Bluetooth Indoor Positioning

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Abstract

In this paper, we describe and analyze a system for indoor positioning, which enables a person with a smartphone to find his or her location within an enclosed space, with an accuracy of up to 2 meters. The idea is to place 3 or more Bluetooth *beacons* at known positions in a room, and have a smartphone record the strengths of the signals emitted from them. This is measured using RSSI (received signal strength indication), which indicates the signal loss (in dB) on the path from the transmitter - beacon, to the receiver - the smartphone. From the RSSI, we can obtain the distances from the individual beacons, and further, using multilateration, the approximate position of our device.

The measured accuracy is in accordance with the current industry standard solutions for indoor positioning, based on this technology.

1 Introduction

An indoor positioning system is a system that allows us to determine our approximate position inside a large enclosed area, such as an airport, or a conference center. Unlike GPS, such a system rarely works outside the designated area, instead it is designed to work the best in areas where the GPS satellite signal is weak, or non-existent.

Our goal is to develop one such system, where s person in need can easily consult an app on their smartphone, and find out where they are.

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In the following sections, we will describe our setup in greater detail, as well as give a theoretical justification for it.

Theoretical background

In telecommunications, the received signal strength indication is a measurement of power present in a received radio signal. Although not completely standardized, the Bluetooth stack reports its value to the user in decibels.

Under the assumption that there are no obstacles between the transmitter and the receiver, the RSSI is described by the free-space path loss equation:

$$\mathrm{FSPL(dB)} = 10\log_{10}\left(\left(\frac{4\pi}{c}df\right)^2\right),$$

where c is the speed of light, d – the distance, and f – the frequency. Thus, if the FSPL is known, we can recover the distance using an equation of the following form:

$$d \approx A \cdot (\mathrm{FSPL})^B + C,$$

where A, B, C are experimentally-measured constants dependent on the environment, and the transmitting and receiving antennas.

Apart from determining those constants, the only thing that is left is to calculate the FSPL from the

RSSI. Luckily, among other data, every Bluetooth device also transmits the reference RSSI at one meter. Experimental data has shown that the following equation is the best "simple" model for this phenomenon:

$$d = A \cdot \left(\frac{\text{rssi}}{\text{rssi}_{1m}}\right)^B + C.$$

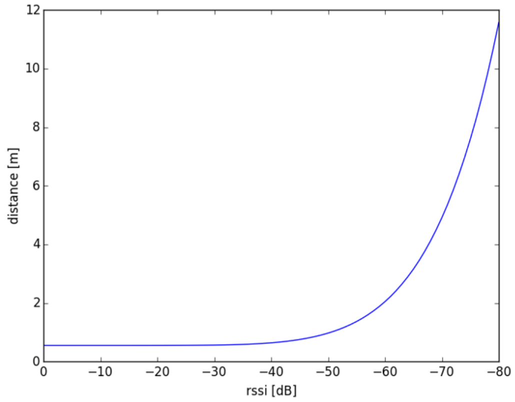

Figure 1: Distance as a function of rssi

2 Our setup

Our system consists of two parts, hardware (the Bluetooth beacons themselves), and software (the software that analyses the data, and determines our position).

Hardware

The hardware side consists of three or more *beacons* placed at known positions in our classroom. A beacon is nothing more than a Bluetooth device that periodically transmits Bluetooth Low Energy (BLE) advertising packets, containing the beacon ID, and its RSSI at one meter.

The last quantity is hardware-dependent, and its value is determined via calibration. This is done by measuring the RSSI at 1 meter during 60 seconds, and taking the average value to be our reference.

At the user end, the only remaining hardware is a smartphone, that will record the signal strengths, and reconstruct the approximate position.

Software

As for the software, due to time constraints, our system is split into two components: a frontend app running on the smartphone, and a backend server running on our laptop.

The frontend is written in the Java programming language, and runs on any Android OS smartphone containing the appropriate Bluetooth hardware. Its only task is to measure the beacon signal strengths, and forward that data to the backend via the local network. The data is sent in plain text using a TCP socket.

The backend is written in the Python programming language. It's workflow can be summarized in the following list:

1. Receive the data from the TCP socket
2. Smooth it out using the exponentially weighted moving average
3. Calculate the distances from the individual distances
4. Recover the original position by fitting a non-linear weighted least squares model through the distances

To aid us with the numerical computations, we used the numpy library. Their implementation of the Levenberg-Marquardt algorithm for the least-squares fitting was especially useful.

3 Results

Although our original plan was to measure the accuracy using a 1m^2 grid drawn on the classroom floor, after initial measurements it turned out that such precision is not needed, since the calculated position was up to two meters away from the original position. Thus, we settled for displaying the position on a real-time heatmap, and visually inspecting them.

For near real-time application, it turned out that we were unable to lower the industry-standard 2m error bound, as the signal was oscillating too much to obtain a stable location.

For offline location processing, a better accuracy of around 1m was achieved, by aggressively filtering the received RSSI data. However, this approach is unsuitable for real-time applications, as its response time is too high, at the order of magnitude of a few minutes.

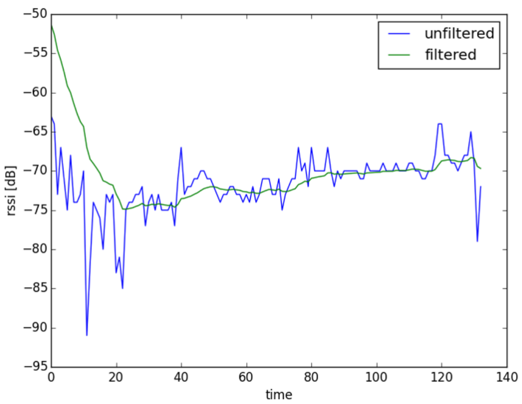

Figure 2: Filtered and unfiltered signal strength over time

4 Discussion and conclusion

During the Summer School, we produced a proof of concept that it is indeed possible to construct an indoor positioning system based on a fixed set of Bluetooth beacons on known positions. The results we got are on par with leading industry and research solutions based on the same technology.

From the data it is evident that a better accuracy would be achieved if we increased the beacon advertising frequency (that is, the delay between sending successive advertising packets). However, there are a few challenges associated with this approach:

The first and foremost is that the battery of both the beacons and the smartphone would be drained more quickly that currently. How much more quickly is yet to be determined by precise battery usage measurements. Furthermore, according to the Bluetooth specification, the maximum advertising frequency for the BLE profile used by the beacons is bounded by 10Hz. This restriction could probably be overcome by having a low-level access to the beacon Bluetooth stack.

Unfortunately, this idea was prevented by a purely logistical problem. Namely, we ordered 6 dedicated programmable Bluetooth beacons from a Chinese supplier. Out of them, we could program only one, since the rest had their flash memory locked. As a last-minute resort, we used our laptops as makeshift beacons. However, due to many layers of abstraction in the Linux kernel, we were unable to modify them to increase the advertising frequency, so we had to settle for 10Hz for all 4 beacons.

To conclude, we believe that (after overcoming the described limitations) this system has a great potential to be used for various applications, including, but not restricted the ones we listed in the introduction.

References

[1] A. Bekkelien, M. Deriaz, and S. Marchand-Maillet. Bluetooth indoor positioning. *Master's thesis, University of Geneva*, 2012.

[2] Q. Dong and W. Dargie. Evaluation of the reliability of rssi for indoor localization. In *Wireless Communications in Unusual and Confined Areas (ICWCUCA), 2012 International Conference on*, pages 1–6. IEEE, 2012.

[3] C.-C. Pu, C.-H. Pu, and H.-J. Lee. *Indoor location tracking using received signal strength indicator*. INTECH Open Access Publisher, 2011.

[4] O. J. Woodman. *Pedestrian localisation for indoor environments*. PhD thesis, Univerity of Cambridge, 2010.