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Comparing WiFi RSS Filtering for Wireless Robot Location System

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Abstract

Wireless infrastructure such as WiFi gained wide interest by researchers and private companies to determine the location of a target object in a building. Hence, we observe an increase in popularity of in building WiFi solutions. However, significant fluctuations in WiFi signal strength are affecting the measurement quality and as a result the fingerprinting positioning approach. The accuracy of the positioning will be improved if the RSS measured at different distances between transmitter (Tx) to receiver (Rx) is distinctly different. Several filtering methods may be applied to reduce the data noise for estimating. Many methods demonstrate great noise reduction. The time taken to compute data becomes limited to mobile robot application since real-time is required. The requirement for real time data singles out mobile robot application as an effective solution. In this paper, the focus will be on the difference of RSS measurements with varying Tx-Rx distances, following the design of experiment (DoE). Further we include a comparison between the Kalman filtering and weight fusion, which is Weight-Average of the Top-n Populated values model (WATP). Errors in estimation and reduction in computation time are taken into consideration.

Keywords: WiFi RSS, Kalman filter, Weight fusion, Indoor Positioning System, Weight-Average of the Top-n Populated values model

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1. INTRODUCTION

When considering the motion of robots and automation equipment both inside and outside a building from one point to another, it is important to drive accurate current position locating. This to assure the robots or the automatic devices can be accurately guided to the correct destination. While GPS is widely used for outdoor applications, this technology does not meet the requirements for indoor applications [5]. In recent years, researchers and private companies popularized the use of wireless indoor positioning systems [6] for client tracking in a building. Many positioning technologies are being explored and researched, in example: Bluetooth networks [5], Infrared, Ultrasonic and RF technologies [7]. Wireless infrastructure, especially WiFi, to drive positioning and navigation solutions has gained a widening interest by researchers to add on / make use of the already incorporated WiFi solutions in buildings. WiFi signal strength database recording technique is known as fingerprinting. Matching the unknown signal strength of the receiving client device to the fingerprinting database can aid locating the client device.

Healthcare mobile robots tasked with assisting medical officers daily routines have recently been developed in the university laboratory [1][2][4]. In the near future this may lead to the widespread use of multiple robotic devices in the general hospitals and healthcare centers as illustrated in Figure 1.

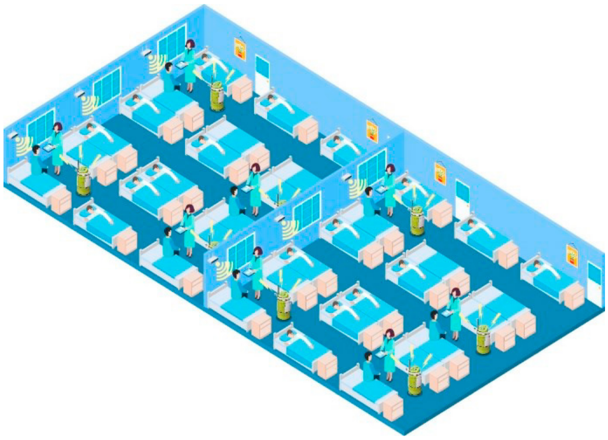

Fig. 1. Artist impression of multiple robot application in hospitals.

Although WiFi is widely applied to the indoor positioning system, bad fluctuations of WiFi signal non-line-of-sight are still casting a shadow on its accuracy. Reflection, scattering, material absorption, people moving around within indoor environment, ... are know influences leading to strong, undesired signal fluctuations [3]. It has been demonstrated in experiments that measurements in same fixed location, set up, equipment, may display unexpected differences in WiFi signal strengths. This is no surprise in indoor environments.

Fig.2 shows the day to day difference in the signal measured results of two signal transmitters. The measurements are affected by changing movement patterns of a varying number of office workers on different days. The different results in measured signal are more or less dependent on the environment, and if we fixed the same setup of receiver and measuring method, the transmitter's ability to transmit signals is also one of the interesting variables to consider.

An average RSS value corresponding with each specific point will be stored in a signal 'fingerprinting' database. The application of randomized measurement order leaves us less at the mercy of variations caused by Wifi signal fluctuations, people movement patterns, signal travel time, ... and is thus more likely to lead to more reliable test results.

Minitab® software is used to help the design of experiments (DoE). A full factorial design, one factor (Tx-Rx distance) with five treatments are considered.

This paper will focus on Data filtering for position estimation, which will allow for precise positioning. In this study, we compare the results from using the popular technique Kalman Filter versus Weight fusion method which in this paper will be referred to as: Weight-Average of the Top-n Populated values filtering (WATP). Errors in estimation and reduction in computation time are taken into consideration.

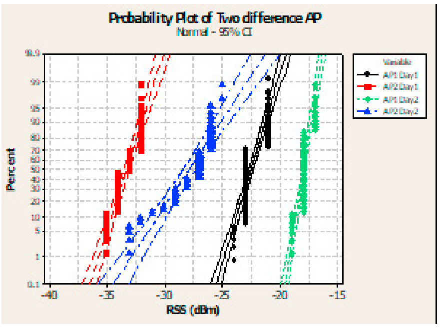

Fig. 2. Observed daily RSS value variations on two different transmitters under same setup and equipment.

Fig. 3. Illustration of the experimental set up.

2. PRELIMINARY SET-UP

2.1 *Experiments Set-up*

The 'playground' and experimental area for this paper is situated on the second floor of Center for Human-Robot Symbiosis Research, Toyohashi University of Technology, which is most of the time populated by students and teachers. This is to be considered a 'non-line-of-sight' environment, which was turned into 'line-of-sight' by our temporary control during signal measurement activities. Hence, this papers result is considered representative for indoor positioning system in line-of-sight environments.

In this experiment the receiver is directly aligned with the transmitter and the variable of interest is the separation distance between the transmitter and receiver. The height of the laboratory ceiling is around 2.5m and we know that the antenna height in indoor environment is not significant to RSS value [4]

The list of hardware and software used is as follows,

(1) The WiFi access point:

Used is high power Alfa AIP-W525H dual antenna with 5dBi gains each. This type of antenna is commonly used in many corporation buildings.

(2) The receiver:

A common adaptor model Broadcom BCM43142 Wireless Network Adaptor with the assumption of unity gain. The receiver is positioned 1 meter high from the floor.

(3) Recording software:

Homedale® [8] wireless surveillance open source code is used to record the wireless strength data in the interval of 2 seconds running in Windows 8.1 operating system.

(4) Other setting:

(4.1) For the WiFi access point, a set-up is built such as none network security, default MAC from Alfa Inc. was used, and network channel set to channel 1.

(4.2) The frequency for this AP is 2.4GHz on AP mode. Access to worldwide internet is not connected since such connections in not required.

(4.3) The number of required RSS data is set to 100 per location per experiment order.

(4.4) The experiment sequence is based on the DoE design schedule.

2.2 *Measurement Order*

Minitab® is a popular software used for the design of experiments. Key to that is its powerful statistical software.

This paper is based on a full factorial design of experiment. The experiments were replicated one time. The randomized measurement order was software generated. The observed parameter is WiFi RSS.

3. METHODOLOGY

3.1 Measurement Methods

Randomized Complete Block Design (RCBD) is a DOE technique based on blocking. In any experiment there are always several variables which can affect the outcome. Some of them cannot be controlled, thus they should be randomized while performing the experiment so that on average, their influence will hopefully be negligible. Some other are controllable. RCBD is useful when we are narrowing down on one particular factor whose influence on the response variable is supposed to be more relevant. By using the Minitab® software, the experiment table is automatically generated for full factorial design with randomization. At the onset of the experiment, Antenna heights and Tx-Rx separation are the investigated factors of the DoE in order to evaluate their effects on the WiFi RSS data. After analysis by ANOVA, the influence of antenna height is considered insignificant [4]. We used the same RSS (measured data) measurements to compare the filtering methods. The five Tx-Rx separation conditions such as 2, 4, 6, 8 and 10 m. are experimental set up.

3.2 Data filtering

3.2.1 Kalman filter

The Kalman filter is a very powerful tool when it comes to controlling noisy systems. The basic idea of a Kalman filter is noisy data in and then hopefully less noisy data out. For the evaluation of measurement data, different functional and stochastic models can be used. In the case of time series, a Kalman filtering (KF) algorithm can be implemented. The predict-update equates as below:

Predict:

$$\hat{X}_{t/t-1} = F_t \hat{X}_{t-1/t-1} + B_t u_t \tag{1}$$

$$P_{t/t-1} = F_t P_{t-1/t-1} F_t^T + Q_t \tag{2}$$

Update:

$$\hat{X}_{t/t} = \hat{X}_{t/t-1} + K_t \left(y_t - H_t \hat{X}_{t/t-1} \right) \tag{3}$$

$$K_t = P_{t/t-1} H_t^T \left(H_t P_{t/t-1} H_t^T + R_t \right)^{-1} \tag{4}$$

$$P_{t/t} = \left(I - K_t H_t \right) P_{t/t-1} \tag{5}$$

Where

$\hat{X}$ = Estimated state
F = State transition matrix
u = Control variables
B = Control matrix
P = State variance matrix
Q = Process variance matrix
y = Measurement variables
H = Measurement matrix
K = Kalman gain

R = Measurement variance matrix
Subscripts are as follows: $t|t$ current time period, $t-1|t-1$ previous time period, and $t|t-1$ are intermediate step

3.2.2 *Weight Average of the Top-n populated value model*

There are several filtering methods to reduce the noise of estimation data. Many methods to achieve great noise reduction. The time taken to compute data becomes limited to something that may not be suitable for use. Robotic applications that require real-time information for processing is an example. This paper presents a method that can reduce the noise and minimize integration time which allows real time data. The predict equations as below:

$$RSStarget = \sum_{i=1}^{n}(RSSi * Wi) \tag{6}$$

$$Wi = \frac{Fi}{\sum_{i=1}^{n} Fi} \tag{7}$$

Or which is,

$$RSStarget = \sum_{i=1}^{n}\left[RSSi * \left(\frac{Fi}{\sum_{i=1}^{n} Fi}\right)\right] \tag{8}$$

where,

RSStarget = the signal strength of the target object
RSSi = an average signal strength of the highest population at position i.
Fi = the frequency of the highest population at position i.
n = number of groups of the interested highest signal strength.

3.2.3 *Mean Squared Error (MSE)*

In statistics, the concept of mean error is an important criterion that is utilized in order to measure the performance of an estimator. MSE is important for relaying the concepts of precision, bias and accuracy during the statistical estimation. The measure of MSE requires a target of prediction or estimation along with a predictor or estimator which is said to be the function of the given data. MSE is defined as the average of squares of the "errors". The formula for mean squared error is given below,

$$MSE = \frac{1}{n}\sum_{i=1}^{n}(\hat{X}i - Xi)^2 \tag{9}$$

where,

$\hat{X}i$ is the vector denoting values of n number of *predictions*.
Xi is a vector representing n number of *true* values.

4. RESULTS AND ANALYSIS

Table 1 presents the data obtained in this research. Prior to each measurement location, the average data is taken while the filtration by means of Kalman Filter and WATP are applied to the measured data. The average of these computations is tabulated. Noted that for Kalman Filter, both the average computation and the last value i.e. the convergence value are taken for comparison. The convergence values are taken since it is proven that the values will finally converge into its mean value despite the time taken [11].

Fig. 4 shows the distribution of WiFi measurement data. The distribution is as expected indeed a normal bell-shaped one. Hence it can be used to analyze or forecast. Fig. 5 on the other hand depicted the probability plot of the three filtering methods. These data are also normally distributed, and can therefore be used to analyze or forecast with confidence.

Table 1. μRSS of signal strength data of block1 and the Rss estimation of taret by applying kalman filtering and weight.

RunOrder	Tx-Rx Separation (m.)	(A) Observation response, μRSS (dBm)	(B) Kalman filtering, RSS (dBm)	(B1) Kalman Filter Last Value (convergence)	(C) WATP , RSS (dBm)
1	6	-39.22	-36.32	-38.29	-39.65
2	8	-40.72	-36.88	-39.71	-40.96
3	2	-40.33	-36.12	-39.45	-40.21
4	10	-46.27	-41.96	-45.28	-46.25
5	4	-41.05	-38.00	-40.13	-40.00
6	2	-37.60	-34.89	-36.71	-37.57
7	4	-41.60	-37.27	-40.64	-41.18
8	6	-41.35	-33.98	-35.89	-41.15
9	2	-36.65	-37.99	-40.44	-36.21
10	4	-38.34	-34.92	-37.56	-36.98
11	4	-46.17	-42.58	-45.23	-46.18
12	8	-38.44	-34.56	-37.59	-37.81
13	10	-45.59	-41.46	-44.68	-45.98
14	4	-40.05	-37.44	-39.11	-41.06
15	8	-48.12	-43.94	-47.24	-49.00
16	10	-45.01	-43.94	-47.24	-45.07
17	2	-39.17	-36.89	-38.40	-41.13
18	6	-44.61	-41.42	-43.64	-44.00
19	10	-45.24	-41.05	-44.24	-45.11
20	8	-39.24	-35.79	-38.42	-36.10
21	8	-41.64	-37.81	-40.72	-41.25
22	10	-37.97	-35.46	-37.13	-37.14
23	6	-33.30	-30.22	-32.59	-32.94
24	2	-37.45	-32.90	-36.65	-36.96
25	6	-40.16	-36.65	-39.22	-40.44

4.1 Graphical plot and analysis

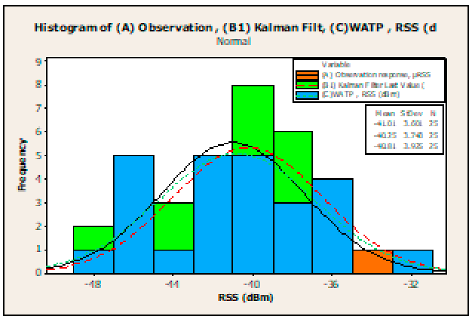

Fig. 4. Histogram plot of (1) μRSS of observations (2) Kalman filtering last value and (3) WATP.

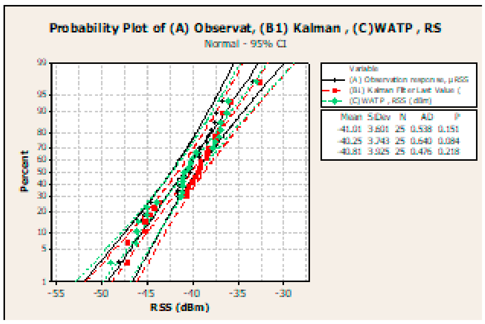

Fig. 5. Probability plot of (1) μRSS of observations (2) Kalman filtering last value and (3) WATP.

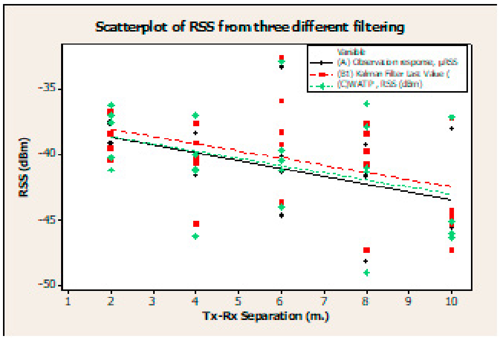

Fig. 6. plot the relation between RSS and Tx-Rx distance.

Figure 6 plots the relation between Tx-Rx distance and the WiFi RSS. In this experiment, the difference RSS value apparently correlate with each of the different Tx-Rx distance. The trendlines of the three different filtering methods applied are heading in the same direction.

Table 2 compares the error of each filtering methods. The real average value of RSS observations of each position is a reference value. From Fig.7 we found that the center of error using Kalman filtering and WATP filtering are very close to zero. WATP shows a narrow range of error distribution. (A)-(B) is not considered because that is not a convergence data of Kalman filtering and shows big deviation compared with the results from other filtering methods.

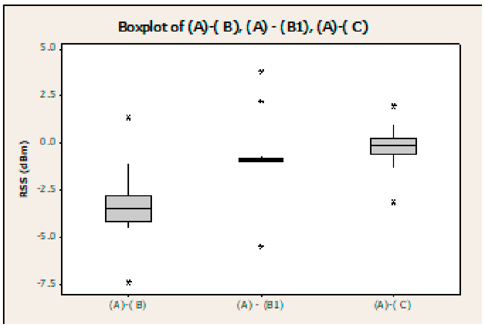

Fig. 7. Boxplot of error of each filtering method

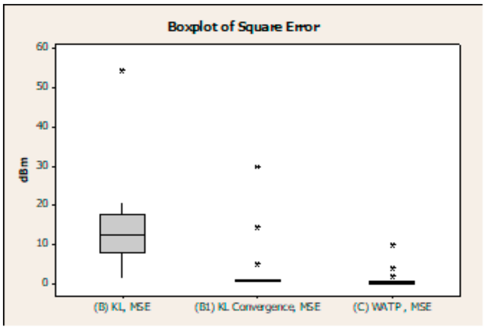

Fig. 8. Box plot of Square Error comparison of different filtering methods

Fig. 8 presents the Squared Error of Kalman filtering versus Weight-Average of the Top-n Populated values filtering (WATP). The center point of the squared error of Kalman filtering is close to zero. However, the error distribution is wider compared to the result of Weight-Average of the Top-n Populated values filtering which has its center point close to zero too.

4.2 *Mean Square Error calculation*

Table 2 shows the computation result of the MSE. The data that are used for calculation are taken from Table 1. The mean squared error result shown in Table 2 explains that the Weight-Average of the Top-n Populated values filtering method is the best filtering method using for filtering in this experiment since its MSE = 0.12, less than the Kalman filtering convergence with MSE = 66.84.

TABLE 2. µRSS of signal strength MSE computation result.

RunOrder	Tx-Rx Separation (m.)	(A) Observation response, µRSS (dBm)	(B) Kalman filtering, RSS (dBm)	(B1) Kalman Filter Last Value (convergence)	(C)WATP , RSS (dBm)
1	6	-39.22	-36.32	-38.29	-39.65

TABLE 2. μRSS of signal strength MSE computation result (cont.).

RunOrder	Tx-Rx Separation (m.)	(A) Observation response, μRSS (dBm)	(B) Kalman filtering, RSS (dBm)	(B1) Kalman Filter Last Value (convergence)	(C)WATP , RSS (dBm)
2	8	-40.72	-36.88	-39.71	-40.96
3	2	-40.33	-36.12	-39.45	-40.21
4	10	-46.27	-41.96	-45.28	-46.25
5	4	-41.05	-38.00	-40.13	-40.00
6	2	-37.60	-34.89	-36.71	-37.57
7	4	-41.60	-37.27	-40.64	-41.18
.	.	.	.	.	.
..	..	..	..	..	..
25	6	-40.16	-36.65	-39.22	-40.44
		MSE	**13.65**	**66.84**	**0.12**

5. CONCLUSION

WiFi is widely researched for its use as locating application inside buildings. So far, due to insufficient positioning accuracy this method was considered not friendly for robotic applications.

This inaccuracy is due to the fluctuations of the WiFi signal coming out through the indoor environment where movement of people, disturbs the signal absorption. In this paper we focused on isolating a method that allows shorter but still precise data analysis. Kalman filtering is the most popular way to improve data smoothness, however it doesn't support the real time requirement of mobile robot. We conclude that the Weight-Average of the Top-n Populated values filtering method proves to be a simpler method that can provide the same accuracy as Kalman filtering, while taking less computing time. Therefore we hope that the Weight-Average of the Top-n Populated (WATP) filtering method which is a new filtering method will be more researched in future.

The signal strength issue and its effects on positioning leads current research to consider it not advisable and insufficient to use WiFi alone to locate a mobile robot inside a building. Combined with a sensor technology to compensate for the defects of WiFi a precise movement, suitable for mobile robot and inside buildings could be obtained.

References

[1] R. Tasaki, M. Kitazaki, J. Miura, and K. Terashima, “Prototype design of medical round supporting robot ‘Terapio,’” in 2015 IEEE InternationalConference on Robotics and Automation (ICRA), 2015, pp. 829–834.

[2] K. Terashima et al., “Medical Round Robot – Terapio –,” J. Robot. Mechatronics, vol. 26, no. 1, pp. 112–114, 2014.

[3] T. Rappaport, Wireless Communications: Principles and Practice, 2nd ed. Upper Saddle River, NJ, USA: Prentice Hall PTR, 2001.

[4] T. Thewan, A. H. Ismail, M. Panya and K. Terashima, “Assessment of WiFi RSS Using Design of Experiment for Mobile Robot Wireless Positioning System”, International Conference on Information Fusion, pp. 855-860, 2016.

[5] Fazli Subhan, Halabi Hasbullah, Azat Rozyyev and Sheikh Tahir Bakhsh, “Indoor positioning in bluetooth networks using fingerprinting and lateration approach”, Information Science and applicatios (ICISA), 2011 International Conference on, 1-9, 2011.

[6] Hui Liu, Houshang Darabi, Pat Banerjee and Jing Liu, “Survey of wireless indoor positioning technique and systems”, IEEE Transaction an Systems, Man, and Cybernatics, Part C (Applications and reviews) 37 (6), 1067-1080, 2007.

[7] Hakan Koyuncu and Shuang Hua Yang, “A survey of indoor positioning and object locating systems”, IJCSNS International Jounal of Computer Science and Network Security 10 (5), 121-128, 2010.

[8] Steffen, “Homedale::Wi-Fi / WLAN Monitor.” [Online]. Available at: http://thesz.diecru.eu/content/homedale.php. [Accessed: 08-Dec-2015].

[9] C. Ververidis and G. C. Polyzos, “Mobile Marketing Using a Location Based Service,” Communication. 2002.

[10]S. Fu, Z. Hou, and G. Yang, “An indoor navigation system for autonomous mobile robot using wireless sensor network,” in 2009 International Conference on Networking, Sensing and Control, 2009, pp. 227–232.

[11]A.H. Ismail and K. Terashima, “Prediction of WiFi Signal using Kalman Filter for Fingerprinting-based Mobile Robot Wireless Positioning System”, Journal of Telecommunication, Electronics and Computer Engineering, Vol. 10 (1-15), pp. 17:21, 2018.