An Enhanced Technique for Indoor Navigation System Based on WIFI-RSSI

Kittipong Kasantikul†, XIU Chundi, YANG Dongkai, YANG Meng
†Master Program of Space Technology and Application,
School of Electronic and Information Engineering,
Beihang University, Beijing China
Email: kittipong.mut@gmail.com, xcd@buaa.edu.cn, edkyang@buaa.edu.cn, ym911209@163.com

***Abstract*—Determining position and route is very important because it helps user get to the destination easier and faster. Nowadays, more and more people move to urban areas and live in complex buildings. Indoor positioning and navigation, therefore, plays an important role for determining position for indoor areas. Anyway, in order to get to the destination, knowing only position is not enough because there are a lot of rooms inside building, for example, airport and shopping center. Thus knowing the route to the destination is also very important so user can reach the destination in time. Indoor positioning focuses on using smartphone to receive Wi-Fi signal due to its convenience and ease of operation. The Wi-Fi Fingerprint based localization with k-Nearest Neighbor (k-NN) algorithm has been commonly used for indoor positioning. For indoor navigation, many researches have used structure of building such as distance space and doors as reference points but this research focus on reference nodes of fingerprint map because reference nodes of fingerprint map are built depending on structure of building. This research is divided into two parts. The first part is to improve accuracy and robustness of positioning by using k-NN algorithm with Particle Filter (PF). The second part is the navigation technique for indoor environment by using Dijkstra's algorithm with reference nodes of fingerprint map to find the shortest route from starting position to the destination. For experimental results, the map of 6^{th} floor of New Main Building (NMB) in Beihang University was used for simulation. In positioning part, the results showed the accuracy of k-NN and PF algorithm by using root mean square error equation to measure errors between real position and estimated position. In navigation part, the results showed time used to calculate the route. Moreover, the results also showed the route between starting position and destination.**

Keywords*— *Indoor positioning, Indoor navigation, Wi-Fi Fingerprint Technique, RSSI, k-Nearest Neighbor, Particle filter

I. Introduction

Nowadays, Outdoor Positioning and Navigation System (OPNS) using Global Navigation Satellite System (GNSS) is a very popular and high-accurate method for estimating the user position [1] and for navigation [2]. Anyway, in urban areas the accuracy of OPNS is decreased due to the crowded buildings. Indoor Position and Navigation System (IPNS) is commonly used for urban areas or inside the buildings. Two important keywords are Positioning, which show where the user is at that time, and Navigation, which shows how to get to the destination. Positioning can be divided into two types; (1) Triangulation technique, this technique measures distance between Access Points (APs) and user position by using geometric properties of triangles, such as, Time of Arrival (TOA) technique [3] and Angulation of Arrival (AOA) technique [4]. (2) Fingerprint technique, this technique is the most popular method because it includes noise environment. The Fingerprint technique are commonly used together with Bluetooth [5], Radio-frequency identification (RFID) [6], RFID combines with Wi-Fi [7], and ZigBee combine with Wi-Fi [8] to build fingerprint map and estimate user position. In this paper, the researcher focuses on the Fingerprint technique. Fingerprint technique is divided into two phases, offline phase and online phase. In offline phase, data is collected from APs in the building in order to build the fingerprint map. King Mongkuts Institute of Technology Ladkrabang used neural network based on ultra wideband (UWB) to update the database of the fingerprint map [9]. In online phase, user Receives Signal Strength Indicator (RSSI) from APs then uses approximation algorithm for the user position. A lot of good approximation algorithms are used, such as, k-Nearest-Neighbor algorithm (k-NN) [10][11], Support Vector Machine (SVM) [12], Artificial Neural Network (ANN) [13], K-means [14] for estimating user position. This paper has proposed a new method, which is the combination of particle filter (PF) [15][16][17] and k-NN in order to improve the accuracy and robustness of the positioning. Navigation is also very important because there are a lot of big buildings nowadays, besides, there are hundreds or even thousands of rooms inside each building, such as, airport, shopping center, office building. Moreover, in emergency case, such as, fire accident, earthquake, knowing only position and destination is not enough, knowing how to get to the destination is more important. For navigation, most researchers used structure [18][19] or symbolic information [20] of building in order to define routing to go to destination. In this paper, the researcher has proposed navigation technique by using Dijkstra's algorithm [21][22][23] to find route in building. The Dijkstra's algorithm is very popular in computer network for finding the shortest path in order to send data or communication. We used Dijkstra's algorithm combining with the reference nodes of fingerprint map because reference nodes of fingerprint map will be defined based on structure of building for positioning.

This paper is organize 4 sections; (I) introduction of IPNS, (II) description about the system model of the radio propagation model, the fingerprint technique, k-NN, PF and the Dijkstra's algorithm, (III) experimental results showed route and user position on 6^{th} floor of new main building at Beihang university and showed time used for calculating route and user position, and error between real position and estimate position, and (IV) summary and conclusion.

II. METHODOLOGY

A. Radio propagation model

The user position can be estimated by using the radio signal propagation from Wi-Fi APs. RSSI value can be measured from APs to estimate user position because the RSSI value decreases with the distance according to the characteristics of the signal between transmitter and receiver. The signal from APs uses Equation 1 logarithm-distance Path loss model to generate the signal, which is used for the simulation.

$$PL(dB) = PL_{d_{\bullet}}(dBm) - 10nlog_{10}(\frac{d}{d_o}) - WL \quad (1)$$

Where $PL(dB)$ is the power receiver measured in decibel, $PL_{d_{\bullet}}(dBm)$ is the power received or RSSI value from APs in first meter of the distance, n is path loss exponent, which value is adjustable depending on the environment. d is the distance between transmitter and receiver, d_0 is the breakpoint distance. WL is sum of wall loss depend on structure in building.

B. Fingerprint Technique

The Wi-Fi Fingerprint has been commonly used for indoor positioning because it includes noise of environment. Fingerprinting is a map for determining the location of the user. Fingerprint technique divides into two parts, the first part is the off line phase, which this part collects the RSSI value in order to build fingerprint map. The first step is to define the reference node in area of building after that collects the data of each reference node and finally the database has RSSI value from each APs in every reference node. The second part is the online phase, for this phase the user position receives the real RSSI of each APs after that uses estimation algorithm to estimate user position in fingerprint map; moreover, reference nodes of fingerprint map can be used to find route in building show in section E

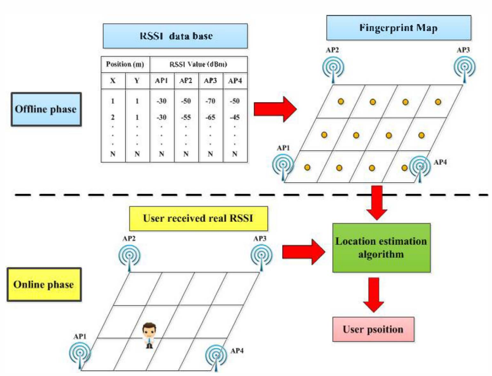


Fig. 1: Two phases of the fingerprint technique

C. k-Nearest Neighbor algorithm (k-NN)

k-NN algorithm is a measure of distances between RSSI in online phase and the reference nodes in fingerprint map for classifying position by using the Euclidian distance in Equation 2. The Euclidian distance will calculate all of reference nodes after that the shortest distance is used to estimate the position.

$$d_i = \|rf_i - up\| = \sqrt{\sum_{i=1}^{n}(rf_i - up)^2} \quad (2)$$

Where d_i is the distance between the RSSI value of user position and the RSSI value of reference nodes, rf_i is the RSSI value of each reference nodes on the fingerprint map, up is the RSSI value of the user position. Section D show the particle filter technique for improving the accuracy of k-NN.

D. Particle Filter (PF)

The Particle Filter (PF) is the method of Monte Carlo Method combining with Bayesian framework. The basic idea of particle filter is to generate particle after that calculate the weight of every particle in order to find the importance particles by using resampling technique finally return to generate particle. Particle filter based on localization method [24] is proposed as shown in Table I.

TABLE I: The Particle Filter

For time steps n = 0,1,2,...	
1:	**Initialization** Draw particle $x_0^{(i)} \sim p(x_0)$,$w_0^{(i)} = 1/N_p$, for $i = 1, ..., N_p$.
2:	**ImportanceSampling** Draw particle $x_n^{(i)} \sim p(x_n \| x_{n-1}^{(i)})$ based on the Brownian motion model for $i = 1, ..., N_p$.
3:	**WeightUpdate** Calculate the importance weights $\{w_n^{(i)}\}$ according to the likelihood $p(\bar{y}_n \| x_n^{(i)})$, where $\bar{y}_n$ is the compensated range measurements.
4:	**Normalization** Normalize the importance weight: $\tilde{w}_n^{(i)} = w_n^{(i)} / \Sigma_{j=1}^{N_{\bullet}} w_n^{(i)}$.
5:	**Resampling** Check effective sample size (ESS) and resample the particles if needed.
6:	Repeat Steps 2 to 5.

System model

The prediction step of PF used particle from time k to generate next particle based on system model. In this paper, the system model for indoor environment was designed based on Dead Reckoning (DR) model. In state vector, $x_k = \begin{bmatrix} P_x & P_y & v_x & v_y \end{bmatrix}$, which P_x and P_y are user position, v_x and v_y are velocity, ΔT is the sample time, k is the time step and Q is noise of system model.

$$\begin{bmatrix} P_{x_{k+1}} \\ P_{y_{k+1}} \\ v_{x_{k+1}} \\ v_{y_{k+1}} \end{bmatrix} = \begin{bmatrix} 1 & 0 & \Delta T & 0 \\ 0 & 1 & 0 & \Delta T \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} P_{x_k} \\ P_{y_k} \\ v_{x_k} \\ v_{y_k} \end{bmatrix} + Q$$

$$Q = \begin{bmatrix} \Delta T^2/2 & 0 & 0 & 0 \\ 0 & \Delta T^2/2 & 0 & 0 \\ 0 & 0 & \Delta T & 0 \\ 0 & 0 & 0 & \Delta T \end{bmatrix}$$

Measurement update

For measurement update, likelihood function was used to find the weight (Pw) between position of k-NN and each PF. Assume that z_{k_r} is the position of k-NN, z_{k_p} is the position of PF, and σ is variance of measurement.

$$P_w = \frac{1}{\sqrt{2\pi\sigma}} \exp\left(-\frac{(z_{k_r} - z_{k_p})^2}{2\sigma^2}\right) \tag{3}$$

Next step is the normalization of importance weight of particle and the resampling technique is then used to find the importance sample from P_{w_k} in order to generate next particle x_{k+1}, then find the average of the particles in order to estimate the user position. In Figure 2, black circle points represent particles and yellow circles represent weight from likelihood function. As shown in Figure 2, number 7 is an importance weight at time k, so at time $k+1$, algorithm will generate next particle around particle number 7. Anyway, the number of particle depends on the weight.

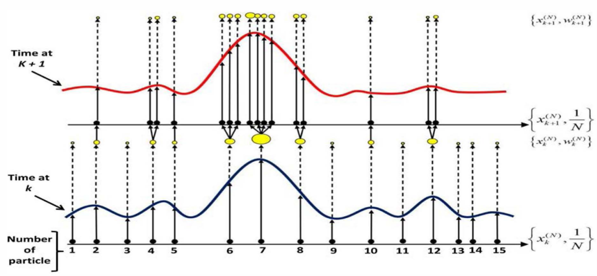
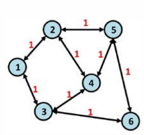


Fig. 2: The resampling technique

E. Dijkstra's Algorithm

Dijkstra's algorithm is one the most popular method used for finding the shortest path in computer science because this algorithm takes short time with high performance; moreover, this algorithm is not too complicated. Dijkstra's algorithm was proposed to find route from start position to destination based on reference nodes of fingerprint map (see Figure 3 (a)). The first step is to build link matrix in every reference nodes of fingerprint map. If the reference nodes are connected, enter distance in matrix. But if the reference nodes are not connected, enter the ∞ in matrix.



(a) Node

Point	1	2	3	4	5	6
1	1	1	1	∞	∞	∞
2	1	1	∞	1	1	∞
3	1	∞	1	1	∞	1
4	∞	1	1	1	1	∞
5	∞	1	∞	1	1	1
6	∞	∞	1	∞	1	1

(b) link matrix

Fig. 3: The relationship of each node

The next step is to receive the user position and destination in order to calculate route by using link matrix as shown in Algorithm 1. Pseudo code of Algorithm 1 can be divided into 2 steps. First, finding neighbors point {matrix(U,k) + distance(U) < distance(k)}, then update the shortest distance {distance(k) ← Matrix((U,k) + distance(U)} and parent {parent(k) ← U}. When U is number of neighbors reference nodes and k is all reference nodes of fingerprint map. The second step is to determine the route using the same pattern of first step {P ← Parent(Target)}, then update the route {Route ← [P Route]}.

Algorithm 1 Dijkstra's algorithm

```
Input : Position and Destination
Output : Route
Step 1 : Find point of position and neighbors points.
distance(position) ← 0
for i = 1 → All reference nodes do
    T ← [ ]
    for n = 1 → Allpoint do
        if Visited(n) = 0 then
            T ← [T  distance(n)]
        else
            T ← [T  Inf]
        end if
    end for
    U ← min(T)
    Visited(U) ← 1
    for k = 1 → All reference nodes do
        if (Matrix(U,k) + distance(U)) < distance(k) then
            distance(k) ← distance(U) + Matrix(U,k)
            Parent(k) ← U
        end if
    end for
end for
Step 2 : Find Route.
if Parent(destination) ≠ 0 then
    Target ← destination
    Route ← [destination]
    while Target ≠ position do
        P ← Parent(Target)
        Route ← [P  Route]
        Target ← P
    end while
end if
```

Indoor system is divided into 2 steps. (see Figure 4) The first step is to estimate the user position in the fingerprint map. The user receives real RSSI from APs in the building after that uses k-NN technique to estimate the user position. In this paper, we combined the particle filter with the k-NN technique in order to improve the accuracy of the user position. The second step is the navigation based on reference nodes of fingerprint map. Dijkstra's algorithm is used to find the route in the building.

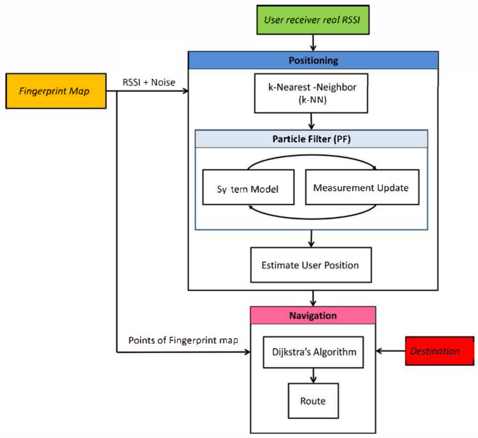


Fig. 4: The indoor position and navigation system

III. Experiment Result

In this paper, the 6^{th} floor of New Main Building (NMB) in Beihang University is used for simulation. There are 33 classrooms, 1 restroom, 3 elevators, and 5 emergency exits within (40 $\times$ 112 m^2). Ten APs (Red circle) in X and Y coordinates are setup around 6th floor, which are AP 1 (5,6.5), AP 2 (20,12), AP 3 (35,25), AP 4 (5,34), AP 5 (5,62), AP 6 (35,73), AP 7 (5,97.5), AP 8 (20,75), AP 9 (35,100) and AP 10 (39,60). Path loss model (Equation 1) is used in order to generate RSSI of each AP; moreover, in real environment have noise from people or wall so for truthfully we plus Gaussian noise N(0,5) in WL of path loss model. The total defined reference nodes of fingerprint map in the building is 194 reference nodes (Blue circle) and the distance of each point is 2 m show in Figure 5.

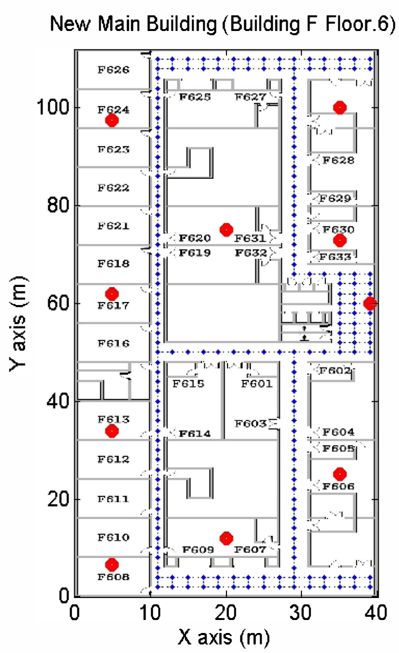
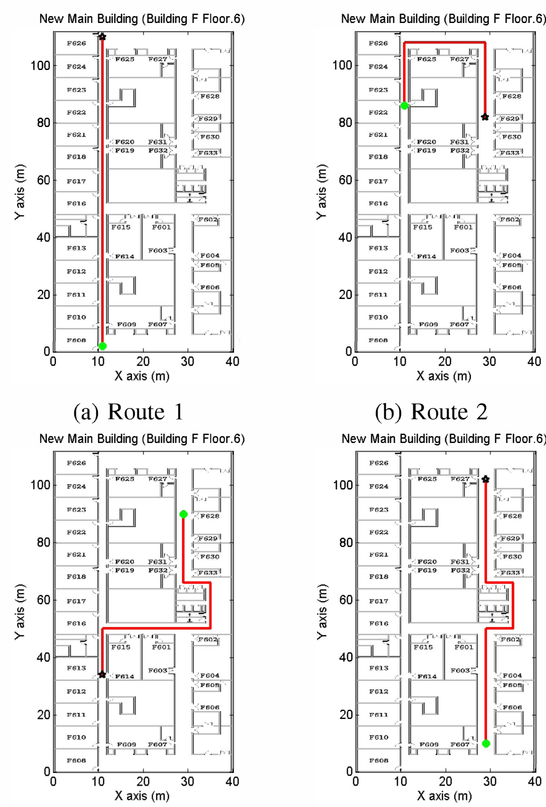


Fig. 5: Map for simulation

Navigation path shows the route from the user to the destination room by using Dijkstra's algorithm. Four routes are defined different start point of user position and destination room, First route: F608 to F626, second route: F622 to F629, third route: F628 to F613, and forth route: F607 to F627 (see Figure 6). The $\circ$ represents the starting point, the red line represents route to the destination and $\star$ represents the destination. Distance of route calculate by used number of reference node multiply with distance of each reference nodes. Direction of each route calculate turn by turn. We used 2 reference nodes in order to calculate angle based on $atan2$ function because angle result of $atan2$ represented in the area $[-\pi, \pi]$. For example first time calculate angle 90° next time calculate again 180° is left hand and 0° is right hand. If first time is 0° next time 90° is left hand and -90° is right hand. We run algorithm 10 times in order to find average time of calculating route.



(a) Route 1

(b) Route 2

(c) Route 3

(d) Route 4

Fig. 6: The navigation paths in building

Table II shows direction, distance, reference nodes, and time of each route. For example in route 1, total distance of walking from room F608 to F626 is 110 m, reference nodes used of fingerprint map are 55 reference nodes in total, time used is 0.1370 s for calculating the route. In route 3, total distance of walking from F628 to F613 is 86 m (including left turn and right turn), reference nodes used of fingerprint map are 43 reference nodes, time used is 0.1417 s for calculating the route.

TABLE II: The detail of route

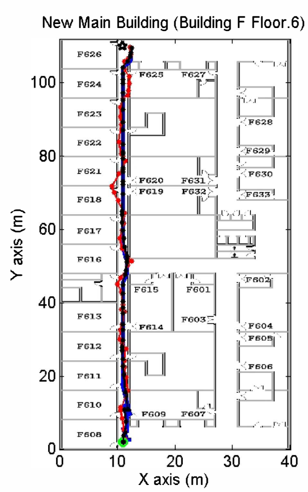
Route	Route 1	Route 2	Route 3	Route 4
Direction	∘ F608 ↑ 110 m ⋆ F626	∘ F622 ↑ 22 m ↱ 18 m ↱ 26 m ⋆ F629	∘ F628 ↑ 24 m ↰ 6 m ↱ 16 m ↱ 24 m ↰ 16 m ⋆ F613	∘ F607 ↑ 40 m ↱ 6 m ↰ 16 m ↰ 6 m ↱ 36 m ⋆ F627
Distance (m)	110	66	86	104
Point	55	33	43	52
Time (s)	0.1370	0.1376	0.1417	0.1397

In positioning path, user receives RSSI from APs then Gaussian noise N(0,3) was added in Equation 1, same as in building reference nodes of fingerprint map. Two routes were chosen, which were route 1 and route 3 in order to test the accuracy and robustness of k-NN (Blue line), PF (Red line) and Unscented Kalman Filter (UKF) [25] (Black line), as shown in Figure 7 (a) and 8 (a). In k-NN path, three points were used for estimating user position. In PF path, results of PF and UKF were compared because the technique is the same. The UKF can be propagate the mean and covariance of the Gaussian approximation to the state distribution. Figure 7 (b) and 8 (b) show the error between real user position and estimated user position and show the time used for estimation.

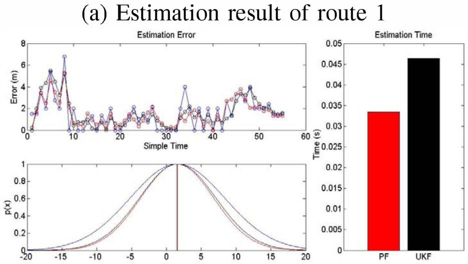
TABLE III: The result of Particle Filter

Algorithm		$k-NN$	PF	UKF
Route 1	Min	0	0.0161	0
	Mean	1.5758	1.5372	1.6164
	Max	6.7987	5.2774	5.5038
	Time	-	0.0334	0.0464
Route 3	Min	0	0.0271	0
	Mean	1.7381	1.8884	1.7174
	Max	6	3.7913	3.8901
	Time	-	0.0275	0.0391

The initial condition of PF, N = 50 particles and variance of measurement, σ = 1.5 as shown in Equation 3. The initial condition of UKF, matrix $Q = diag\{1,1,1,1\} \times 10^1$ and $R = diag\{1,1,1,1\} \times 10^2$. We used trial and error technique in order to find out the initial condition. The results of Table III can show the relative of error, time, and particle. This paper focuses on PF because error from PF is less than error from k-NN and similar to UKF; moreover, time for estimating the user position is shorter. From Figure 7 (b) and 8 (b), mean error of k-NN, PF and UKF are similar, which are around 1.65 m but maximum error of PF and UKF are less than k-NN, which is around 2 m.

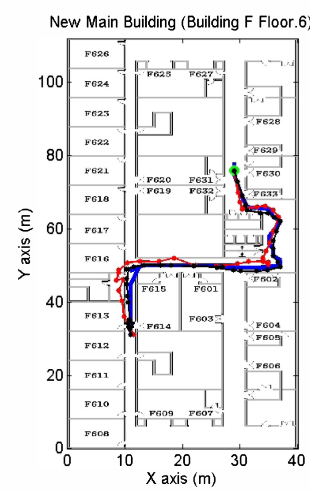


(a) Estimation result of route 1

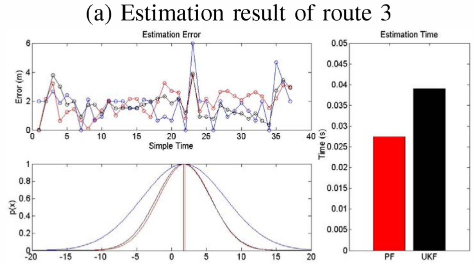


(b) The error and time of route 1

Fig. 7: The simulation tracking result of route 1



(a) Estimation result of route 3



(b) The error and time of route 3

Fig. 8: The simulation tracking result of route 3

IV. Conclusion

The paper has proposed positioning and navigation technique for indoor position and navigation system (IPNS). The 6^{th} floor of New Main Building in Beihang University was selected for the simulation. For positioning technique, k-NN combining with PF were used in order to improve accuracy and robustness of user position. For navigation technique, Dijkstras algorithm combining with reference nodes of fingerprint map were used in order to find route inside the building. The results showed that the navigation system can show the route between user position and the destination room, and also show details of each route. For positioning, two best navigating results were selected in order to test accuracy of estimation algorithm. This paper used estimation algorithm based on DR model focus on PF because PF has error similar with UKF but used short time to estimate user position.

Acknowledgment

The authors would like to thank the scholarship from Asia-Pacific Space Cooperation Organization (APSCO) and Beihang University and we are also grateful to the reviewers for their detailed reviews and constructive comments. Supported by the National High Technology Research and Development Program of China (2013AA12A201).

References

[1] M. Glocker, H. Landau, R. Leandro, M. Nitschke, *Global Precise Multi-GNSS Positioning with Trimbel CenterPoint RTX*. NAVITEC 2012 ⊤ European Workshop on GNSS Signals and Signal Processing, 5-7 December 2012.

[2] J. Sang, K. Kubik, *GNSS Navigation System Accuracy Requirement for Vehicle Driving Automation*. Position Location and Navigation Symposium, April 1998, pp.426-431.

[3] K. Pahlavan, *Taking Positioning Indoors Wi-Fi localization and GNSS*. Inside GNSS. Magazine, May 2010, pp.40-46.

[4] M. Roshanaei, M. Maleki, *Dynamic-KNN: A Novel Locating Method in WLAN Based on Angle of Arrival*. IEEE Symposium on Industrial Electronics and Applications, Kualalumpur Malaysia, October 2009, pp.722-726.

[5] F. Subhan, H. Hasbullah, A. Rozyyev, Sheikh T. Bakhsh, *Indoor Positioning in Bluetooth Networks using Fingerprinting and Lateration approach*. International Conference on Information Science and Application (ICISA), April 2011, pp.1-9.

[6] S. Phimmasean, T. Chuenurajit, P. Cherntonomwong, *Indoor Localization System based on Fingerprint Technique using RFID Passive Tag*. 10^{th} International Conference on Electrical Engineering/Electronics, Computer, Telecommunication and Information Technology (ECTI-CON), May 2013, pp.1-6.

[7] M. Gunawan, B. Li, T. Gallagher, Andrew G. Dempster, G. Retscher, *A new method to generate and maintain a WiFi fingerprinting database automatically by using RFID*. International Conference on Indoor Positioning and Indoor Navigation (IPIN), November 2012, pp.1-6.

[8] J. Niu, B. Lu, L. Cheng, Y. Gu, L. Shu, *ZiLoc: Energy Efficient WiFi Fingerprint-based Localization with Low-Power Radio*. Wireless Communications and Networking Conference (WCNC) 2013, April 2013, pp.4558-4563.

[9] W. Vinicchayakul, S. Promwong, L. Shu, *Improvement of Fingerprinting Technique for UWB Indoor Localization*. 4^{th} Joint International Conference on Information and Communication Technology, Electronic and Electrical Engineering (JICTEE), March 2014, pp.1-5.

[10] P. Torteeka, X. Chundi, *Indoor Positioning based on Wi-Fi Fingerprint Technique using Fuzzy K-Nearest Neighbor*. 4^{th} International Bhurban Conference on Applied Sciences and Technology (IBCAST), January 2014, pp.461-465.

[11] J. So, Joo Y. Lee, Cheal H. Yoon, H. Park, *An Improved Location Estimation Method for Wifi Fingerprintbased Indoor Localization*. International Journal of Software Engineering and Its Applications, Vol. 7, No. 3, May 2013, pp.77-86.

[12] Lersan B. Del Mundo, Rafael Lean D. Ansay, Cedric Angelo M. Festin, Roel M.Ocampo, *A Comparison of Wireless Fidelity (Wi-Fi) Fingerprinting Techniques*. International Conference on ICT Convergence (ICTC), September 2011, pp. 20-25.

[13] L. Gogolak, S. Pletl, D. Kukolj, *Indoor Fingerprint Localization in WSN Environment Based on Neural Network*. 9^{th} International Symposium on Intelligent Systems and Informatics (ISISY), September 2011, pp.293-296.

[14] S. Bai , T. Wu, *Analysis of K-Means Algorithm on Fingerprint Based Indoor Localization System*. 5^{th} International Symposium on Microwave, Antenna, Propagation and EMC Technologies for Wireless Communications (MAPE), December 2013, pp.44-48.

[15] J. Han, L. Ma, Y. Xu, Z. Deng, *Auxiliary Particle Filter-Based WLAN Indoor Tracking Algorithm*. 6^{th} International ICST Conference on Communications and Networking in China (CHINACOM), August 2011, pp.600-603.

[16] I. Kim, E. Choi, H. Oh, *Indoor User Tracking with Particle Filter*. COGNITIVE 2012 : The Fourth International Conference on Advanced Cognitive Technologies and Application, July 2012, pp.59-62.

[17] Sabbir R. Sakib, A. Quyum, K. Andersson, K. Synnes U. Korner, *Improving Wi-Fi based Indoor Positioning using Particle Filter based on Signal Strength*. IEEE Ninth International Conference on Intelligent Sensors, Sensor Networks and Information Processing (ISSNIP), April 2014, pp.1-6.

[18] H. Lu, X. Cao, Christian S. Jensen *A Foundation for Efficient Indoor Distance-Aware Query Processing*. IEEE 28^{th} International Conference on Data Engineering, April 2012, pp.438-449.

[19] D. Li, Dik L. Lee *A lattice-based semantic location model for indoor navigation*. 9^{th} International Conference on Mobile Data Management, April 2008, pp.17-24.

[20] G. Sriharee, *Indoor Navigation using Semantic Symbolic Information*. IEEE 16^{th} International Conference on Computational Science and Engineering, December 2013, pp.1167-1173.

[21] H. Juzoji, I. Nakajima, T. Kitano, *A Development of Network Topology of Wireless Packet Communications for Disaster Situation with Genetic Algorithms or with Dijkstra's*. IEEE International Conference on Communications, June 2011, pp.1-4.

[22] Jehn R. Jiang, Hsin W. Huang, Ji H. Liao, Szu Y. Chen, *Extending Dijkstras Shortest Path Algorithm for Software Defined Networking*. 16^{th} Asia-Pacific Network Operations and Management Symposium (APNOMS), September 2014, pp.1-4.

[23] Z. Yan, Z. Jun, *Dijkstra's Algorithm Based Robust Optimization to Airline Network Planning*. International Conference on Mechanic Automation and Control Engineering (MACE), June 2010, pp.2783-2786.

[24] Z. Chen, *Bayesian filtering: from kalman filter to particle filter, and beyond*. Journal Statistics 2013, Vol.182, pp.1-69.

[25] Chun J. Sun, Hong Y. Kuo, Chin E. Lin, *A Sensor Based Indoor Mobile Localization and Navigation using Unscented Kalman Filter*. Position Location and Navigation Symposium (PLANS), May 2010, pp.327-331.