorithms

For the experimental setup, we have chosen an area of size 8m by 10m in the laboratory block of the university. The area is divided into grids of size 2m by 2m to make future measurements and placements easier. In our topology, there will be one room, one hallway, one bathroom (for long stay situation) and a forbidden zone. The layout (places and their coordinates describing our topology) and the actual photographs of our laboratory setup are shown in Fig. 2 and Fig. 3 respectively. The physical conditions of the environment, the signaling power of the beacons, and the layout of the rooms have to be taken into consideration when placing the beacons. The distances between the devices have been determined by considering the fact that a beacon's useful range for signal reception is approximately 10m within the thick walled building structures. Thus, beacons were placed so that the target person could get a good signal from at least three beacons from each point in the vicinity. In most cases, if you want to detect presence of users in a certain zone, installing beacons at a height of 2m from the ground level works out well. If they are placed higher, signal range will decrease [5]. As beacons transmit signals spherically around themselves, it would be a wise idea to put them in midpoints of rooms instead of corner points. In this way, BLE module in the special box or mobile phone can receive signals from all of the beacons in every point of the designated area. We have put one of the beacons inside the room and close to the wall. In this way, it is easier to identify whether the person is in the room or in the hallway when he/she is near the wall. Another beacon is placed near to the exit gate in the hallway so that we can track the target in case it is in the forbidden zone. Rest of the beacons are placed symmetrically to each other. The layout and coordinates of the beacons are shown in Fig. 2.

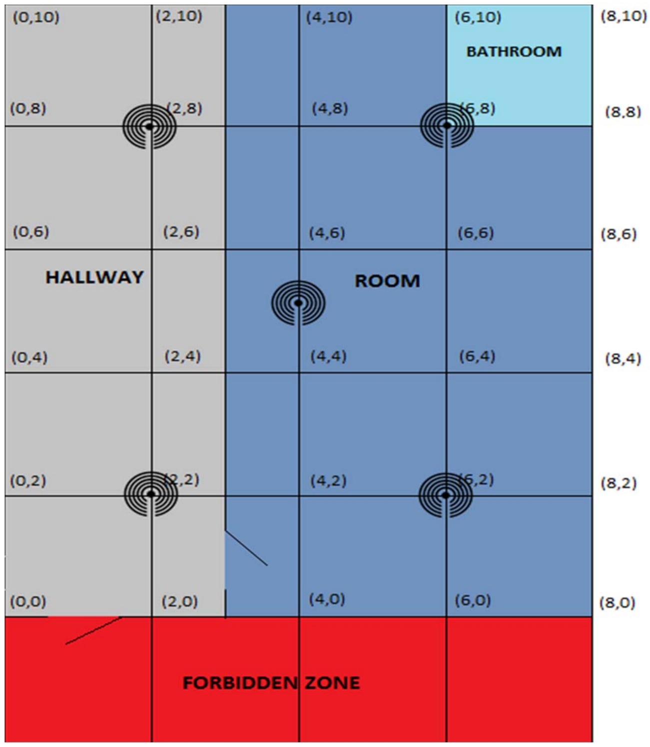

Figure 2. Layout of the test area to model a house environment.

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Figure 3. Pictures of the different zones: hallway, room and forbidden zone (from left to right).

The characteristics of BLE signal propagation varies dramatically with the type of indoor environment, the position of the transmitters within this environment (how far they are placed from walls, ground and furniture). Some empirical formulations were developed based on experimental measurements. The Log-Distance Path Loss model is one of most commonly used relationships for BLE signal attenuation [6] as given in Eq. 1,

$$RSSI = A_0 - 10\, n\, \log_{10} \frac{d}{d_0} \tag{1}$$

where $RSSI$ is the received signal strength at distance d, A_0 is the average RSSI value of one beacon from different points at a distance of d_0 (here d_0=1m), d is the distance between the beacon and the receiver device. This equation can be used to calculate distance from measured RSSI values, provided that the value of *n* (path loss index) is known. This index varies dynamically with any change of environmental factors including building structure, room's layout, types of construction materials, and the presence of moving objects [7]. Thus, it is essential to determine the path loss index for the spaces of interest. For this purpose, the test area has been divided into grids and an extensive process has been carried out to determine an average path loss index value based on RSSI measurements from beacons at each point of the grid. After that, n values have been calculated at each point, for each beacon using Eq. 1. The results will be given in the next section.

For the position estimation, the well-known trilateration algorithm is utilized [6]. This approach is based on the geometrical interpretation of the receiver's position as the intersection point of three circles (Fig. 4). The geometrical positions of the beacons (pairs of coordinates (Xa,Ya), (Xb,Yb), (Xc,Yc)) and the distance of the receiver to each beacon (da, db, dc) are known. Then, one gets three independent, non-linear equations whose simultaneous solution gives the receiver's position. Using the method proposed by Dixon to obtain radical plane for circle intersection as in [6], Eqs. 2-5 can be used for the solution of the receiver's position (x, y).

$$v_a = \frac{(d_b^2-d_c^2)-(x_b^2-x_c^2)-(y_b^2-y_c^2)}{2} \tag{2}$$

$$v_b = \frac{(d_b^2-d_a^2)-(x_b^2-x_a^2)-(y_b^2-y_a^2)}{2} \tag{3}$$

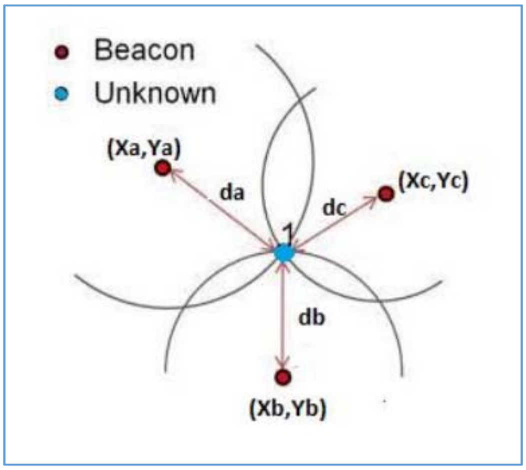

Figure 4. Trilateration for position estimation.

$$y = \frac{v_b(x_c-x_b)-v_a(x_a-x_b)}{(y_a-y_b)(x_c-x_b)-(y_c-y_b)(x_a-x_b)} \tag{4}$$

$$x = \frac{v_a-y(y_c-y_b)}{(x_c-x_b)} \tag{5}$$

Based on the position estimates obtained, the smart Android phone or the microcontroller box can also be used for alert generation when patient's location is in the forbidden zone or there is a long stay in the bathroom. In this work, Android Studio [8] and related libraries for BLE processing [9] have been used for coding the tracking and alert application. Tracking application will get the position of the patient and this data will be stored in a database (MSSQL) for further processing. The alert application can track the location of the patient and use this data for alert generation when the rules are violated. For example, these alerts (alarms) are triggered when the person enters into the forbidden zone and doesn't end until the target returns to the free zone (Room, Hallway, etc.).

IV. MEASUREMENTS AND RESULTS

The critical point in this work has been the determination of the path loss index. Extensive measurements have been carried out to calculate the index. The procedure for this purpose included carrying out repetitive measurements at grid points using the microcontroller board and the smart phone. Fig. 5 gives a sample set of measurements displaying the signal strength obtained from a beacon versus the distance from the beacon. The logarithmic character is evident, however, a large amount of deviation from ideal behavior is also indicative. The reasons for those deviations are reflections on surfaces, instability of the transmitter, and the changes in the environment such as walking people. It should also be mentioned that each beacon exhibits a similar "noisy" behavior. Furthermore one can obtain the value of *n* either using the fitted curve in Fig. 5, or using the measurements at each grid point separately. As an example, the average values of the path loss index found at each grid point for a specific beacon is given in Fig. 6. The variations in the value of n is also evident in this graph. As a result, the average values of all measurements for *n* are listed in Table 1 for the beacons installed.

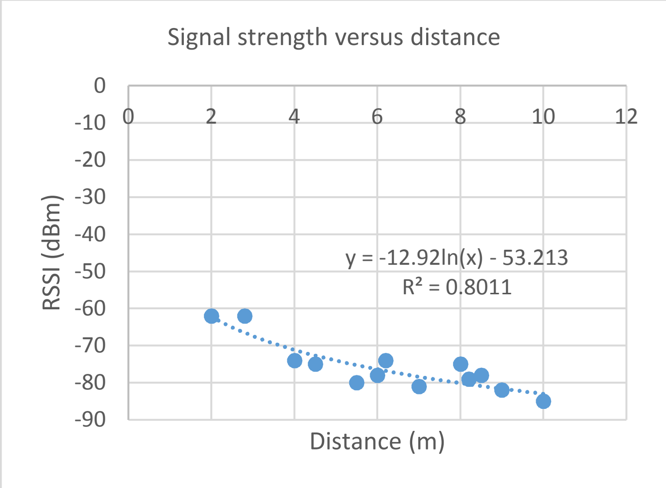

Figure 5. Variation of RSSI with respect to distance from the beacon.

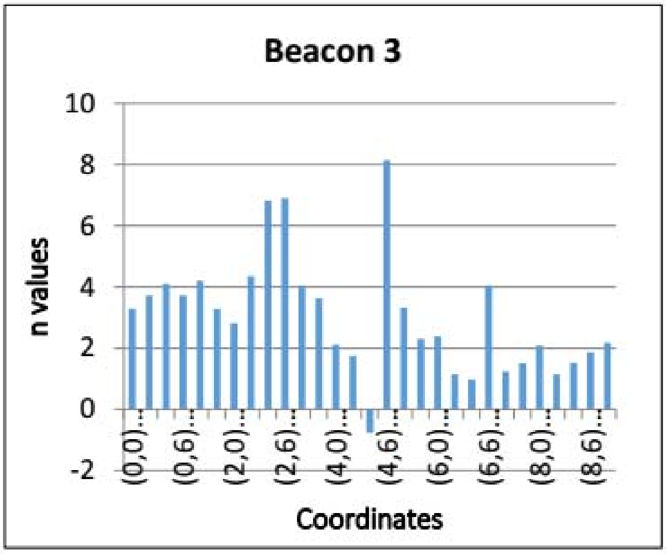

Figure 6. Variation of *n* based on measurements at grid points.

Table 1. Average *n* values for each beacon.

Beacon #	MAC Address	n
1	E0E5CF9900A0	3.30
2	D0B5C2E2FBF8	2.33
3	D0B5C2E2EF2F	2.96
4	E0E5CF9905E3	2.90
5	D0B5C2E31722	2.32

For obtaining the performance of the system, firstly, exact positioning tests are carried out. Measurements are done at 90 points across the test area using both the microcontroller box and the smart phone. The distribution of the error, distance between the actual position of the receiver and the calculated position, is given in Fig. 7 and Fig. 8 for the microcontroller box and the smart phone respectively. The mean error is 2.5 m with a standard deviation of 1.5 m for the microcontroller. For the smart phone, the mean error is 2.2 m with a standard deviation of 1.4 m. Those measurements indicate that both types of the receiver yield approximately the same performance which cannot be considered satisfactorily as the dimensions of the test area is 8m by 10m.

As a second test, a random path has been set in the topology which can be accepted as a walk in the room. Measurements are done as the receivers are moving on that path. The difference between the actual path to be monitored and the path as the system output is given in Fig. 8 for the smart phone. The weak performance in exact positioning is also evident in path following.

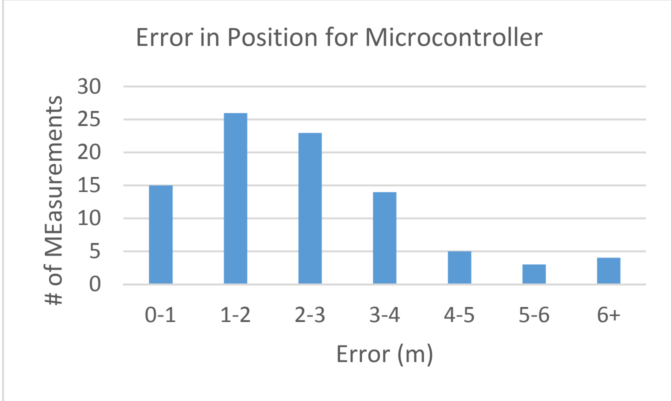

Figure 7. Error distribution using the microcontroller box.

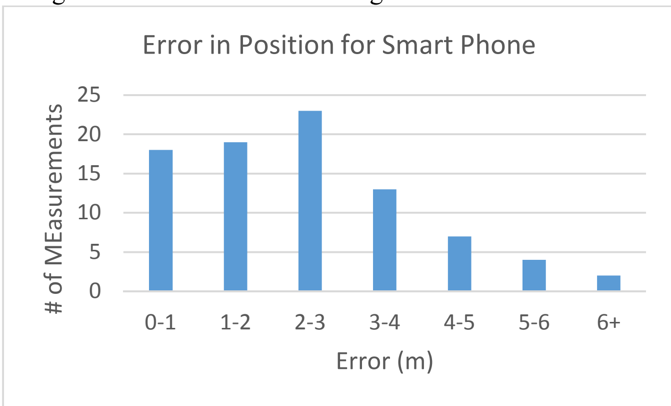

Figure 7. Error distribution using the smart phone.

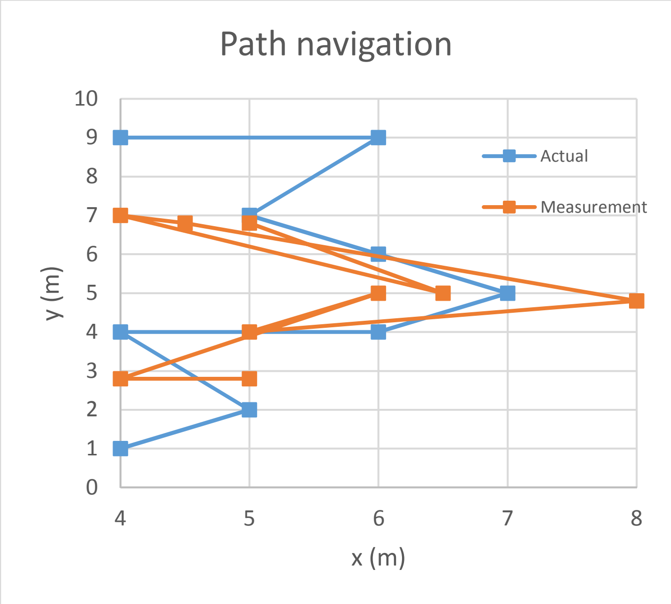

Figure 8. Performance in path navigation with the smart phone.

The third set of tests focused on the performance of those systems in the prediction of the location only: Here, we were interested to know whether the receiver is in the "room" or in the "hallway" or outside, i.e. in the forbidden zone. The results are given in Table 2 and Table 3. Table 2 compares the performance of the systems in about 44 to 79 measurements in the room and in the hallway. These data show that our systems give better results in location estimation than exact positioning. The position of the receiver cannot be pointed exactly but the room information can be obtained at an accuracy of above 83%. According to these results, the system can easily send an alert if the patient is in a banned area or s/he has been in a zone for a long time. Similarly, Table 3 displays confusion matrices of forbidden/permitted zone tests. Here, the performance of the microcontroller is considerably higher than the smart phone, with an average success of 82.5% for the microcontroller over 77% success using the smart phone.

Table 2 Location (room or hallway) estimation results

	Microcontroller		Android phone	
	Actual position			
Displayed position	Room	Hallway	Room	Hallway
Room	68	59	41	58
Hallway	11	7	3	12
Accuracy	86%	89%	93%	83%

Table 3 Confusion matrices for the forbidden zone tests

	Microcontroller		Android phone	
	Actual position			
Displayed position	Forbidden	Permitted	Forbidden	Permitted
Forbidden	85%	20%	60%	6%
Permitted	15%	80%	40%	94%

V. CONCLUSION AND FUTURE RESEARCH

In this work, beacons transmitting BLE signals have been used to perform position estimation, location estimation and alert generation for specific rule violations. The beacons are positioned in an experimental setting to perform extensive measurements. Two systems have been developed to track the position: a microcontroller box and a smart phone. Initially, measurements are carried out in order to create a simple model of the propagation. Using this model, our systems are tested for exact positioning, location estimation and alert generation. The measurement results indicate that the systems are able to send an alert message if the target person goes to the forbidden zone or remains at a location for a long time. Our system gives better results for location estimation than exact positioning due to non-ideal effects. As a summary, this work has showed that hardware and software systems can be combined for this job. For future work, more accurate and efficient measurements have to be made by controlling the signal levels of the transmitters. Also, calibration can be made according to the location because the value of n is affected by many factors in the environment. Another future work theme can be to track the target by using a different kind of signal such as ultra-wide band technology. More research and development are necessary to obtain reliable products to be used in the market.

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