A Preliminary Study on Indoor Positioning by Angle-of-Arrival Approach Using Existing Wireless Access Points

Zen-Wei Tu[1] Sendo Wang[2]
[1] Graduate Student, Department of Geography, National Taiwan Normal University
162 HePing East Road Sec.1, Taipei City 10610, Taiwan, R.O.C.
Email: 60323013L@ntnu.edu.tw
[2] Assistant Professor, Department of Geography, National Taiwan Normal University
162 HePing East Road Sec.1, Taipei City 10610, Taiwan, R.O.C.
Email: sendo@ntnu.edu.tw

KEY WORDS: Indoor Positioning, Angle of Arrival (AOA), Wireless Access Point, Space Resection

ABSTRACT: The Global Navigation Satellite System (GNSS), such as GPS and GLONASS, directly delivers 3D coordinates of almost any points on Earth, has stimulated the rapid growth of many location based services (LBS). The weakness of the GNSS is that the radio signal transmitted from satellites is too weak to penetrate the roof and wall. Therefore, the GNSS is not applicable for indoor environments, which makes indoor positioning become a very popular research topic in recent years. Some of the image-based researches rely on the scene recognition and analysis. Due to the variety of indoor scene, these image based methods usually requires setting up specific pattern, such as QR Code, in advance. So the user must find where the pattern is before positioning. Some other researches rely on matching characteristics of the magnetic or gravity field. This approach requires the whole field map, which means the user has to walk throughout the whole place before positioning. Therefore, most of the researches look for other radio wave sources to replace GNSS, such as LTE, Wireless LAN, Bluetooth, Infra-red, i-Beacon, or ZigBee. Since Wireless Access Points (APs) has been widely deployed in many public area and each has reasonable coverage range up to 100m, it is very suitable as the positioning source. There has been several positioning algorithms based on radio wave, such as TOA (Time of Arrival), TDOA (Time difference of Arrival), RSS (Received Signal Strength), and AOA (Angle of Arrival). Both of the TOA and TDOA algorithms calculate the distance based on the travel time of the radio signal. It requires synchronous clocks on all equipment and transmitting time stamp. The Wireless APs cannot meet the requirement. The RSS algorithm compares received signal strength to existing fingerprint map. The accuracy and the stability of the fingerprint map is the key to positioning. However, the disturbance come from other sources will affect the received signal strength. Furthermore, some APs are designed to automatically adjust power according the clients, which makes the fingerprint map no longer represent the real scenario. Some research try to deploy more reference APs to produce real-time fingerprint map, but it will increase the cost and the signal traffic. To achieve indoor positioning without extra cost or modification to existing equipment, this research apply the AOA algorithm based on the space resection of the nearby APs. The direction of each nearby AP is determined while it’s signal reaches strongest during the rotation of user’s smartphone. The experiments are carried out in 3 different site, a classroom, a corridor, and a stadium. The results shows the potential of the proposed method, but there is still some issues need to be worked out.

1. INTRODUCTION

The APP Pokémon Go has become the most popular APP around the world. Not only the America but also the Asia. It is a kind of Location Based Services (LBS) which is the application that rely on the user’s location giving some information that can help the user or the information the user wants. Global Navigation Satellite System (GNSS) can locate or provide a coordinate to user, but indoors or the place with no satellite signal the GNSS cannot be used. In indoor can use Assisted-GPS (A-GPS), but it still need satellite signal the difference is that GPS need at least four to five satellite signals to locate and provide coordinate and A-GPS need one or two satellite signals with some other information such as ephemeris, estimated initial position and so on to locate.

Recently, there are more and more research about indoor positioning. There are some signal source that can be used to indoor positioning such as Radio Frequency Identification (RFID), Infrared (IR), Ultra-sound、Radio Detecting and Ranging (RADAR), Bluetooth, Inertial measurement unit (IMU) , ZigBee and Wireless Local Area Network (WLAN) and so on. The most of these research using WLAN because now there are lots of indoor fully equipped with WLAN not only connect with each other but also surf the net. So there are lots of algorithm about the indoor positioning using WLAN more than other signal source.

The algorithm of WLAN indoor positioning can be divided into Triangulation, Angulation Techniques and Scene Analysis. Algorithm of Triangulation such as Time of Arrival (TOA), Time Difference of Arrival (TDOA) and Differential Time Difference of Arrival (DTDOA) but these algorithm transfer the time difference to distance. Three Aps can intersect one point infer to user′s position. There is extra cost to buy the clock or timestamp to record the time. There is another cost. And the accuracy of this algorithm is that good because one second brings $3x10^8$ meters error. Scene Analysis is the algorithm that compare the signal user receive compare with the fingerprint which was built before work. In other to enhance the positioning accuracy need to set up reference APs to collect the signal strength and make the footprint simultaneously. The Angulation Techniques is the algorithm AOA by knowing the direction of the AP signal come from. Knowing two APs′ direction of signal source can intersect to one point regarded as user′s position.

This paper using fully equipped WLAN signal and AOA algorithm to do indoor positioning. The direction or the angle of AP signal comes from is the important thing. Figure out new method that no need another cost or another equipment just use the AP and the mobile devices such as mobile phone or tablet. Test this method and algorithm in our school using real APs. Discusses the accuracy of indoor positioning.

2. RELATED WORK

Based on Gu *et al.* (2009), Liu *et al.* (2007) and Makki *et al.* (2015) these three surveying papers. Algorithms using WLAN that can be divided into three classes includes Triangulation, Angulation Techniques and Scene Analysis. First, Algorithms of Triangulation such as TOA, TDOA, DTDOA these three algorithms are all based on recording time difference and transfer to distance. The difference between these three algorithms is different AP transmit at the same time or not or receive the signal at the same time or not. But the AP equipped with no clock or timestamp. So cannot record time or calculate the time difference. And the time error brings the error of accuracy.

Scene Analysis is the algorithm that compare the signal user receive with fingerprint that was built before work. Fingerprint is a kind of signal strength map (see Figure 1). So the algorithms about the Scene analysis is to calculate the real time signal that user receive to locate the user in the fingerprint. But the power of AP is not steady causes the signal strength is unstable. In order to enhance the positioning accuracy, build the fingerprint and user receive signal at the same time by setting up reference AP but needs another cost.

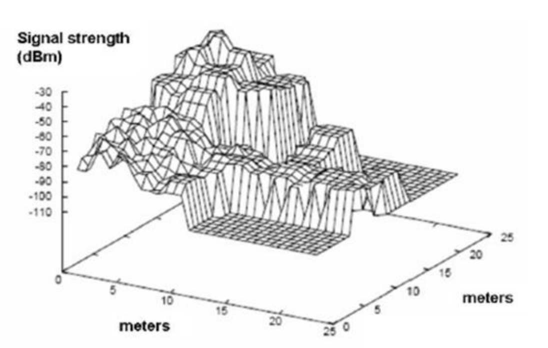

Figure 1 Fingerprint example (Gu et al., 2009)

The main algorithm of Angulation Techniques is AOA. The most important thing of AOA is how to find the angle or direction of signal source. The AOA algorithm concept is AP (R_1, R_2) and corresponding azimuth angle (θ_1, θ_2) and can intersect to one point (X_0 ,Y_0) and finish positioning (see Figure 2). Some of research knowing the angle by using antenna array to get the direction of signal source.

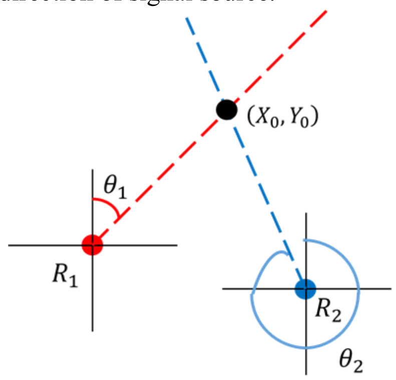

Figure 2 AOA concept

3. Algorithm

This paper using AOA as the algorithm to indoor positioning. Figure out one method to determine the direction of signal come from. The method is spinning the mobile phone 360 degrees and receive all APs′ signal strength by each degree (see Figure 3). Then, can plot a signal strength print by using different angle same AP′s signal strength. Find the signal strength print which direction is the AP′s signal is the strongest and determine this corresponding direction is the AP signal comes from. Regarded this direction is the AP′s direction (see Figure 4).

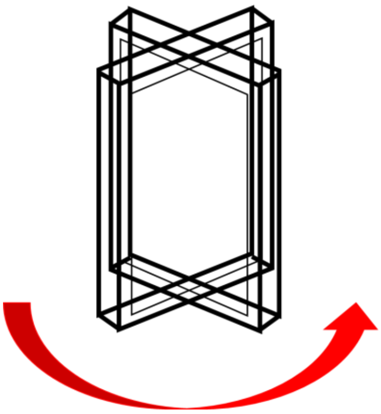

Figure 3 spinning mobile phone 360 degree

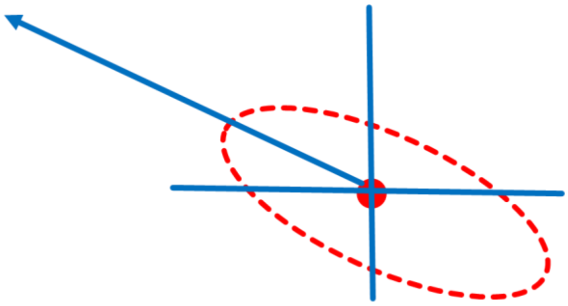

Figure 4 determine the direction based on signal strength print

3.1 Data

Program a simple APP on android to collect the data by using the android wifiscan and orientation. Wifiscan is the function that shows all the wifi that can receive and supply their name (SSID), Mac Address (BSSID), Level (signal strength) and so on the information about the wifi. Orientation is the function that supply the orientation of the phone included azimuth, pitch and roll angle. This two function can make APP meet to the purpose of this research. The screenshot of the APP (see Figure 5) save as the table (see Table 1). Table 1 shows that one direction can receive all the APs and corresponding signal strength (level). Sort out all 360 degrees data by one AP make new table (see Table 2) and can also plot the signal strength print (see Figure 6).

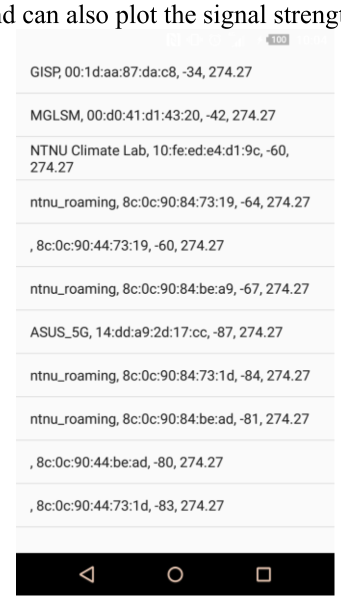

Figure 5 APP screenshot

SSID	BSSID(MAC address)	Level	Azimuth
nullGISP	00:1d:aa:87:da:c8	-39	359.73
NTNU Climate Lab	10:fe:ed:e4:d1:9c	-59	359.73
MGLSM	00:d0:41:d1:43:20	-41	359.73
RT003	1c:5f:2b:8b:0d:a0	-25	359.73
RT004	1c:5f:2b:8a:f7:62	-26	359.73
RT002	1c:5f:2b:8a:f9:d8	-42	359.73
ntnu	8c:0c:90:84:be:a8	-56	359.73
ntnu_guest	8c:0c:90:c4:be:a8	-60	359.73

Table 1 data by one direction

SSID	BSSID(Mac Address)	Level	Azimuth
RT001	1c:5f:2b:8a:fa:08	-45	359.98
RT001	1c:5f:2b:8a:fa:08	-42	359.96
RT001	1c:5f:2b:8a:fa:08	-36	79.32
RT001	1c:5f:2b:8a:fa:08	-36	92.82
RT001	1c:5f:2b:8a:fa:08	-36	213.84
RT001	1c:5f:2b:8a:fa:08	-37	72.63
RT001	1c:5f:2b:8a:fa:08	-37	72.64
RT001	1c:5f:2b:8a:fa:08	-37	148.12
RT001	1c:5f:2b:8a:fa:08	-37	212.64
RT001	1c:5f:2b:8a:fa:08	-38	63.94

Table 2 arrange all the table by one AP

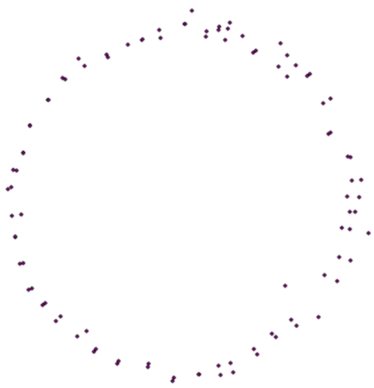

Figure 6 signal strength print

3.2 Determine Angle

Sort all the signal strength by high to low and extract top 10 signal strength and corresponding angle (see Figure 7) the blue line is the signal strength sort by high to low and orange line is the corresponding angle of signal come from. Extract top 10 signal strength divided into 16 classes by determining the corresponding angle suit to 16 cardinal direction (see Figure 8) 16 cardinal direction the angle can be divided into 16 classes they are 0 to 22.5 degree, 22.5 to 45 degree and so on. Each class 22.5 degree. Then pick up the most volumes of the class and take the average of the angle of these data and determine this AP direction. In Figure 8 the volumes of class between 157.5 to 180 degree is the most so take the average of these four angle.

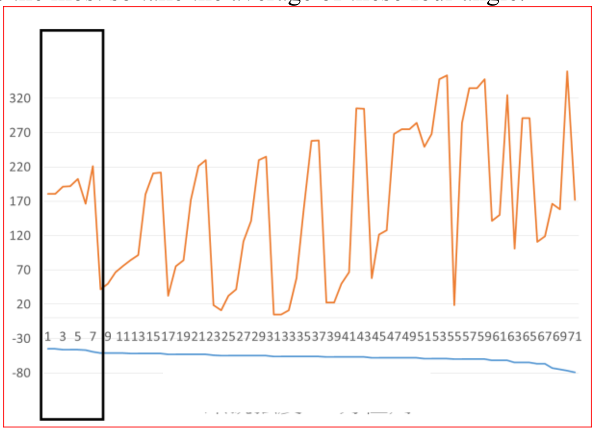

Figure 7 sort signal strength by high to low and corresponding angle and pick up top 10

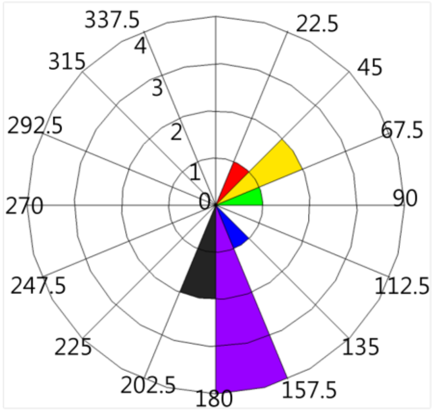

Figure 8 top 10 signal strength divided into 16 classes by 16 cardinal directions

3.3 Intersect Point

After determining angle using linear equation (1) two AP have two linear equation and solve these two equation and get X coordinate and Y coordinate. Linear equation (1) where a means $\tan\alpha$, α means the direction signal come from (azimuth angle) and b means $y - \tan\alpha\, x$ where x and y is the AP coordinate X and Y. Two equations can intersect one pint (see Figure 9).

$$y = ax + b \tag{1}$$

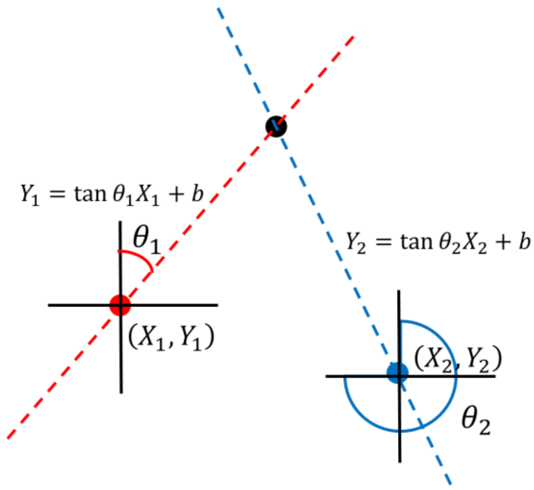

Figure 9 solve two equations concept

4. EXPERIMENT DESIGN

4.1 Equipment

4.1.1 Signal Receiver: This research use Sony z5 as the mobile device to receive wifi signal (see Figure 10) shows the antenna is on the right side of the phone in the red rectangle. As the antenna is on the side of the phone so the devices (see Figure 11) put vertical in order to receive good wifi signal. As the Figure 11 shows put the phone straight on the tripod that can rotate 360 degree.

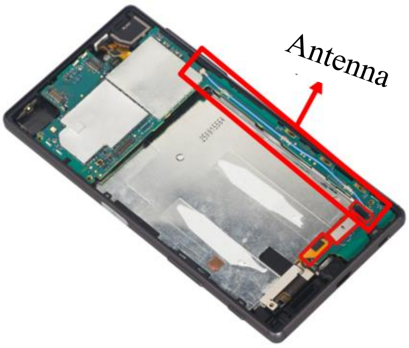

Figure 10 Antenna of Z5 (Lenka)

Figure 11 signal receive equipment

4.1.2 AP: In order to test the same specification, this paper use the four same APs (D-Link Wireless N300). To do the research based on the sane basement (see Figure 12).

Figure 12 four same specification APs

4.2 Test Site

Choose four different sizes of indoor place. Respectively, gym (see Figure 13), first floor of classrooms (see Figure 14), computer room (see Figure 15) and laboratory (see Figure 16). And put the four APs distributed in gym, first floor of classrooms and computer room.

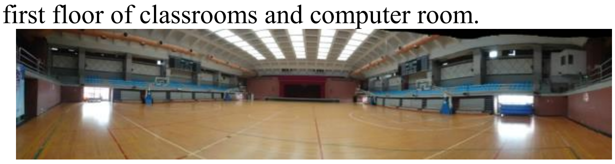

Figure 13 gym

Figure 14 first floor of classrooms

Figure 15 computer room

Figure 16 laboratory

5. RESULT

The conclusion of these four indoor places test using the algorithm that mentioned in 3. Algorithm. And discusses the accuracy of the result. Calculate the distance the points that intersected by each two directions of two APs as the accuracy. Gym, first floor of classrooms and computer use the four D-Link APs to indoor positioning and the laboratory use the real APs in the school.

5.1 Gym

The four D-Link APs distributed in the gym (see Figure 17) based on the plane of gym. Each two directions of APs intersect points (see Figure 18) the red points are the intersect points. The result (see Table 3) shows that distance between the real user position and the intersect point. The mean accuracy is up to 23.71 meters and standard deviation is 18.14 meters.

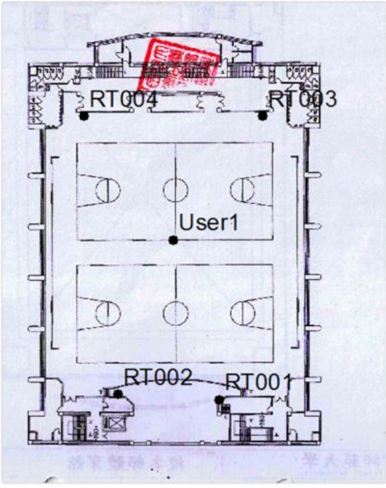

Figure 17 The APs distributed in gym

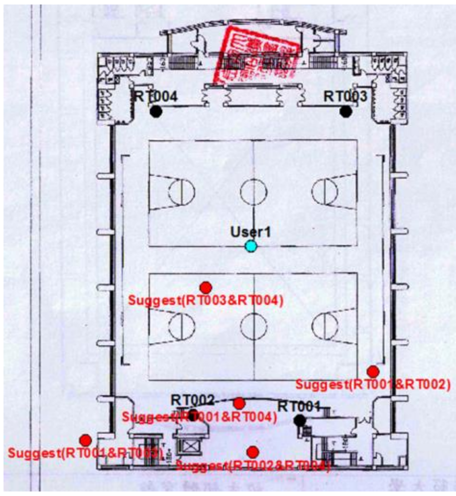

Figure 18 The intersect points in gym

ID	X	Y	Distance
User1	5	7.3	0
Suggest(RT001&RT002)	8.99	3.21	17.15
Suggest(RT001&RT003)	-0.41	0.96	25.01
Suggest(RT001&RT004)	4.61	2.16	15.47
Suggest(RT002&RT003)	-7.34	-7.77	58.44
Suggest(RT002&RT004)	5.06	0.56	20.21
Suggest(RT003&RT004)	3.53	5.94	6.00

Table 3 the result of the intersect points

5.2 First Floor of Classrooms

The four D-Link APs distributed in the first floor of classrooms (see Figure 19) based on the plane of first floor of classrooms. Each two directions of APs intersect points (see Figure 20) the red points are the intersect points. The result (see Table 4) shows that distance between the real user position and the intersect point. The mean accuracy is up to 13.76 meters and standard deviation is 9.06 meters.

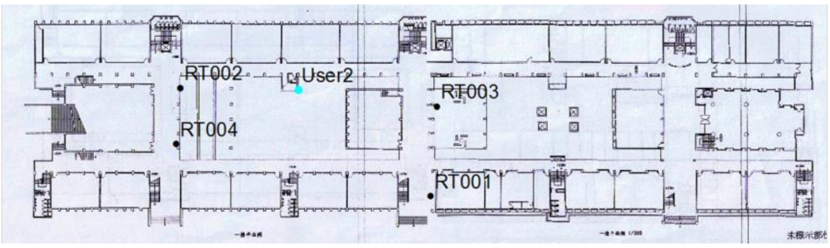

Figure 19 The APs distributed in first floor of classrooms

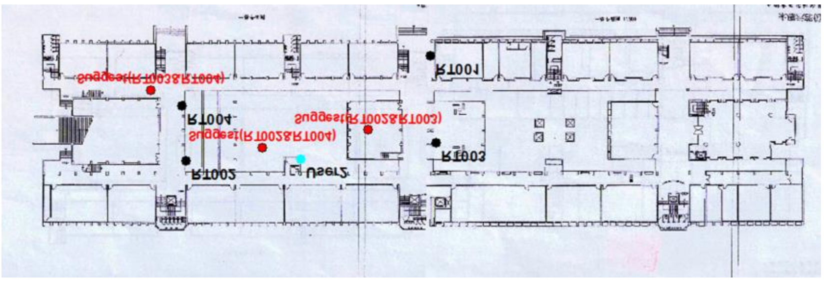

Figure 20 The intersect points in first floor of classrooms

ID	X	Y	Distance
User2	12.8	6.1	0
Suggest(RT002&RT003)	16.10	4.67	10.77
Suggest(RT003&RT004)	5.37	2.71	24.51
Suggest(RT002&RT004)	10.87	5.56	6.00

Table 4 the result of the intersect points

5.3 Computer Room

The four D-Link APs distributed in the computer room (see Figure 21) based on the plane of computer room. Each two directions of APs intersect points (see Figure 22) the red points are the intersect points. The result (see Table 5) shows that distance between the real user position and the intersect point. The mean accuracy is up to 14.45 meters and standard deviation is 11.88 meters.

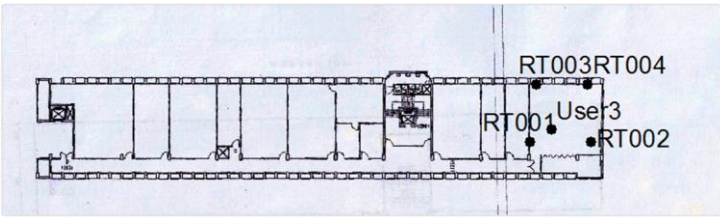

Figure 19 The APs distributed in computer room

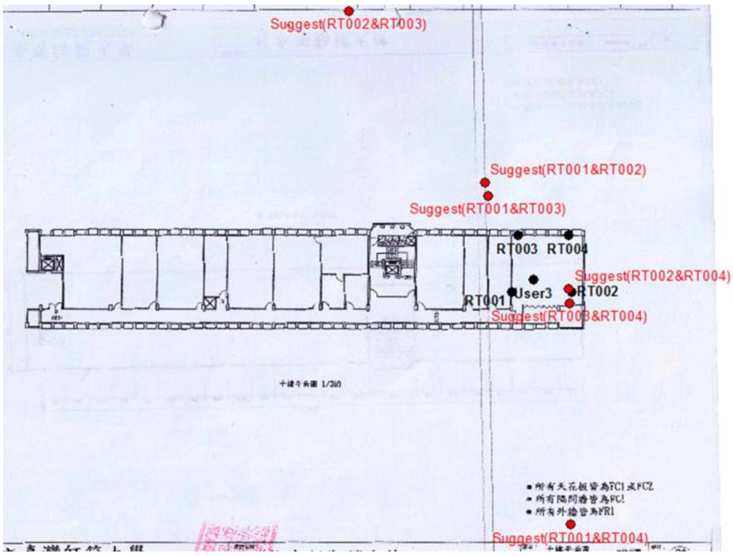

Figure 20 The intersect points in computer room

ID	X	Y	Distance
User3	17.1	1.6	0
Suggest(RT001&RT002)	15.47	4.89	11.01
Suggest(RT001&RT003)	15.58	4.45	9.68
Suggest(RT001&RT004)	18.37	-6.63	24.98
Suggest(RT002&RT003)	10.88	10.66	32.98
Suggest(RT002&RT004)	18.31	1.31	3.74
Suggest(RT003&RT004)	18.32	0.83	4.32

Table 5 the result of the intersect points

5.4 Laboratory

There are five APs that school use to surf the net and connect distributed (see Figure 21). The intersect points distributed (see Figure 22) shows as the red points. And the result of these intersect points between the user′s position (see Table 6). The mean accuracy is up to 29 meters and standard deviation is 63.3 meters.

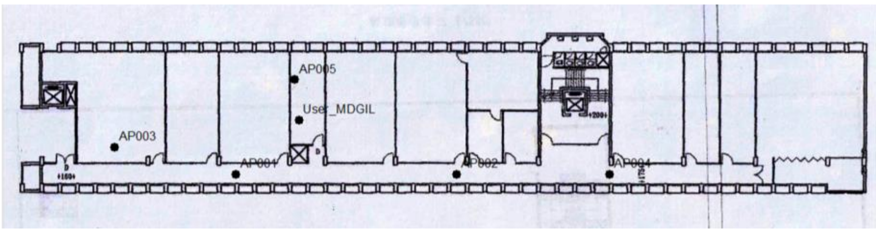

Figure 21 Five real APs distributed in laboratory

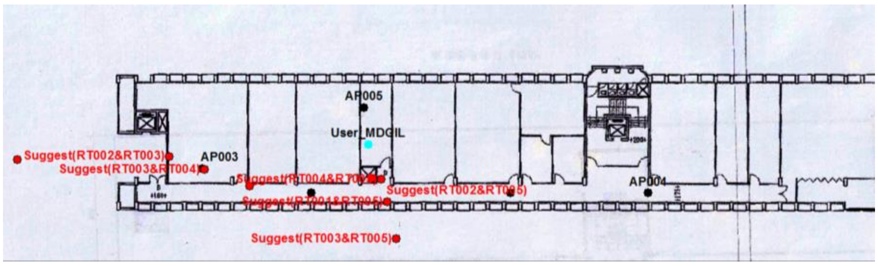

Figure 22 Intersect points distributed in laboratory

ID	X	Y	Distance
User_MDGIL	6.2	1.6	0
Suggest(RT001&RT002)	-62.75	8.72	207.95
Suggest(RT001&RT003)	3.28	0.57	9.27
Suggest(RT001&RT004)	-2.44	1.22	25.96
Suggest(RT001&RT005)	6.66	0.19	4.45
Suggest(RT002&RT003)	1.30	1.29	14.74
Suggest(RT002&RT004)	6.30	0.76	2.54
Suggest(RT002&RT005)	6.53	0.74	2.77
Suggest(RT003&RT004)	2.16	0.98	12.27
Suggest(RT003&RT005)	6.88	-0.73	7.27
Suggest(RT004&RT005)	6.52	0.75	2.73

Table 6 the result of the intersect points

6. DISCUSSION

The accuracy of these four tests are not that good. The accuracy are 10 to 30 meters. But see the four tables can find there is one intersect point distance can be 3 to 6 meters. As the (Table 7, 8, 9 and 10) in the red rectangle shows the gym best distance is 6 meters, the first floor of classrooms is 6 meters, the computer room best is 3.74 meters and laboratory best is 2.54 meters.

ID	X	Y	Distance
User1	5	7.3	0
Suggest(RT001&RT002)	8.99	3.21	17.15
Suggest(RT001&RT003)	-0.41	0.96	25.01
Suggest(RT001&RT004)	4.61	2.16	15.47
Suggest(RT002&RT003)	-7.34	-7.77	58.44
Suggest(RT002&RT004)	5.06	0.56	20.21
Suggest(RT003&RT004)	3.53	5.94	6.00

Table 7 the best accuracy in gym

ID	X	Y	Distance
User2	12.8	6.1	0
Suggest(RT002&RT003)	16.10	4.67	10.77
Suggest(RT003&RT004)	5.37	2.71	24.51
Suggest(RT002&RT004)	10.87	5.56	6.00

Table 7 the best accuracy in first floor of classrooms

ID	X	Y	Distance
User3	17.1	1.6	0
Suggest(RT001&RT002)	15.47	4.89	11.01
Suggest(RT001&RT003)	15.58	4.45	9.68
Suggest(RT001&RT004)	18.37	-6.63	24.98
Suggest(RT002&RT003)	10.88	10.66	32.98
Suggest(RT002&RT004)	18.31	1.31	3.74
Suggest(RT003&RT004)	18.32	0.83	4.32

Table 7 the best accuracy in computer room

ID	X	Y	Distance
User_MDGIL	6.2	1.6	0
Suggest(RT001&RT002)	-62.75	8.72	207.95
Suggest(RT001&RT003)	3.28	0.57	9.27
Suggest(RT001&RT004)	-2.44	1.22	25.96
Suggest(RT001&RT005)	6.66	0.19	4.45
Suggest(RT002&RT003)	1.30	1.29	14.74
Suggest(RT002&RT004)	6.30	0.76	2.54
Suggest(RT002&RT005)	6.53	0.74	2.77
Suggest(RT003&RT004)	2.16	0.98	12.27
Suggest(RT003&RT005)	6.88	-0.73	7.27
Suggest(RT004&RT005)	6.52	0.75	2.73

Table 7 the best accuracy in laboratory

7. CONCLUSION AND FEATURE WORK

Because the direction of the wifi signal come from is not the error but is the mistake. If can judge the direction of the signal come from which is wrong or mistake and exclude these wrong directions use the right directions can get a better result and good accuracy.

In the future can judge the direction of AP by the geometry of AP position. Compare the direction with the geometry of the AP. That help to delete the mistake and enhance the accuracy. There is only one test point using the real AP cannot represent the real world can test more points and one point have to test in different timing. And use this algorithm to 3D indoor positioning not only the 2D.

8. ACKNOWLEDGEMENTS

The author deeply appreciates the grant (NSC 102-2511-S-003-035-MY4) sponsored from the National Science Council of Republic of China.

9. REFERENCES

Gu, Y., Lo, A., & Niemegeers, I. (2009). A survey of indoor positioning systems for wireless personal networks. *Communications Surveys & Tutorials, IEEE, 11*(1), 13-32.

Lenka, Sony Xperia Z5 Teardown, Retrieved August 31, 2016, from https://www.ifixit.com/Teardown/Sony+Xperia+Z5+Teardown/52300

Liu, H., Darabi, H., Banerjee, P., & Liu, J. (2007). Survey of wireless indoor positioning techniques and systems. *Systems, Man, and Cybernetics, Part C: Applications and Reviews, IEEE Transactions on, 37*(6), 1067-1080

Makki, A., Siddig, A., Saad, M., & Bleakley, C. (2015). Survey of WiFi positioning using time-based techniques. Computer Networks, 88, 218-233.