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A Study of WLAN RSSI Based Distance Measurement Using EEMD

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Abstract—Received Signal Strength Indicator (RSSI) was deemed that it is not applicable for WLAN localization directly, as it is highly influenced by environment and limited by the measurement device. This distortion must be avoided to improve RSSI based distance measurement accuracy. Some method has been introduced to achieve this purpose such as Statistical Mean Value Model (SMVM) and Gauss Model (GM). This paper studies a new method namely Ensemble Empirical Mode Decomposition (EEMD) to process RSSI. A WLAN infrastructure includes one transmitter and one receiver was setup in outdoor and indoor environment to evaluate the performance of this method. The experiment consists of two aspects of transmitter movement reproduction and error analysis followed by a performance comparison with other well-known existing methods. Based on the experiment result, EEMD can efficiently normalize the RSSI reading related to distance and reproduce the movement of transmitter. In addition, EEMD presented more valid accuracy in outdoor environment than indoor environment.

Keywords—RSSI; EMD; EEMD; Localization; WLAN;

I. INTRODUCTION

The Global Positioning System (GPS) is a well-known location technology that used in location based service (LBS) such as Google Map GPS is reliable and accurate in most conditions. However, GPS is still limited by the environment condition like indoor and urban canyons. With mobile communication technology rapidly developed, the market requires a ‘bridge’ to close the gap and reduces the cost of GPS. In the past few years, with the widely using of WLAN technology the Wi-Fi positioning system (WPS) has been discussed. WPS relies on WLAN infrastructure to implement signal measurement and convert measurement information to geographical location by using propagation model or empirical model [1, 2]. Received Signal Strength Indicator (RSSI) is a parameter that presents measured signal in any of the WLAN device. However, RSSI is not a suitable candidate for a localization parameter because the RSSI reading is highly influenced by environment and device internal noise. Fig.1 demonstrates a typical RSSI reading from a device [3].

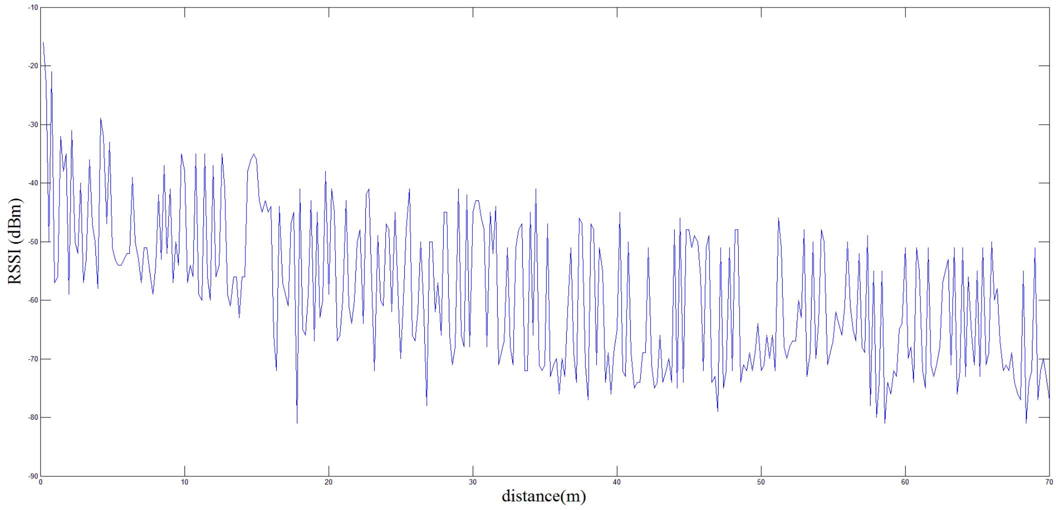

Fig. 1: A Typical RSSI Reading

In order to adopt the RSSI to determine the distance, the instability of RSSI must be avoided. There are some data process method has been introduced for RSSI: Statistical Mean Value Model (SMVM) and Gauss Model (GM) [4]. This paper proposed a method to process RSSI data by using Ensemble Empirical Mode Decomposition (EEMD) and this method can eliminate the influence by the environment and device. In this paper, some experiments were carried out to examined the proposed method and compare with SMVM and GM methods. In the rest of this paper, section II introduces the RSSI model, SMVM method, GM method and the proposed EEMD method; Section III discusses the test bed scenario. The experiment result and discussion is given in section IV and Section V draws the conclusion.

II. METHODOLOGY

A. Received Signal Strength Indicator

Although RSSI uses dBm as unit, but RSSI does not present the received power directly. It is calculated by the Wi-Fi device based on the received power, device sensitivity and calculation mechanism. Therefore, the RSSI readings are significant different from different Wi-Fi chipset [5]. Despite all, RSSI still follows the shadowing model [6] which is widely used in wireless signal propagation:

$$P_r(d)_{dBm} = P_r(d_0)_{dBm} - 10nlog_{10}\left(\frac{d}{d_0}\right) + X_{dBm} \tag{1}$$

Where d is the distance between transmitter and receiver, P_r is the received signal power or RSSI, X is a Gaussian distributed random variable with 0 mean value, d_0 is the reference distance which is usually 1m and n is the path loss exponent which makes the Eq. 1 suitable for different propagation condition like multipath reflection. Typically, $2 \le n < 4$ is for outdoor environment and $4 \le n \le 6$ is for indoor environment. When use 1m as the reference distance, the Eq. 1 can be simplified as following:

$$P_r(d)_{dBm} = A_{dBm} - 10nlog_{10}(d) + X_{dBm} \tag{2}$$

where A is the received signal power at 1m.

As mentioned above, different Wi-Fi chipsets have different RSSI reading, therefore the value of A is determined by the chipset. If a method can avoid the instability of RSSI, the X can be removed from Eq.2. Thus, this equation can be further simplified as:

$$P_r(d)_{dBm} = A_{dBm} - 10nlog_{10}(d) \tag{3}$$

The Eq.3 has a clear relationship between received signal power or RSSI and distance and it can be used to implement the RSSI based location.

B. Statistical Mean Value Model (SMVM)

Using statistical mean value model, a set of unknown RSSI value is divided into several groups with group size m. the mean value of each group consists of a new set of RSSI value.

$$Set_i = \{RSSI_1, RSSI_2, RSSI_3, \dots\dots, RSSI_i\} \tag{4}$$

$$Set_j = \left\{\frac{1}{m}\sum_{j=1}^{m} RSSI_j, \frac{1}{m}\sum_{j=m+1}^{2m+1} RSSI_j, \dots\dots, \frac{1}{m}\sum_{j=i-m}^{i} RSSI_j\right\} \tag{5}$$

If there is enough sample in Set_i , a bigger group size m can make the new RSSI Set_j much more stable and keep certain accuracy at the same time. Therefore, a large simple size or a high RSSI measurement rate is required to achieve this method.

C. Gauss Model

In a set of unknown RSSI value, some values are small probability events and some other values are high probability events based on Gaussian distribution principle. Therefore, the Gauss model can be used to abandon the small probability events so that improves the accuracy.

$$f(RSSI) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{(RSSI-m)^2}{2\sigma^2}} \tag{6}$$

$$m = \frac{1}{n}\sum_{i=1}^{n} RSSI_i \tag{7}$$

$$\sigma^2 = \frac{1}{n-1}\sum_{i=1}^{n}(RSSI_i - m)^2 \tag{8}$$

$$k \le f(RSSI) \le 1 \tag{9}$$

The k is the critical point for RSSI value selection. When the $RSSI_i \in Set_i$ from Eq.4 can fulfil with Eq. 9, this RSSI value is selected into new RSSI set_j. The accuracy can be changed by adjusting the critical point k. Similarly, in statistical mean value model, Gauss model requires large sample size as well.

D. Principle of EMD and EEMD

Empirical Mode Decomposition (EMD) is a data analysis method which is developed on an assumption that signal consists of different simple intrinsic oscillations or intrinsic mode functions (*IMFs*). Therefore, EMD decompose a signal (S_n) into a series of IMFs and a residue (r_n) [7].

$$S_n = \sum_{k=1}^{N} imf_{k,n} + r_n \tag{10}$$

For IMFs, they must satisfy two conditions:

- In the whole data set, the number of extrema and the number of zero-crossings must either be equal or differ at most by one.
- At any point, the mean value of the envelope defined by the local maxima and the envelope defined by the local minima is zero.

  This process is implemented by shifting using local extrema point and the shifting follows the steps below:

  a) Find out the local maximum and minimum points and use these point to obtain upper and lower envelop by using cubic spline;
  b) Obtain the mean value h for upper and lower envelop;
  c) Treat h as a new signal and repeat step a and b till the h meets the two IMF conditions;
  d) Set the final h as one imf_i and subtract it from the original signal and get a new signal r_j
  e) Repeat above steps to r_j

This process is repeated until the last residue r_n becomes a constant or monotonic function.

An improved EMD method is called Ensemble Empirical Mode Decomposition (EEMD) to avoid the mode mixing problem in EMD. The mode mixing which leads to fitting error of upper and lower envelop is occurring when the investigated signal cannot provide enough uniform distributed local extrema [8]. To avoid mode mixing, EEMD adds uniform distributed white noise into the signal and the process is [9]:

1) Add a white noise series to the signal;
2) decompose the data with added white noise into IMFs;
3) Repeat step 1 and step 2, but with different white noise series
4) Obtain the means of corresponding IMFs of the decompositions as the final result

By using EEMD, two parameters must be set: the number of ensemble (*N*) and the amplitude of added white noise (*a*) which is also represented as the standard deviation ratio (α) between added noise ($\mathcal{E}_n$) and original signal ($\mathcal{E}_o$). The relationship between final standard deviation of error ($\mathcal{E}_e$) and the number of ensemble is shown in Eq.12.

$$\alpha = \frac{\varepsilon_n}{\varepsilon_o} \quad (11)$$

$$\ln \varepsilon_e + \frac{\alpha}{2} \ln N = 0 \quad (12)$$

To avoid the mode fixing, the added noise amplitude cannot be too small to contribute to the local extrema of investigated signal. In other words, the added noise should not affect high-frequency components but have to change distribution of low-frequency components [10]. However, a large number of ensembles can reduce the added noise effect to a negligibly level. Therefore, the number of ensemble set to a few hundred can keep the EEMD efficiency. In addition, in order to reduce the contribution which made by added noise to the decomposed components, the number of ensemble should be increased with the added noise amplitude increasing. In most case, the amplitude standard deviation of added noise be 0.2 the standard deviation of the investigated signal [11]. In other words, α should be chosen around 0.2 and higher for low-frequency dominated investigated signal or lower for high-frequency dominated investigated signal.

E. *RSSI Processing by Using EEMD*

From Eq.2, it is clear that RSSI consists of a monotonic function which is $A\text{-}10n\log_{10}(d)$, a random altered variable *X* and oscillated noise which is from environment condition and devices. As mentioned above, EEMD can decompose a signal into IMFs and a residue. Moreover, the monotonic residue is match with the feature of RSSI value. Therefore, the idea is apply EEMD to RSSI and select the residue as the final result.

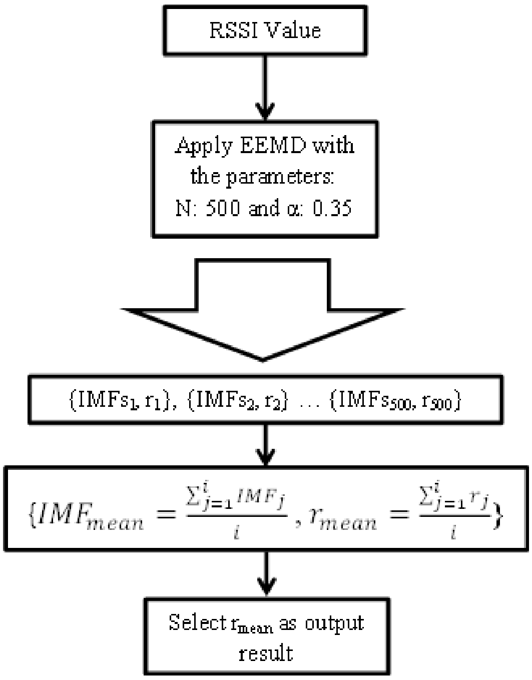

Fig. 2: The RSSI Processing Using EEMD Method

Fig. 2 shows the RSSI processing using EEMD method with number of ensemble as 500 times and the standard deviation ratio (α) between added noise and original signal as 0.35.

III. EXPERIMENT TEST BED

In this paper, some experiments are conducted for comparing EEMD with other methods in movement reproduction, and error analysis aspects. All data were collected by using the same equipment either in outdoor and indoor environment. .

The test bed was established at CRIN on Lv22, the Tower Building of UTS for indoor test and Jones Street, Sydney for outdoor test. The environment is demonstrated in Fig. 3.

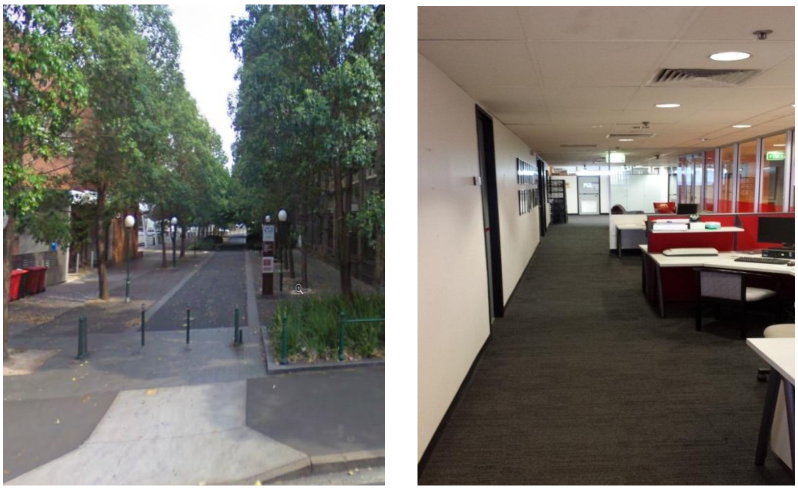

Fig. 3: The View of Jones Street (Google Map) and CRIN

One *ALFA* and *EDIMAX* USB Wi-Fi adapter was installed on two *HP* laptops which were used as receiver and transmitter respectively. The details are shown in the Table I.

Table I: The Experiment Equipment

	Type	Chipset	Antenna Gain	Sensitivity/Transmit Power
Receiver	*ALFA AWUS036H*	Realtek RTL8187L	2dBi	-93dBm/ -
Transmitter	*EDIMAX EW-7318USg*	Ralink RT2571WF	4dBi	- /17dBm ± 2dBm

IV. Experiment Result and Discussion

A. Reference Point RSSI Determination

As the 1m reference RSSI is determined by environment and devices, therefore the value should be measured for above experiment conditions. 70 RSSI values at 1m distance were collected in outdoor and indoor condition and the result is presented in Table. II.

Table II: The 1m Reference RSSI

	Maximum Value	Minimum Value	Average Value	Standard Deviation
Outdoor	-7dBm	-9dBm	-8.024dBm	0.410
indoor	-8dBm	-67dBm	-17.471dBm	16.599

Based on the measurement result, the value of A_{dBm} from Eq.3 has been set to -8.024 for outdoor condition and -17.471 for indoor condition and 2.4 and 4.5 are selected as the path loss exponent for indoor and outdoor condition, respectively. Thus, the Eq.3 can be rewritten as:

For outdoor condition

$$P_r(d)_{dBm} = -8.024 - 24log_{10}(d) \quad (13)$$

For indoor condition

$$P_r(d)_{dBm} = -17.471 - 45log_{10}(d) \quad (14)$$

B. The Movement Reproduction

In this experiment, transmitter moved around 60m continually along a straight line from the position fixed receiver. At the same time, the receiver measures and collects the RSSI values. Three methods SMVM, GM and EEMD were used to process collected RSSI values and Eq.13 was selected to calculate the distance as this experiment was carried out in outdoor. In addition, this experiment provides two different sample sizes: 117 RSSI value and 60 RSSI values for same movement. The parameters *k, m* in Eq.5 and Eq.9 are set to 0.6 and 3 respectively.

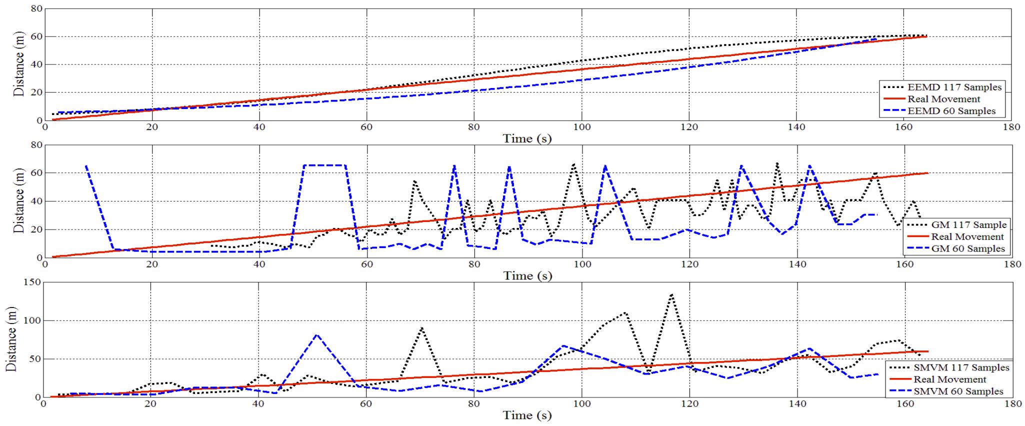

Figure 4: The Experiment Results Processed by EEMD, GM and SMVM

Table III: The Correlation of Between Real Movement and Processed Result

	120 samples	60 samples
EEMD	0.9938	0.9754
GM	0.6979	0.1299
SMVM	0.6033	0.4942

In Fig. 4 red solid line is the real distance change between transmitter and receiver, blue dot line is the processed result for 60 RSSI sample size and black dash line is the processed result for 117 RSSI sample size. The Table.III shows the correlation of each result and the value in the table is correlation coefficients. Correlation coefficients give value 1 means total correlation and value 0 means total independence. From the figure and table, it is clear that the result obtained by using EEMD method presents higher reducibility for transmitter movement. It is the closest to the red line and is the smoothest result compared with others. On the other hand, the result obtained by using GM method has the weakest reducibility and SMVM method has the highest distance error.

C. EEMD Method Error Analysis

In this experiment, RSSI values were collected from 1.5m to 30 with 0.5m increment in outdoor environment and from 1.5m to 20m with 0.5m increment in indoor environment. The collected data and processed result for each point is presented in Fig. 5.

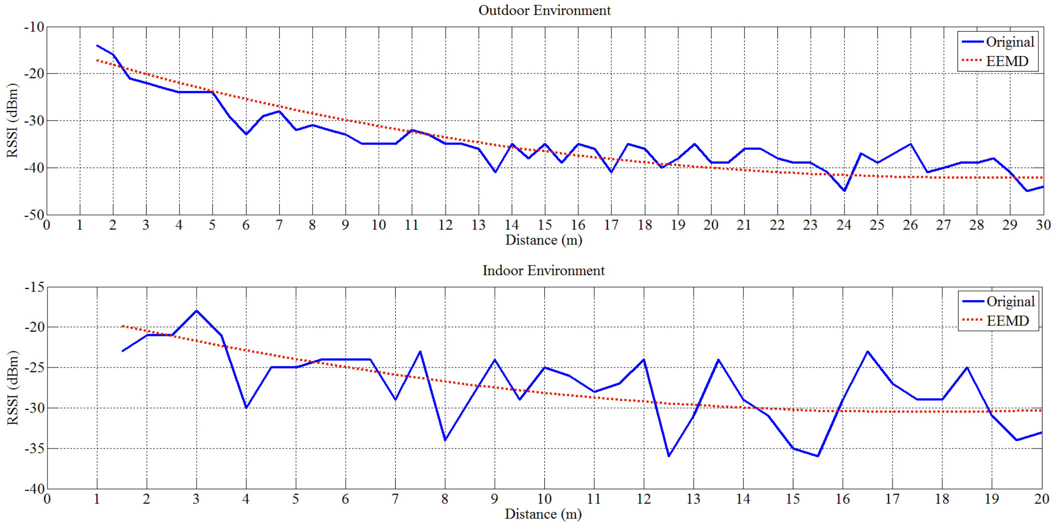

Figure 5: The RSSI Values for Outdoor and Indoor Environment

In Fig. 5 the red dot line is the processed RSSI values by using EEMD and solid line is the original RSSI values. Then, apply Eq. 13 and Eq. 14 to the processed data to calculate the distance and compare with the recorded distance to obtain the error which is demonstrated in the Fig. 6 and Table. IV. For SMVM and GM, they are not valid for this experiment as they merge/abandon lots of points which can/cannot meet the conditions. Moreover, there is no chance in a localization processing for a method to abandon or merge points. Therefore, the comparison would not to be conducted.

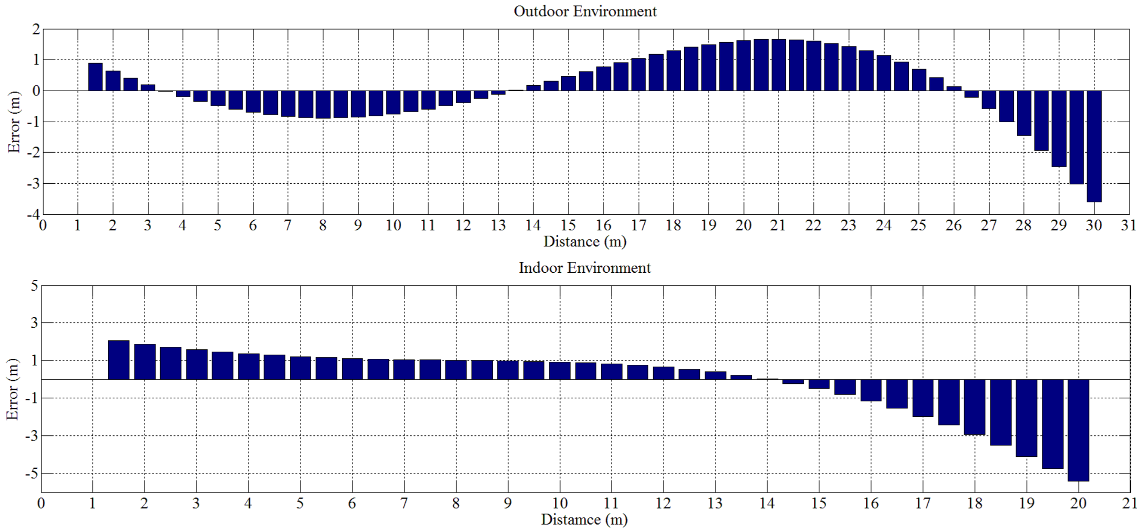

Figure 6: The Error for Outdoor and Indoor Environment

Table IV: The Result of Error Analysis

	Maximum Error	Minimum Error	Average Error	Standard Deviation
Outdoor Environment	3.606m	0.016m	0.947m	0.702
Indoor Environment	5.411m	0.019m	1.485m	5.412

EEMD is a method aim to process the data entirety instead of any individual data. Thereby, the error is not affected by distance directly. The experiment result cannot point out the error at a specific distance but it shows EEMD can reduce the error within 3.6m under outdoor condition and 5.4m under indoor condition.

V. CONCLUSION

In this paper, the EEMD has been introduced into RSSI processing. Based on EEMD principle, it focuses on the feature of whole data set instead of any individual one inside. It is applicable for the RSSI reading in a period of time. Compare with other methods like SMVM and GM, EEMD can efficiently avoid the vibratility of the RSSI value change with distance. An RSSI to distance equation which is for one specific Wi-Fi device also has been discussed. After applying the equation to the EEMD processed RSSI, the result presented 0.947m average error for outdoor condition and 1.485m average error for indoor condition. Therefore, EEMD method is more applicable to outdoor RSSI based localization.

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