Indoor Human Localization with Orientation using WiFi Fingerprinting

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ABSTRACT
Localization in indoor environment poses a fundamental challenge in ubiquitous computing compared to its well-established GPS-based outdoor environment counterpart. This study investigated the feasibility of a WiFi-based indoor positioning system to localize elderly in an elderly center focusing on their orientation. The fingerprinting method of Received Signal Strength Indication (RSSI) from WiFi Access Points (AP) has been employed to discriminate and uniquely identify a position. The discrimination process of the reference points with its orientation have been analyzed with 0.9, 1.8, and 2.7 meter resolution. The experimental result shows that the WiFi-based RSSI fingerprinting method can discriminate the location and orientation of a user within 1.8 meter resolution.

Categories and Subject Descriptors
A.0 [**General**]; C.2.1 [**Network Architecture and Design**]: Wireless communication; H.3.4 [**Systems and Software**]: Information networks; H.5.2 [**User Interfaces**]: Interaction styles

General Terms
Experimentation, Human Factors.

Keywords
WiFi Fingerprinting, WiFi Positioning System, Indoor Localization, Indoor Positioning System, IEEE 802.11 technology, Orientation-based Localization, Human-Robot Interaction, RSSI Fingerprinting

1. INTRODUCTION

1.1 Overview

Indoor positioning system (IPS) using WiFi is being studied in many fields recently. It is used to localize the user of the system in order for them to know their estimate position in an indoor environment. The system used Wi-Fi signals from existing public and private Wi-Fi wireless access point (AP) to provide location information of persons or devices. The approach to use existing wireless networks have its own advantages because it is easy to deploy, cheap and no extra infrastructure is required.

As far as indoor positioning and localization technique is concerned, research in IPS in the past few years has shown that fingerprinting technique (or radio energy mapping) using Wi-Fi Received Signal Strength (RSS) is the most promising approach to determine the position of a mobile device in diverse indoor settings [2][3], with very different signal propagation characteristics. A lot of research focused on solving the problems that arise when using Wi-Fi RSS to fingerprint a location.

Meanwhile, as the populations of the elderly people in the world are increasing gradually especially in developed countries [1], they are usually being taken care by caretakers or living in an elderly home. This trend has led to the existence of many elderly center that give services of taking care of the elderly. To assist or reduce the tasks of the caretaker in the elderly center, service robots can fulfill this gap by performing various errand tasks and reducing the risk of home accident by integrating WiFi-based localization as the initial interaction between the human and the robot.

This paper presents a research with the main contribution is to localize human (particularly elderly in this case) together with their orientation information as well. The estimation position and orientation of the human is performed using Android application with Wi-Fi RSS fingerprinting method. This is the first step of the research so that in the later stage, the position and orientation information of the elderly will be transmitted to a service robot; and the information will be used by the service robot to locate the elderly and offer services to them.

1.2 Fingerprinting Method

In indoor environment, positioning by GPS has its limitations because signals cannot penetrate into the buildings. One possible positioning technique to counteract this is WiFi fingerprinting, which assumes that each position has a unique set of WiFi signal strengths, the so-called fingerprint. By retrieving previously recorded fingerprints, a location can be returned [5]. Wi-Fi fingerprinting requires formulating a robust RSS database which will be used for generating signal strength maps as well as used for matching. Each reference point includes signal strength measured from all accessible AP. Live RSS data can then be compared to find the closest match from the database which stores the location of each reference point [2].

By recording the signal strengths in dBm unit over time at a certain position, a fingerprint can be created. These fingerprints can be unique in the sense that it is possible to distinguish positions [6]. Wi-Fi fingerprinting method have been shown to typically outperform other methods based on cell of origin, lateration and angulation in terms of providing accurate location estimates [9][10].

Fingerprint matching algorithm generally consists of two components: the radio map and the estimation method. The radio map must be established as part of the training phase (offline phase) to building up the database. Then, in the online phase, the most commonly used estimation method is the Nearest Neighbour method. Other methods include the Support Vector Machine, as well as Hidden Markov Model.

2. RELATED WORK

Many research in WiFi-based indoor localization demonstrate the feasibility of its implementation within 3 to 5 meter error rate [3][4][7][11]. However, none of them specifically concentrating on localizing the user by taking into consideration the orientation of the user as our paper is focusing on.

Recent research such as [6] demonstrates the feasibility of indoor localization and has even been applied into an indoor navigational context operating on an Android device. However, the precision of the user location (let alone the orientation) is not very well explored as the focus of the research was on traversing from point A to B. As such, it is more of a symbolic representation of locations. It is, however, a useful first approximation of the user's location.

RADAR [7] is one of the first indoor positioning systems that make use of WiFi-based network. The RADAR system was developed by Microsoft Research includes two phases, the Training Phase and the Online Phase. In the training phase, an area is divided into a 1x1 meter grid where the signal strength measurements of the access points are taken at each intersection. The mean of the signal strengths which have been obtained, is recorded to create a radio map to be used in the online phase. In the online phase, when the user looks for its location, the mobile station will detect and record the signal strength from as many access points as possible. Then, the signal strength received will be compared to the radio maps to determine the location of the user.

Bolliger [8], on the other hand, explored the issue of localization accuracy using multiple deterministic and probabilistic methods based on WLAN fingerprinting and tested the feasibility of crowdsourcing to improve the radio map precision in the database. Bolliger has developed an indoor positioning system named Redpin that allows user to voluntarily upload their location to their server to help contribute and enhance the accuracy of their positioning system. By increasing the location point density, the fingerprint matching can also become more precise. And while multiple methods have been considered, they are all fingerprint matching related.

The closest to our work is [4] where they developed an indoor WiFi positioning system for Android-based smartphone. However, they did not take into consideration the orientation perspective.

3. EXPERIMENT SETUP

The location of the environment setup of the experiment was performed in a demo room in Intelligent Systems Research Institute (ISRI), Research Complex 2, Sungkyunkwan University, South Korea.

3.1 Setup Area

The setup was prepared in a controlled environment in an area of 4.5 meter by 3.6 meter. The area was divided into 20 cells with equal size (90cm x 90cm) and each of them is named 1 to 20 as shown in Figure 1. The center of the area is called the reference point, where it is the spot that has been used to collect the reading of the Wi-Fi RSS data.

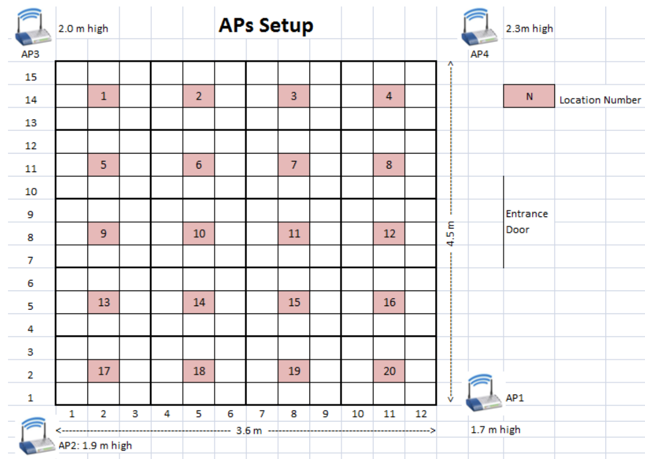


Figure 1. Setup Area of the Controlled Environment

3.2 Devices

Four Wi-Fi APs were installed for the experiment. Two of them are N2e 300 Mbps 802.11n made by ipTIME, one N8004R also made by ipTIME, and AirPort Extreme 802.11n made by Apple. Each of the AP is named as AP1, AP2, AP3 and AP4 respectively. All of the APs are placed in each corner of the experiment area as shown in Figure 1.

To collect the Wi-Fi RSS data, a smart phone has also been used; it was Samsung Galaxy S II HD LTE with Android version 4.0.4 operating system.

4. DATA COLLECTION

4.1 Method

In order to come up with the fingerprint database (also called as energy map) of the experimental area, a massive data collection has been carried out. The data of the Received Signal Strength (RSS) of each AP on each reference point was taken.

The RSS data of each AP on each reference point was taken based on the following parameters:

- Orientation (4 sides: 0º / 90º / 180º / 270º)
- Height (standing/sitting)
- Time of the day (morning/afternoon/evening/night)
- Lighting (on/off)
- Time Intervals between RSS readings

A total of 100 sets of reading have been taken for all 20 cells for each AP (4 APs altogether) (a total of 8000 data) with each reading are in different combination of the parameters. Figure 2 shows the sample of RSS data taken using the Android-based mobile application that was developed purposely for this project. The application is used to take RSS reading, and in later stage it is upgraded and is further used to display the estimation position.

The algorithm of the mobile application filters the list of the AP. Only RSS reading from AP that are controlled by this experiment are identified by the mobile application as shown in Figure 2. This is done for easy recording of the data. There are 4 APs involved in this experiment as mentioned in the previous section.

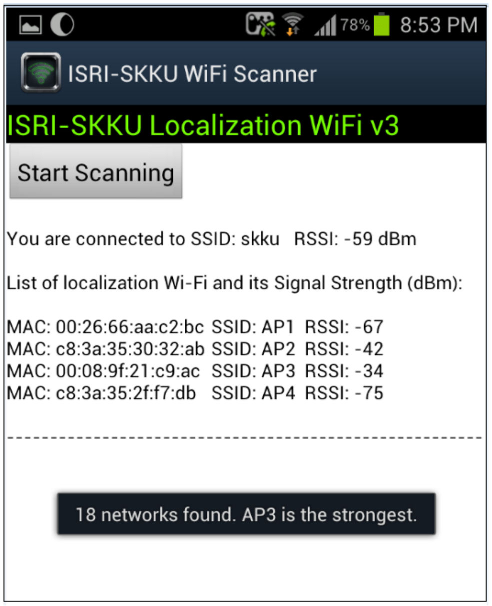
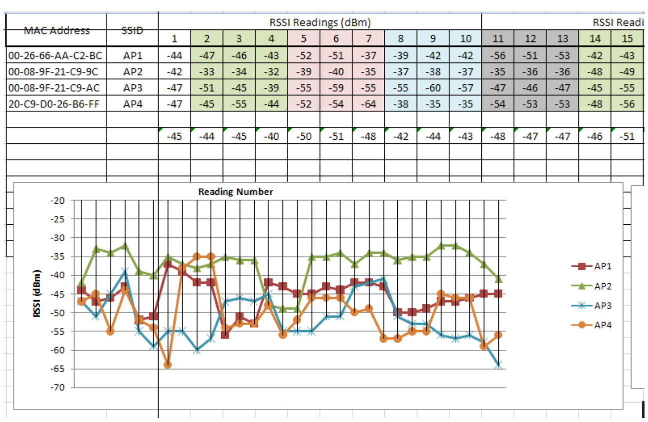


Figure 2. Android application that was developed and used in RSS data collection – only APs that are controlled by the experiment are displayed after filtering the non-related APs

After the RSS reading of the data was taken from the mobile application, the data was transferred into a spreadsheet as shown in Figure 3, and then it will be accumulated iteratively after each reading until all 100 sets is completed for all 20 reference point.



MAC Address	SSID	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
00-26-66-AA-C2-BC	AP1	-44	-47	-46	-43	-52	-51	-37	-39	-42	-42	-56	-51	-53	-42	-43
00-08-9F-21-C9-9C	AP2	-42	-33	-34	-32	-39	-40	-35	-37	-38	-37	-35	-36	-36	-48	-49
00-08-9F-21-C9-AC	AP3	-47	-51	-45	-39	-55	-59	-55	-55	-60	-57	-47	-46	-47	-45	-55
20-C9-D0-26-B6-FF	AP4	-47	-45	-55	-44	-52	-54	-64	-38	-35	-35	-54	-53	-53	-48	-56
		-45	-44	-45	-40	-50	-51	-48	-42	-44	-43	-48	-47	-47	-46	-51

Figure 3. Snapshot of the spreadsheet that store the RSS reading in one of the reference point

5. RESULTS AND DISCUSSION

After completing the data collection of the Wi-Fi RSS, a complete and detail fingerprint (based on WiFi energy map) has been produced as shown in Figure 4. This fingerprinting is not only providing the average value of the extensive 100 sets of training phase, but it also provides fingerprint of 4 different orientation for each of the reference point.

The rationale to include the energy map of the orientation is to find whether the localization could uniquely discriminate the location by its 4 different orientation of the user when they request for their location.

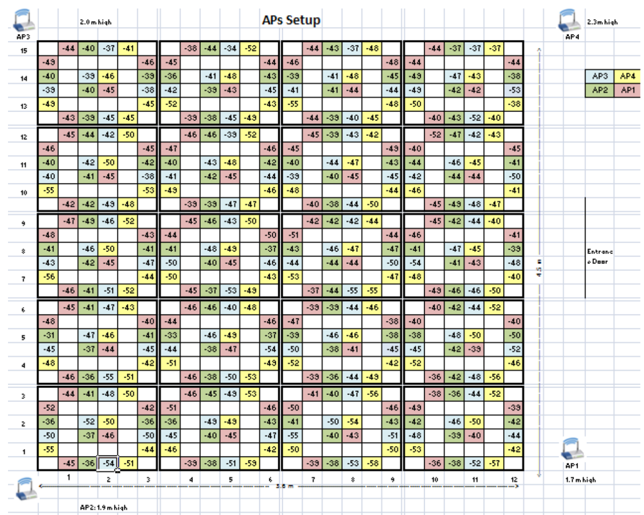


Figure 4. Complete fingerprint of the experimented area – Overall and 4 Orientations

In each of the reference point, the fingerprint consists of the average reading values of (1) overall, (2) 0º orientation, (3) 90º orientation, (4) 180º orientation, and (5) 270º orientation. Figure 5 give a better view of the energy map fingerprint in a particular reference point.

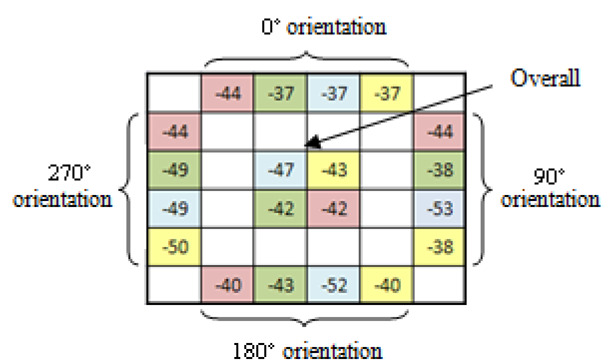


Figure 5. Parts in the reference point fingerprint containing RSS average of each AP for every orientation

5.1 Discrimination of the RSS Reading

The first task is to investigate whether there are any overlaps in the signal strength of the power in each reference point. If there are many overlaps, it is likely that the reference point is hardly to be discriminated.

To know whether a location can be uniquely identified, a 2-dimensional space of graph is plotted by comparing RSS average between 2 APs. If there are no overlaps in the ellipses of the 2D plane, it means the position is already uniquely discriminated and localization in that particular reference point is successfully achieved.

In order to find the possible overlaps of signal strength, an ellipse is drawn. The ellipse is drawn based on the intersection of RSS average of the 2-dimensional space between 2 APs with the variance (standard deviation) of both APs in each particular reference point. Overlapping of the ellipses means the reference point cannot be discriminated to uniquely identify the position. To reduce or eliminate the overlaps, a higher resolution reference point has been investigated.

This analysis has been done in 3 different resolutions: 0.9m, 1.8m and 2.7m. The original reference point setup is in 0.9m resolution; whereas Figure 6 shows that we took the reading of the selected reference location to analyze the 1.8m and 2.7m resolution respectively by eliminating the other non-selected points.

The result shows that the discrimination of the overall RSS is achieved by AP3 & AP4 in 1.8m resolution and it is fully achieved when the resolution is 2.7m.

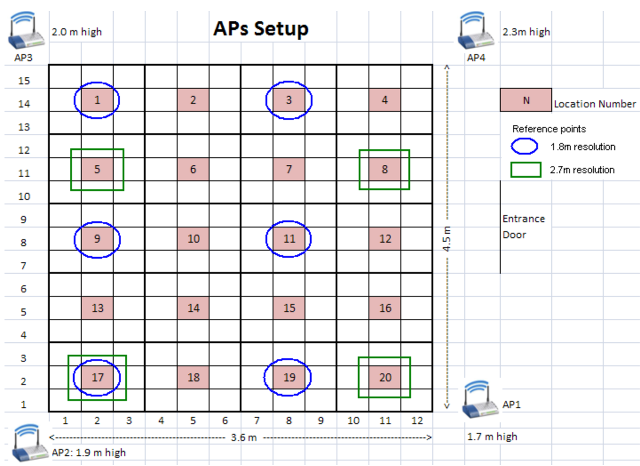


Figure 6. Reference point setup for resolution 1.8 meter (blue ellipse) and resolution 2.7 meter (green rectangle)

5.2 Orientation Affects RSS Reading

Based on the result of the fingerprinting, it was found that the parameter that most significantly affected the RSS reading is the orientation. If the body of the person who take the RSS reading from the smart phone is in between the AP and the smart phone, the reading of the RSS was drop around 15 dBm compared to when the smart phone is in the line-of-sight with the AP.

Other parameters: lighting, time of the day and time intervals between each reading shown no significant effects on the RSS reading. Although different height (between standing and sitting) shows dissimilar RSS value (slightly higher RSS during standing), but the value is not as significant as the orientation.

Thus, this research was not only depending on the average RSS reading in any particular reference point, additionally it also focusing towards the orientation. Can each orientation in a reference point distinguishable from each other? The answer is yes. The detail of the analysis will be explained in section 5.3.

5.3 RSS Discrimination by Orientation

As the main contribution of this paper, the analysis is further applied into discrimination of signal strength by orientation (0º, 90º, 180º, 270º). This has been carried out to investigate whether each reference point can also be discriminated by the orientation or not.

The same as the overall analysis of the fingerprint, the discrimination process by the orientation has been carried out with the resolution of 0.9m, 1.8m and 2.7m. Sample result of these analyses is shown in Figure 7 to Figure 9.

All 4 orientations at each reference point have been analyzed to discriminate the signal strength to uniquely identify the orientation of the human. The analysis also has been further carried out to discriminate the same orientation at each different reference point.

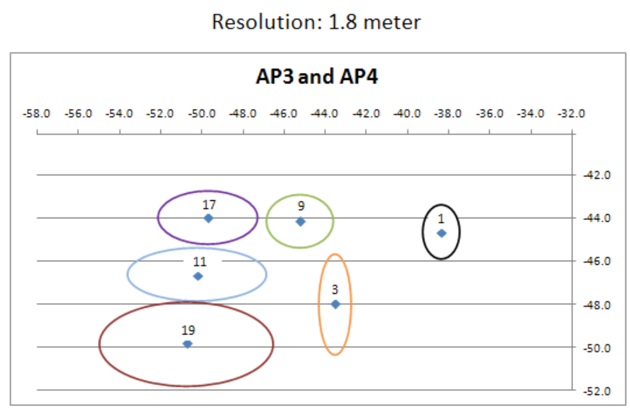


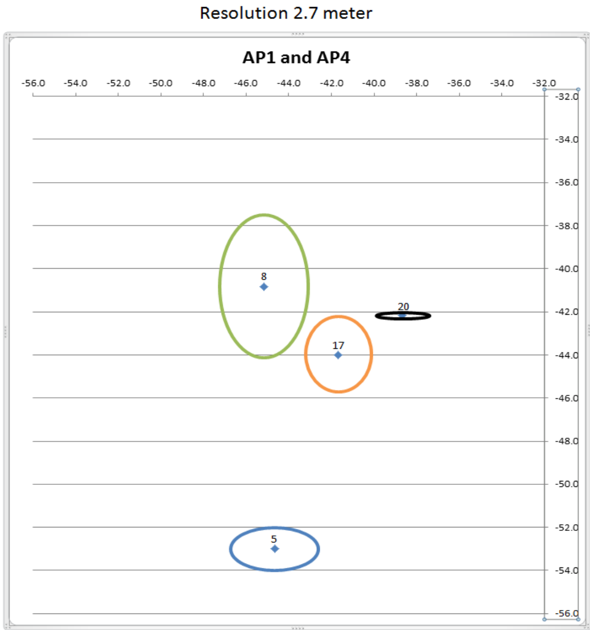
Figure 7. Resolution 1.8m of 90º orientation– reference point's discrimination can be done with AP3 & AP4

Based on the analysis, it was found that the energy map cannot be discriminated with 0.9m resolution because there are so many overlaps of signal strength from the APs. However it was successfully discriminated with 1.8m resolution by AP3 & AP4 as shown in Figure 7. As for the 2.7m resolution, it can be strongly discriminated by the combination of AP1 & AP4, and AP2 & AP3 as shown in Figure 9.

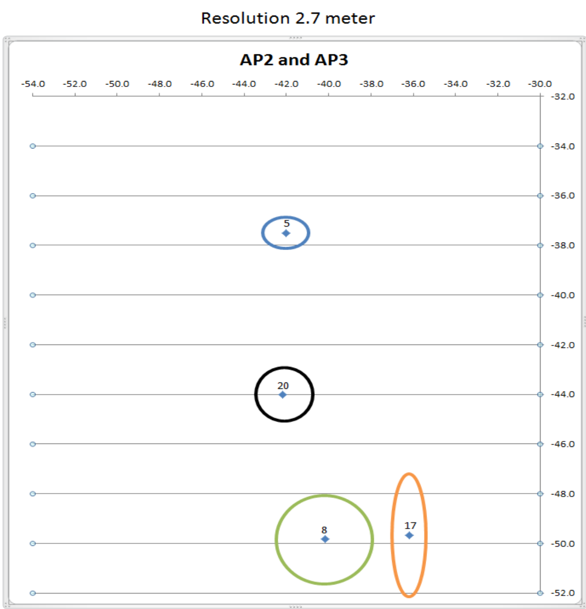
Data for Orientation facing East

	AP1		AP2		AP3		AP4	
	Avg	SD	Avg	SD	Avg	SD	Avg	SD
Loc 5	-44.7	1.7	-42.0	1.0	-37.5	0.6	-53.0	1.0
Loc 8	-45.2	2.1	-40.2	2.0	-49.8	1.7	-40.8	3.2
Loc 17	-41.7	1.7	-36.2	0.6	-49.7	2.5	-44.0	1.7
Loc 20	-38.7	0.6	-42.2	1.0	-44.0	1.0	-42.2	0.0

Figure 8. RSS average and standard deviation (in dBm) of resolution 2.7m for 90° orientation



(a)



(b)

Figure 9. Resolution 2.7m of 90º orientation – Each reference point is successfully discriminated by (a) AP1 & AP4 (b) AP2 & AP3

The result shows that discrimination of the reference points (by orientation) is clearly detached when the resolution is 2.7m by 2.7m.

Since this experiment was using the resolution in the multiplication of every 0.9m, the discrimination is expected can be done in less than 2.7m resolution, which is in between 1.8m and 2.7m. This is based on the findings that combination of AP3 & AP4 successfully discriminate all reference point with 1.8m resolution.

6. CONCLUSION AND FUTURE WORK

This paper describe that by using WiFi fingerprinting method, the location of the elderly can be discriminated and uniquely identified in indoor environment not only by their position and location, but also according to their orientation. This means that the position of the elderly could be identified together with which orientation they are facing to, which past research did not include orientation-based localization in their work.

This is a very useful contribution because in the later stage of this research, a service robot will be notified on the position of the elderly, and the robot should approach the elderly on the correct orientation. The localization accuracy is between 1.8 and 2.7 meter. Each reference point has been successfully discriminated by 2 APs in 1.8 meter resolution, and strongly discriminated by all APs in 2.7 meter resolution. This result is acceptable because after reaching that range of distance, the robot can be further being called by the elderly by gesture recognition (for example by waving their hand) so that the robot can come exactly in front of them.

Another contribution of this paper is the solution that we proposed are using low-cost equipment. One may even use the existing devices available in our building to implement it.

The outcome of this paper will be continued further by sending the identified location and orientation information of the elderly to a service robot, and the robot will then should approach the elderly to the identified location with the correct orientation based on the given information.

Further investigation should also be carried out to know the exact resolution of the discrimination resolution in between 1.8m and 2.7m. The same setup of this work will also further be applied in multiple rooms' scenario, so that the service robot may move around in a floor with many segmented area.

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