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Indoor Navigation and Location-Based Narration System using Bluetooth Low Energy (BLE) Beacons

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ABSTRACT

With the huge advances in the field of wireless communication technology, Bluetooth Low Energy (BLE) beacon has attracted attention to provide a variety of services. Services like public safety, healthcare, mobile payment, asset tracking and proximity-based service have been proposed using beacon technology. Most of all, navigation system using BLE beacon is an effective approach to provide information about the culture and history of a particular spot to a tourist. In this paper, we suggest a tourist information system with an integrated feature of route finding for the user to the desired destination. It can deliver location based narrations to the visitors, thus providing navigation and interactive learning. Narration starts automatically at the right places without any effort on the behalf of the visitors. Instead of using satellites to triangulate our position in the world as GPS does, beacons transmit a low energy signal from a device with a radius of 50-100 meters to provide unprecedented location services. A Beacon's transmitting range can be configured to trigger messages at the most appropriate distance. Each beacon is given a unique identifier. When a user's device enters the beacon area, the audio corresponding to this unique identifier will be played.

Keywords: Indoor Navigation, Bluetooth Low Energy, Beacons, Tourist Information System.

I. INTRODUCTION

Street navigation systems that rely on Global Positioning System (GPS) satellites are used by lots of people every day. Unfortunately, this kind of technologies can only be used to navigate in open spaces and are not available indoors. It is because of this, the indoor navigation techniques using Wi-Fi and Bluetooth signals, along with effective positioning algorithms, have been an object of study in recent years.

Ideally, deploying an indoor navigation system must be easy and cost effective. Most of the time, signals received from Wi-Fi devices present in a building are used as reference, however, other technologies such as Bluetooth Low Energy (BLE) better suited for indoor navigation.

BLE is a subsystem of the traditional Bluetooth technology capable of broadcasting data using a minimal amount of power. This makes it ideal for devices operating on small batteries which need to function uninterrupted for long periods of time. For the purpose of indoor navigation, BLE devices known as beacons seem to be the best choice.

Beacons are small devices that broadcast packets of data in short time intervals. These packets contain information about the beacon, as well as telemetry readings commonly used in distance calculations. A Bluetooth device is used to pick up BLE signals and the data broadcasted by them is read by a microcontroller, which in turn can be used in indoor navigation applications.

II. METHODS AND MATERIAL

RF signals broadcasted by wireless devices are used differently depending on the positioning method being implemented. During the last years, several of these methods have been developed [1], the most common of these being Fingerprinting and Triangulation. Before moving on to explaining these positioning methods, it is important to understand how RF signals can be measured in order to be used as reference.

Signal strength measurement is made by using a signal parameter known as Received Signal Strength Indicator (RSSI). As it name suggests, RSSI is the measurement of the power present on a received radio signal expressed in dBm ranging from -100 dBm for a very low signal level to -50 dBm or more for a strong one. This value should not be confused with output power, which is measured using the same units but represents something totally different.

Some positioning methods collect RSSI values as they are while others use them, along with additional information, to calculate the distance between transmitting and receiving devices. The results of these calculations tend to be inaccurate, since the relationship between RSSI and distance is not always the same and changes according to many factors.

For the purpose of our project, RSSI is used to measure the distance between the transmitting beacons and the user. As mentioned before, these calculations are not very accurate but give an idea of how far one is from the other.

A. Fingerprinting

Fingerprinting uses the RSSI values of a group of devices to create a signature (Fingerprint) of a specific location. This is done by storing these values, along with the addresses of their corresponding devices, in a database. Once several Fingerprints of different locations are created, continuous scans are performed and a runtime Fingerprint is generated every time. This last one is then compared to each one of the saved Fingerprints in order to obtain the closest match which represents the location where the user is.

Fingerprinting offers reasonable accuracy and is easy to implement. In the case of Wi-Fi [4], existing APs in a building are used. One disadvantage, however, is that the availability of the APs used to create the Fingerprint cannot be assured. Even though this issue can be easily addressed by replacing missing RSSI values with arbitrary measurements, this could decrease the accuracy significantly, especially if more than one of these values is missing.

BLE Beacons are also used for Fingerprinting [2]. They can be positioned strategically in order to obtain as many necessary readings as possible and offer lower power consumption. Having dedicated devices for this purpose is definitely favourable; however, a large quantity of them must be purchased in order to cover a large area.

Regardless of the type of signal being used, Fingerprinting has some drawbacks. First of all, the collection of Fingerprints around a building is time-consuming. While using Beacons, a survey of the building is needed to be done to evaluate the best locations to place. Changes in the building can also affect the signal readings and many times the Fingerprints need to be re-calibrated.

B. Triangulation

The triangulation method uses RSSI readings in a different way from Fingerprinting. Instead of only limiting to collect these values, these are also used to calculate the distance between the broadcasting and receiving devices. For this method to work, three or more reference devices must be positioned in a way they cover an area. Next, distances to the reference devices are roughly calculated by the receiving device and an interception point between these is found, which is usually where the user is located [3]. The simplified concept of this method is shown in Figure 1.

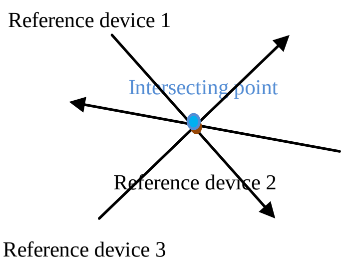

Figure 1 Concept of Triangulation by distance interception

Another version of this method uses imaginary circles drawn around the reference devices in order to find interception points between them. The radii of these circles is calculated based on the RSSI readings picked up from each of the reference points and the time it takes for the signal to travel to the receiving device [5]. Once three or more of these circles overlap, the interception points between them can be found and it is between these points were the user usually is. A simple representation of this method is shown in Figure 2.

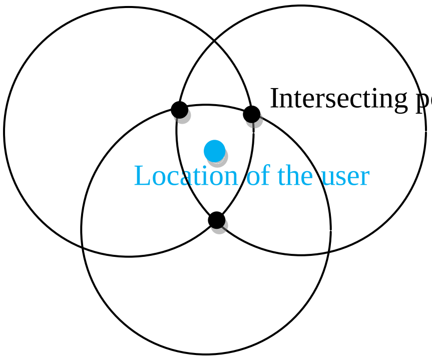

Figure 2. Concept of Triangulation using multiple interception points

Both the Fingerprinting and Triangulation methods were considered, since they are easy to implement and have been proven to work in other positioning systems. However, one disadvantage is that the necessary amount of reference devices would have to be quite high. In Fingerprinting, for example, as many RSSI samples as possible will be needed, otherwise the accuracy will decrease considerably. As for Triangulation, as the user moves along, let us say a corridor in a museum, many devices would have to be positioned and the complexity of the algorithm will increase in order to calculate the user's position at all times.

C. Distance Calculations Using RF Signals

RSSI values can be used in distance calculations. These values normally change depending on how far the transmitting device is. If we compare the transmitted signal strength to the received one, we can somehow measure how much the value decreased over the travelled distance and use this information to know the distance between devices. Nevertheless, due to many factors that may affect the signal on its way from one point to another, the relation between distance and RSSI is not always constant.

For the purpose of this project, a method to calculate the distance between the reference devices and the user must be found. Unfortunately, this is not as simple as it sounds and several factors must be taken into account when trying different methods. Due to the characteristics of RF signals, distance calculations are somehow inaccurate and vary depending on factors such as signal attenuation, reflection among others.

The most basic concept to understand is signal propagation. First of all, signals attenuate as they travel (propagate) between the transmitting and receiving device. This attenuation, also known as path loss, increases with distance and is also affected by other factors such as obstacles present in the environment, temperature, weather, etc. Signals might also collide against obstacles and be diffracted or absorbed depending on the obstacle's material.

Different models have been created in order to understand signal propagation. These models take into account diverse factors, including path loss, and can be used in order to calculate distances [8]. One of the most popular propagation models is known as the Free Space Friis Model (FSFM).

FSFM makes a comparison between the transmitted and received RSSI to know how much the signal attenuates over distance. As it names suggests, this model can be applied only to calculations made in free space, that is, in an environment without obstacles that may interfere with the signals.

FSFM also takes into account another factor known as antenna gain, a measurement of the antenna's ability to concentrate radio frequency energy in a particular direction [9], from both transmitting and receiving devices. Both RSSI and antenna gain values can be used to calculate distances using the following formula (1),

$$d = \sqrt{\frac{Pt}{Pr}} \cdot \left(\sqrt{Gt \cdot Gr}\right) \cdot \left(\frac{c}{4\pi f}\right) \qquad (1)$$

wherePt and Pr are the transmitted and received powers, Gt and Gr the antenna gain values of the transmitter and receiver, c is the speed of light and f the signal frequency.

A simplified graph representing the relation between distance and RSSI, according to FSFM [10], is shown in Figure 3. There we can see how the RSSI value decreases as the distance increases. This change is not always linear, however, and it is at distances over 7 meters where the RSSI values seem to stagnate.

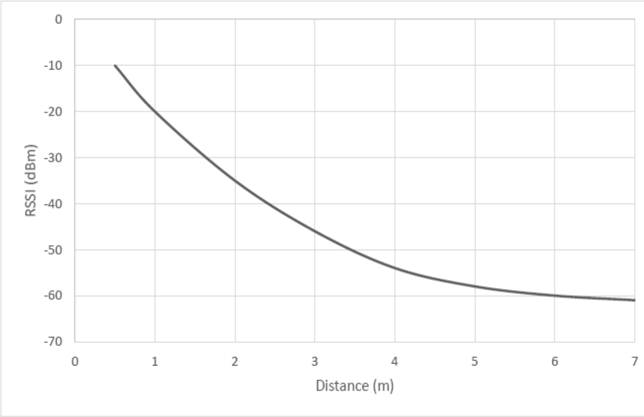

Figure 3. Relation between RSSI and distance according to FSFM

Even though this model seems simple enough for its use in this project, values such as antenna gain and exact signal frequencies cannot be easily found by using tools such as mobile phones and beacons. Furthermore, this model is designed to work only in open spaces. Due to these reasons, a more suitable method is needed.

An even simpler propagation model proposed in [11] seems like a formidable option for this thesis work. This same model has been used in other systems [5, 9, 12, 13, 14] and has proven to work relatively well for distance calculations based on RSSI. This model is represented by the following formula,

$$RSSI = P_{tx} + G + 20\log\left(\frac{c}{4\pi f}\right) - 10\log(d) \quad (2)$$

where Ptx is the beacon's transmit power in dBm, G is the combined antenna gain of both the transmitting and receiving device; c is the speed of light or 300,000 km/s; f is the frequency of 2.44 GHz; d is the distance between the transmitter and receiver and n is the attenuation exponent. This exponent ranges from 4 to 2 and is calculated using the following formula,

$$n = -\left(\frac{RSSI-A}{10log_{10}d}\right) \quad (3)$$

where A is the beacon's RSS at 1m distance in a non-obstacle environment [11]. The attenuation exponent must be calculated for each reference device and will change depending on the environment. That is, the obstacles and interferences affecting the signal. In an environment where no obstacles are present (free space) the value of the attenuation exponent is 2 [11].

As mentioned before, values such as antenna gain and exact frequencies cannot be easily acquired since they are not transmitted by the beacon. It is because of this that (2) can be further simplified as shown in (4).

$$RSSI = A - 10n\log(d) \quad (4)$$

Using this model, distances between devices, using only the information broadcasted by the beacons, can be easily calculated.

Distance calculations are performed at 1 sec intervals using formula (4), explained in the previous chapter. As mentioned before, the beacon advertising interval was set at 100 ms, which means, an average of ten RSSI readings is collected every second. For each one of these readings, a distance calculation is performed and the results used to obtain an average distance. The reason for doing this is to decrease the difference between calculations caused by RSSI fluctuation. The distances are rounded to the nearest meter.

III. RESULTS AND DISCUSSION

For this project, an embedded C program was developed for interfacing a beacon, LCD and Apr9600 voice recording playback system with a ARM7 microcontroller. This relies on information gathered from several slave beacons to function. The main reason for developing this is for better understanding of the indoor navigation and to show how a common microcontroller can be used for navigation purpose.

Beacons are placed at several positions in the building. They send Bluetooth signals to a master beacon interfaced with the ARM microcontroller. Like that, it is possible to determine their position continuously and transmit it to the indoor navigation system. Beacons battery lasts from some days to several years and they can span up to 30 meters inside buildings.

The number of beacons needed in a building depends on the size of the area and the required accuracy. The Indian Museum, for example can use 500 beacons. The accuracy can be about 1-2 meters. Retailers need a higher accuracy of about 50 cm. Beacons can be operated with batteries and hence they are easy to install and maintain

A. The concept of Micro-location

Micro-location, also referred as indoor navigation, is still considered to be in its early development stages. One might think that, by now, with all the advances in geolocation, such a simple concept as navigating inside a building would have been already addressed. Although there is extensive research going on for several years, no definite method for such purpose has been agreed upon yet.

In order to find out one's position inside an enclosed space, some kind of reference is needed. GPS satellite signals cannot be received indoors, which means that indoor positioning systems must rely on other kinds of technologies to function. Usually, reference data in the form of radio signals, infrared, ultrasound or magnetic field readings [6] is used for this purpose. Once collected, this data can be interpreted and used in positioning algorithms, providing different levels of accuracy.

For the purpose of developing an indoor navigation system that is easy to implement, as well as widely available to the public, one must consider using common and simple technologies. Positioning methods such as those using magnetic field readings [7] offer great accuracy but their implementation is difficult and pricy, not to mention, they cannot be easily made available to the public. On the other hand, Radio Frequency (RF) signals, such as those emitted by Wi-Fi Access Points (AP) and Bluetooth devices, are fairly common and may be also used as reference for indoor navigation systems.

Just as those relaying on GPS, indoor navigation applications can be also designed to provide additional information, either on request or automatically, related to the user's location. A company building or university, for example, can offer guidance to visitors about the location of a classroom or conference room, including schedules, features, etc. Another good example is an airport that chooses to provide information about flights as soon as the clients walk through the door, as well as ways to check-in and find their luggage. The list goes on and on and the possibilities are become more interesting. Being able to provide contextual and audio information can be highly valuable not just for the user but also for companies and services that choose to implement this system.

B. Working principle

The navigation system consists of ARM7 LPC2148 microcontroller, a scanner beacon, a group of transmitting beacons, LCD and a APR9600 board with headphones connected. An Embedded C program is developed using Micro Vision Keil software. The developed embedded C program is then loaded into the ARM7 LPC2148 microcontroller using Flash Magic software.

The system works as follows: first, few beacons are positioned around an area. Then, the scanner beacon scans for them and gathers their RSSI readings. These readings are, in turn, used to calculate the distance between the user and each beacon. The LCD displays the distance value in meter and the additional information about the location will be conveyed to the user in audio form through APR board with headphones.

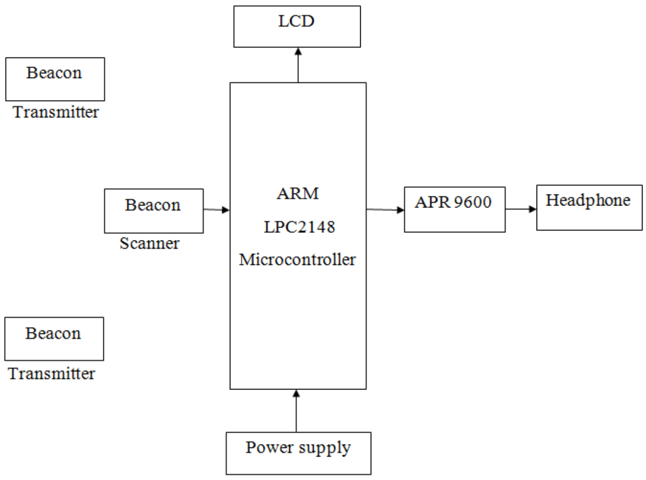

Figure 3. Block Diagram

C. Implementation

At this point, all necessary concepts related to indoor navigation have been explained. Information about the technologies used in this project as well as a way to use them in positioning algorithms has been also covered. In this chapter all this information is put together and implemented into a navigation system consisting of ARM7 microcontroller, a scanner beacon, a group of transmitting beacons, LCD and a APR board with headphones.

The system works as follows: first, few beacons are positioned around an area. Then, the scanner beacon scans for them and gathers their RSSI readings. These readings are, in turn, used to calculate the distance between the user and each beacon. The LCD displays the distance value in meter and the additional information about the location will be conveyed to the user in audio form through APR board.

IV. CONCLUSION

As the user passes within the range of a beacon, the user will be notified with the distance value and the corresponding audio will be played automatically without any effort on the behalf of the user. As opposed to the well-established concept of outdoor navigation, indoor navigation must still overcome many challenges before becoming an everyday use commodity. One example is the limited amount of technologies that can be used for this purpose, as well as the accuracy offered by these. Furthermore, how to make indoor navigation systems available to the public is still a great challenge.

The main purpose of this project was to introduce indoor navigation and show how, by using common devices, it is possible to create an indoor navigation system. Taking advantage of the both the beacons and the APR board interfaced with the microcontroller, a simple but functional application was developed.

Future work will focus on finding new ways to improve the functionality regarding both the positioning algorithm and the hardware configuration. Making the system adaptable to different environments will be a top priority.

The information presented in this document discusses only the most essential concepts that need to be understood when working on a project such as this. Most of the research carried out was related to RF signals and the possible ways to implement them into this kind of system. This work represents only a small part of what indoor navigation really is. As technology advances, more sophisticated and interesting solutions related to this topic will continue emerging. At the same time, more people will have access to these and they will, eventually, become part of the everyday life.

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