A New Received Signal Strength Based Location Estimation Scheme for Wireless Sensor Network

Yu-Yi Cheng, *Member*, IEEE and Yi-Yuan Lin

Abstract-*The two-step indoor location estimation method based on received signal strength in wireless sensor network is proposed. Measuring the received signal strength* (*RSS*) *of radio signals transmitted by multiple training points in wireless sensor network, least-squares approach has been applied to determine parameters of signal propagation model. Consider the estimated parameters of the signal propagation model obtained in the first step, minimum mean squares error*(*MMSE*) *method is applied to estimate the position of target node. Experiment results show that the proposed method has good performance.*

Index Terms-location estimation method, received signal strength, wireless sensor network

I.INTRODUCTION

Wireless sensor networks are widely used in the safety monitor application, e-Health environment, energy management, and home automation control…etc. For these applications, Location Based Service (LBS), especially indoor wireless positioning system that locates physical assets and people, is an innovation technology that has received increasing attention[1-2]. For instance, patient monitors in the hospital are needed for doctors. When a patient that is not in the sickroom needs to help, doctors can know where the patient is via positioning system and give him assistance immediately.

Many location estimation methods have been proposed in the literature. There are three general categories of location estimation algorithms. The first is time based location estimation, e.g., time of arrival (TOA) [3], time difference of arrival (TDOA) [4]. The second is direction based location estimation, such as angle of arrival (AOA) or direction of arrival (DOA) [5]. A third category of location method is received signal strength (RSS) based location approach [6-8]. Based on the signal traveling time between target node and fixed nodes in wireless sensor network, the distance between them is estimated by TOA (or TDOA) location method. The estimation result derived by this method has good accuracy; however, precise timing synchronization is needed. The signal direction of transmitted signal from a target node can be estimated by AOA method. This method doesn't need timing synchronization. However, this technique is complicated because the hardware for a fixed node requires antenna array in order to derive the direction information of target node.

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Based on received power measured by the fixed nodes that the locations are known, the RSS location method provides location information of target node. Compare with other location technique (time and direction based location method described above), the main drawback of RSS-based method has lower location accuracy. Although this, RSS-based location method is suitable used in wireless sensor networks because some system constraints, such as miniature hardware size and lower battery power, should be considered for the practical application in wireless sensor networks. Now the RSS location techniques can be directly applied to wireless sensor networks based on IEEE 802.15.4 standard [9] since the low-complexity hardware for measurement of RSS is readily available in these systems.

For indoor wireless channel environment, the high accuracy of location estimation isn't achieved easily because the multipath propagation and non line of sight (NLOS) condition. Consider the RSS-based estimation method, the location accuracy depends on the radio propagation model that defined the relationship among received signal power, distance between target node and fixed node, and signal path-loss factor. Refer to typical values of path-loss factor shown in the literature, [6-7] setup the value before performing proposed location algorithm. Although efficient, in fact, path-loss factor depends on practical deploy environment of wireless sensor network. [8] proposed the estimated methods, which can determine parameters of the radio propagation model from measurement power. In this paper, the new two-step location estimation based on RSS is proposed. The features of the proposed method are: 1)unlike [6,7], for our proposed method, the parameters for signal propagation model can be estimated that don't be randomly assumed, 2)unlike [10], the equal distances between fixed nodes are not needed. The sensor nodes are installed flexible for proposed approach. The first step for proposed two-step location method is that the parameters of radio propagation model are estimated by least-squares approach. Based on the results obtained in the first step, the location of target node is estimated by minimum mean squares error (MMSE) algorithm. From the experimental results, the proposed method can achieve good performance with lower computation complexity. The estimation error for target node location is less 1 m.

II.LOCATION ESTIMATION METHOD

A.THE PARAMETERS ESTIMATION FOR SIGNAL PROPAGATION MODEL

In this section, the first step that estimated parameters of signal propagation model is proposed. Assuming the N fixed nodes for wireless sensor network are located at (x_i, y_i),

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i=1,…,N. At sampling time T_s, the target node transmits the power P_t, and the power that each fixed nodes received is P_{r_i}. Let $\mathbf{P} = \begin{bmatrix} P_{r_1} & P_{r_2} & \cdots & P_{r_N} \end{bmatrix}^T$. The simple signal propagation model is given by [11]

$$P_{r_0} - P_{r_i} = 10\varepsilon \log(\frac{d_i}{d_0}) + v_i \quad i=1,\ldots,N \qquad (1)$$

where P_{r_0} is the signal power received at reference point. d_i is the distance between the fixed nodes and target node, and d_0 is the distance between target node and reference point. In general, d_0 is assumed to be 1 m. ε is the path-loss parameter, and $v_i \sim N(0, \sigma_v^2)$ is Gaussian random variable representing lognormal shadowing effects in indoor multipath environments.

In order to estimate parameters of signal propagation model, some training points are set in the wireless sensor network system. Consider a wireless sensor network system for location estimation shown in Fig.1, for the sake for briefly, we assume one training point that the known position (x_0, y_0) is located in wireless sensor network system. Let the received power measured by each fixed node is known, and $d_i = \sqrt{(x_i - x_0)^2 + (y_i - y_0)^2}$ where d_i is the distance between the fixed nodes and training point. From (1) and d_0=1 m , we have

$$\begin{bmatrix} P_{r_1} \\ P_{r_2} \\ \vdots \\ P_{r_N} \end{bmatrix} = \begin{bmatrix} 1 & -10\log d_1 \\ 1 & -10\log d_2 \\ \vdots & \vdots \\ 1 & -10\log d_N \end{bmatrix} \begin{bmatrix} P_{r_0} \\ \varepsilon \end{bmatrix} + \begin{bmatrix} v_1 \\ v_2 \\ \vdots \\ v_N \end{bmatrix} = \mathbf{DC} \qquad (2)$$

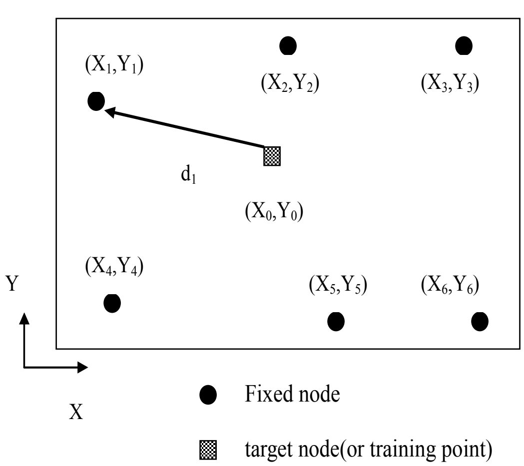

Fig.1. A wireless sensor network for location estimation

By least-squares approach[12], we have

$$\mathbf{C} = (\mathbf{D}^T\mathbf{D})^{-1}\mathbf{D}^T\mathbf{P} \qquad (3)$$

The parameters for signal propagation model, P_{r_0} andε, are obtained from vector **C** shown in Eq.(3). Here the number of training points is increased, the computation results for P_{r_0} andεhave higher accuracy.

B.MMSE LOCATION ESTIMATION

Based on the estimated parameters of signal propagation model derived in the first step, the location of target node is estimated in the second step. Assuming the sampling duration time for power signal is T (ms), and the number of sampling point in this duration is M. The sample period between each sampling point is T_s. Let the location of target node at mT_s is (X_m,Y_m), and the distance between target node and i-th fixed node is $d_i^{(m)} = \sqrt{(X_m - x_i)^2 + (Y_m - y_i)^2}$ .We define $P_i^{(m)} = P_{r_0}^{(m)} - P_{r_i}^{(m)}$, i=1,...,N , m=1,...,M, and $\mathbf{a}^{(m)} = \begin{bmatrix} X_m & Y_m \end{bmatrix}^T$. Then Eq.(1) can be rewritten as follows:

$$\begin{aligned} P_i^{(m)} &= 10\varepsilon \log(d_i^{(m)}) + v_i^{(m)} \\ &= f_i(\mathbf{a}^{(m)}) + v_i^{(m)} \end{aligned} \qquad (4)$$

Staking N equations shown in Eq.(4), the vector form is expressed in Eq.(5)

$$\widetilde{\mathbf{P}}^{(m)} = \mathbf{f}(\mathbf{a}^{(m)}) + \mathbf{v}^{(m)} \qquad (5)$$

Here $\mathbf{v} = \begin{bmatrix} v_1^{(m)} & v_2^{(m)} & \cdots & v_N^{(m)} \end{bmatrix}^T$, $\widetilde{\mathbf{P}}^{(m)} = \begin{bmatrix} P_1^{(m)}(\mathbf{a}^{(m)}) & P_2^{(m)}(\mathbf{a}^{(m)}) & \cdots & P_N^{(m)}(\mathbf{a}^{(m)}) \end{bmatrix}^T$,and $\mathbf{f}(\mathbf{a}^{(m)}) = \begin{bmatrix} f_1(\mathbf{a}^{(m)}) & f_2(\mathbf{a}^{(m)}) & \cdots & f_N(\mathbf{a}^{(m)}) \end{bmatrix}^T$. $\mathbf{f}(\mathbf{a}^{(m)})$ is a vector that the elements $f_1(\mathbf{a}^{(m)})$,…,$f_N(\mathbf{a}^{(m)})$ are non-linear functions. Using the first-order Taylor series expansion, the linearize equation for Eq.(5) is shown as follows:

$$\mathbf{f}(\mathbf{a}^{(m)}) \approx \mathbf{f}(\mathbf{a}_0^{(m)}) + \mathbf{J}^{(m)}(\mathbf{a}^{(m)} - \mathbf{a}_0^{(m)}) \qquad (6)$$

where $\mathbf{a}_0^{(m)} = \begin{bmatrix} X_0^{(m)} & Y_0^{(m)} \end{bmatrix}^T$ is a random initial estimated vector of $\mathbf{a}^{(m)}$. The initial estimated position falls into the cover region of wireless sensor network. $\mathbf{J}^{(m)}$ is a Jacobian matrix that the elements of $\mathbf{J}^{(m)}$ are $\mathbf{J}_{i,j}^{(m)} = \frac{\partial f_i(\mathbf{a}^{(m)})}{\partial a_{j1}}\Big|_{\mathbf{a}=\mathbf{a}_0^{(m)}}$.

Combining Eq.(5) and (6), we have

$$\widetilde{\mathbf{P}}^{(m)} = \mathbf{f}(\mathbf{a}_0^{(m)}) + \mathbf{J}^{(m)}(\mathbf{a}^{(m)} - \mathbf{a}_0^{(m)}) + \mathbf{v}^{(m)} \qquad (7)$$

Let $\mathbf{u}^{(m)} = \widetilde{\mathbf{P}}^{(m)} - \mathbf{f}(\mathbf{a}_0^{(m)}) + \mathbf{J}^{(m)}\mathbf{a}_0^{(m)}$. Using MMSE approach[12], the error function is shown in Eq.(8)

$$e(\hat{\mathbf{a}}^{(m)}) = E[\left|\mathbf{u}^{(m)} - \mathbf{J}^{(m)}\hat{\mathbf{a}}^{(m)}\right|^2] \quad (8)$$

where $\hat{\mathbf{a}}^{(m)} = \begin{bmatrix}\hat{X}_m & \hat{Y}_m\end{bmatrix}^T$ is the estimated vector of $\mathbf{a}^{(m)}$. $\hat{\mathbf{a}}^{(m)}$ can be computed by Eq.(9)

$$\hat{\mathbf{a}}^{(m)} = \mathbf{J}^{(m)+}\mathbf{R}_{\mathbf{u}}(\mathbf{u}^{(m)+})^T \quad (9)$$

in which $\mathbf{R}_{\mathbf{u}} = E[\mathbf{u}\mathbf{u}^T] = \frac{1}{M}\sum_{m=1}^{M}\mathbf{u}^{(m)}\mathbf{u}^{(m)T}$, $\mathbf{J}^{(m)+}$ and $\mathbf{u}^{(m)+}$ are pseudo-inverse matrix of $\mathbf{J}^{(m)}$ and $\mathbf{u}^{(m)}$ respectively. In order to obtain optimum solution of estimated location, the iteration method can be used. By iteration algorithm, the present location estimated vector can be the initial estimated vector for next iteration. That is,

$$\widetilde{\mathbf{P}}^{(m)} = \mathbf{f}(\mathbf{a}_k^{(m)}) + \mathbf{J}_k^{(m)}(\mathbf{a}_{k+1}^{(m)} - \mathbf{a}_k^{(m)}) + \mathbf{v}^{(m)} \quad (10)$$

where $\mathbf{a}_k^{(m)}$ and $\mathbf{J}_k^{(m)}$ are the location vector and Jacobian matrix at k-th iteration respectively. Based on the same procedure described above, $\mathbf{u}_k^{(m)} = \widetilde{\mathbf{P}}^{(m)} - \mathbf{f}(\mathbf{a}_k^{(m)}) + \mathbf{J}_k^{(m)}\mathbf{a}_k^{(m)}$. The estimated location vector that converges to a certain location $\hat{\mathbf{a}}_{k+1}^{(m)}$ at the k+1-th iteration can be formulated as follows:

$$\hat{\mathbf{a}}_{k+1}^{(m)} = \mathbf{J}_k^{(m)+}\mathbf{R}_{\mathbf{u}_k}(\mathbf{u}_k^{(m)+})^T \quad (11)$$

III. EXPERIMENTAL RESULTS

In our department, the wireless sensor network is deployed to evaluate the performance of our proposed method. The IP-Link 2220 Zigbee modules that produced by Helicomm Inc. are installed in the first floor. The area in the first floor is 300 m^2. Two types of fixed nodes, client node and master node, are installed in the position system. The master node is connected to computer(or server). Measuring received power that the signal transmitted from the target node, client nodes installed at ceiling send received signal strength index(RSSI) to master node. The proposed location algorithm estimates the target location and this result is shown in the screen. The number of fixed nodes is 16. One is master node, others are client nodes. The number of signal sampling point M is 16. The distance between each client node is not the same. The number of training points that are deployed in the wireless sensor network covered area is 100. The location of all client nodes and some training points on the floor plan are shown in Fig.2. In order to derive the position of target node, the parameters of signal propagation model should be estimated first. Based on signal strength measured by fixed nodes and the proposed method shown in section II-A, the path-loss parameter ε and received signal power at reference point P_{r_0} can be estimated. The estimated results are ε=3.17 and P_{r_0} =-11 dBm.

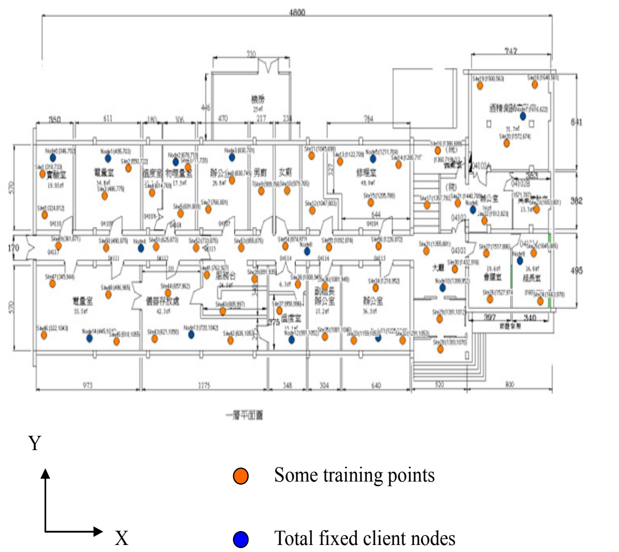

Fig.2 The locations of training points and client nodes on the floor plan

After the parameters ε and P_{r_0} have been estimated in the first step, the training points are totally removed. Using signal strength measured by client nodes and the estimated results for ε and P_{r_0} , the location of target node can be

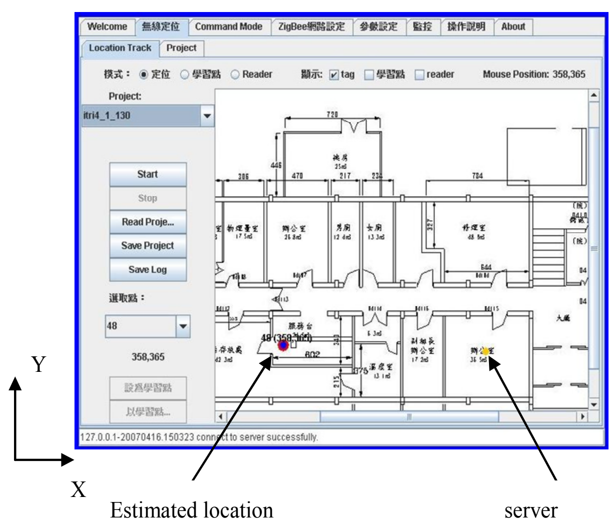

Fig.3 Experimental result for location estimation of target node

estimated in the second step. In this case, the condition that forces the iterative computation procedure to be stopped is $\left|e(\hat{\mathbf{a}}_{k+1}^{(m)}) - e(\hat{\mathbf{a}}_k^{(m)})\right| < 0.05$. The experimental result is shown in Fig.3. Here the unit of x-y axis shown in Fig.3 is "point". The distance between each point is 0.055 m. In order to evaluate the performance of our proposed method for this case, the distance estimation error is defined in Eq.(12):

$$error \equiv \sqrt{((X-\hat{X})\times 0.055)^2 + ((Y-\hat{Y})\times 0.055)^2} \quad (12)$$

where (X,Y) and $(\hat{X},\hat{Y})$ are real and estimated position of target node respectively. In Fig.3, the location of target node is (381,357). Performing our proposed algorithm, the estimated location is (358,365) and the distance estimation error is 0.6 m. The experimental result shows that our proposed algorithm can achieve good performance.

In order to investigate the computation complexity of our proposed method, for various iteration numbers, the experimental results for location error are shown in Fig.4. Here the different iteration number is set to perform the proposed algorithm in the second step. In this case, the location method referred to Reference[2] provides a baseline for comparison. The location of target node is (635,372). The initial value of (X,Y) that used in the second step for proposed algorithm is (500,200). The unit of X-Y axis is defined previously. The location error (distance) is defined as $\left|d-\hat{d}\right|/d$, where real distance $d \equiv \sqrt{X^2 - Y^2}$, and $\hat{d}$ is estimated distance value. Otherwise, Refer to the definition of location error shown above, the estimated error for X and Y can be defined. For our proposed method, only with 3 iterations, the estimated error can be reduced

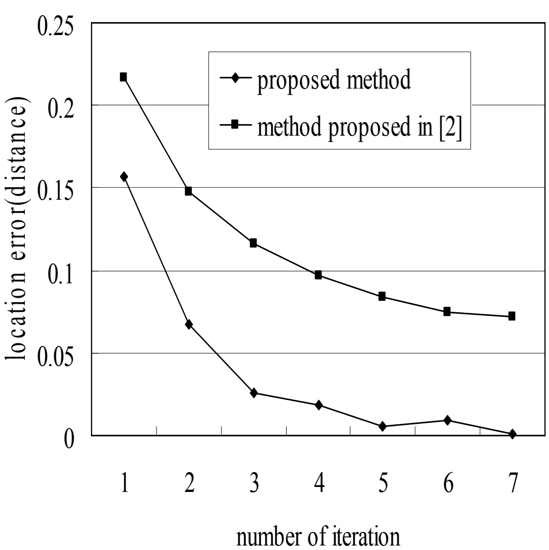

Fig.4 The location error vs. number of iteration for different location algorithms

below 5%. Based on this experiment results, our proposed method has good performance without much computation time.

Fixed the number of iterations, Fig.5 shows the location estimation performance of proposed method that the number of fixed node varied. In this case, the location methods referred to Reference[2] and CC2431 (location engine provided by Chipcon[13]) provide a baseline for comparison. Consider the completeness of our experiment, except for the distance error, the location error of X and Y is also presented. The location estimation performance and computation complexity of proposed algorithm depend on the number of fixed node. However, because of signal reflection and multipath propagation effect, the received signal strength for some fixed nodes is weaker then threshold value. For IP-Link 2220 Zigbee modules, the threshold value of received signal strength is setting to -95 dBm. If received signal strength of fixed node is lower then threshold value, the information of fixed nodes (received signal strength, X and Y position) are not adopted. For testing environment shown in this paper, the maximum number of fixed node that its measured received signal strength is larger than -95 dBm is 7. In[13], only eight received signal strength indices (RSSI) are chosen to perform the location algorithm. From Fig. 5, for proposed location method, the experimental results show that when the number of fixed node is larger than 5, the estimation errors for X and Y are less than 5%. Consider the location methods proposed in[2] and [13], the location errors for X and Y are less than 10% when the number of fixed node is larger than 9. Choose the threshold value appropriately, the proposed algorithm can achieve good performance with lower computation time.

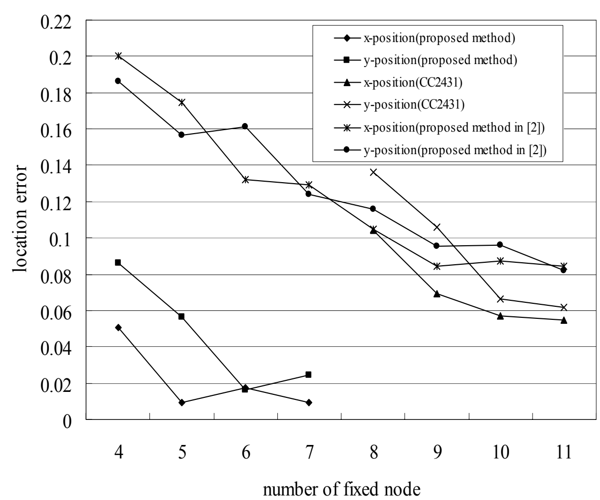

Fig.5 The location error vs. number of fixed node for different location methods

V. CONCLUSION

The new two-step location estimation method that used in wireless sensor network is proposed in this paper. The environment parameters for signal propagation model are fist estimated by least-squares method. Using MMSE approach, the location of target node can be estimated. Performing the algorithm in the physical environment and comparing with another location methods, experimental results show that the proposed approach can achieve high location estimation accuracy without high computation complexity.

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