Preliminary Analysis of Organic Wireless Positioning System in an Indoor Environment

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Abstract. The massive deployment of wireless infrastructure especially in the trending 4th Industrial Revolution (IR4.0) has opened the opportunity for wireless-based positioning and localization. The works on wireless positioning system revolves on two techniques, the geometrical technique employing either triangulation or trilateration, and mapping technique employing signal fingerprint method. The later is more favoured since the accuracy was superior to geometrical technique. However, the signal fingerprint method required enormous efforts in order to record and stored the signal fingerprint. This paper investigates the new approach in constructing the signal fingerprint using organic approach. The signal is recorded using the developed apps, and then the user sends the signal data into the cloud. The organic fingerprinting data were compared to the conventional fingerprinting. The preliminary results show promising accuracy in the experimented indoor environment.

1. Introduction
Positioning of an object of interest in an indoor environment typically uses integrated sensors on the objects, for instance the proximity sensors and sometime visual sensors to locally map the targeted indoor environment [1]. From the information of these sensors, the position of the object of interest can be computed, recently at great accuracies. The other alternative of indoor positioning could be realized by manipulating wireless signals detectable by the object of interest. The later positioning approach are more cost facilitative with ubiquitous wireless infrastructure deployment in recent years [2][3]. It is cheaper solution compared to integrated sensors and could be extended into numerous other applications.

The indoor positioning technique employing wireless solution such as WiFi can be categorized by two different approaches, the geometrical method, and fingerprinting technique. The geometrical method uses mathematical computation for example the triangulation and trilateration technique. This method works by converting the wireless signal parameter i.e. the Received Signal Strength (RSS) into distance metric, usually by suitable signal propagation models. However, there are no generic signal propagation models that suit any environment, thus limit the practicality of the triangulation and trilateration technique. Often, the accuracy studies of triangulation and trilateration method were unacceptable [4][5].
The fingerprinting technique on the other hand, works by comparing the present RSS signal with the constructed radio map (also known as the signal fingerprint) beforehand. This technique has been with proven significant accuracy by many [4][6]. The use of more complex fingerprinting algorithm [5], and state-of-the-art filtering technique such as Kalman Filter has further increased the positioning accuracy [6][7]. Figure 1 depicts the fundamental difference between the triangulation/trilateration and fingerprinting technique.

![Figure 1. Wireless positioning system, (a) triangulation and trilateration technique and (b) signal fingerprinting technique.](image)

The principal problem with the fingerprinting method is the database creation. In our earlier works, a considerable amount of efforts was required to record all the signal data at all required locations which has led to the development of automatic database creation by mean of interpolation [8][9]. However, such method although significantly improve positioning accuracy is also prone to other errors for instance when the arrangement of the environment has changed. Thus, the database must be re-made. This issue is troublesome and not sustainable for longer time, and not suitable particularly in the fourth industrial revolution (IR4.0) application.

Hence, a new approach of database creation for signal fingerprinting is proposed. This new method takes anonymous participants to voluntarily upload their obtained data to the database stored in the online cloud. This method is called organic fingerprinting method or crowdsourcing fingerprinting [10]. This paper explored the potentials of organic fingerprinting by comparing the initial result between the conventional fingerprinting technique and the proposed organic fingerprinting technique. To realize the organic fingerprinting technique, we developed a simple android apps, and used the signal recorded by the apps to update our database regularly. In the same time, the signal data acquisition using conventional data recording software is also conducted. Finally, the accuracy between the two are compared by using the KNN matching algorithm.

2. Methodology

2.1. Overview
In order to conduct the experiment and data collection, the environment must be firstly identified. The environment must be indoor, easy access, less people wandering around to minimize the signal fluctuations, as well as large enough to cover a there WiFi Access Point (AP). The Mechatronic System Design (MSD) Laboratory located at School of Mechatronic Engineering, Universiti Malaysia Perlis satisfies all the requirement.
The Android apps were later developed for organic data collection. A user is asked to stay at predetermined locations, and then recorded the data before uploading them into an excel file stored in the cloud. On the other hand, the conventional data collection were recorded using Homedale® software [11]. The WiFi RSS data are collected over 2 minutes time with 2 seconds interval. Finally, the average of RSS were calculated for the fingerprinting database for both conventional and organic method for all reference locations.

The K-Nearest Neighbour (KNN) matching method was used to evaluate the positioning accuracy of both methods. Euclidian distance between the test data and database are computed. Then, the location is the one that has the most minimum value among the error matrix of the Euclidean distance between the test data and database.

2.2. Indoor Environment

Figure 2 shows the 2-dimensional layout of the experimented indoor environment. The experiments were conducted at the MSD Lab. The lab area is 171×90 metre with typical arrangement of teaching facilities such as tables, chairs and projector. These facilities are marked as boxes for easier visualization. The lab was unoccupied during data collection periods, and thus minimizing signal fluctuation due to human movements.

A total of 24 locations are identified as ‘reference’ locations and marked with ‘×’ symbol, and three WiFi are used and set up as prior database. Therefore, the database vector matrix is 24×5 arranged such as way that depicted in equation (1),

\[ \mathbf{d_{b_{c/o}}} = [x_n \ y_n \ s_{AP1} \ s_{AP2} \ s_{AP3}] \]

where parameter \( \mathbf{d_{b_{c/o}}} \) is the database for both conventional and organic database, \( x \) and \( y \) represent the Cartesian coordinates at \( n \) reference location, \( s_{AP1-3} \) is the average of RSS from AP1, AP2 and AP3 at \( n \) location, respectively. As a concern, more WiFi AP is advisable for larger environments, however in our case, these three WiFi AP are enough to serve the purposed.

![Diagram](image.png)

**Figure 2.** Layout of Mechatronic System Design (MSD) Lab at Universiti Malaysia Perlis, the locations marked with ‘×’ were the reference locations. Also shown the placement of the three WiFi Access Points.
2.3. Android Apps Development
The Android apps is developed in the Android Studio Ver 3.2.1 software. The WiFi connectivity is managed by a dedicated API i.e. Wifimanager at a very low level. The information that can be accessed includes network link and speed, IP address, negotiation state and many other information. With proper programming, permission and syntax, the API can scan, add, save, terminate as well as initiate WiFi connections. The developed Android apps run on Android 6.0 and above since the lower Android version has connectivity problem with WiFi. Figure 3 shows the interface of the developed Android apps.

![Figure 3. (a) Interface of developed Android Apps running on Android 6.0 and above, (b) List of detectable WiFi Access Points and their wireless properties uploadable into the cloud storage.](image)

2.4. Data Collection
The locations marked with ‘×’ as depicted in Figure 2 were the reference locations. These locations were in fact the locations where the user stays for data collection. For the conventional database collection, the user recorded the WiFi data i.e. WiFi RSS for 2 minutes in the interval of 2 seconds using the Homedale® software installed in a laptop. With 24 locations, the data collection took about one hour to complete including initial setting time. For organic database, the user was asked to install the developed Android apps to his smartphone, then he/she can immediately scan for WiFi and send the required data into the cloud storage (Gdrive). In term of ease of operation, the use of Android apps is simpler and user-friendly. Moreover, the data collection can be extended for multiple users at the same time. Hence, it is convenience.

To compare the positioning accuracy between both approaches, two test locations are taken into consideration. The first location is $L(0,0)$. It is near to AP2, moderate to AP1 and far enough from AP3. Hence, the signal should be linearly separable. The second test location on the other had is chosen at $L(3,4)$ as it bears almost the same distance from all three APs. Figure 4 and 5 shows the signal from these two locations. It can be seen from Figure 4 that the signal obtained from AP2 is much stronger compared to other two APs. Figure 5 shows the WiFi RSS from test location $L(3,4)$ where it shows chaotic signal from the three APs. The complex behavior of WiFi signal such as this example shows the challenges faced in this research topic, and as of our knowledge, there is no common solution to solve this signal fluctuations yet.
3. Results and Discussion

The K-Nearest Neighbour (KNN) technique is used to compute the estimated position. In this work, the most nearest neighbour is applied, i.e. K is set to 1. The metric that is used to evaluate the neighbour is Euclidean distance. Then the minimum value of the metric is reflected back to database matrix taking corresponding \((x_n, y_n)\) as the estimated position. Equation (2) and (3) explain this technique.

\[
\arg \min_{x \in \mathbb{R}^2} e_i = \sum_{i=1}^{n} \sqrt{(s_i - s_{AP1})^2 + (s_{i2} - s_{AP2})^2 + (s_{i3} - s_{AP3})^2},
\]

\[
\% \text{acc} = \frac{(\hat{L} - L)}{L} \times 100\%
\]

where \(e_i\) is the error between the test signal \(s_i\) and signal in the database \(s_{AP1-3}\) at iteration \(i\). The iteration is computed for all the data in the database of size \(n\), respectively with \(n\) reference locations. The parameter \(% \text{acc}\) represent the positioning accuracy, by comparing the estimated location \(\hat{L}\) and the known exact location \(L\).
For simplicity, two test locations as described previously are presented in this paper. The first location is taken at \(L(0,0)\) which is closer to AP2. The data are linearly separable, and thus matching with the database is fair. The conventional fingerprinting results in 53.33% positioning accuracy while the organic fingerprinting is at 93.33% accuracy. This tremendous difference between the two databases is expected since the organic database creation is sustainable as the user uploaded the data in the cloud storage more recently compared to the conventional database. The operation is somewhat easier to the user to upload their data.

At the test location 2 i.e. location \(L(3,4)\) where the signal has roughly similar data between each APs due to similar distance from the APs result in poor accuracy. The conventional fingerprinting has only 23.33% accuracy while the organic fingerprinting has 33.33%. The issue of wireless signal fluctuations and instability remained a tough challenge for the researchers in this field.

Table 1 summarises the result of accuracy study between the conventional and organic fingerprinting. Comparing between the two databases, the organic fingerprinting outdone the conventional database at both test locations. This experiment is simple and principle for both signal fingerprinting techniques. Since the organic fingerprinting is proven better than conventional technique, the research will continue to explore relevant algorithms for the indoor positioning system.

| Test Location | Conventional Database | Organic Database |
|---------------|-----------------------|------------------|
| \(L(0,0)\)    | 53.33%                | 93.33%           |
| \(L(3,4)\)    | 23.33%                | 33.33%           |

4. Conclusion
This paper studies the accuracy between the conventional database and organic database of the fingerprinting technique for wireless positioning system. Three WiFi Access Point and systematic reference locations for data collection of both databases has been initialized. The conventional database is made by collecting and recording the wireless data using computer's software, while the organic database is made and collecting and storing the wireless data using the developed Android apps, and efficiently uploaded the data into cloud storage. Two test locations have been taken for consideration and finally the position is computed by using the K-Nearest Neighbour algorithm by setting K=1. It has been observed that at both test locations, organic fingerprinting outperforms the conventional fingerprinting. This is due to the fact that the organic database has primary advantage over conventional database which is the ease of operation as well as sustainable to environment arrangement changes. Hence, better quality.

In the future, an enhancement of Android apps is to be made. A more user-friendly apps with better navigational operation will be considered. Furthermore, a more advanced positioning algorithm will be also investigated, especially to suit the 4th industrial revolution.

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