Human Counting and Indoor Positioning System Using WiFi Technology

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***Abstract*—The position that inside the building are unable to be tracked precisely due to the signal blocking by the wall and rooftop. It is difficult to measure the population of people inside the building such as shopping centre, airport, hospital and so on by current GPS system. Thus, WiFi network is suggested to be used for improvement the positioning technology inside the building where the wireless sensor network are commonly used in the building nowadays. This project study the behavior of RSSI (received signal strength indicator) value. The presentation of RSSI behavior are discussed with Butterworth lowpass filter, Savitzky-Golay smoothing filter, and satistical analysis in section IV. After the experiment, the satistical analysis is the chosen algorithm to obtain filtered RSSI value from WiFi embedded devices and radio map. Thus, by comparing the filtered target device's RSSI value with the radio map, the position can be estimated precisely.**

***Index Terms*— Indoor Positioning, Human Counting**

I INTRODUCTION

Most of the market were growing in the large indoor places such as shopping centre, airport, theme park and so on. Therefore, marketing strategies are important in marketing industry in order to grow business. Consumer behaviour patterns observation is one of the marketing strategies where it can provide the useful information to the business owner (Horner & Swarbrooke 2016). For example, in order to persuade consumer spending large money in shopping centre, the management have to find out which retail shops are popular. In the future, the new incoming retail shop can be located near to that popular shop so that the crowd support the business grow in the new incoming retail shop. Although the crowd can be observed by CCTV camera, there is a difficulty to observe the crowd completely in the big area indoor such as blind spot. Even though nowadays people are carrying smartphone devices that can provide location information to the software developers who already get authorization from their consumer, the smartphone devices are unable to calculate an accurate positioning data in the indoor area.

Global Positioning System (GPS) is the first positioning system that determine the coordinate on Earth by launching the Russian Sputnik satellite in 1957 applied with an optical triangulation method (Hofmann-Wellenhof et al. 2012). There are numbers of satellite electronically visible on the orbit that surround the Earth. In order to determine the user's position on which surface of the Earth, the GPS satellites were configured to provide the latitude, longitude, and elevation by recording the time spent of the signal sent from satellite to receiver (Hofmann-Wellenhof et al. 2012). General Packet Radio Services (GPRS) is a service that transmit the information data by GSM network. As the GSM networks has large area coverage around the world, it had been proposed to implement with GPS to improve the positioning accuracy and real-time tracking (Chadil et al. 2008). With filtering system and triangulation algorithm, the global positioning system has become a common tracking system in this century.

However, due to the rooftop and obstacle of the building is blocking the signal from the satellite, the positioning system is unable to track the objects that inside the building but only can be estimated by the GSM network. There are some indoor positioning technique had been commercialized in the market where it can be categorized IR-based (infrared), ultra-sound, RF-based (radio frequency), and sensor network which is based on physical environment condition (Gu et al. 2009). RF-based is lowest-cost positioning system compared to others.

WiFi technology is commonly used in recent year. Most of the public area have free internet access by installing WiFi routers. Thus, there is a possibility that utilize the existing WiFi technology to perform as a localization services for indoor used where the satellite and GSM networks are not able to identify the positioning in indoor area. In fact, localization services is important for people to get navigation guide in an unknown area or monitoring the traffic inside the building. The aim of this project is to develop human counting system and indoor positioning system based on the current WiFi technology.

II LITERATURE REVIEW

RFID technology utilize Faraday's principle of magnetic induction between tag and reader (Want 2006). The RFID tag consist of semiconductor chip and antenna with some form of encapsulation. The antenna is a coil type to receive the energy through electromagnetic transmission from the tag reader and send the information data to the reader. There are two types of

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RFID tag which are active and passive. Active RFID tag has an additional power source which can transmit the signal in long distance. However, due to the active types required integrated battery it has a limitation in the lifetime spend and high cost. Samer S. Saab and Zahi S. Nakad (2011) proposed a solution by using passive RFID tags for indoor positioning system. The concept is places a number of passive tags on the pathway and use the RFID reader to sensing the nearby RFID tags to identify the current position in the indoor. However, it need to carry the RFID reader to locate the current position.

From the Bluetooth 2.0 standard version, it is able to communicate with the devices within 100 m where it replaced the IR communication function on mobile devices (Gu et al. 2009). Bluetooth beacon for indoor localization is available for commercial. iBeacon is a device that implementation of BLE beacon technology by Apple (Newman 2014). It only broadcasting information data to the smartphone devices by emitting low power Bluetooth energy. In order to estimate the distance between smartphone devices and the BLE beacon, a smartphone application is necessary to calculate the distance on smartphone based on the RSSI value between BLE beacon and smartphone. Ultra-wideband is another RF based positioning system choice. It has large bandwidth or less than 1 ns short durations pulse that able to filter out the reflected noise signals which is provided high accuracy of information data signal (Ingram et al. 2004). In order to transmit and receive the UWB radio frequency, it required a UWB chipset (Anon 2016).

WLAN is a common technology which is available in every indoor public areas such as shopping centre, university, airport, hospital, and etc. The signal strength between the access points and the devices such as smartphone, table, and laptop depending on how far the distance is from access points to devices. RADAR is a RF-based system proposed by Bahl and Padmanabhan (2000) where the solution for indoor positioning system is using the signal strength information from existing multiple WLAN access points to identify the coordinate of the user inside the building. (NNSS) algorithm had been applied to analyses and estimate the position of the laptop in the floor map. The idea of NNSS algorithm is measuring a number of signal space samples and marking on the floor plan. The gathered signal strength information data will be analyzed and determined the target is close to which sample point (Bahl & Padmanabhan 2000). COMPASS is a localization system with probabilistic algorithm (King et al. 2006). The comparison of all techniques is summarized in table 1. WiFi technology is common used in public area, there is high possibility that most of the smartphone users switch ON the WiFi connection permanently. Although it has huge of signal noise reflections, it still can be eliminated by filtering system. In fact, there is an advantage that the system able to track most of the smartphone users.

Table 1: RF based indoor positioning system comparison (Mautz 2012).

Technology	Typical coverage (m)	Typical accuracy	Pros	Cons	Algorithm
RFID	1 – 50	dm - m	High accuracy	Need to carry additional hardware	Triangulation, reference tag
Bluetooth	20 – 50	m	Low energy	Most of the users might turn off Bluetooth	Triangulation, power level
Ultra-wideband (UWB)	1 – 50	cm – m	Less reflection, high accuracy	Not available for current smartphone	Triangulation
WLAN fingerprinting (WiFi)	20 – 50	m	Most of the smartphone user always ON WiFi feature	Huge signal noise reflection	Triangulation, NNSS

III METHODOLOGY

The signal process of the entire project can be categorised into four individual steps. WLAN fingerprinting is a technique that using WiFi technology to collect data where the data are MAC address and signal strength (RSSI reading) from the devices. The MAC address of the devices is unique where the first 6 digits of hexadecimal is the WiFi chip manufacturer's registered ID and the last 6 digits of hexadecimal is unique ID for the individual devices. The purpose of collecting MAC address is to identify the devices during the RSSI reading data collection. In the next block is RSSI data analysing. It sorts all the samples data with MAC address that collected from the previous block and applied statistical analysis to determine the best RSSI value for indoor positioning estimation. The analysed data will be applied NNSS algorithm by comparing the detected device's RSSI with the radio map. Last, the final result will be presented on graphical user interface (GUI). The details for each of the block had been described and discussed in the section below.

WLAN Fingerprinting

The first step of the overall process is WLAN fingerprinting where it sensing the surrounding mobile devices and references points by sniffing the RSSI value of the target devices with the unique MAC address as identification. There are four APs (access point) are placed on the wall of the electronic and communication laboratory showed as Figure 2. Each of the AP provide maximum 60 unit samples RSSI reading from the surrounding devices in 1 minute in order to be analyzed in the next step.

The AP has to put on higher place to avoid the signal distortion by the obstacle showed as Figure 2. As the behavior of triangulation algorithm, each of the positioning points has at least three unique different length among the multiple points. Based on the different RSSI reading from each of the access points, the distances between the target device and each of the access points can be estimated by measuring the RSSI reading in each position so that the multiple access points is necessary for this project.

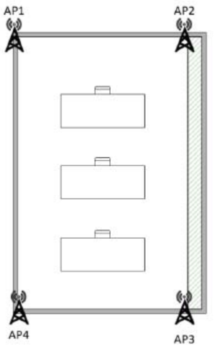

Figure 1: Top view of hardware setup in electronic and communication laboratory

RSSI data analysis

The second step of the block diagram is data analyzing. Noise cancelling process is the critical challenge in this entire project. Obstacles and walls inside the building affecting the reading of RSSI seriously where the WiFi signal packets can be bounced by the obstacles and walls. The bouncing packets could be delay the transmission time where it could take extra time to send the signal from transmitter to receiver. The bouncing effect had been illustrated in Figure 3.

NNSS algorithm (radio map)

In order to obtain the actual position in the real world, the radio map of the floor plan is necessary for positioning references and measurement. NNSS algorithm is the chosen localization algorithm to obtain the radio map of the experimental site and compare the target devices is corresponding to which position of the experimental site area.

As the cells arrangement showed in Figure 4, it had been separated into 15 cells where it had 3 columns and 5 rows. The width of the room size is 550cm and the length is 900cm. The size of each cells is 180*183.33 cm2. In order to obtain the radio map, a references tag was placed in the middle of a cell, for example: A1. The four APs collect 20 samples from the references tag synchronously and saved into csv (comma-separated values) file with specific name. After finishing the data collection, the references tag will be moved to the next cell (either A2 or B1) and the four APs will start collecting the samples same as the previous cell. Therefore, each cell must have 4 individual RSSI values from four APs to represent as the “ideal” RSSI reading in that cell. It usually took less than 10 minutes to collect the 20 RSSI samples reading for each cell. Typically, radio map calibration once per week is good enough for positioning references.

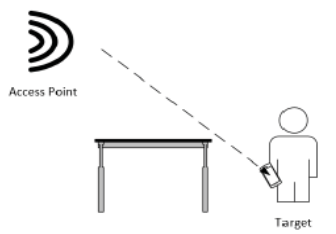

Figure 2: Side view of AP setup in electronic and communication laboratory

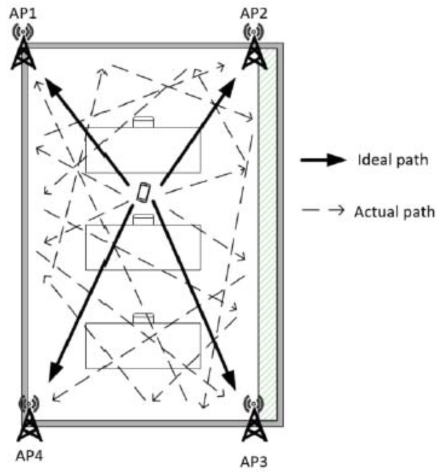

Figure 3: Bouncing effect illustration

With four valid radio maps from each of the AP, an NNSS algorithm can be applied for positioning. The analyzed RSSI from the previous block will be compared with the obtained radio map from four APs. Thus, the positioning of the target will be estimated when the target device’s RSSI values is closest to “ideal” RSSI values in one of the cells. The detail of NNSS algorithm positioning analysis will be discussed with experimental result in the next chapter.

GUI (Graphical user interface)

GUI is the destination block in the signal processing block diagram. It has 4 section which are the positioning display, operation selection panel, radio map display selection panel, and program status panel. There are 5 buttons in selection panel and radio map panel. In the selection panel, the “calibration” button is to read the csv file where it predefined by the previous block and save the radio map data in the workspace. The “clear” button is to clean every data included radio map data in workspace. “Show label” button is to show the label for the radio map cells arrangement. Finally, “Start” button for execute the counting and positioning program repeatedly and “Stop” button is to stop the program. In this radio map panel, there are four selections for displaying the radio map with color and RSSI value in AP1, AP2, AP3, and AP4. The “reset” button return a blank floor map in the positioning display.

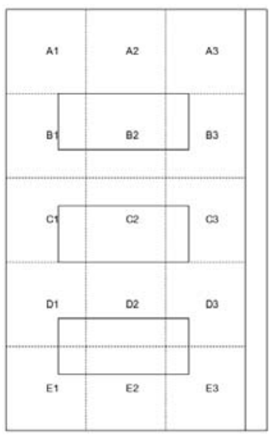

Figure 4: Cells arrangement

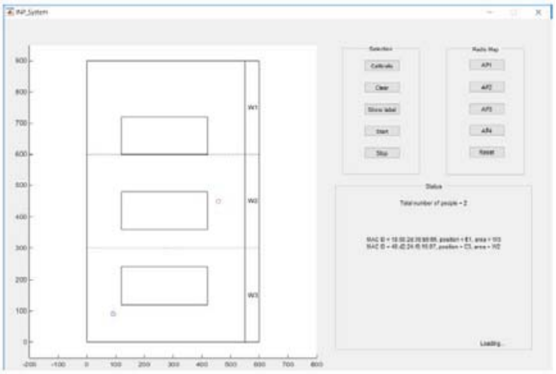

Figure 5: GUI result display with two detected devices in electronic and communication laboratory

The results showed in Figure 5 showed that there are two devices detected in E1 position, W2 area, followed by C3 position, W2 area displayed in the positioning display in graphic and status panel in text. In the right below corner, it displays the progress of the program. When it show "Loading…" the program is calculating the RSSI data that collected from the APs by predefined algorithm and display the data in the GUI. After the calculation, it will display "Recording…" with progress percentage to show the current progress of the RSSI recording from the APs.

IV Presentation of Data

RSSI data analysis

The original RSSI reading had been obtained through experiment where it shown as Figure 6. The RSSI reading linearly proportional to the distances is an ideal relationship between the RSSI reading and distances. In theoretically, if the devices close to the access points it should have stronger signal strength to the access points. By indicating the RSSI strength level, -30 dBm has strongest signal strength and -90 dBm has weakest signal strength to the access points. However, the RSSI reading showed in Figure 16 was obtained by putting a range of 100cm between the access points and target device in static mode. It contained the entire RSSI indicator level range where it is hard to identify which are the actual RSSI readings.

In order to obtain the usable RSSI reading, several of filtering studies and experiments had been executed and presented in next section.

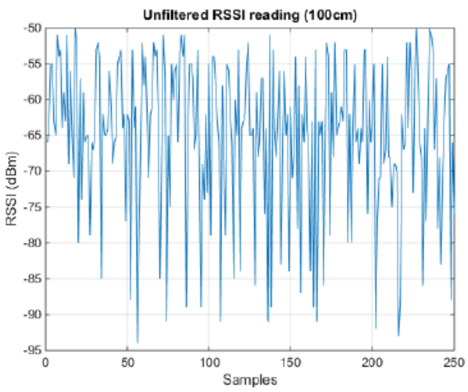

Figure 6: Noisy RSSI reading in 100cm between access point and device.

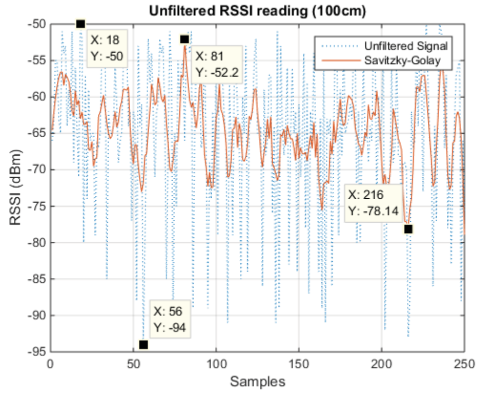

Figure 7: Filtered RSSI reading (Savitzky-Golay)

Savitzky-Golay filter

As the Savitzky-Golay filter is a signal smoothing filter that smoothing the signal waveform from the original signal waveform. It makes the signal waveform smoother by utilized every single samples and smooth out the spiky waveform. The result of the Savitzky-Golay filter had been shown in Figure 7.

As the result of Savitzky-Golay, it reduced the spiky by smoothing the original signal waveform. The range of the entire waveform had been reduced from -50 dBm and -94 dBm to -52.2 dBm and -78.14 dBm. Although the range had been reduced, the signal waveform are still unstable in a static 100cm test. This filtered signal waveform is not satisfy for this project.

Butterworth low pass filter

Butterworth low pass filter is an infinite impulse response (IIR) filter where it can eliminate the ripple in the stopband attenuation by selecting the bandwidth of the passband frequency. In order to observe the frequency domain of the obtained reading, fast fourier transform had been applied. The samples rate of this data collection is 1 second for each of the sample. The frequency response of the data had been shown as below.

As the frequency response shown in Figure 8, the maximum amplitude fall on 0 Hz frequency and the useful information are in the bandwidth of 0 Hz and 0.004 Hz. The ripple was occurred at the greater of 0.02 Hz frequency. Based on the graph of frequency response, the bandwidth of the low pass filter had been decided where the stop band frequency is set on 0.02 Hz.

As the results shown in Figure 9, the ripple noise had been eliminated by the low pass filter. However, the bandwidth of the frequency domain had been increased from 0.004 Hz to 0.036 Hz.

The filtered RSSI reading showed in Figure 10 does not contain any spiky waveform. This signal waveform is useful where it showed a smooth stable reading where the following RSSI value is -66.53 dBm. However, it took 80 samples to reach to the steady state which is slow and time consuming. It could drag the system into a lagging system when the system need to process a number of data set

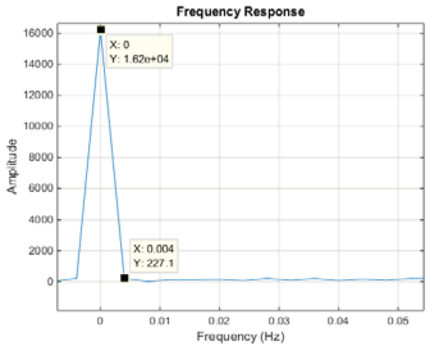

Figure 8: Frequency Response of 100cm RSSI reading.

Statistical analysis

As the RSSI reading from the system are integer and the waveform are unstable even in a static distance test, it is suggested to be analyzed in statistical way. The distances measurement testing setup had been showed in Figure 2. In order to obtain the relationship graph between distances and RSSI reading, there are 15 sets of distances testing measurement, which are from 100cm to 800cm with 50cm interval, were been tested during the experiment. The purpose of 50cm interval is to determine the resolution in distances measuring and the best RSSI measurement in order to perform indoor positioning.

The RSSI reading were been collected 250 samples for each of the distance references. The filtered (F) results was applied butterworth low pass filter. Due to the reason that the signal waveform that had been filtered by butterworth filter has rising state before the 80th sample shown in Figure 10, the minimum value of the filtered data are the starting value in the first sample so that it is not satisfy for analysis. In order to observe the relationship between distances and RSSI reading, the relationship graph had been shown as Figure 11.

Radio map analysis

As the radio map showed in Figure 12, each individual cell had four different RSSI reading from each APs. The RSSI reading that above -70 dBm consider best signal performances, between -70 dBm and -75 dBm are good signal performances, and below -75 dBm are fair signal performances. Theoretically, the cells that nearby to the AP are having best RSSI reading and the faraway cells are having fair RSSI reading. However, there are some not logical RSSI reading in the radio map such as E2 cell in AP1 reading, B2 cell in AP2 reading, C2 cell and E1 cell in AP3 reading, and B3 cell in AP4 reading.

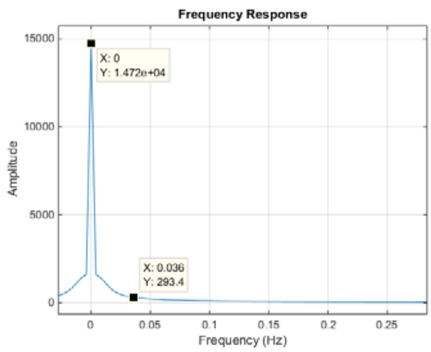

Figure 9: Filtered signal frequency response (Butterworth)

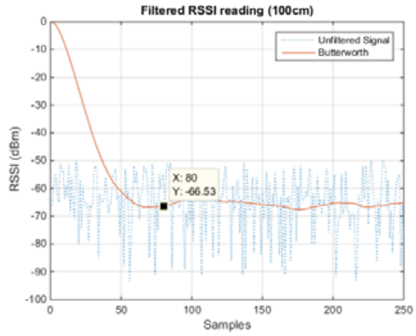

Figure 10: Filtered RSSI reading (Butterworth)

As the radio map results showed in Table 2, each cell has it own significant RSSI based values among the 4 primary APs. Each cell need to have at least two different levels of signal strength in 4 APs reading in order to estimate the position.

The method of identify the position of the devices is to calculate the deviation between the device RSSI value and the radio map one. For example, when the system detected a device has -60.23 dBm from AP1, -61.11 dBm from AP2, -71.89 dBm from AP3, and -73.89 dBm from AP4, the system calculates the deviation between the device and the radio map cell by cell.

With additional 3 secondary APs, those APs determine the device is closest to one of the AP by measuring the signal strength. Theoretically, the strongest signal strength level represent short distances to the APs. Secondary AP1 detect W1 area, secondary AP2 detect W2 area, and secondary AP3 detect W3 area. For example, if the device has three different signal strength level which are -61.45 dBm, -70.48 dBm, and -72.13 dBm detected by secondary AP1, secondary AP2, and secondary AP3, the device is estimated in the W1 area.

As the results showed, the accuracy of area detection is higher than the positioning. The second test pattern had 100% accuracy of area detection from laptop PC although the positioning accuracy is just 20%. Based on the results obtained, the accuracy of area detection is higher than positioning. In this experiment, the Android version for old smartphone is 4.1.2 and the Android version for new smartphone is 7.0. The charging/discharging status of the old smartphone is affecting the results where the third test pattern results showed that the discharging old smartphone is less frequently being detected where the rate of detecting this old smartphone in third testing pattern is 10%. For new smartphone, the rate of detecting this new smartphone is just 7.5%.

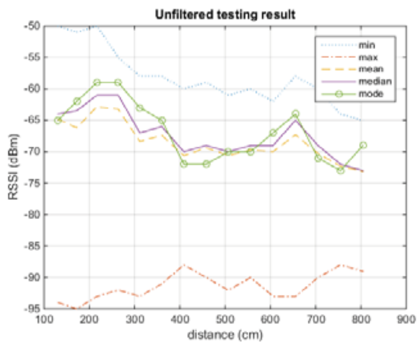

Figure 11: Relationship between distances and RSSI

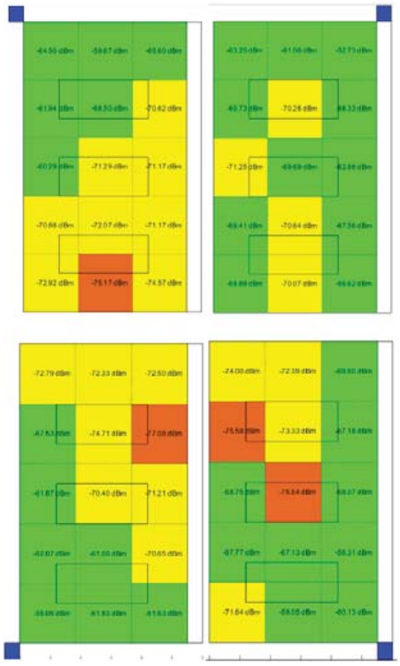

Figure 12: Radio map of each APs, green – best, yellow – good, orange – fair, blue – AP.

Table 2: Combined radio map statistical data

AP1	1	2	3	AP2
	-64.5	-59.67	-65.6	
	-63.25	-61.06	-52.73	best
	-74	-72.39	-69.6	good
A	-72.79	-72.33	-72.5	fair
	-61.94	-68.5	-70.62	
	-69.73	-70.25	-66.33	
	-75.58	-73.33	-67.18	
B	-67.53	-74.71	-77.08	
	-60.29	-71.29	-71.17	
	-71.25	-69.69	-62.88	
	-68.75	-75.54	-68.07	
C	61.87	-70.4	-71.21	
	-70.88	-72.07	-71.17	
	-69.41	-70.64	-67.56	
	-67.77	-67.13	-58.31	
D	-62.07	-61	-70.65	
	-72.92	-75.17	-74.57	
	-68.88	-70.07	-66.62	
	-71.64	-59.05	-60.13	
E	-56.06	-61.83	-61.63	
AP4				AP3

CONCLUSIONS

This project contained huge of challenges in RSSI analysis and studies. It is difficult to use the unstable WiFi RSSI data to estimate the distances and position. Thus, the research of WiFi RSSI data and the localization algorithim brings useful knowledge and technique in order to estimate the positioning in the building. Although the RSSI data is a bad measurement to estimate the distance, the distorted signals are still a valid and useful measurement for obtaining radio map if the indoor environment are static. Besides, due to the un-stability of the WiFi RSSI data, statistical analysis method overcome the issue of getting the desire data where it had been proved during the experiment. However, the resolution of distances measuring by using WiFi technology is low where the tested distances resolution is 200cm. Regardless of low distances resolution, this technique can be used in the indoor place that have wide space such as shopping center to track the population or the missing people by identify their smartphone or WiFi tag.

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