Indication of Pedestrian's Travel Direction Through Bluetooth Low Energy Signals Perceived by a Single Observer Device

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***Abstract*—This paper presents a study to understand the directional sensitivity of a Bluetooth Low Energy (BLE) monitoring device (Observer) and whether, using a single such Observer, the characteristics of its antenna can be used to identify the direction of a pedestrian's movement. To comprehend the directional characteristics of the antenna of the Observer employed for this study, the device is subjected to BLE signals emitted from a BLE beacon (Broadcaster) in an anechoic chamber. The results of this study confirmed that in the clean, noiseless environment of the chamber, the antenna we employed is clearly more receptive to signals emerging from certain directions. To confirm the validity of these results in an outdoor noisy environment, we performed another experiment where BLE Received Signal Strength (RSS) values were recorded from a Broadcaster held by a stationary volunteer pedestrian at different chosen points on a linear walkway. The results suggest that the directional sensitivity of the Observer's antenna holds true in outdoor settings. Finally, to determine the likelihood of inferring a pedestrian's travel direction, we deployed an Observer on a linear walkway where a volunteer pedestrian was recorded each time they passed over a series of chosen location markers. Overall, the results suggest that an assertion of travel direction through this method is indicative rather than conclusive and while the directional sensitivity of the Observer can be observed in controlled environments such as an anechoic chamber, it may not be as pronounced or reliable in outdoor settings. The findings highlight the importance of considering environmental factors when analysing BLE signals to infer pedestrian direction.**

***Index Terms*—Bluetooth Low Energy, pedestrian behaviour, travel direction, privacy preservation**

I. Introduction

The ability to accurately gather data about pedestrian behaviour is essential to inform reliable urban (re-)development decisions. Many sensing technologies such as Global Positioning System (GPS), optical imaging sensors [1]–[6], WiFi and BLE, are employed to understand the behaviour of pedestrians. However, the establishment of comprehensive privacy regulations such as General Data Protection Regulation (GDPR) has impacted the data collection, storage and analysis process in this field of study. Consequently, a need for privacy-preserving techniques for monitoring any public information, even for societal benefit, has emerged.

BLE is one of many technologies that are employed to understand pedestrian behaviour. While the usage of BLE has become common in many applications in indoor environments, its outdoor applications are limited. This is due to several factors including its unreliability at larger distances [7], the presence of metallic objects in the surrounding environment [8] that affect the signal, and even the nature of the electromagnetic wavelength that BLE operates in [9]. Despite the shortcomings, BLE has garnered the attention of the research community and established itself in several application areas such as positioning and localisation [10]–[14], activity recognition [15], [16], and resource management [17]–[19].

In this study, we examine the use of BLE to identify pedestrian direction on a linear walkway by analysing RSS values from a passing beacon device (Broadcaster) intercepted by a single observer device (Observer). Three experiments are conducted. First, we investigate features in the BLE Observer's antenna that can aid in inferring direction. We collect RSS values from different angles (0°, 45°, 90°, 135°, and 180°), with respect to the Observer in an anechoic chamber. The second experiment involves stationary volunteer on the walkway at select marked locations for three measured periods of 1-minute each. We correlate the obtained results with those from the anechoic chamber to check for similarity in the pattern of RSS values. Finally, we collect data from the Broadcaster held by a volunteer pedestrian walking on a linear walkway, as well as 'ground truth' data from a mobile app that the pedestrian uses to record their presence, without impacting their walking pace, when they pass through those select locations. This analysis explores the potential of inferring pedestrian direction using BLE RSS values from a single Observer.

In section II, we discuss BLE technology and the tools employed in the experiments. The methodology is discussed in section III, encompassing the system and experimental design, and analysis. Section IV elucidates our findings and a discussion follows in section V.

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II. BACKGROUND

The Bluetooth (BT) Special Interest Group (SIG) released BLE communication protocol as part of their BT 4.0 standard in 2010 [20]. Unlike classic BT, BLE is designed for low energy consumption [21]. As per the BLE protocol, a BLE device can take on one of four specified roles, viz. *Broadcaster*, *Observer*, *Central* or *Peripheral*, and can have one of two states before connection, *Advertising* or *Scanning* [22].

To communicate with another specific device, a BLE device must first establish a connection with it. The connection process requires the device to *advertise* its availability to its neighbour, called connection-less operation [23]. In this connection-less process, the device performs a one-way broadcast of small data packets which are called advertisement messages, or simply, advertisements. These advertisements contain relevant information to establish the connection, called a scan request-response message. When the advertisement signal is intercepted by another BLE device, the signal's strength is evaluated and is referred to as the RSS value. However, Received Signal Strength Indicator (RSSI) is a somewhat unpredictable indicator that is affected by external factors such as weather conditions [24], objects in the surrounding environment [8], and path loss and fading [9]. Moreover, as antenna design, signal transmission power and other features vary, even the RSS value at the same distance but from devices manufactured by different vendors is often different [25]. This adversely affects the application of BLE in outdoor environments. However, since our approach here relies on the spatial pattern of collected RSS values and not on the values themselves, this limitation is not considered an encumbrance.

Understanding pedestrian behaviour encompasses several aspects such as choice of route, direction of travel, atypical pedestrian movement, and pace and gait. These aspects play a crucial role in understanding the usage of a public space, providing a data-driven approach to the (re-)development of spaces. Insights into pedestrian behaviour are useful in many disciplines such as transportation, urban planning [26], land-use [27], marketing [28], and architecture [29]. In the literature, we find several techniques and technologies that have been employed to understand the behaviour of pedestrians. These include simulation of models [30], social media mining [31], statistical models [6], optical imaging sensors [1]–[3], and BLE [22], [32]. Imaging sensors and techniques dominate this research space, however, recently due to privacy regulations, technologies such as BLE that are comparatively easier to use in a non-invasive manner are attracting more attention. The advantage of BLE that allows it to be employed for both opportunistic as well as participatory monitoring, as defined in [22], makes it a viable option for understanding pedestrian behaviour.

III. METHODOLOGY

A. Rationale

One of the primary rationales for the design of our system is to align with Privacy-by-Design (PbD) principles. This sets the tone for the choice of devices, components, and techniques in this study. Driven by this motivation, we select BLE as the sensing technology to observe pedestrian behaviour. Features of BLE such as those listed below allow for privacy preservation in monitoring.

- *Advertisement packets:* The advertisement packets have limited information and hence make personal identification of the carrier of the Broadcaster more difficult.
- *Choice of device role:* BLE offers choices of roles. One role worth noting is that of an *Observer*. An Observer can only listen to the advertisement and has no capability to establish a connection, even if the *Broadcaster's* advertisement contains a scan request-response message. Therefore, the chance of an intruder sniffing personal information post connection is eliminated.
- *Whitelisting:* The BLE core specification since BT version 4.2 has included an additional link-layer feature, *whiltelisting* [33]. This constrains the *Observer* to only receive messages from the devices mentioned in a whitelist, which means that an *Observer* can be configured to only receive advertisements from selected *Broadcasters*.

Our system is designed so that the Observer receives signals only from a whitelisted Broadcaster that is being carried by a volunteer pedestrian. This design ensures no stray signals from other passing BLE devices are ever intercepted by the Observer.

Some other important aspects of our design choices are driven by cost-effectiveness, ease of use and availability. To ensure our experiments are replicable, we choose off-the-shelf devices that involve minimal setup overhead. A Raspberry Pi (RPi) 4B is used for our Observer, this is widely available, requires no additional components as it features an on-board BLE 5.0 chipset, and has a large online support community. The RPi is mounted inside an enclosure which also includes an off-the-shelf portable power bank [34]. The architecture of the system is shown in figure 1. For the Broadcaster, a BLE beacon, Ruuvi Tag [35] is employed. This beacon is inexpensive and advertises its presence at a frequency of 2Hz.

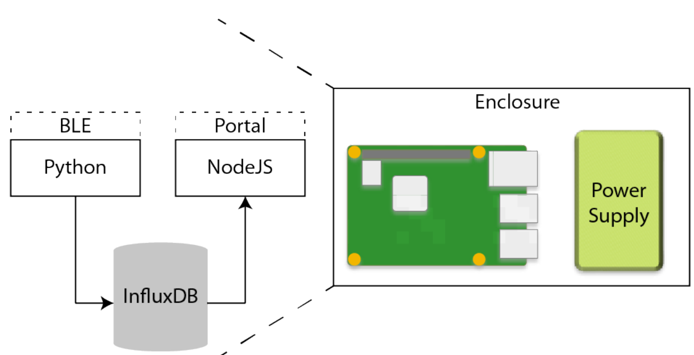

Fig. 1. System architecture of the Observer

Finally, to record the times at which the volunteer pedestrian reaches exact preset locations, we developed an Android phone application, *Blue Dot* [36]. This app has a simple interface which includes a button that when pressed communicates this button press event using BLE. A Python script running on the Observer listens for button press events from the app and records the event times and locations.

B. Experimental Setup

1) Location: To conduct our outdoor experiments, we select a vacant area next to an office building. Our decision is based on several factors. Firstly, this chosen location offers a relatively simple layout, devoid of any substantial structures except for the presence of the office building itself and a wall on which the Observer is mounted. This simplicity in geometry facilitates a clutter-free space where the effects of physical objects on the propagation of signals are minimal. Furthermore, we considered the level of activity in the area. The selected ground is infrequently utilised, ensuring that the movements of a single volunteer can be observed without significant interference from other pedestrians. This deliberate choice further reduces the likelihood of reflections or occlusions caused by any other individuals sharing the space. 2 provides a visual representation of the chosen space.

2) Experiments: The experiments were conducted in two environments: an anechoic chamber and an outdoor linear walkway. For the experiments we selected an angular resolution of 45° for the Broadcaster with respect to the plane of the Observer leading to the following angles - 0°, 45°, 90°, 135°, and 180° angles. This resolution was chosen because a finer angular resolution outdoors would yield insufficient samples, while a larger angle might miss important nuances between the chosen angles. In the first experiment, the Observer was mounted in the anechoic chamber on a rotating platform at a fixed radial distance of 3 meters from the Broadcaster. Collecting RSS values at each angle for 1 minute intervals, we repeated the experiment three times to identify the directional sensitivity of the Observer's antenna.

The second experiment aimed to replicate, in an outdoor environment, the directional sensitivity observed in the anechoic chamber. The Observer was deployed at distances of 3 meters and 5 meters from the walkway, with a volunteer pedestrian at each one of five locations along the walkway, corresponding to the angles measured in the chamber, named *start*, *approach*, *centre*, *depart*, *end*. However, due to the linear nature of the walkway, the distances between the Broadcaster and the Observer were only 3 meters and 5 meters at the *center* point. Moving away from the *center*, the propagation distances increased. For example, at the *approach* and *depart* regions, with the Observer deployed 3 meters away from the *center* point, the distance was 4.24 meters, and with a 5-meter deployment, it was 7.07 meters, as shown in figure 2. The results of the outdoor experiment were presented using a line chart showing the deviation of RSS values from the median and a bar chart on top corresponding to the number of samples captured between consecutive points.

In the final experiment, a volunteer pedestrian walked along the linear walkway while carrying a Broadcaster. The objective was to analyse the RSS values collected during the pedestrian's movement and determine if the direction of travel could be inferred using a single Observer. While the pedestrian was walking, they were required to establish 'ground truth' location and time data by pressing a button on the *Blue Dot* phone app as they passed over the selected marked points on the walkway. The pedestrian traversed the walkway in both directions, that is from *start* to *end* and from *end* to *start*. This final experiment experiment was conducted distances of 3 metres and 5 metres between the Observer and the *center* point of the walkway, and was also repeated for the case when the Broadcaster was held facing the Observer, that is the case of line of sight (LoS), and when the Broadcaster was held facing away from the Observer, that is the case of non-LoS.

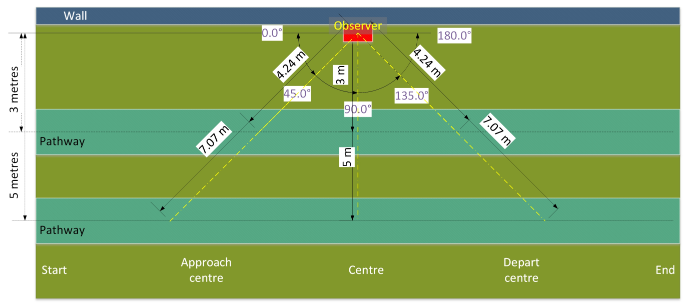

Fig. 2. Experimental location and setup

3) Analysis: We employ fundamental statistical techniques to quantify the underlying patterns in the collected RSS values. For the experiment in the anechoic chamber, the median value at each angular location was calculated. The median is preferred over the mean in our case as the former is inherently better at countering the effect of anomalous samples in the data, while the mean value is skewed by even a single large anomalous sample in the data. We calculate the error bars using the following equation to understand the span of RSS values at each angular distance. The same analysis is repeated in the second experiment with stationary pedestrians at selected locations.

$$Error_{positive} = max(rssi) - median(rssi) \quad (1)$$

$$Error_{negative} = median(rssi) - min(rssi) \quad (2)$$

For the final experiment, we use simple moving average (SMA) to filter the RSS values. Equation 3 shows the formula used to calculate the moving average.

$$sma_{rssi}(i) = \begin{cases} \frac{1}{i}\sum_{j=0}^{i} rssi_j, & 1 \leq i < k, \\ \frac{1}{k}\sum_{j=i-k+1}^{i} rssi_j & i \geq k, \end{cases} \quad (3)$$

Here, sma_{rssi} is the RSS value filtered through SMA, n is the size of RSS samples in $rssi$, $rssi_j$ is the individual element in $rssi$, k is the window size, i is the iterator element, and j is the index of elements within the window.

Further analysis of the frequency of intercepted signals and strength of signals between two subsections of the walkway is used to infer the direction of pedestrians.

IV. RESULTS

In the experiment in the anechoic chamber, we observed clear directional sensitivity of the Observer's antenna towards BLE signals arriving from certain directions. At a fixed distance of 3 metres, the antenna is able to receive signals propagating from an angle of 45° and 135° with less attenuation than the signals emerging from an angle of 90°. However, it is important to note that the distance between the Observer and Broadcaster remained unchanged for each angular location. This is not analogous to a real-world linear walkway, where the distance between a walker carrying a Broadcaster device and the Observer device is shortest at an angle of 0° and it continually increases as the walker moves away from a 0° location on either side of the linear walkway. This was not possible to recreate in our anechoic chamber facility due to the constraints imposed by the size of the anechoic chamber. Figure 3 depicts the median values and the deviation of RSS values from the median as observed in an anechoic chamber by the Observer.

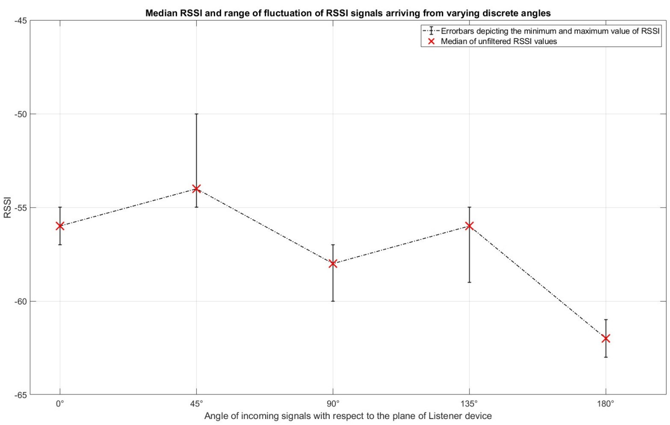

Fig. 3. Broadcaster RSSI range and median emanating from different angles in an anechoic chamber

It is noteworthy that the minimum RSS value of all the samples received from the Broadcaster placed at an angle of 45° is above the maximum RSS value of all the samples received for the Broadcaster placed at an angle of 0°. Therefore, there is a strong likelihood of finding a peak in the collected RSS values of a Broadcaster carried by a pedestrian in motion at an angle of 45° from the plane of the Observer. We call the region at this angle the *approach* point or approach region on the walkway. Also, the median value of all the RSSI samples collected at 135° is higher than the median of all the RSS values collected at 0°. However, we can observe from the error bars in figure 3 that the ranges of RSS values in both of these cases have overlapping RSS values, suggesting that there is less likelihood of another peak in the plot at an angle of 135°.

Since, the distance on a linear walkway would be greater between the Observer and a Broadcaster carried by a pedestrian at 45° and 135° region in comparison to the distance at 0°, the second experiment was used to determine whether or not the pattern in the RSS values observed in the anechoic chamber is observed in an outdoor linear walkway. As opposed to the anechoic chamber's noiseless environment, outdoor settings are prone to several physical and environmental factors affecting the signal's propagation. The results from conducting experiments in a linear outdoor walkway, as seen in figure 4, shows that the peak is present at the *centre* or 0° region when the Observer is deployed 3 metres away from the walkway. However, the difference is marginal. It must also be noted that in this case, while the *centre* zone is exactly 3 metres away from the walkway and therefore, for a pedestrian carrying a Broadcaster, the distance between the walkway and the Observer at *approach* (or 45°) and depart (or 135°) zones is 4.24 metres, as also mentioned in section III and depicted in figure 2. Similarly, when the Observer is deployed 5 metres away from the walkway, we observe the median RSS value at both the *approach* and *depart* zones to be higher than that at the *centre* zone. This pattern is akin to the *double hump* pattern that we observe in an anechoic chamber. Since the voluntary pedestrian was standing still at each location for this experiment, to ascertain the possibility of being able to infer a pedestrian's walking direction using a single Observer, we performed a third experiment to observe whether the same pattern repeats when the pedestrian is walking.

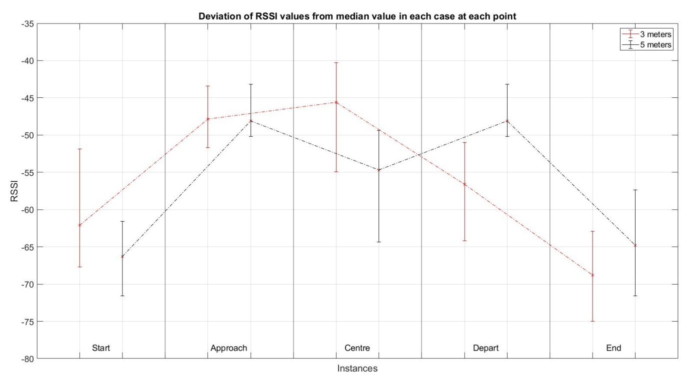

Fig. 4. Deviation of RSSI values from median value in each case at each point on a linear walkway

In the final experiment, where a volunteer pedestrian walked across the selected linear walkway, we find that the pattern of the RSS values diverges from the expected values based on the previous experiments. It is already well understood that the reliability of BLE signals in outdoor settings is questionable and that collected RSS values should be filtered using techniques such as SMA to improve reliability and usefulness [32]. It is also been identified that SMA with a window size of 10 is suitable for filtering BLE RSS values [37]. However, when the pedestrian is walking a short linear walkway, as in our case, the time it takes for a *supposedly* purposeful walker to traverse the entire walkway is short and it is likely that sufficient samples may not be intercepted by the Observer in order to represent a finer spatial resolution, hence, SMA with a large window size will skew the analysis. This becomes more apparent from table I, where the mean walking time to the subsequent point and the number of samples collected during

6 repetitions of each case is presented. The mean sample rate across each case is less than 1 Hz whereas the advertisement frequency is 2 Hz on the Broadcaster used, and since it takes between 4.78 seconds and 5.64 seconds to travel between any two selected points on the walkway, a window size of anything over 5 would mean that the representation of RSS values has been skewed from RSS values at the previous location. Despite that, filtering is necessary to reduce the effect of anomalous RSS values. We hence subjected the collected RSS values to SMA filtration over a window size of 3 samples.

To understand the possibility of inferring the direction of travel of a pedestrian using a single BLE Observer, we divide each journey into two parts – the part between the start point and centre point, and the part between the centre point and endpoint. When the pedestrian is walking from the start point towards the endpoint, the journey is analysed as mentioned previously. If the pedestrian is travelling from the endpoint to the start point, the journey is analysed vice-versa. The objective is to calculate the mean RSS values between these regions and compare them. If the directional sensitivity is indicated through the results of the previous two experiments, the results of this experiment will indicate greater RSS values for a journey to and fro between the start point and centre point in comparison to the journey in either direction between the centre point and endpoint.

Table II represents mean RSS values for each part of the journey at each deployment distance and for both LoS and non-LoS cases. We observe and compare the journeys by categorically dividing them based on the direction of travel. First, we assess the category where the pedestrian walks from the *start* point and goes towards the *end* point. In the case of 3 metres when travelling from the *start* point to the *end* point, we observe that there is only one journey, in both LoS and non-LoS cases combined, that has a higher mean RSS value in the centre point to end point part of the journey. Further, averaging all of the mean RSS values for both cases combined, categorised by the region in which travel has taken place, we see that journey between the start point to the *centre* point has an average RSS value of -61.85 dB and that between *centre* point to end point has an average RSS value of -67.64 dB. Similarly, at a deployment distance of 5-metres, we observe two occurrences of higher mean RSS values in the region between the *centre* and *end* point out of six total journeys. The average of mean RSS values between the start to the centre region travel is -64.20 dB, whereas, the equivalent for the centre-to-end part of the journey is -66.45 dB.

The category where the journey is taking place from the endpoint to the start point resembles the outcome of the previous category. At a deployment distance of 3 metres, there was no instance out of the six repetitions combined across LoS and non-LoS cases where the mean RSS value during the journey between the endpoint and the centre point is higher than that of the journey between the centre point and start point. The average of mean RSSI for the former is -70.98 dB, whereas that for the latter is -64.44 dB. At a distance of 5 metres, there are two occasions out of six where the mean RSS value for a journey between the end to centre point is greater than that of the centre to the start point. The average of those means here has a marginal difference but again in favour of the journey between the centre and the start region with the value of -66.42 dB against -67.62 dB. Therefore, out of the combined 24 cases, we only find a higher mean RSS value between the centre and end region 5 times, that is for 20.83% of the cases.

Finally, figure 5, 6, 7, and 8 represents RSS values filtered using the SMA technique over a window of 3 samples using the line chart and the number of samples captured by the Observer between consecutive select points using the overlaid bar chart. While a clear occurrence of the 'double-hump' pattern as seen in the clean environment of the anechoic chamber is a relatively rare occurrence in the outdoor experiments, we can identify peak or climbing RSS values around the approach region in most of the cases.

TABLE I
MEAN DURATION AND SAMPLES AT EACH DEPLOYMENT DISTANCE FOR BOTH LOS AND NON-LOS CASES

Locations	**3-metres LoS**		
	Duration (s)	Samples	Samples per second
Start → Approach	5.40	5.25	0.97
Approach → Centre	5.06	4.16	0.82
Centre → Depart	5.52	5.16	0.93
Depart → End	5.58	5.08	0.91
	3-metres non-LoS		
Start → Approach	5.06	3.92	0.77
Approach → Centre	4.88	3.92	0.80
Centre → Depart	5.06	4.50	0.89
Depart → End	4.85	3.50	0.72
	5-metres LoS		
Start → Approach	5.01	4.58	0.91
Approach → Centre	4.95	4.67	0.94
Centre → Depart	5.14	5.08	0.99
Depart → End	4.78	3.3	0.70
	5-metres non-LoS		
Start → Approach	5.64	4.25	0.75
Approach → Centre	5.18	4.5	0.87
Centre → Depart	5.57	4.75	0.85
Depart → End	5.34	3.83	0.72

V. DISCUSSION

In this study, we find that understanding the characteristics of the antenna on a BLE Observer can be used to purposefully deploy the Observer in a manner that enables the resulting intercepted signals create a useful pattern. In this case, the first experiment with a RPi 4B based Observer highlighted that the antenna on the device is sensitive towards signals emerging from the region around 45° with respect to the plane of the Observer. Therefore, in the case of continuous monitoring, the RSS values of a BLE Broadcaster passing by this Observer, will result in a peak just before the Broadcaster is directly opposite the Observer. The second study is to confirm that this pattern holds true even in an outdoor environment. In this case, unlike in the anechoic chamber when the distance between the Observer and Broadcaster was fixed, the distance between the

TABLE II

MEAN RSS VALUE BETWEEN THE TWO PARTS OF THE JOURNEY FOR EACH DEPLOYMENT DISTANCE FOR BOTH LOS AND NON-LOS CASES

Mean RSSI from Start to End region						
Case	Rep 1 (dB)		Rep 2 (dB)		Rep 3 (dB)	
	S → C[1]	C → E[2]	S → C	C → E	S → C	C → E
3m LoS	-57.68	-64.47	-61.82	-67.75	-63.53	-59.88
3m non-LoS	-60.25	-76.75	-63.38	-73.13	-65.25	-66.50
5m LoS	-59.97	-64.27	-65.64	-64.66	-59.23	-65.47
5m non-LoS	-67.61	-65.78	-65.83	-68.28	-66.96	-70.23
Mean RSSI from End to Start region						
Case	Rep 1 (dB)		Rep 2 (dB)		Rep 3 (dB)	
	E → C[3]	C → S[4]	E → C	C → S	E → C	C → S
3m LoS	-68.93	-64.16	-64.19	-59.58	-77.77	-63.88
3m non-LoS	-75.42	-69.28	-71.16	-67.22	-74.38	-62.54
5m LoS	-63.33	-61.60	-57.29	-67.17	-65.81	-63.41
5m non-LoS	-80.53	-70.40	-66.47	-67.38	-72.29	-68.59

[1] Start → Centre. [2] Centre → Start. [3] End → Centre. [4] Centre → Start.

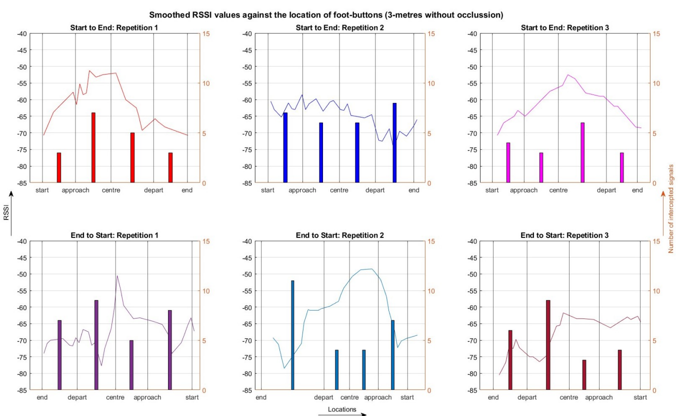

Fig. 5. RSSI values of a Broadcaster in LoS of Observer when the pedestrian is walking on a walkway 3-metres away, LoS

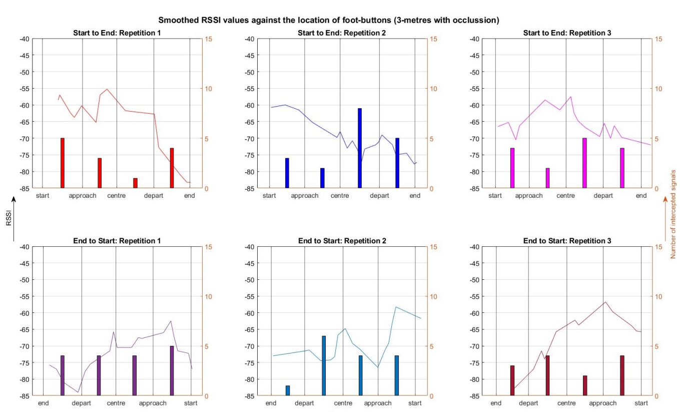

Fig. 6. RSSI values of a Broadcaster is in non-LoS of Observer when the pedestrian is walking on a walkway 3-metres away

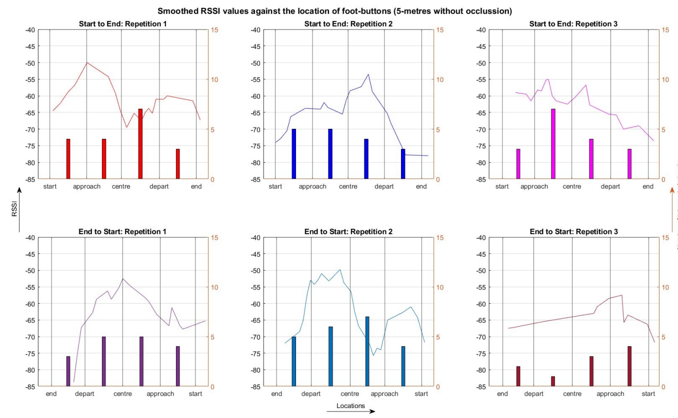

Fig. 7. RSSI values of a Broadcaster in LoS of Observer when the pedestrian is walking on a walkway 5-metres away

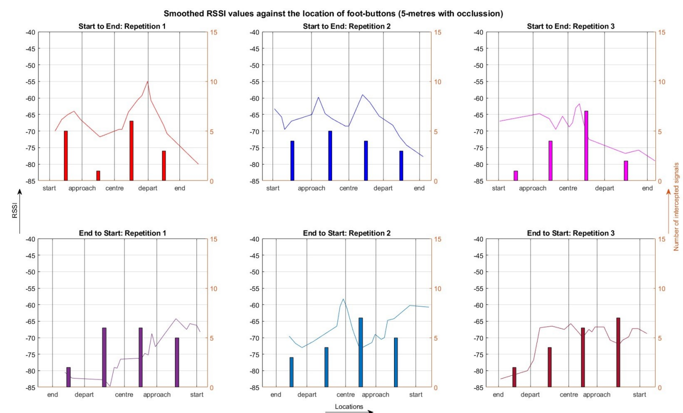

Fig. 8. RSSI values of a Broadcaster is in non-LoS of Observer when the pedestrian is walking on a walkway 5-metres away

devices increases as the pedestrian, holding the Broadcaster device, moves along the linear walkway in either direction from the centre point or 0° region, that is directly opposite the Observer. Another factor that comes into play is the noise in the outdoor environment which affects the propagation of signals and hence, dissipates their energy before they are intercepted. Despite those factors, we still find a resemblance in the pattern of RSS values when the deployment distance between the Observer and the Broadcaster at the centre point is 5 metres. At 3 metres, the pattern doesn't hold true, however the difference in the median RSS values at *approach* (45°) and *centre* (0°) is small.

The results obtained in the previous experiment, while they do not explicitly dismiss the presence of similar patterns in the collected RSS values in the anechoic chamber and outdoor environment with stationary volunteer, they also do not completely rule out the likelihood of identifying the direction of travel of a pedestrian. Therefore, we perform the final experiment with a pedestrian walking on a linear walkway in both directions, *start* to *end* and *end* to *start*, both in *los* and non-*los* conditions at deployment distances of both 3 metres and 5 metres. The pattern in the RSS values here is not apparent, and when looking at the plots of those values against time, the results look inconclusive. However, just some basic statistics unearth nuances that are useful for forming assertions. By dividing each journey into phases, travelling to and from the *start* and *centre*, and to and from the *centre* and *end*, we are able to see that the mean of the SMA-filtered RSS values is higher for travelling in either direction between the *start* and *centre* region. If we know the orientation of the Observer, through temporal location of the onset of that local peak, we can identify the direction of the travel. That is, a sharp climb to local peak followed by a long tail with the possibility of second lesser peak (double hump) when the direction of travel is from start to end. And, a slow climb with a lesser peak followed by a local peak and sharp decline when the travel direction is reversed. Moreover, as shown in [22], the sample rate identified in table I is also indicative of interference between the Observer and the Broadcaster. Finally, while we find the likelihood of asserting the direction of travel of a pedestrian in a linear walkway using a single Observer based on RPi 4B by exploiting the characteristics of its antenna, the uncertainties in the environment do affect the performance and hence the confidence of the assertion. The chosen walkway here is infrequently used and is devoid of large physical objects. If these factors were present, the likelihood of inference will be even less reliable. Future work could apply this approach on a frequently used walkway and use multiple Observers for increased reliability.

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