Using Raspberry Pi and Bluetooth Low Energy Signal Strength to Detect Distance While Walking

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Abstract:

This project describes a process for determining if two people are within six feet of each other while walking using Raspberry Pi and Bluetooth Low Energy (BLE) signals. This project describes the process used for measuring and collecting the BLE signal strength and the use of detection algorithms to estimate the distance. This distance estimation technique may be used to build a successful Bluetooth-based automated contact tracing system. Contact tracing is the process used by health departments to prevent the spread of infectious diseases by identifying people who might have come into contact with infected individuals [1]. During a pandemic, like the current COVID-19 situation, traditional manual contact tracing methods don't scale well [2]. Therefore, automated contact tracing is necessary to limit the spread of disease. The scope of the study is limited to measuring only BLE signal strengths and doesn't consider other signals like Wi-Fi, ultrasound, and GPS. Further only Raspberry Pi 4, model B were used as the sole device for transmitting and receiving signals.

Keywords: Bluetooth Low Energy, Bluetooth Low Energy Beacon, Received Signal Strength Indication, Automated Contact Tracing, Raspberry Pi, COVID-19, Pandemic.

I. INTRODUCTION

A. Project Description

Private Automated Contact Tracing (PACT) is an effort led by the Massachusetts Institute of Technology (MIT) to develop a standard/specification to build automated contact tracing using smartphones and Bluetooth [3]. PiPACT is an instance of PACT using Raspberry Pies instead of smartphones. This project addresses if it is possible to confidently determine if two people are too close, (within 2 meters) while they are walking in the open. Walking is common, real-life activity during which individuals can come into close contact.

The experiment uses two Raspberry Pies, one of which acts as an advertiser and continuously emits BLE advertisement chirps, while the other Pi continuously scans for the BLE advertising signal. The scanning Pi records the Received Signal Strength Indicator (RSSI) of the received BLE signal once every second. Two different experiments were conducted, one where two human experimenters were walking with the Raspberry Pi in their front side pant pockets at different distances within two meters. The second test is similar to the first one, except the distance was outside of two meters.

B. Background Information

BLE is a wireless technology operating at 2.4 unlicensed GHz radio band to interconnect nearby devices [4]. BLE uses lower power consumption as compared to classic Bluetooth. Relative Signal Strength Indication (RSSI) is a quantitative measure of the strength of a received Bluetooth signal [5]. RSSI is measured in decibel per watt(dBm) units. Any reference to signal strength in this paper is based on this measure. Raspberry Pi is a small, single-board computer running a Linux operating system that can be used for numerous low-level applications [6]. The project assumes the experimental walking scenarios studied here is a good representation of various real-life outdoor walking scenarios. Signal attenuation due to different antenna orientations and weather-based factors like humidity and temperature are not considered.

II. HYPOTHESIS/HYPOTHESES

Hypothesis: Can we confidently determine if two people are within two meters while walking using the measured RSSI value of Bluetooth signal transmitted and received using Raspberry Pi?

- This project uses an automatic way of recording RSSI of BLE chirps to estimate the distance and hence could be used to develop a contact tracing system.
- By anonymizing the BLE chirps and using cryptographic techniques we would ensure the privacy of the users, which is a critical consideration in PACT.
- Testing the indicated hypothesis provides important information into the possibilities/limitation of using BLE signals for contact tracing.

The aspect of the hypothesis that requires the most investigation is building a reliable detection algorithm to estimate whether two people are within or outside two meters based on the BLE RSSI value.

III. EXPERIMENTS AND DATA COLLECTIONS

The experiment setup involves running one Raspberry Pi as a BLE Beacon broadcasting its identity to nearby devices. The advertisement packet consists of a Universally Unique Identifier,

Bluetooth address, metadata, and radio transmit power. The other Raspberry Pi continuously scans for the BLE Beacon signal and records information about the advertisement Packet along with the RSSI value. Both the Pies are running a Python program for broadcasting and receiving. This project used the BWSI PiPact python reference code for advertising, scanning, and data collection. The following experiments were done by two human experimenters walking with Raspberry Pi in the front side pant pockets. The environment in which data was collected had minimal physical obstructions and hence low signal attenuation.

TABLE I.   EXPERIMENTS OVERVIEW

Experiment	Hypothesis	Reason	Repetitions / Total Duration
1	Effects of walking	Collect RSSI values at various distances within 2 meters	6 tests for a total duration of 1 hour
2	Effects of walking	Collect RSSI values at various distances outside 2 meters	6 tests for a total time of 1 hour

A. Plan and Execution

All the repetitions of both the experiments were collected on the same walking path with no physical obstruction between the two people. The RSSI values were captured once per second on the scanning Raspberry Pi. The scanning Raspberry Pi was filtering out any irrelevant signals. There was no overlap in the physical distance between the two experiments - the distance was strictly within two meters in the first experiment and strictly outside two meters in the second experiment. The maximum distance in the second experiment was limited to eight meters.

All the repetitions of both the experiments consisted of having the devices in the same orientation in the front side pant pocket. This is not very representative of various real-life device scenarios.

B. Data Relevance

The motivation for both experiments was to identify if there is a critical RSSI threshold value that can be used to separate the data from the experiments into two separate groups. Using this critical RSSI threshold value (assuming that one exists), a binary hypothesis test can be conducted.

C. Examples

Here are a few summary diagrams of the collected data.
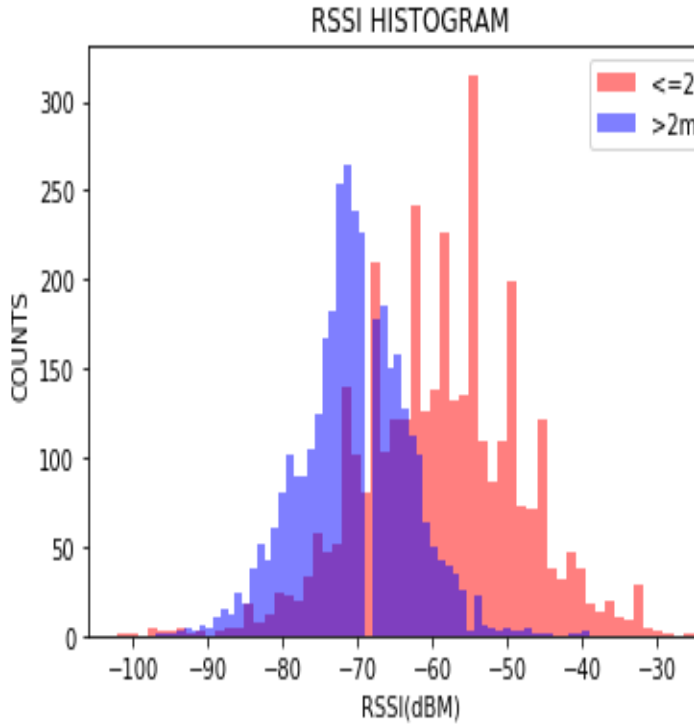

Fig. 1. Boxplot

FIGURE II. HISTOGRAM

Fig. 2.   Histogram of collected data

TABLE II. SUMMARY STATISTICS

	RSSI - Within 2 Meters	RSSI - Outside 2 Meters
count	3544	3544
mean	-59.05	-70.48
std	10.54	7.15
min	-102.00	-97.00
25%	-66.00	-74.00
50%	-59.00	-70.00
75%	-52.00	-66.00
max	-24.00	-39.00

IV. ANALYSIS AND ALGORITHMS

A. Description

To test the initial hypothesis, I conducted a Binary Hypothesis Test. A Binary Hypothesis Test is a statistical analysis used to distinguish between two different classes called the null(H0) and alternate hypothesis(H1). In this study, the null hypothesis is that two people are outside 2 meters while walking, and the alternate hypothesis means that two people are within 2 meters while walking.

To conduct a Binary Hypothesis Test, a specific test must be devised to map the measurements into possible outcomes. The specific test that I have used for this Binary Hypothesis Test is a critical value/threshold test. A critical value/threshold test simply means that if a measurement is greater than the threshold, it will be classified as part of the alternate hypothesis (within 2 meters). The below illustrates an example of critical value threshold.
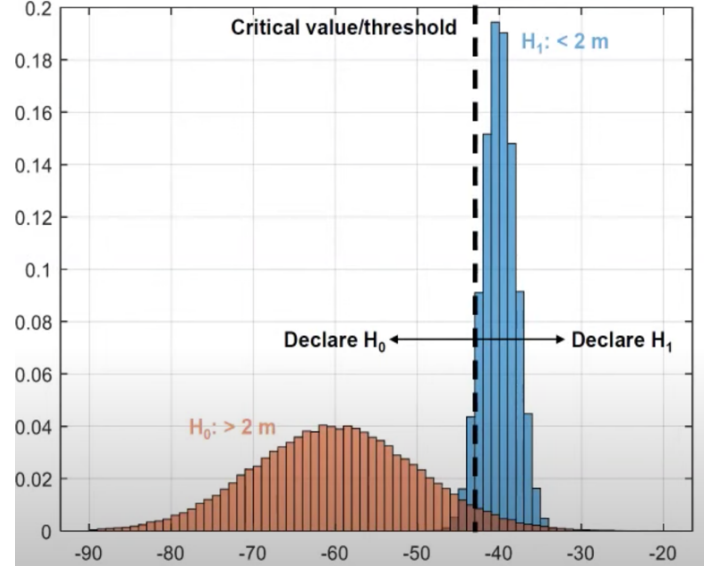

Fig. 3.   Example of critical value/threshold test [7]

The success of a selected threshold is determined by measuring the true positive rate and false positive rate. A true positive rate (TPR) refers to the percentage of measurements that were classified correctly as part of the alternate hypothesis, whereas false positive rate (FPR) refers to the percentage of measurements that were part of the null hypothesis but were classified as part of the alternate hypothesis.

$$TPR = \frac{True\ Positive}{True\ Positive + False\ Negative}$$

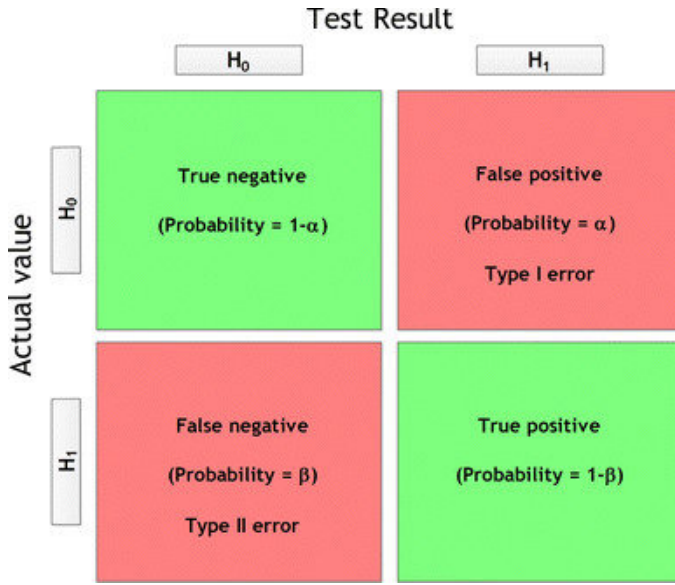$$FPR = \frac{False\ Positive}{True\ Negative\ +\ False\ Positive}$$

Fig. 4.   Confusion Matrix [8]

Area Under the Curve - Receiver Operating Characteristics (AUC-ROC) curve is a performance measurement of the binary hypothesis test at various threshold settings. It tells us how well the threshold can distinguish between the two hypotheses. The ROC curve is plotted with true positive rate on the y-axis and false positive rate on the x-axis. Area under the curve (AUC) represents the measurement of separability [9].
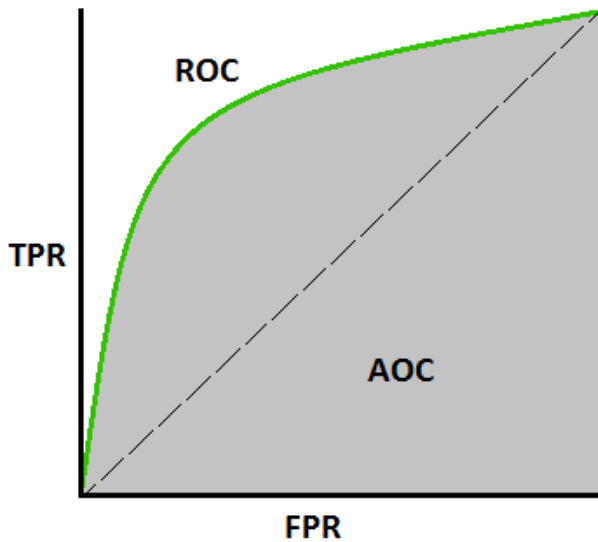

Fig. 5.   Example of AUC-ROC Curve [9]

The various test used for the finding threshold setting:
- Threshold of single RSSI Measurement
- Threshold of average of M RSSI Measurement
- At Least M of N measurements exceed threshold
- Weighted average of M measurements

Python and Jupyter Notebook were to compute and plot the various AUC-ROC curves.
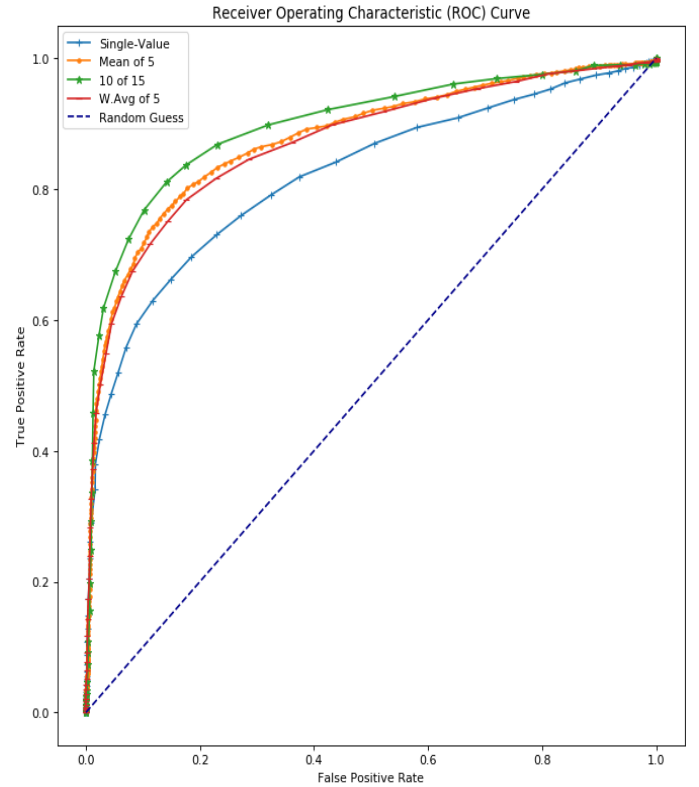
B. Results and Examples

Fig. 6.   AUC-ROC Curve for collected data

The ROC curve demonstrates that certain threshold settings have a higher TPR compared to other thresholds. Also, the TPR is much greater than the FPR at most of the thresholds. One important aspect to note is that all the tests conducted here have performance better than random guessing. The high AUC for the various tests conclusively proves the binary hypothesis tests can separate the data into two distinct categories. The single-value test performed the worst, as indicated by the area under the curve. The M of N test (M = 10, N = 15) performed the best. One interesting case noticed here is that Mean of 5 and the weighted average of 5 had a very similar performance. However, it might be beneficial to repeat these tests at different weights.

Further, by repeating the M of N test at different values of M and N show the AUC is higher for larger M and N values. Similar characteristics are observed for test different mean sizes.
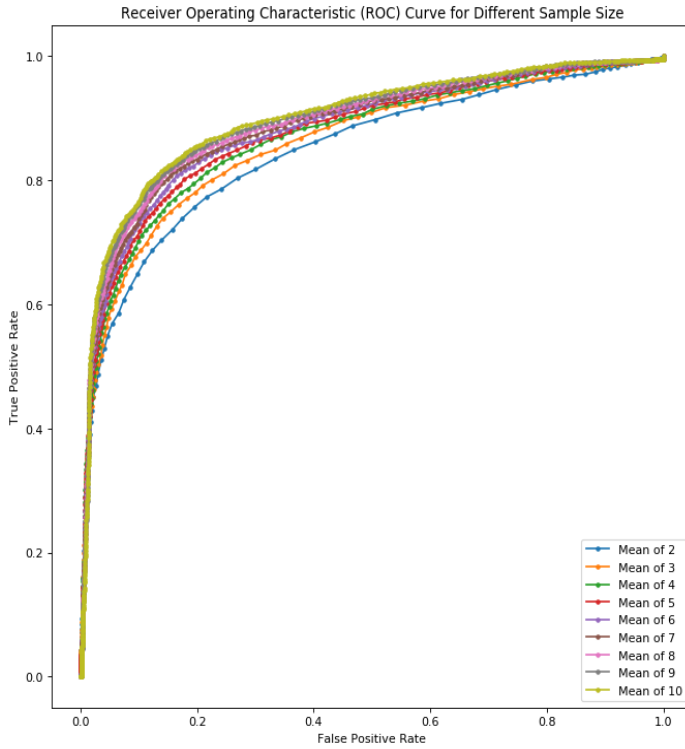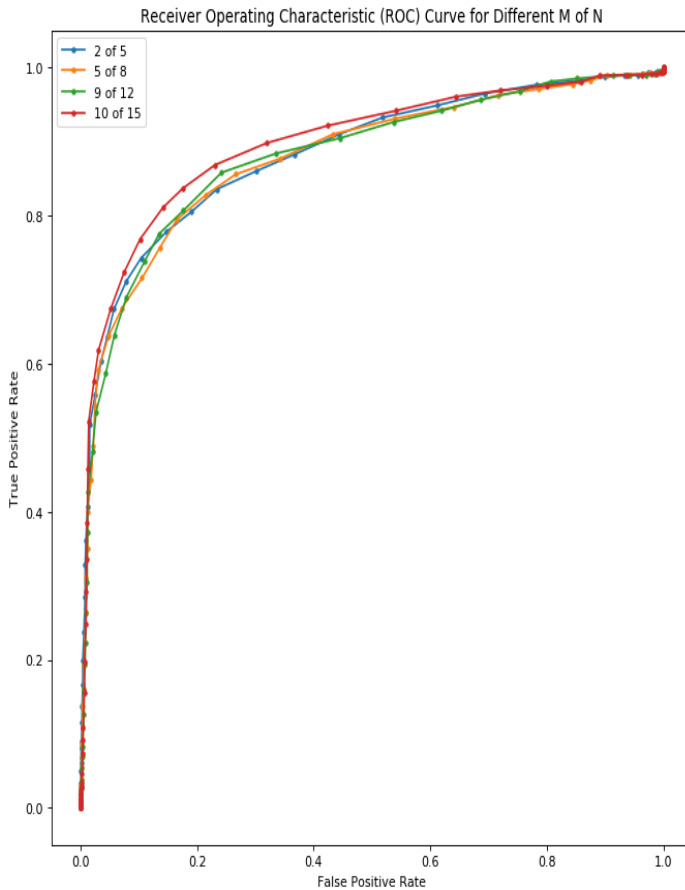
Fig. 7. AUC-ROC Curve for different sample sizes

Fig. 8. AUC-ROC Curve for different M of N

V. CONCLUSIONS

A. Hypothesis Evaluation

The binary hypothesis tests we conducted confirms our hypothesis to be true. Hence, we conclude we would confidently determine if two people are within two-meter while walking using the measured RSSI value of Bluetooth signal. The ROC curve and AUC plots provide sufficient evidence to our conclusion. Further, we figured using a threshold based on multiple RSSI values always yields better results compared to using a single value.

B. General Lessons Learned

Despite the success of my hypothesis, further testing will need to be conducted to ensure the reliability of Bluetooth-based contact tracing in a real-world setting. This study did not consider numerous other factors that could impact the measured RSSI value. This specific hypothesis, where the human testers were out in the open, did not have to deal with the various nuances associated with signal attenuation.

VI. NEXT STEPS

As the next step, I would like to test my hypothesis using smartphones instead of Raspberry Pi. In addition, I would like to consider more real-life scenarios that might have an impact on the measure RSSI values due to signal attenuation.

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