Wireless Indoor localization using fingerprinting and Trilateration

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Summary
Indoor positioning has gained more interest as one of the upcoming applications due to its use in a variety of services. Multiple technologies such as Bluetooth, Wi-Fi, RFID. However, Wi-Fi based localization in indoor environment offers significant advantages utilizing installed wireless infrastructures and good performances with low cost. With this study, we aim to provide a compromise between accurate positioning and feasibility of the system for practical applications. For this purpose, we minimize the fluctuations of Wi-Fi received signal strength (RSS) by filtering and we combine two approaches to locate a mobile user. At first, we implemeted the traditional fingerprinting technique that uses a real time matching of pre-recorded received signal strength (RSS) from the location data of the user transmitted to nearby access points (AP). Secondly, we used distance-based trilateration technique which determines positions using three known access points. The combination of the two methods provides enhancement of accuracy and wide indoor locating coverage. Regardless the locating data number, experiment confirmed a significant and a consistent performance in term of execution time and accuracy.

Key words:
Indoor positioning, Wireless, Wi-Fi, Fingerprinting, Trilateration, RSS.

1. Introduction

Demands on Indoor positioning services endlessly increment the improvement of the utilization of wireless devices and mobile communication technology. Consequently, the occurrence and emergence of a technology in long term are determined by if it meets the user's needs, its consistency and its accuracy. Outdoor positioning has advanced and principally relies on Global Positioning System [1] (GPS). Due to the interferences and their low propagation signal levels within indoor environment, GPS has limitations and can only be effective in outdoor. Many technologies, such as Radio Frequency ID (RFID) [2-3], ZigBee [4], Bluetooth [5], and Wi-Fi [6] brought to life adopting the present indoor wireless technologies.

With the advancement of Wi-Fi networks nowadays, access points can be found worldwide so we found a built-in Wi-Fi module almost in every device. Subsequently, Wi-Fi positioning has been considered with the increasing of indoor positioning systems improvement. In healthcare environments, Wi-Fi locating methods proves to be dangerous especially in hospital as Wi-Fi signal could easily interfere with hospital equipment. On the other side, when densely placed Wi-Fi access points provide an expanded and solid coverage in most urban settings. As a result, Wi-Fi has become the logical choice for positioning and tracking exploiting the pre-existing Wi-Fi infrastructure. The calculation of position requires algorithms applied to receive and process signal from access points (AP). However, fingerprinting is the most used one recently.

In this paper, we propose a locating system based on Wi-Fi technology using fingerprinting method. Thus, we combine this typical method with trilateration to enhance our system accuracy and consistency. Firstly, we process the RSS signal received [7-8] from nearby Wi-Fi access points to reduce its fluctuations. The processed signals are then compared to the fingerprinting radio-maps stored in the database. The second complementary approach is the trilateration using distances between three known access points coordinates thereby the determination of the relative distance of a mobile user.

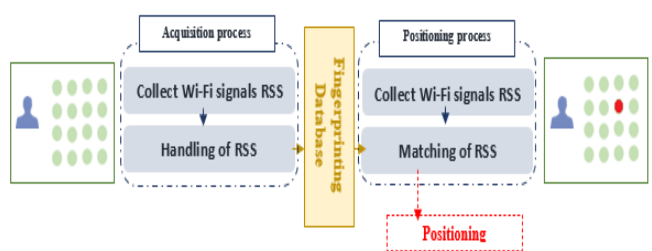

Fig. 1 Methodology of the proposed algorithm

2. Background and Motivation

Due to the presence of Wi-Fi installations in most indoor environment, multiple researches on indoor locating highlight the use this technology [9- 10]. Therefore, our focus shifts toward the improvement of the locating process performances using a Wi-Fi-based method. In fact, we aim to establish the integration of locating services in indoor tracking services with the conception of an

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automatic and flexible tracking system and the exploration of its feasibility.

Research [11-12] explores the localization accuracy issue using probabilistic methods and deterministic WLAN fingerprinting. The author has developed Redpin [13] indoor positioning system allowing the upload to sever to contribute to the enhancement of the accuracy of the positioning. The matching of fingerprints is more precise by increasing the density of the location point. As such, our present study proposes the use of Wi-Fi access points installed within the locating environment, and calculate the location using the property of the signal intensity using Fingerprinting and trilateration.

2.1 Locating techniques

2.1.1 Fingerprinting

Fingerprinting consists of two phases:

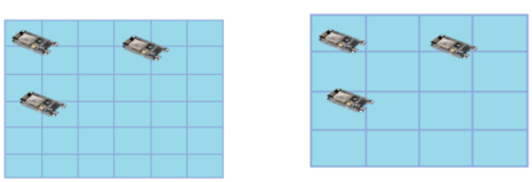
- **Phase1:** Indoor Wi-Fi signal collection

The collecting points form a map by dividing the positioning environment into a grid. Then, we collect Wi-Fi signal by using the mobile device in every single point.

- **Phase2:** Matching location fingerprints

Compare collected data to measured ones to find the higher match from the database that stores each reference point locations. [14]

When using the fingerprinting technique, the accuracy and error of locating vary depending on the size of locating cells within the indoor environment. Figure below shows that the smaller the size of the grid, the lower the accuracy as the locating probability within the same grid becomes lower. Thus, it is important to choose an appropriate grid size [15].



(a) (b)

Fig.2 Grid split for the same locating grid

Table 1: Comparison of the grid size and the error/accuracy

Grid Size	Range of error	Accuracy
Small	Small	Low
Large	Large	High

2.1.2 Trilateration

With the utilization of each network parameters [16, 17] such as signal strength frequency (2.4 GHz in our case), RSS, real coordinates of Wi-Fi access point in the network and Mac addresses. We exploit the received signal strength RSS for distance estimation between the access points and the mobile device. We consider three or more access points (AP) to determine an approximate radius and device the intersection to obtain position.

2.2 Properties to consider when conceiving the system

2.2.1. Multipath propagation of the signal

It is important to consider a value range when matching database signal values and collected RSS due to the nature of the multipath.

2.2.2. Locating or positioning

In order to conceive an indoor locating system, we should distinguish:

- ***Localization:*** determination of a relative asset or device coordinates.
- ***Positioning:*** main step for trilateration as to determine distance with a priory known coordinates.

2.2.3. Wi-Fi signal collecting error

In an indoor complex structure, multiple interfaces affect collected signals quality consequently the locating process. We distinguish between:

- ***Gross Error:*** caused by burst such as people movement. A statistical method is used to reduce it.
- ***Systematic Error:*** caused by the difference of hardware device. Setting an offset value is used to handle this error.
- ***Random error***: caused by interferences of the Wi-Fi signal. We used a median filter to eliminate it because the Wi-Fi signal follows normal distribution.

3. System conception methodology

This system is aimed toward ESP8266 [18] locating system users due to its flexibility and low cost. ESP8266 node has an algorithm that allows RSS data from the mobile node to be sent to database for processing, thereby computing location of the mobile users.

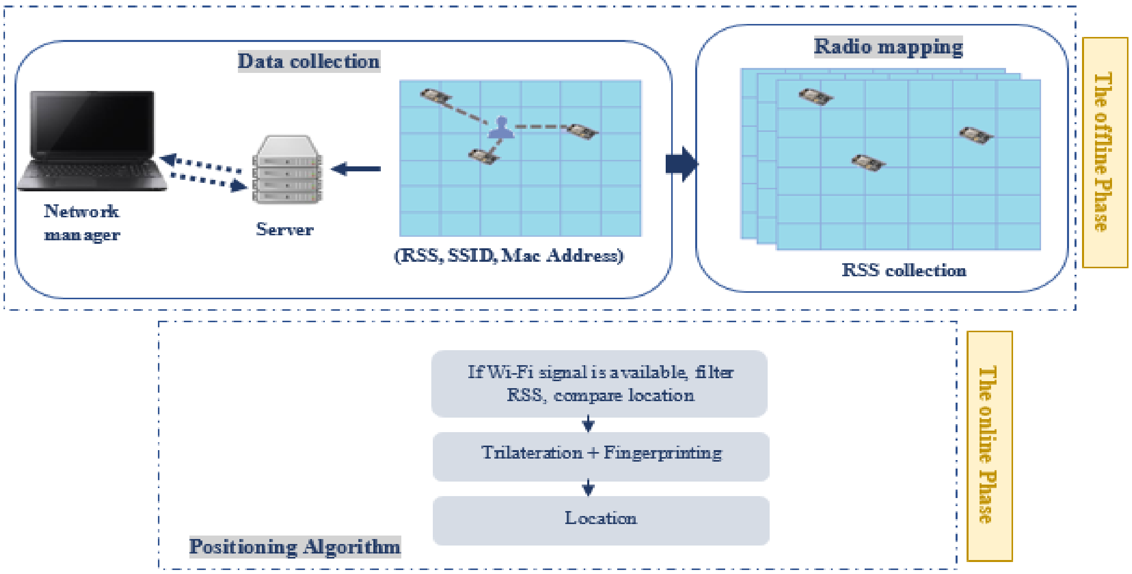


Fig. 3 Our locating system overview

Based on the collection of the data, we construct radio maps [18], which are regarding RSS, SSID and the location of the Wi-Fi access point for each grid within the indoor environment. Using the constructed radio map, we compare each new collection of the locating information to the stored ones and accept locations with higher matches. In this case, we process Wi-Fi signals with trilateration method and we return the final result.
In our study, we divide our indoor environment into square grids with an interval of 1m to minimize the position error, and put 7 access points (ESP8266 Modules) for accuracy purposes.

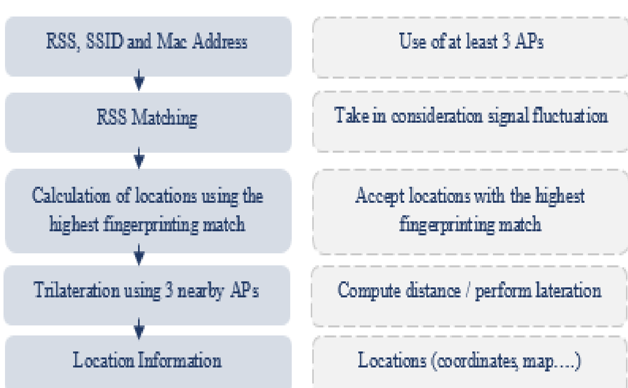


Fig. 4 Our locating method logic presented in a sequential char

3.1 Radio Map Building

We build a radio map within our locating environment by dividing it into grids. Using an ESP8266 module as a Wi-Fi tag, we collect the signal at each position within the localisation grid, and we collect the strongest RSS and SSID. We construct then radio maps, and as shown in figure below, are RSSI- based and location-based from each Wi-Fi access points radio map with fingerprinting and trilateration methods.
We address the location accuracy issue caused by the accumulation of the Wi-Fi access points' signal intensity. Although the comparison number increases with the increasing of the numbers with the same intensity of the signal, we can improve the speed of the processing by finding and only accept the locations with the highest matches.
We build the RSS radio map first, and the location-based map is the constructed. We construct the SSID, RSS, and values of the location from each Wi-Fi from each access point maps using the fingerprinting at the same time as we are building the map using the trilateration. The location-based map is built based on the result of the first step of the fingerprinting process. The first fingerprinting map is a radio-map which filters the grid locations with similar SSIDs in the same location. In fact, this map is constructed to speed up the process of locating performances by only looking to the highest number of matches when comparing

to find the location. We compare then to the radio-map of trilateration for a higher accuracy.

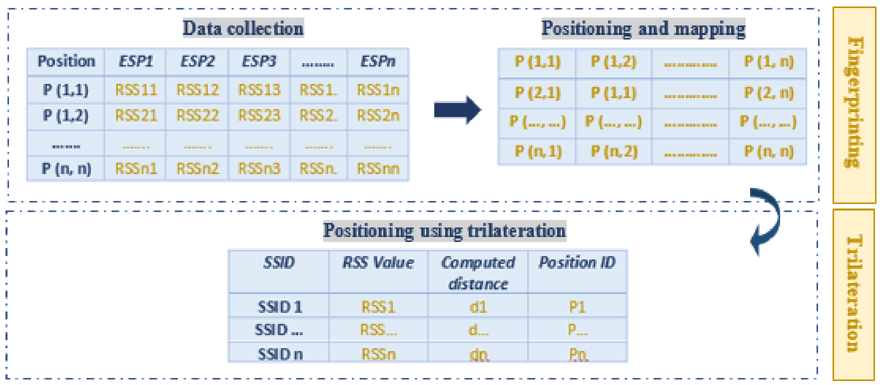


Fig. 5 Construction of radio maps using fingerprinting and tritrilateration

When constructing the map, the most important aspect is the time. Also, we obtain the RSS and SSID information at each grid. As the process of the locating progresses, we improve the accuracy at a certain level; yet if the locating data amount is large, it takes longer to find higher matches so as the location. Consequently, the information of the appropriate number of the processing time remains important. Figure 6 shows the execution time and the accuracy of the location according to the processing time. We notice from the graph, that higher the number of processing times, the longer the locating process is.

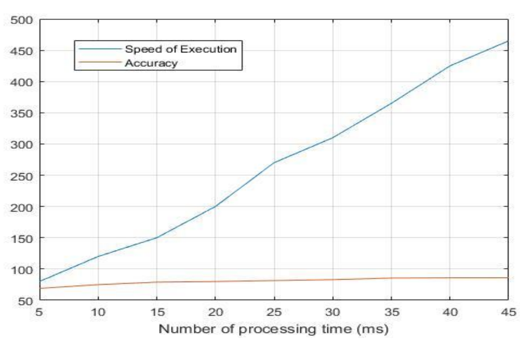


Fig. 6 Speed of execution and accuracy according to number of processing time

The processing time can be shortened through finding matches of both RSS and SSID. With the use of the conventional method such as the signal strength intensity, differences in RSS values at each grid location are difficult

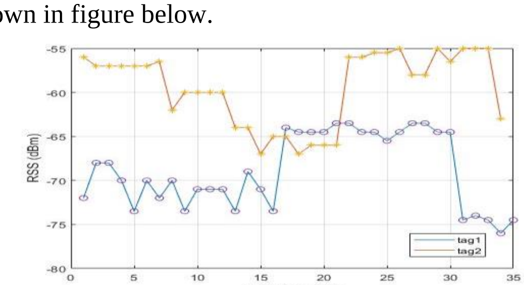
to be seen due the influence of the environment. Thus, we apply refinement to reduce the slight errors during the collection process of each location within the same grid.

3.2 Collection of data

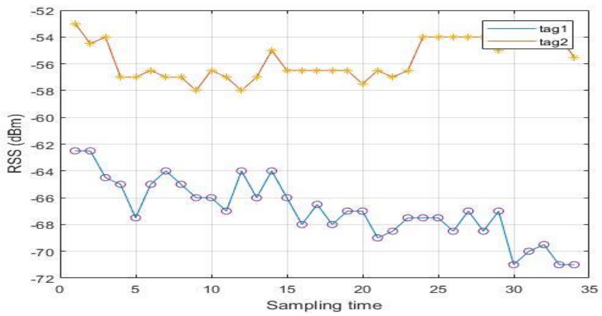
All used access points are ESP8266 [19 - 20] modules that supports 802.11b band operating at 2.4 Ghz only. At full strength, ESP8266 nodes are transmitting at 25mW which correspond to 14Bm.

Fig. 7 ESP8266 modules used for the experiment

The RSS are measured in units of dBms, using an implemented algorithm in our access points along with its corresponding SSID, channel and MAC address. However, original RSS signal fluctuates sharply and constantly. These fluctuations present an obvious time varying characteristic and consequently affect positioning accuracy. To handle this issue and verify its reducing, we correct the RSS signal and making it more stable by eliminating part effects of Wi-Fi signal fluctuations, as shown in figure below.



(a) Raw RSSI signal



(b) Corrected RSSI signal

Fig. 8 RSS Wi-Fi signal

Signal fluctuation becomes smoother after the correction. In fact, the processed signal demonstrates low strength fluctuation in long duration compared to the original signal. Finally, the matching process consists of 12 locations distributed on the same grid constituting the data of reference stored in the database.

For computing the distance between the nearby access point (AP) and the mobile users we principally use the path loss equation [21]:

$$PL = 20\log(d) + 20\log(f) - 27.55 \quad (1)$$

Where:

PL: Received signal Path loss (dBm)
d: Distance between receive and sender
f: Frequency of the signal in MHz

Using the equation above, we compute distance "d" from the specific access point (AP). The computed distance represents a radius "d" around the access point (AP) in meter unit. We apply then the trilateration to solve the point of intersection where the user would be positioned.

3.3 Method of indoor locating process

We use an ESP8266 module as a sink to transmit the Wi-Fi RSS and SSID periodically to our server. As shown in figure below, at first, we collect the RSS of the user at a certain position in order to transmit it to the server. Secondly, we compare this collected data to the existing radio map to find the highest number of matches. At this stage, trilateration method is applied.

First, we compare the measured RSS to the existing constructed radio map, which are storing all the collected locating data at different locations, and we filter based on the high match excluding the grids with low number of matches. Then, we apply a filtering by combining the fingerprinting and trilateration processes results within the appropriate locating grid. Figure 8 shows that P (1, 2) is the final position after applying the locating process.

With the use of the typical fingerprinting method, the complexity of locating decreases with the decreasing of the size of the locating grid (only the strength of the signal is analyzed). Indeed, we use the radio map we constructed previously and perform two operations of filtering. With the addition of filtering, we reduce the processing time of the final position.

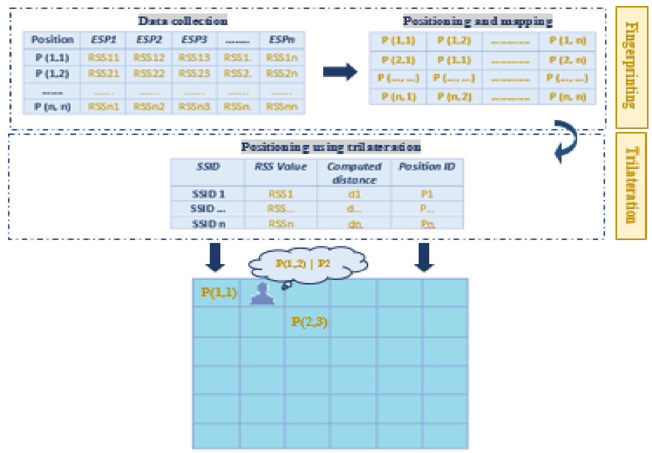


Fig. 9 Sequence of finding the location

4. Results

During the scanning process, the SSID and RSS nearby our access point are stored at every cycle of measurement (Table 2). Next, we select the strongest Wi-Fi signal intensities and look for the highest matches. At this stage, the first filtering is performed, RSS for the locating grid is obtained and those results are stored. By combining the previous results to those generated using the trilateration method, we determine the final location. We store it then in the server according to its time of measurement.

The indoor experimental environment is with no walls. We use an Intel Core i5 CPU, 8 GB of memory, Windows 8 pro 64-bit server. We use ESP8266 as access points (AP), a sink and a mobile user. We divided this space into a total of 12 square cells. Seven access points are installed to enable the detection of signals at each cell of this environment. We defined a minimum time to collect RSS, SSID and location by taking into consideration the measurement time for each location and the time for moving from a cell to another.

4.1 First approach: Fingerprinting

The mobile user receives signals from a pre-stored access point (AP) list. Each AP has its unique respective MAC address and SSID (Table 2). As demonstrated below, we tested an unknown mobile user location.

Table 2: List of MAC Address, SSID, RSS (dBm) measured at an unknown location from user

MAC address	SSID	RSS value, dBm
5C:CF: 7F:0B:98: D8	ESP 1	-55.05
A0:20: A6:00: F7:3A	ESP 2	-61.71
5C:CF: 7F:1B: 7A:C2	ESP 3	-68.12
A0:20: A6:00: F7:3A	ESP 4	-53.1
A8:D9: B3:0D: AA:CE	ESP 5	-74.7
18: FE:34: A5:91:60	ESP 6	-48.9
A0:68:84: E3: FE:EF	ESP 7	-63.2

This list above gives a list of unique SSID and MAC address. We compare then this list in table I to the master database list. Evidently, in this case (Table 3) we conclude the user position is at P (3, 1) which is a real reference point.

Table 3: Determine location by matching database pre-recorded RSS and the user's RSS/ Mac Address

Location ID	Number of matches	Location ID	Number of matches	Location ID	Number of matches
P (1,1)	0	**P (2,1)**	0	**P (3,1)**	5
P (1,2)	1	**P (2,2)**	0	**P (3,2)**	1
P (1,3)	0	**P (2,3)**	1	**P (3,3)**	0
P (1,4)	2	**P (2,4)**	0	**P (3,4)**	0

4.2 Second approach: Trilateration

For the same unknown position, we compute "d" using (1) with parameters similar to empirically value. We use then the three known distance to derive the intersection point where the mobile user is positioned [22]. Table 4 Shows computed distance from three highest RSS signal in a certain position.

Table 4: Distance away from access points computed using RSS

MAC Address	RSS value	Computed distance (m)
5C:CF: 7F:0B:98: D8	-55.05	1.202
A0:20: A6:00: F7:3A	-61.71	3.120
5C:CF: 7F:1B: 7A:C2	-68.12	2.365

4.3. Experimental Result

For this experiment, we proceed by comparing the accuracy and the processing time between the typical fingerprinting method and the proposed approach. We average results after performing the test for eight times. Furthermore, our experiment included data of our indoor environment in order to evaluate the influence of the locating data on the accuracy and the speed of execution of the locating process.

Based on the locating information we collect from the ESP8266 module configured as a tag, we determine the location according to the proposed process. For the experiment, we divide the indoor environment into twelve grids, and we determine six positions for the test.

Considering the execution time, the existing fingerprinting method takes longer processing time if the number of locating data increases. Hence, our proposed method proceeds locating through a filtering of RSS values and the trilateration approach. Consequently, the number of locating data at the current place increases and takes longer to obtain the learning location. Our filtering is not influenced by the quantity of locating data for places. Considering the accuracy of location, the existing fingerprinting method performs using all the available data in the environment, the locating accuracy then decreases due to the consideration of signals with similar RSS as the same signal. Contrary, although the presence of signals with similar intensity our method with its filtering maintain the locating accuracy.

Lastly, Figure 10 and 11 present respectively the results of the experiment for the locating accuracy and the execution time. While the speed of execution increases with the increase of the number of locating data regarding the time of execution, no significant variation is noticed with the filtering introduced by our method. Thus, we are not concerned by this because we do not increase the locating data. In fact, we performed the locating process with an excellent accuracy value which is about 98% with the typical fingerprinting method has about 91%.

In this experiment, we do not consider the noise and other locating signal when measuring RSS of the Wi-Fi signal. RSS value is stable and consistent due to the elimination of part effects of Wi-Fi signal fluctuations therefore the exact location is obtained without difficulties.

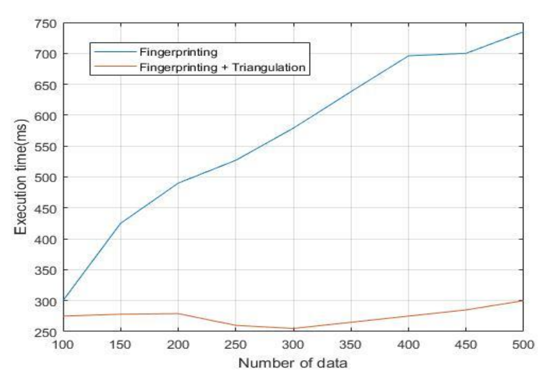


Fig.10 Influence of number of data on execution speed

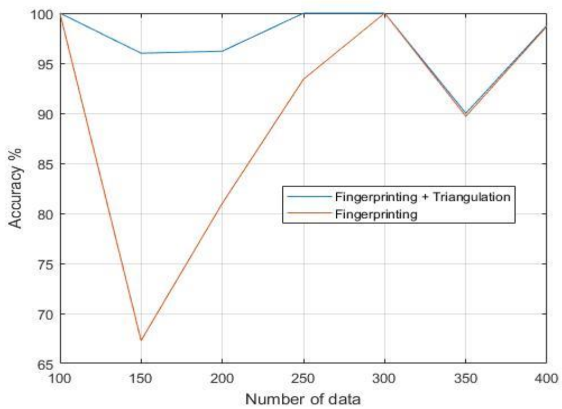


Fig. 11 Influence of number of data on accuracy

5. Conclusion

For this work, we focus on the improvement and implementation of the current algorithm to enhance accuracy and effectiveness of the locating system. We propose a combination of two approaches fingerprinting and trilateration. We divided the system into steps to collect the locating data through an ESP8266 module, building radio-maps by dividing our indoor environment into grids with same sizes. At the first stage of the locating process, we use processed RSS signal to reduce errors in the offline acquisition and achieve better fingerprinting radio-maps. Based on the highest number of matches at the second stage, we apply trilateration to complement an accurate locating process. Our algorithm has an improved the execution time so as accuracy (about 98%) by using filtering operations during the locating process.
Many cases still need to be tested to finalize the system in order to enhance user's experience. In fact, we can significantly improve the fingerprinting approach by incorporating database correlation algorithm. Largely, trilateration method has the inability to determine common intersection point from the three distances simultaneously. Finally, our proposed work provides a foundation of a locating system with a great spatial coverage.

Perspectives

Besides accuracy, reducing cost remains an important issue as well. Our future works will focus on the construction of an automatic database with a K neighbors or probabilistic algorithms also database maintain without the interference of human and take into consideration interferences caused by obstacles in indoor environment.

References

[1] Kaplan, E.D.; Hegarty, C. Understanding GPS: Principles and Applications, 2nd ed.; Artech House: Norwood, MA, USA, 2006.

[2] J. Mhamdi and S. El Abkari, "Contriving an RFID system for Alzheimer patients tracking," *2015 Third International Workshop on RFID And Adaptive Wireless Sensor Networks (RAWSN)*, Agadir, 2015, pp. 23-28.

[3] S. El Abkari, A. Jilbab and J. El Mhamdi, "Real time positioning over WSN and RFID network integration," *2018 4th International Conference on Advanced Technologies for Signal and Image Processing (ATSIP)*, Sousse, 2018, pp. 1-5.

[4] J. Blumenthal, R. Grossmann, F. Golatowski and D. Timmermann, "Weighted Centroid Localization in Zigbee-based Sensor Networks," *2007 IEEE International Symposium on Intelligent Signal Processing*, Alcala de Henares, 2007, pp. 1-6.

[5] A.K. M. M. Hossain and W. Soh, "A Comprehensive Study of Bluetooth Signal Parameters for Localization," *2007 IEEE 18th International Symposium on Personal, Indoor and Mobile Radio Communications*, Athens, 2007, pp. 1-5.

[6] J. Biswas and M. Veloso, "WiFi localization and navigation for autonomous indoor mobile robots," *2010 IEEE International Conference on Robotics and Automation*, Anchorage, AK, 2010, pp. 4379-4384.

[7] D. Capriglione, L. Ferrigno, E. D'Orazio, V. Paciello and A. Pietrosanto,"Reliability analysis of RSSI for localization in small scale WSNs",proceedings of IEEE International Instrumentation and MeasurementTechnology Conference (I2MTC) 2012, pp. 2149

[8] L. Xu, F. Wang, Y. Jiang, L. Zhang, C. Fengl and N. Baol, Variation ofReceived Signal Strength in Wireless Sensor Network Proc. of 2011 3rdInternational Conference on Advanced Computer Control (ICACC2011), pp. 151-154

[9] Montaser A, Moselhi O (2014) RFID indoor location identification for construction projects. Autom Constr 39:167–179

[10] Chen G, Meng X, Wang Y, Zhang Y, Tian P, Yang H (2015) Integrated WiFi/PDR/Smartphone using an unscented kalman filter algorithm for 3D indoor localization. Sensors 15(9):24595–24614

[11] Bolliger Philipp Lukas, "Robust Indoor Positioning through Adaptive Collaborative Labeling of Location Fingerprints", PhD‟s thesis, ETH Zurich, http://e-collection.library.ethz.ch/eserv/eth:5267/eth-5267-02.pdf

[12] Haenselmann Thomas, 2005. "Lecture on Sensor Networks", University of Mannheim, Germany. http://www.slideshare.net/netfet/localization-presentation (13 Jan. 2012).

[13] Navarro Eduardo, 2011. "Wi-Fi Localization Using RSSI Fingerprinting", California Polytechnic State University, United States of America. http://digitalcommons.calpoly.edu/cpesp/17/ (17 Aug. 2011).

[14] Son S, Park Y, Kim B, Baek Y (2013) Wi-Fi fingerprint location estimation system based on reliability. J Korean Inst Commun Inf Sci 38(6):531–539

[15] Wei Ting, 2010. “Indoor localization method comparison: Fingerprinting and Tritrilateration algorithm”, University of Saskatchewan, Canada. http://rose.geog.mcgill.ca/ski/system/files/fm/2011/Wei.pdf (2 June, 2011)