Hybrid Technique for Indoor Positioning System based on Wi-Fi Received Signal Strength Indication

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***Abstract*—An indoor positioning system based on Receive Signal Strength Indication(RSSI) from wireless access equipment has become very popular in recent years. This system is very useful in many applications such as tracking service for older people or customer inside living communities, mobile robot localization, logistics systems etc. While outdoor environment using Global Navigation Satellite System(GNSS) and cellular network work well and are widespread used for navigation. However, there is a problem with signal propagation from satellites or cell site. They cannot be used effectively inside complex building areas or even in an urban environment. In general, the widely used method for indoor environment positioning based on Wi-Fi consists with two main categories, which are trilateration technique and location fingerprint technique(LF). It is already known that the explicit positioning performance of trilateration technique is more sensitive to noise effect than LF technique. Nevertheless, the accuracy of LF technique depends on training data set and it does not work well when environment changes. In this article, we propose the hybrid algorithm, the combination of the advantages of both systems, which is able to improve the accuracy stability and robustness. The performance of this algorithm is evaluated by the experimental results, which shows that our proposed scheme can achieve a certain level of positioning system accuracy.**

Keywords*— Indoor Positioning System; RSSI; Wi-Fi trilateration technique; Location Fingerprint technique; Extended Kalman Filter(EKF); K-Nearest Neighbor(K-NN);

I. Introduction

Indoor positioning by using wireless radio signal technology 2.4GHz is based on IEEE 802.11 a/b/g/n standards protocol, also named Wi-Fi. The registration for using this system is not required and does not require new infrastructure, moreover, the devices equipped with Wi-Fi technology can be reused. The Wi-Fi signal is not only used for communication but it is also indirectly proportional to the distance from Wi-Fi Access Points(Wi-Fi APs). It is able to calculate the position, for all that, the mathematical model of wireless radio signal is a non-linear function and the variations of the environment affect the signal. There are significant trends for many researchers; both in academia institution and industry. They are still exploring the possibility of high accuracy, precision and robustness.

For the related work, the RADAR is the first indoor positioning system based on Wi-Fi signal strength developed by Microsoft Research's laboratory using LF technique[53]. The multiple base stations are installed with signal overlapping converge in the operation area. This system has used template matching algorithm to compare the real time user RSSI with the set of pre-survey RSSI database system to identify the users position. In recent years, indoor positioning system [15] not only the qualification for Wi-Fi signal is used, but infra-red(IR) technology is also used to indicate the location as well. The Active Badge System developed by AT&T Cambridge has used diffuse IR technology based system, which is a network sensors working together with IR Code every 15 seconds and using the information based on triangulate theory. Anyway, short-range transmission and line-of-sight (LOS) of IR technology are limited and cannot be applied in large and complex buildings. The LANDMARC indoor location sensing uses active Radio Frequency IDentication(RFID) by a well-known system named SpotON RFID sensing [50]. This system equips with RFID tags, RFID reader and the signal communication between these two. This system is based on the radio signal strength information from each tag to reader, and then uses a classifier algorithm to estimate the user position. The Cricket Location Support System by MIT Laboratory for Computer Science has used radio frequency (RF) and ultra-sonic technology based on Time-of-Fight(TOF)[23] to measure time difference of pulses signal collection between radio frequency and ultrasonic in order to provide location information. Nevertheless, the cost is exorbitant and it is unaffordable to most users. The indoor positioning systems mentioned above are very popular, while the applications depend on cost-effective and acceptable tolerances. The XIHE indoor positioning system developed by Chinese researcher based on mobile communication network using the Turbo Code OFDM technique [44] based on TOF technique can provide indoor and outdoor seamlessly service with the integration signal of BeiDou satellite navigation system.

The Wi-Fi trilateration technique [4],[25],[31] uses geometric properties of triangles to estimate the user location. It can be divided into three sub-categories, which are angulation, lateration and RSSI-based in order to measure distance from multiple Wi-Fi APs with mobile devices. See in [13] has showed the angulations of arrival(AOA) technique locate user position by measuring angles relative to multiple Wi-Fi APs (at least two stations). However, the accuracy is inversely with distance. In case of lateration techniques [13], the signal time of arrival (TOA) and Round-trip time of flight(RTOF) have been used to estimate user position by time difference. The TOA method [15] is more accurate because the multi-

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path effect in indoor situation will be reduced. Nonetheless, it is complicated to implement. The RSSI-based using the attenuation of emitted signal strength defines by propagation loss equation [46] to calculate the pseudo-range between transmitter and receiver. The advantages of this technique are low cost and suitable for using with a mobile rescue robot because the database system is not required, and there is no switching position problem.

Moreover, the LF technique [14],[36],[38],[41] uses information of survey RSSI values. It depends on sample location coordinates to generate radio frequency map called Fingerprint Map for training/labeling databases then classify by using template matching algorithms. For example, the K-Nearest Neighbor(K-NN) algorithm is the deterministic process that has been used in the RADAR system, The Microsoft Company has proposed a selection of the closest K-neighbors around the mobile device to estimate user position by calculating Euclidean distance between the fingerprint database system and the real-time RSSI values then determine the location. The Maximum likelihood (ML) is based on probabilistic theory with analysis histogram method; however, the weight ML has a better performance than traditional ML. The Support Vector Regression(SVR) as well as, Artificial Neural Network(ANN)[17],[28] are widely used in non-linear or unknown characteristics transfer function system. For example, Rey-Chue Hwang et al.[51], has purposed the ZigBee wireless sensor network by ANN to locate the high accuracy position when the signal strengths are unstable and they found that the accuracy of polar form is better than rectangular form, besides, ANN can approximate the parameter in function of radio signal power delay profile and then calculate the user location, which has been presented by Szumny et al.[28] Nevertheless, ANN is not commonly used in the indoor position system because of computational complexity. The advantages of LF technique are simple to implement and more robust in case of the unchanged infrastructure, because noise is included in the survey map. Besides, the accelerometer, gyroscopes sensor, digital magnetic compass and digital camera are widely used to integrate with both techniques of Wi-Fi RSSI-based because they are equipped in the smart phone. For example, W.Xiao et al. [47] has combined the inertial measurement unit(IMU), which consists of 9 degrees of freedom, with LF technique, which is fused by the Kalman Filter. This method can reduce the positioning error in the LF technique because dynamic change in environment is not affect with inertial sensor. Hattori k. et al. [52] has purposed the hybrid information Wi-Fi and build-in camera on smart-phone to locate the position. This approach has many marker figures(QR code) stick on the floor. They can locate the relative position and combine with absolute position of user based on centroid method. The result showed that it can reduce ambiguous point in real environment.

In this article, we propose a novel approach to combine the advantage of both techniques, which are Wi-Fi trilateration technique using RSSI-based and LF technique based on Extended Kalman Filter(EKF). We will show how to integrate those two methods. The contributions of this work are three fold. First, the positioning accuracy were improved. Second, The system has more robustness in the sudden change dynamics and environment noise. Third, the approximate positioning is continuous. The rest of this paper is organized as follows. Section II outlines system model and expressions, and give the detailed procedure of our approach followed by the problem formulation in Section III. and simulation results are provided in Section IV. Finally, Section V concludes the paper.

II. System Modeling

From the previous section, we introduced the indoor position techniques, both LF method and trilateration method. The LF technique provides more simplicity mathematical model [19] than trilateration method because it does not include the kinematics model and tracking algorithm.

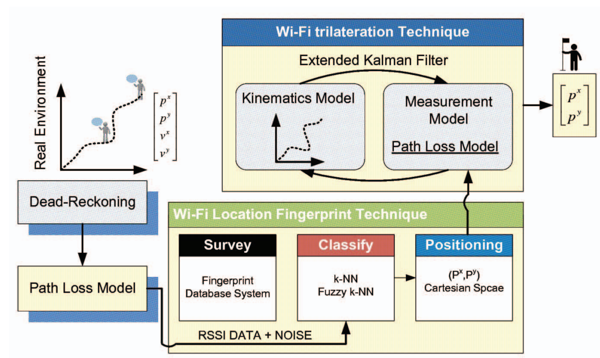


Fig. 1: The Hybrid Architecture of Indoor Position System

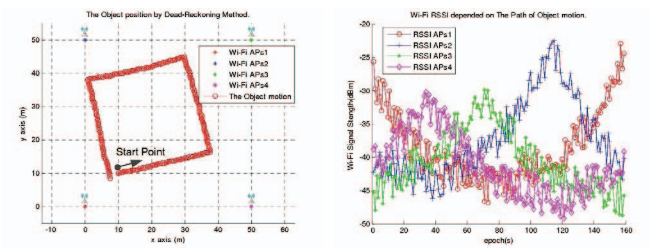
From Fig.1. In our work, we simulate both methods of indoor positioning techniques. Firstly, the algorithm generates the RSSI values based on propagation loss model. Wi-Fi radio signal propagation model can be used to estimate the human position in target areas where the signal is distributed by measuring the RSSI value with the path loss model, because the characteristics of the signal decreases with the distance between transmitter and receiver (see Fig 2b). This can be modeled by using the function of logarithm-distance path loss model as follows:

$$P_{rx}(dB) = P_{d_o}(dBm) - 10\ell log_{10}(\frac{R}{R_o}) - wallLoss. \quad (1)$$

Here P_{rx} is the power receiver in decibel, P_{d_o} is the received power at the reference distance or initial RSSI value at one-meter distance in decibel, ℓ is path loss exponent, it can be varied from 2 to 6 depending on the propagation environment, $R_o and R$ are breakpoint distance and distance between transmitter and receiver in meter respectively. Finally, $wallLoss$ is the sum of the losses introduced by each wall. This factor depends on the building layout, construction material, numerous reflecting surfaces, local based infrastructures and object movement[2].

$$\begin{aligned} x_i &= x_{i-1} + v_i \Delta t cos(\theta_i) \\ y_i &= y_{i-1} + v_i \Delta t sin(\theta_i) \end{aligned} \quad (2)$$

where x_i, y_i are the current object position and x_{i-1}, y_{i-1} are the previous position reference in the Cartesian coordinate system, which is the human orientation. The other variables v_i and Δt are the velocity and sampling period respectively. The DR method generates path of object motion in 2D Cartesian space. It consists with three types, which are straight line, circular and quadrilateral-path. In case of the LF technique, we observed that the static infrastructure noises are included in the fingerprint map at that time. Therefore, its advantages can improve the trilateration method with a positioning, rather than continuously without the need to add the inertial sensing or others. The novel hybrid algorithm, which is the integration of advantages of both trilateration and LF technique, is useful for reducing the $walLose$ disturbance as well as the quantization error from rang [39] of calibration points.



(a) The Path of object motion (b) The Wi-Fi Signal Propagation

Fig. 2: The Characteristics of Wi-Fi RSSI according to Path of object motion.

From Fig 2. shows that, the path of object motion in simulation area generated by DR Method. The red-circle line represents the quadrilateral pattern The x and y axis are the reference direction in Cartesian Space in meter unit. The Wi-Fi Signal Propagation from each Wi-Fi APs in Fig.2(b) are dependent on the distance. We can observe the increase or decrease of signal strength variable with path of object motion as shown in Fig.2(a)

III. Hybrid Indoor Positioning Technique

A. The Location Fingerprint Technique

The fingerprint indoor positioning system requires a combination of a radio frequency map geographical coordinate. 2-Dimension Cartesian Space and RSSI value which received by several Wi-Fi APs (see Fig 3.),it consists of two phase: offline training step and online positioning step.

Firstly, offline training step is a survey of IEEE 802.11 a/b/g/n Wi-Fi signal strength and collects the physical location for a training database. Second, online positioning step is a mobile device measuring RSSI value through the survey area ($50 \times 50m^2$) and the location estimated by matching the similarity to the training database. The location fingerprint technique requires a reasonable number of reference devices and a stable environment prior to calibration because the result is sensitive to environment change, such as moving objects in the building that it could affect the signal properties. Hence, it is necessary to improve the training database.

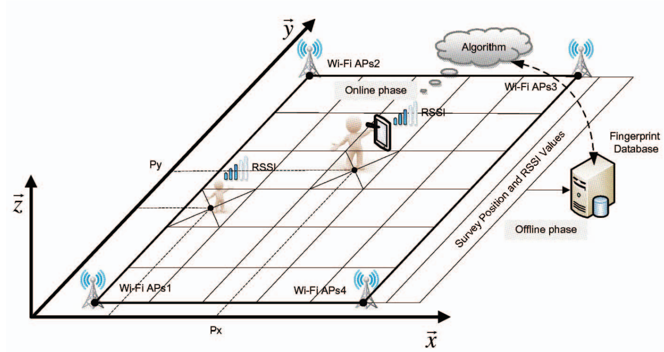


Fig. 3: The Location Fingerprint (LF) Technique

The simulation model is able to use radio signal propagation model (1) to create a signal strength map with cut-off areas every 0.5 m. That means simulating signal propagation builds a signal strength map.(see table I.) It will rely on propagation-based positioning systems techniques.

TABLE I: The training database of simulation area $50 \times 50m^2$

Label	Position(m)		Wi-Fi RSSI values(dBm)			
	Px	Py	APs#1	APs#2	APs#3	APs#4
1	0.5	0.5	-28.5444	-98.0028	-116.1865	-97.9270
2	0.5	2.5	-8.5020	-96.1747	-115.2744	-97.3915
3	0.5	4.5	-31.0888	-95.3758	-108.3236	-97.5877
4	0.5	6.5	-39.4552	-95.6074	-108.2118	-103.3934
5	0.5	8.5	-51.4846	-101.3113	-114.0727	-99.2605
6	0.5	10.5	-56.1878	-96.4758	-106.7949	-99.7674
7	0.5	12.5	-58.7022	-91.1860	-111.1025	-101.1894
8	0.5	14.5	-60.6448	-93.6851	-107.4312	-106.055
⋮	⋮	⋮	⋮	⋮	⋮	⋮
623	48.5	44.5	-106.5988	-104.4962	-36.7480	-96.0346
624	48.5	46.5	-113.6203	-105.6766	-27.1309	-96.0279
625	48.5	48.5	-116.6311	-97.6614	-4.5795	-103.2196

1) The K-Nearest Neighbor Algorithm: The widely used basic matching algorithm to find the best classifier, actually perform and non-parametric classification method is the *K*-NN algorithm. In the process of online positioning step, the *K*-NN algorithm was used to search for *K* neighbor closest between classes of training database and measure RSSI point based on Euclidean distance. Before we get into details of the *K*-NN we need to define the minimum distance using Euclidean distance based on Bayesian classifier[21].

Assume that, the first set of data is a offline radio frequency map from each N Wi-Fi APs. Given a location of radio frequency vector $\gamma = \{\gamma_1, \gamma_2 \ldots \gamma_n | \gamma_i \in \Re^n\}$ collected from APs in the fingerprint area. The second set of data contain online RSSI values, $\xi = \{\xi_1, \xi_2 \ldots \xi_N | \xi_j \in \Re^N\}$ from N APs at a particular location and $i = 1, 2 \ldots, n$ is the number of cut-off area. The Euclidean distance d_i between vector γ and ξ is defined as:

$$d_i = |\gamma_i - \xi| = \sqrt{\sum_{i=1}^{n}(\gamma_i - \xi)^2}, \qquad (3)$$

when the Euclidean distance equation is calculates all of elements in the radio frequency map, the vector of distance D is suggested between all radio frequency map vectors γ_i and vector ξ can be calculated as:

$$D = [d_i] = [|\gamma_i - \xi|] = \left[\sqrt{\sum_{i=1}^{n}(\gamma_i - \xi)^2}\right]. \qquad (4)$$

The element of vector of distance D with minimum distance defines the K neighbor closest point to ξ. Its position is recorded within the radio frequency map and location coordinates are considered the estimate user position.

2) The Fuzzy K-Nearest Neighbor: The principle of this algorithm is to assign membership as a function of the Euclidean distance vector from the basic K-NN algorithm and memberships in the probable label. The Fuzzy K-NN algorithms[23] have two main advantages over the basic K-NN algorithms based on crisp set theory. Firstly, while determining the class of the test sample, the algorithm is capable of taking into consideration the ambiguous nature of the neighbors if any. The algorithm has been designed such that these ambiguous neighbors do not play a crucial role in the classification of the sample. The second advantage is that the sample is assigned a membership value in each of the k-classes rather than binary condition. The advantage of such assignment is that these membership values act as strength or confidence with which the test sample belongs to a particular class.

The form of the Fuzzy K-NN classifier adapts to this work using one nearest neighbor classifier. Let $\mu_i(\gamma)$ is the membership of value of point γ_i given by the following expression:

$$\mu_i(\gamma) = \frac{1/\|\gamma_i - \xi\|^{2/(m-1)}}{\sum_{j=1}^{K}(1/\|\gamma_i - \xi\|)^{2/(m-1)}}. \qquad (5)$$

where $j = 1, 2 \ldots, K$ with K is number of nearest neighbors. The fuzzy strength parameter m is used to determine how the heavily the distance is weighted when calculating each neighbor's contribution to the membership value and its parameter is usually chosen as $m \in (1, +\infty)$.

B. Wi-Fi trilateration technique

The principle of Wi-Fi trilateration method based on RSSI requires at least three Wi-Fi APs stations with known set up coordinate. That means if the system has a lot of Wi-Fi APs stations, the accuracy will be improved. The characteristics of signal strength and distance are given by (1) ability to approximate the radian (R_N), after that a circle with an R_N can be drawn around each Wi-Fi transmitter. That means the probability area of position is just only a distance. However they do not know the direction of the target object. A minimum of n+1 Wi-Fi APs stations are needed to provide a position estimation in n-number of dimensions [1]. For example, at least three Wi-Fi APs stations are required for a 2D position estimation. Refer to Fig.4 the Circles intersect means operating area.

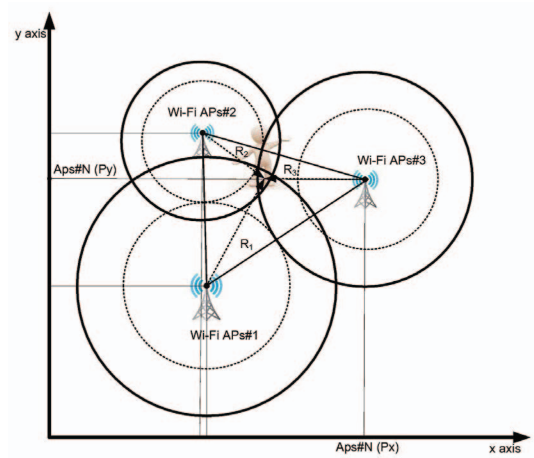


Fig. 4: The Wi-Fi trilateration Technique

Indoor environment radio signal propagation is very unfavorable, which is caused by the followings. Non-Line-of-Sight (N-LOS), effect of multipath propagation with wall, floors and building layout. The dynamics of target object position inside operation area that can be affected with the orientation of receiver antenna, therefore, the signal strength is affected significantly [4]. The position cannot be calculated directly, the mathematical technique such as Least Square Estimation (LSE), Kalman Filter are used to approximate the position. Another way, Inertial Measurement Unit (IMU is used, the objective of inertial data processing can determine the acceleration and orientation in three axis of the mobile device that can reduce the approximation position error.

1) Kinematics model: The system model of human motion in the 2-dimension space, the position and velocity are considered. The functional is a linear state transition matrix (A_k) that is time-invariant system. The system model were designed based on DR method refers to (2). Now, let $x = [\, p^x \;\; p^y \;\; v^x \;\; v^y \,]^T$ denote the position and velocity in and axis respectively. And define the state vector related with (6) as.

$$x_{k+1} = A_k x_k + w_k, \qquad \forall k \in \mathbb{Z}^+, \qquad (6)$$

where

$$A_k = \begin{bmatrix} 1 & 0 & T_k & 0 \\ 0 & 1 & 0 & T_k \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}.$$

Here, T_k is the non-uniform sampling period depending on sampling k

2) Measurement Model: The radio signal propagation is a non-linear system by the function of logarithm. The observation vectors can approximate Euclidean distance between the target position and the set up position from multiple Wi-Fi APs(R_N). In our work, four Wi-Fi APs are installed at the corner of operation area. The non-linear measurement function $h(\cdot)$ and The Jacobian matrix ($H^{[1]}$) of first order partial derivative of $h(\cdot)$ are used to approximate states variable. A novel approach; hybrid technique using the trilateration technique as the main function, because the estimated position is more continuously than LF technique. Therefore, the hybrid algorithm is applied to be the main function of our indoor positioning system and using the estimated position from the LF technique are including in hybrid observation vector y_k. So the hybrid measurement model can be expressed as:

$$y_k = \begin{bmatrix} P_{LF}^x \\ P_{LF}^y \\ y_{P_{rx_1}} \\ \vdots \\ y_{P_{rx_N}} \end{bmatrix} = \begin{bmatrix} P_{LF}^x \\ P_{LF}^y \\ P_{R_o} - 10\ell log_{10}(\dfrac{R_1}{R_o}) \\ \vdots \\ P_{R_o} - 10\ell log_{10}(\dfrac{R_N}{R_o}) \end{bmatrix}. \tag{7}$$

where P_{LF}^x and P_{LF}^y are the estimated position in Cartesian coordinate system from the LF technique respectively.

The extended version of Kalman filter (KF) is to fuse the information from each Wi-Fi APs. The property of the KF is a recursive process of minimum mean-square (RMMS) state filter. The classical-KF is based on linear system and a set of equations that determines a method to estimate the state of a system in discrete-time domain, which consists with two main steps: the prediction state equation and measurement update. In case of Wi-Fi trilateration technique based on RSSI, the measurement model refer to (1) is non-linear system can be linearized by Taylor series expansions. The equations are given as follow: Now considering the following general non-linear dynamics system:

$$x_{k+1} = f_k(x_k, k) + w_k;$$
$$y_k = h_k(x_k) + v_k,$$

In addition, w_k and v_k are system and measurement noise. Those noises are assumed to be white Gaussian noise with known covariance matrix as $E\left[w_k \cdot w_k^T\right] = Q_k$ and $E\left[v_k \cdot v_k^T\right] = R_k$. Hence $E\left[\cdot\right]$ is the mathematics expectation. In practices, that noise covariance serve as tuning parameters of the filter and could be adjusted based on empirical experiment. Linear first order approximation are defined as following Jacobian matrix: $\Phi^{[1]}(\hat{x}, k) \approx \frac{\partial f(x,k)}{\partial x}|_{x=\hat{x}_k}, H^{[1]}(\hat{x}, k) \approx \frac{\partial h(x,k)}{\partial x}|_{x=\hat{x}_k}$. The system prediction and measurement correction of EKF are summarized as follows:

1^{st} Step: System Prediction$^{(-)}$

$$\hat{x}_k^- = f(\hat{x}_k, k);$$
$$P_k^- = \Phi_{k-1} P_{k-1}^+ \Phi_{k-1}^T + Q_k;$$

2^{nd} Step: Measurement Correction$^{(+)}$

$$K_k = P_k^- H_k^T (H_k P_k^- H_k^T + R_k)^{-1};$$
$$I_k = y_k + H_k \hat{x}_k^-;$$
$$\hat{x}_k = \hat{x}_k^- + K_k I_k;$$
$$P_k = P_k^- - K_k H_k P_k^-;$$

where K_k is optimal Kalman gain, the innovation between actual and predicted measurement is I_{k+1}. And, P_k is error covariance matrix.

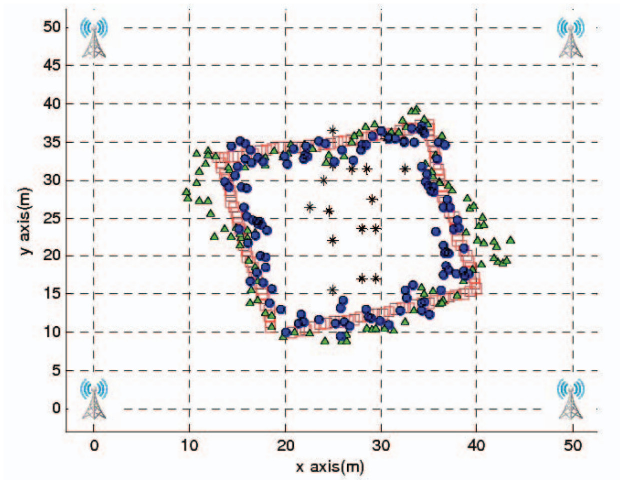
IV. Experimental Result

In this section, we conducted the simulation environment using the DR method to generate the path of object motion [26],[27] in 2D Cartesian coordinate system. We assumed that each Wi-Fi APs signals are fully covered the whole area. The positioning performance consists with accuracy and robustness of the proposed systems; they are compared with the three types of indoor positioning technique, which are the LF technique, EKF-propagation based and Hybrid-EKF method. The process of simulation as follow: Firstly, the simulation parameters are set up and the size of symmetric simulation area is 2,500 m^2, the Wi-Fi APs with four stations are set up at the Conner of symmetric area. The coordinates x and y directions of the four Wi-Fi APs are $APs\#1(0,0)$, $APs\#2(0,50)$, $APs\#3(50,50)$ and $APs\#4(50,0)$ whereat, generated RSSI value of each Wi-Fi APs were dependent on the position of the object motion, which is the online phase of the LF technique. C.L. Wang et al[46] has described the radio signal straight fairly consists with a variance $\sigma^2 \approx 4.35$ in the office environment over long periods. In this article, we assumed the measurement noise or $wallLose$ is the normal random variable with zero mean and variance $N(0, \sigma^2)$. There are two patterns generated by the DR method, which were used to simulate the path of kinematics model in actuality, circular-path, and quadrilateral-path. The Algorithm starts with the initial condition are shown in table II.

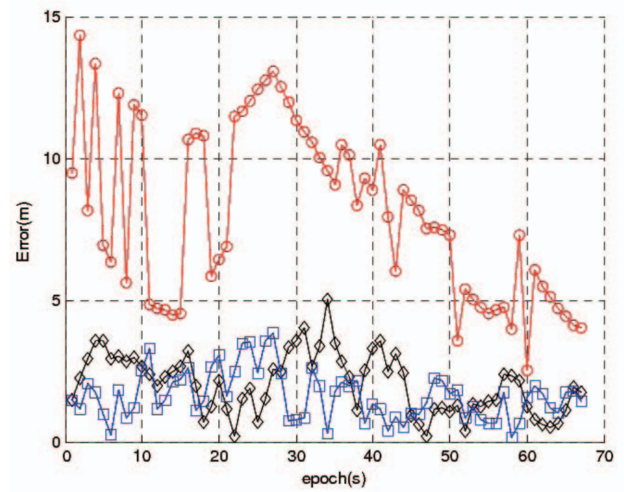
TABLE II: The Summary of User-specified parameters

Name	Symbol	Value
Cut off areas	-	2m
Number of fingerprint labels	-	625
The velocity of the object motion	v	0.75m/sec
Sampling period	Δt	1.0sec
The initial RSSI value at one-meter	P_{d_o}	3.0dBm
The Breakpoint distance	R_o	1m
The path loss exponent	l	3
The number of nearest neighbors	K	5
The fuzzy strength parameter	m	2

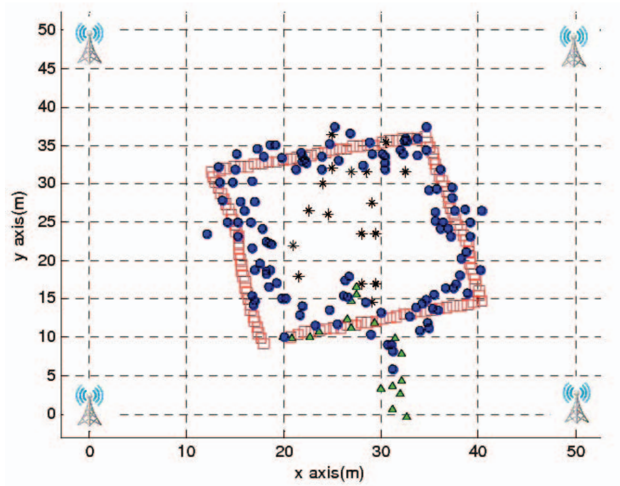
In the part of Wi-Fi trilateration technique based on EKF, the covariance matrices of process noise and measurement noise for the EKF are Q_k and R_k.



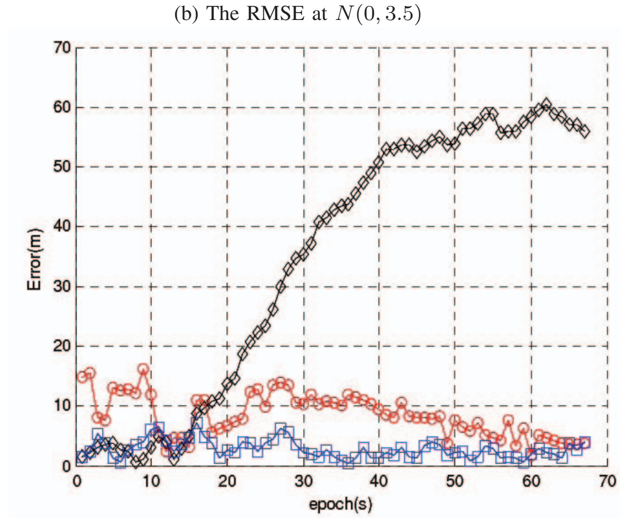
(a) Noise $\approx N(0, 3.5)$



(b) The RMSE at $N(0, 3.5)$



(c) Noise $\approx N(0, 6.5)$



(d) The RMSE at $N(0, 6.5)$

Fig. 5: The simulation result of Indoor Positioning algorithm with Quadrilateral-path including three categories are shown in (a) and (c) consist with LF-Technique (Black-Asterisk), EKF-propagation based (Green-Triangle) and Hybrid-EKF method (Black-circle). They are comparing with Real-circular path with calculating the accuracy by RMSE method shown in (b) and (d) the red-circular-line is LF technique, the black-diamond-line is EKF-propagation based and blue-square-line is Hybrid-EKF method.

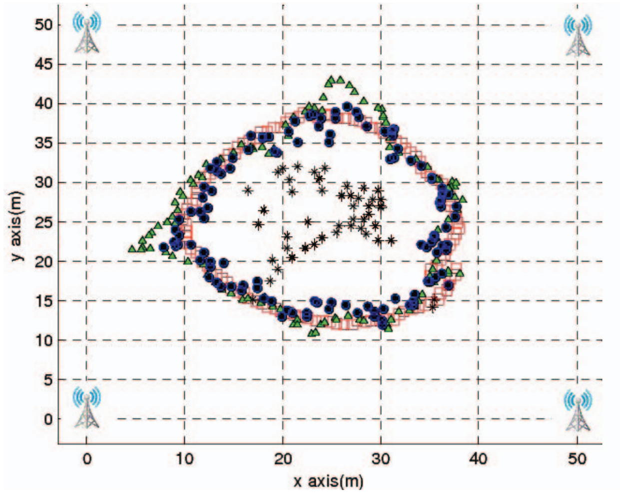
They can be used to adjust the optimal gain depends on the path of object motion and noise level. The parameters used in EKF-propagation based algorithm from beginning are shown as follow:

$$Q_k = diag\{0.1,\ 0.1,\ 1.0,\ 1.0\} \times 10^{1.850},$$
$$R_k = I_{4\times4} \times 10^{4.565}.$$

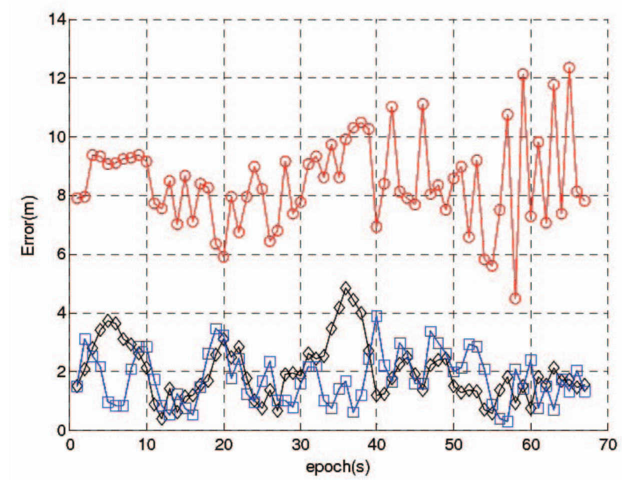
For the Hybrid-EKF method the initial parameter of and as follow:

$$Q_k = diag\{0.1\,0.1\,1.0\,1.0\} \times 10^{1.650},$$
$$R_k = I_{6\times6} \times 10^{3.650}, R(1,1) = 50, R(2,2) = 50.$$

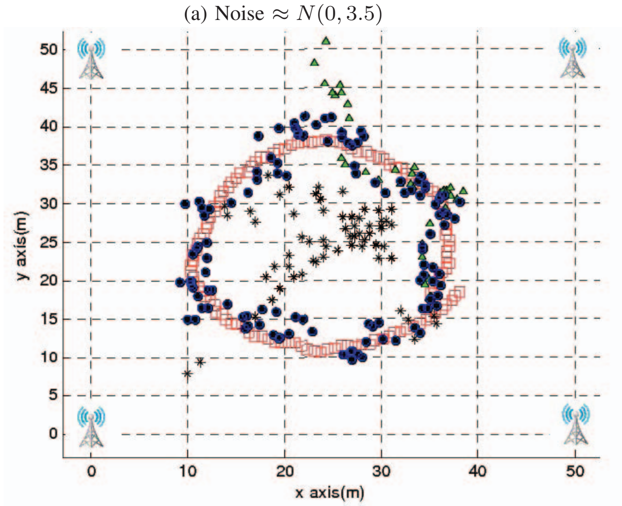
The simulation results are shown in Fig.5. and Fig.6. It can be separated into three categories by considering simple dynamics of object movement scenarios in an office environment. For example, walking along the walk-way to another room, turn left or right to the destination. This track can provide the positioning of mobile robot system. The straight line path (part of quadrilateral-path) or unchanged direction from Fig.5a. and Fig.5c. is the simple dynamics, which means the system model can predict the future state variables easier. From the simulation results, we have tested the robustness of three indoor positioning algorithm by modulating the different level of noise variance including $\sigma^2 = 3.5, 6.5$ and fixed the covariance matrices at the similar values from the beginning. That means it is optimal for the first value of noise variance, which is the estimation of interference in the office environment.The performance of positioning algorithm is still in the acceptable range.



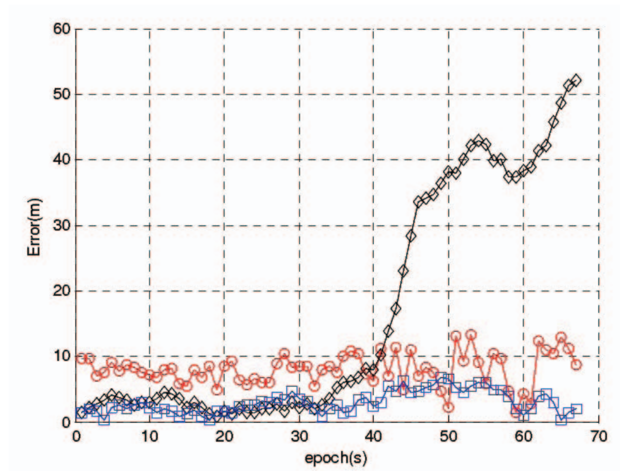
(a) Noise $\approx N(0, 3.5)$



(b) The RMSE at $N(0, 3.5)$



(c) Noise $\approx N(0, 6.5)$



(d) The RMSE at $N(0, 6.5)$

Fig. 6: The simulation result of Indoor Positioning algorithm with Circular-path including three categories are shown in (a) and (c) consist with LF-Technique (Black-Asterisk), EKF-propagation based (Green-Triangle) and Hybrid-EKF method (Black-circle). They are comparing with Real-circular path with calculating the accuracy by RMSE method shown in (b) and (d) the red-circular-line is LF technique, the black-diamond-line is EKF-propagation based and blue-square-line is Hybrid-EKF method

Fig.5b and Fig.5d show that the accuracy of LF technique is lower than another algorithm; nevertheless, it does not have the effect of initial conditions, which is the advantage of this technique. In case of EKF propagation-based, both of covariance matrices should be re-adjusted again to identify the better precise coordinate; however, in fact the dynamics noises change over time from many sources. For example, the temperature in a whole day, the electro-magnetic field from electronics equipment, the multiple people movement. Azadeh et al [3]. has proposed the reflect situation where the user stops along a simple path to interact with another person. Due to the body of the second person causes N-LOS propagation and absorbs radio signal, etc. In case of the reversed direction, the circular path such as human walking from first place to another by following the layout of the building or the path of four wheels-mobile robot system [18]. From Fig.6a. and Fig.6c, the circular track is resemble to the simple motion, which the track is gradually increasing to 180 degree along the turns and then is back to the origin point. The dynamics of circular path is more difficult to predict than straight-line, as a result of the change in direction all the time. For example, in Fig.5c. together with Fig.6c. showed that the simulation result when we modulated the level of noise covariance at 6.5. The LF technique accuracy is decreased but the trend of tracking is not divergent. In the same noise covariance, the EKF-propagation based can be tracked only the beginning period of the track, when comparing with the proposed scheme, the accuracy of Hybrid-EKF method is more robustness than another algorithm. In case of the sudden dynamics such as quadrilateral-path, which are shown in Fig.5a and Fig.5c.

TABLE III: Comparison accuracy of three indoor positioning algorithms with difference level of noise covariance.

Walking Patterns	The Level of noise Covariance	The RMSE (meter)								
		LF Technique			EKF-propagation based			Hybrid-EKF		
		Min	Mean	Max	Min	Mean	Max	Min	Mean	Max
1.Circular Path	3.5	4.9172	8.3510	12.7405	0.2488	1.8220	4.7420	0.2841	1.8079	4.1838
2.Quadrilateral-Path		2.5020	8.0804	14.3509	0.1963	2.0658	5.0163	0.1542	1.6345	3.8388
1.Circular Path	6.5	1.3901	8.0168	13.3112	0.9098	16.6507	51.9987	0.2416	2.9962	6.7566
2.Quadrilateral-Path		1.7813	8.3873	16.0578	0.4959	34.4580	60.4507	0.2440	2.7454	7.1628

This walking pattern is commonly occurred in daily life. For example the layout of the super market, omni-wheel mobile robot or flying robot system and etc. [22], which 90 degree change in direction in a short period, the high precision measurement values were needed to update the system model. In Fig.6d the high-level of noise covariance at 6.5. We observed that the LF technique and Hybrid-EKF can locate the position; however, the EKF-propagation based is divergent at nearing the first turn of the quadrilateral-path.

The position accuracy can be computed as the Root Mean Square Error (RMSE) between the real position and their estimated position . First, to find the horizontal tolerances for the epoch of the track and then calculate the RMSE as follow:

$$RMSE = \sqrt{\frac{1}{L}\sum_{i=1}^{L} \|P_R - P_{es}\|_i^2}. \tag{8}$$

where L is the length of the track. Note that the RSME can consider both bias and variance of the approximate position. The summaries of the three indoor positioning algorithms are shown in table III. We also simulated a non-symmetric Wi-Fi APs set-up position, which means the problem of Dilution of precision (DOP), which depends on the Wi-Fi APs set-up position relative to the user. To evaluate the performance of propose algorithms, it is quite a difficult task to adapt the process and measurement noise covariance. Moreover the fingerprint map from LF technique should be re-surveyed, when the infrastructure is changed. The new initial parameter for the EKF-propagation based as follow:

$$Q_k = diag\{0.1,\ 0.1,\ 1.0,\ 1.0\} \times 10^{1.650},$$

$$R_k = I_{4\times 4} \times 10^{3.950}.$$

For the Hybrid-EKF method the initial parameter of Q and R as follow:

$$Q_k = diag\{0.1\,0.1\,1.0\,1.0\} \times 10^{1.950},$$

$$R_k = I_{6\times 6} \times 10^{2.250}, R(1,1) = 40, R(2,2) = 40.$$

From Fig.7. the non-symmetric coordinates x and y directions of the four Wi-Fi APs are suggested in the fig 7. Our Hybrid-EKF algorithm can provide the better result than another with the RSME mean at 2.1529 meter.

V. Conclusion

This article presents, a novel approach of the indoor positioning algorithm in wireless signal propagation area, by combining the advantage of LF technique based on RSSI database map matching algorithm and the RSSI trilateration model, named is Hybrid-EKF method. Several problems limit the performance of the both technique, which are RSSI noise, sampling rate and spatial variability all affect accuracy. Complexity of the positioning by using the characteristics of radio signal strength is estimating the form of interference and change over time. Anyway, LF technique can indicate the position very well only when the radio map is new generated however when the environment has changed the database map should be re-generated. The EKF-propagation based was used to fuse the RSSI data from each Wi-Fi APs with neither fluctuate by distance nor require the RSSI database system. However, the interference factors effect the most for this technique. The proposed Hybrid algorithm provides considerable improvement in the tracking accuracy and the robustness compare with the LF technique and standard EKF- propagation model as shown in table 4 by calculating the RSME. Our algorithm provides good performance when the level of noise covariance has been changed, which cover the range of the actual interference. We also simulate the scenario when the object move in two patterns and the problem of DOP is show in Fig 8. to see the tracking performance of our algorithm. The result from our algorithm is better in performance than the EKF-propagation based as shown in Fig. 5 and Fig. 6.

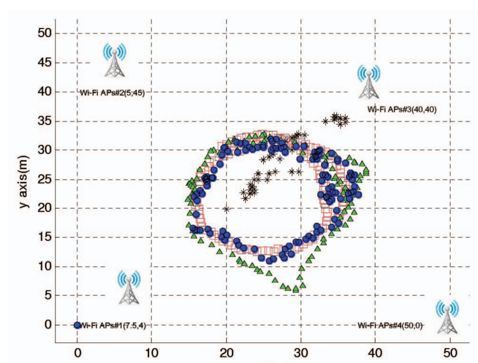


Fig. 7: The result of Indoor Positioning algorithm with DOP scenario at $N(0,3.5)$ consist with LF-Technique (Black-Asterisk), EKF-propagation based (Green-Triangle) and Hybrid-EKF(Black-circle).

Additional planned research includes data fusion from inertial sensor. For example accelerometer, gyroscope sensor and electronics compass equipped with mobile smart phone system and then refine the measurement model, test our system in real environment.

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