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Development of Indoor Positioning and Location Based Information Test Bed*

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ABSTRACT

There are many applications using Global Navigation Satellites System (GNSS) as their navigation and guidance sensors. However, these applications are limited by the reception of GNSS signal. When the GNSS signal strength is weak or the signal is blocked in certain environments, for example, indoor area, these applications might not be able to provide the positioning information. Therefore, this paper develops a Wireless Sensor Network (WSN) positioning system to provide users the positioning information in the indoor area. As part of this work, this paper also develops an indoor Geographic Information System (GIS) which can provide users some information based on their locations. This paper uses the Department of Aeronautics and Astronautics building of National Cheng Kung University as an example to demonstrate the developed positioning and location based information test bed.

Keywords: Indoor positioning, Location based service (LBS), Wireless sensor network (WSN), Geographic information system (GIS)

I. INTRODUCTION

Nowadays the Global Navigation Satellite System (GNSS) can provide a certain accurate positioning service for users. Since the signals transmitted from the GNSS satellites will be blocked or reflected by the buildings in some crowded areas, and it will produce the multipath which affects the positioning result. In indoor circumstances, the signal strength of GNSS is too low to position. There are many researches focusing on how to find the possible solutions for the indoor cases [1-4]. Among them, the advantages of using the Wireless Sensor Network (WSN) are the mobility and the low cost, and the advantages of using the ZigBee radio are the low power consumption and the flexibility. Therefore, this paper uses WSN with ZigBee radio to provide an indoor positioning solution.

This paper uses two kinds of WSN positioning methods including the Received Signal Strength (RSS) triangular positioning method and the fingerprinting positioning method. In order to use the RSS triangular positioning method to estimate the user position, the distance between the transmitter and the receiver must be determined first [4]. Therefore, the simplified path-loss model [5] is utilized to represent the relationship between the RSS and the propagation distance. On the other hand, the fingerprinting positioning method does not use the signal model, but it needs to establish the fingerprinting database before it can be used for positioning. Both WSN indoor positioning methods are able to estimate the user's position, and the advantages and drawbacks of these methods will be discussed later on in this paper.

The second objective of this paper is to integrate the indoor positioning system with the Geographic Information System (GIS) which will be based on the Virtual Reality Modeling Language (VRML) for a three-dimension (3D) map [6] to provide a prototype Location Based Service (LBS) system. The Department of Aeronautics and Astronautics building of National Cheng Kung University is used as an example to demonstrate the developed system.

Accordingly, this paper is organized as follows: the

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discussions of the concept and the algorithm of the WSN indoor positioning methods are given in Section II. In Section III, we explain the development of the LBS system. A description and analysis of the experimental results are given in Section IV. Section V presents the conclusions.

II. INDOOR POSITIONING METHODS

The RSS positioning method is one of the solutions to implement the WSN indoor positioning system. The main idea of the RSS positioning method is that the signal strength decays as the transmitting distance increases. Two RSS indoor positioning methods are developed based on this characteristic and they are the RSS triangular positioning method and the fingerprinting positioning method. This paper first introduces their algorithms and then discusses the positioning performance of these two positioning methods based on the experiment results.

The RSS triangular positioning method is to estimate the user position by obtaining the distance between the receiver and the transmitter. If the relationship of the signal strength loss and the propagation distance can be established, we can measure the RSS value to estimate the distance between the transmitter and the receiver. The simplified path-loss model [5] is used in this paper to represent the relationship between the signal strength decay and the transmitting distance. The simplified path-loss model is shown in Equation (1) [5].

$$P_r(d) = P_t + K - 10\gamma \log_{10}(d/d_0) - \psi_{dB} \tag{1}$$

where, d is distance between the transmitter and the receiver, d_0 is the reference distance, $P_r(d)$ is the RSS value of the receiver, P_t is the transmitting power, K is a unitless constant that depends on the antenna characteristics and the average channel attenuation, γ is the path loss exponent, and ψ_{dB} is a Gauss-distributed random variable with mean zero and variance $\sigma^2_{\psi_{dB}}$ [5]. To use this model to estimate the distance between the transmitter and the receiver, the path loss exponent must be determined first. This paper implements the self parameter determination algorithm to estimate the path loss exponent [7]. The self parameter determination algorithm calculates the appropriate path loss exponent by the Minimum Mean Square Error (MMSE) method [8]. The procedure of the self-parameter-determination algorithm is as follows:

Step 1: The constant K can be obtained by measurement at d_0 using $K = P_r(d_0)/P_t$ [5]. In order to estimate $P_r(d_0)$, an appropriate reference distance, d_0, is selected to measure the RSS value at d_0 [5].

Step 2: Implement the MMSE error equation for the dB power measurements as

$$\begin{aligned} &F(\gamma) \\ &= \sum_{i=1}^{N}\left[P_{r,measured}(d_i) - P_{r,model}(d_i)\right]^2 \\ &= \sum_{i=1}^{N}\left[P_{r,measured}(d_i) - \left(P_t + K - 10\gamma\log_{10}(d/d_0)\right)\right]^2 \end{aligned} \tag{2}$$

where, $P_{r,measured}(d_i)$ is the RSS measurements at distance d_i, $P_{r,model}(d_i)$ is the path loss at d_i based on Equation (1), and N is the total number of measurements.

Step 3: Find γ to minimize Equation (2) by differentiating $F(\gamma)$ relative to γ and setting it to zero yields the path-loss exponent (i.e. γ) of the simplified path-loss model.

$$\frac{\partial F(\gamma)}{\partial \gamma} = 0 \tag{3}$$

Step 4: Determine the variance $\sigma^2_{\psi_{dB}}$ for the shadow fading by calculating the measurements deviations from the simplified path-loss model as

$$\begin{aligned} &\sigma^2_{\psi_{dB}} \\ &= \frac{1}{N}\sum_{i=1}^{N}\left[P_{r,measured}(d_i) - P_{r,model}(d_i)\right]^2 \\ &= \frac{1}{N}\sum_{i=1}^{N}\left[P_{r,measured}(d_i) - \left(P_t + K - 10\gamma\log_{10}(d/d_0)\right)\right]^2 \end{aligned} \tag{4}$$

By the self-parameter-determination algorithm, all the parameters in Equation (1) have been determined. As long as the user receives the RSS value from the transmitter, the distance between the user receiver and transmitter can be estimated by Equation (5).

$$d = d_0 \times 10^{\frac{(P_r(d) - P_t - K)}{10\gamma}} \tag{5}$$

After estimating the distances, the triangulation technique is used for estimating the user position. One of the popular triangulation techniques is the Iterative Least Square (ILS) method [9]. The main idea of the ILS method is to linearize a non-linear equation and to estimate the result by the iterative calculations. The ILS technique takes the first order of the Taylor expansion in the linearization process, and the higher order terms are neglected. It works well in the far field cases such as GNSS. However, the ILS technique can't be used for the indoor positioning because the distance between the transmitter and the receiver is relatively short. Therefore, this paper used the Quadratic ILS (QILS) method [10] to estimate the user position. The QILS not only takes the first order term but also takes the second order term of the Taylor expansion to estimate the user position in the indoor scenario. The procedures of the QILS are shown below:

Take the two-dimensional (2D) plane as an example, if there are N reference points, the position of the i^{th} reference point is presented by (x_i, y_i). The user is at position (x_u, y_u), and the distance between the reference point and the user position can be expressed as Equation (6).

$$d_i = \sqrt{(x_u - x_i)^2 + (y_u - y_i)^2} \tag{6}$$

At first we guess the user's position at (x_0, y_0) and generally the geometric center of the distributed ZigBee radio transmitters is used as the initial guess of (x_0, y_0). These distributed ZigBee radio transmitters are at precise known locations. As a result, the Equation (6) is linearized and the procedures can be shown in Equations (7) to (10).

$$\hat{d}_i = \sqrt{(x_0 - x_i)^2 + (y_0 - y_i)^2} \tag{7}$$

$$\delta\hat{d}_i = \nabla d_i(x_i, y_i) + \nabla^2 d_i(x_i, y_i) \tag{8}$$

$$\nabla d_i(x_i, y_i) = \begin{bmatrix} \frac{(x_0 - x_i)}{d_i} & \frac{(y_0 - y_i)}{d_i} \end{bmatrix} \begin{bmatrix} \delta x \\ \delta y \end{bmatrix} = H \cdot \delta\hat{u} \tag{9}$$

$$\begin{aligned} &\nabla^2 d_i(x_i, y_i) \\ &= \frac{1}{2} \begin{bmatrix} \delta x \\ \delta y \end{bmatrix}^T \begin{bmatrix} \frac{\partial^2 d}{\partial x_i^2} & \frac{\partial^2 d}{\partial x_i \partial y_i} \\ \frac{\partial^2 d}{\partial x_i \partial y_i} & \frac{\partial^2 d}{\partial y_i^2} \end{bmatrix} \begin{bmatrix} \delta x \\ \delta y \end{bmatrix} \\ &= \frac{1}{2d_i^3} \begin{bmatrix} \delta x_i \\ \delta y_i \end{bmatrix}^T \begin{bmatrix} (x_0 - x_i)^2 & -(x_0 - x_i)(y_0 - y_i) \\ -(x_0 - x_i)(y_0 - y_i) & (y_0 - y_i)^2 \end{bmatrix} \begin{bmatrix} \delta x_i \\ \delta y_i \end{bmatrix} \\ &= G \cdot \delta\hat{u} \end{aligned} \tag{10}$$

By substituting Equation (9) and Equation (10) into Equation (8), a equation is obtained and shown in Equation (11),

$$\delta\hat{d} = H \cdot \delta\hat{u} + G \cdot \delta\hat{u} = (H + G) \cdot \delta\hat{u} = Z \cdot \delta\hat{u} \tag{11}$$

and rearrange the Equation (11) into (12)

$$\delta\hat{u} = (Z^T Z)^{-1} Z^T \delta\hat{d} \tag{12}$$

Through iterative update and to calculate until that the value of Equation (12) approaches zero, and finally the user's position can be estimated. Figure 1 summarizes the RSS triangular indoor positioning method based on WSN.

The advantage of the RSS triangular positioning method is that it only needs to determine the parameters of the path-loss model before positioning. However, the path-loss parameters are different under different environments. Once the path-loss model is not the proper one, the positioning results estimated by the RSS triangular positioning method may not be reliable.

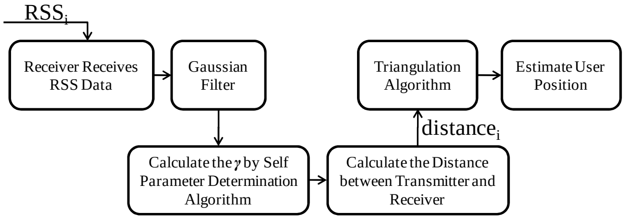

Figure 1 The flow chart of the RSS triangular indoor positioning method based on WSN

On the other hand, there are many researches focusing on the other positioning method, the fingerprinting positioning method. The fingerprinting positioning method includes two steps for positioning and the first one is to establish the database. In order to build the database of the fingerprint of all the calibration points, the RSS values of each calibration point from the nodes (i.e., wireless sensors) have to be measured. Secondly, when the RSS values are received by the user receiver, they will be compared with the fingerprinting database to find the nearest point, and this nearest point will be the estimated location of the user. The fingerprinting positioning method used in this paper is the Nearest Neighbors in Signal Space (NNSS) algorithm. This NNSS positioning algorithm uses the decision distances to find the user location, and it calculates the decision distances according to the stored RSS value in the fingerprinting database and the received RSS value of the user. After calculating all the decision distances, the shortest decision distance can be found. Finally the user position can be determined by the position with the shortest decision distance which recorded in the fingerprinting database. The equation used to calculate the decision distance is shown as follows,

$$d_q = \frac{1}{N} \left(\sum_{i=1}^{N} \left| u(i) - k(i) \right|^p \right)^{\frac{1}{p}} \tag{13}$$

where d is the decision distance, N is the numbers of the total transmitters, $u(i)$ is the user received RSS value from the i^{th} transmitter, $k(i)$ is the RSS value of the i^{th} transmitter which recorded in the fingerprinting database, q is the calibration point, and p represents the characteristic between the distance and user position and this paper uses the Euclidean distance (p=2). For example, if there is a case with 9 transmitters and 25 grid points, the size of the database is 25-by-9. After constructing the fingerprinting database, the user can use the fingerprinting positioning method to position. For instance, if the user receiver receives the RSS value from each transmitter, then user can obtain 25 decision distances by Equation (13). Finally, the estimated user position is the position corresponding to the shortest decision distance in the database. The flow chart of the fingerprinting indoor positioning method based on WSN is shown in Figure 2. The positioning accuracy of the fingerprinting positioning method strongly depends on the number of the calibration points. Similar to the RSS triangular positioning method, the database is different under the different environments. If we want to construct a more precise positioning system by the fingerprinting positioning method, it may increase the cost of the system development.

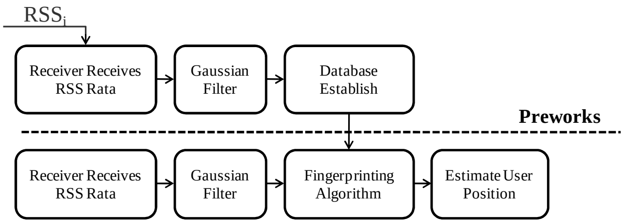

Figure 2 The flow chart of the fingerprinting indoor positioning method based on WSN

III. LOCATION BASED SERVICE

This paper develops a prototype Location Based Service (LBS) system for users by integrating the indoor positioning system with the indoor 3D Geographic Information System (GIS). The first step of this 3D GIS development is to set the goal of this system, and to determine the requirement of this system. With the system goal, we collect all the information required for this system, such as the name of the streets, and the size of the building, etc. For the different systems, the additional information might be required. With this information, we can construct the map of this system. If there are accessible maps, such as Google Map API, it will reduce the time of the map development. For some local area, these commercial maps usually could not provide the detail information adequately to meet our requirements, such as the floor information inside buildings. This involved developing our own maps to fulfill our requirements. Take the 3D GIS of the Department of Aeronautics and Astronautics building of National Cheng Kung University as an example, once the detail information of this building is obtained, the Computer Aided Design (CAD) is used to draw the 3D maps. This paper utilizes the CATIA® to generate this 3D map. In order to combine the developed 3D GIS with other applications, such as Visual Basic, C++ Builder, the format of the 3D GIS file has to be changed. In this paper, the file format of the maps is changed to "wrl" format to meet the standard of the Virtual Reality Modeling Language (VRML). The virtual reality means that users can use the computer to simulate and construct a virtual world that the viewing angle can be selected by users. In addition, users can make interaction with the objects in the virtual world [11]. The last step is to use the VRML player to display the 3D GIS information. If users want to view this 3D GIS, the users must install some specific VRML viewers. In this paper, we use the Cosmo player as our viewer; the Cosmo player has several control buttons including zoom, pan, rotate, etc. The flow chart of the 3D GIS development is summarized in Figure 3. Figure 4 shows one example of the developed 3D GIS in this paper. Finally, this paper blends the developed indoor positioning system with the developed indoor 3D GIS to form a prototype LBS system.

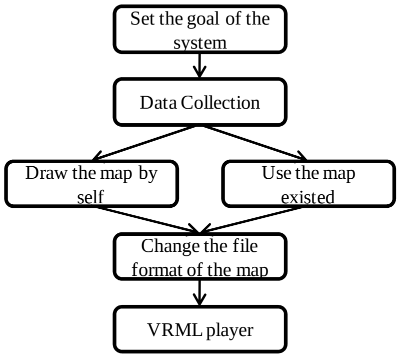

Figure 3 The flow chart of the 3D GIS development

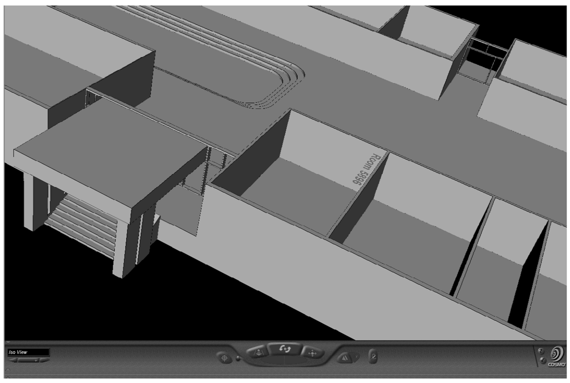

Figure 4 The developed 3D GIS of this paper

IV. EXPERIMENTAL RESULTS

The wireless sensors used in this paper are the ZigBee wireless modules. These wireless modules can be treated as receivers or transmitters in the constructed WSN. A gateway is used to connect the wireless receiver to the personal computer. When one wireless module is set as a transmitter, the Radio Frequency (RF) chip of this wireless module can broadcast the signal to all the receivers. In contrast, when one wireless module is acted as a receiver, the RF chip of this wireless module indicates the signal strength which will be used to measure the RSS values. Moreover, the ZigBee wireless modules used in this paper includes the time stamp information. With this time stamp, when the receiver receives the signal from the transmitter, it will calculate its RSS value of this transmitter-receiver pair, and it can also obtain the transmitted time associated with this RSS measurement. The architecture of the WSN used in this paper is depicted in Figure 5. In Figure 5, there is one receiver which receives the signals from multiple transmitters, and this receiver can indicate the RSS values from multiple transmitters. The RSS data and the time stamp information are sent to a personal computer via the USB port and they are used for positioning. Additionally, the synchronization between the transmitters and receiver must be considered for a positioning system. In this paper, we use the time stamps from all transmitting nodes to solve this problem. When the user receives the RSS values from all the transmitters, the synchronization mechanism will ensure that the time difference between the transmitted time stamps of all transmitter are less than 0.1 second. If time differences between these time stamps are greater than 0.1 second, then these RSS values can't be used for positioning. Once the synchronized RSS values are obtained, the indoor positioning techniques can be executed. Finally the location of the user can be estimated.

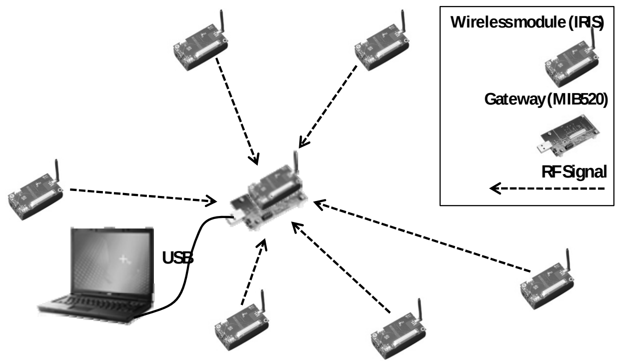

Figure 5 The architecture of the WSN

In this paper, the classroom 5821 on the first floor and the hallway on the second floor of the Department of Aeronautics and Astronautics building of National Cheng Kung University are used as the experiment places. The arrangement of the ZigBee sensors in the classroom 5821 is shown in Figure 6, and all sensors are attached on the ceiling of the room. In Figure 6, we use nine sensors as the transmitting nodes, and the room is specified by twenty five calibration points. Initially, the user receiver is placed at each reference grid point and measures the RSS values from the 9 transmitting nodes. These RSS values are used to estimate the path-loss model and build the fingerprinting database. After these processes, the RSS triangular positioning method and the fingerprinting positioning method are utilized to conduct the static and dynamic experiments.

The positioning results of the static experiment using two positioning methods are shown in Figure 7. In this static experiment, the receiver is placed at the calibration point 7. In Figure 7, the plot on the left is positioning result using the RSS triangular positioning method and the plot on the right is the positioning result with the fingerprinting positioning method. As shown in Figure 7, the positioning results of this static experiment are accurate, and the mean positioning error

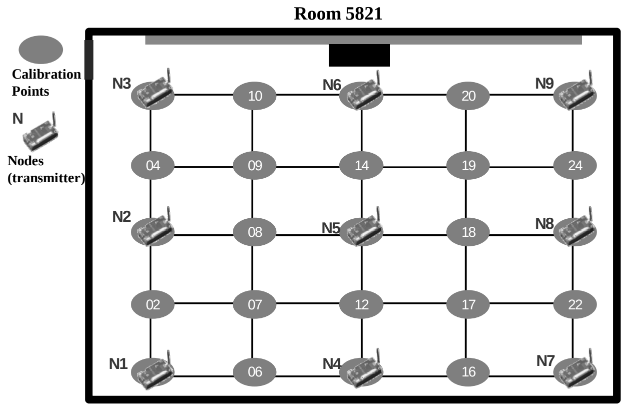

Figure 6 The arrangement of the wireless sensors in classroom 5821

of this static positioning experiment is 1.01 meters for using the RSS triangular positioning method and it is 0.00 meters for using the fingerprinting positioning method. The positioning result of the fingerprinting positioning method is perfect for this particular static experiment. In general, the mean errors of the fingerprinting positioning method for other static experiments conducted in this work are in the range of 0.50 meters. From the static experiment results, the performance of the fingerprinting positioning method is better than that of the RSS triangular positioning method.

In the dynamic experiment, the user moves straight from the calibration point 16 to the calibration point 20. The dynamic positioning results using two positioning methods are shown in Figure 8. From Figure 8, both the RSS triangular positioning results and the fingerprinting positioning results are not straight lines from the calibration points 16 to 20, but the tendency of the user can be observed from both results. Comparing these two positioning results, one can see that the performance of the fingerprinting positioning method is also better than that of the RSS triangular positioning method. Based on the results of the static and dynamic experiments, the fingerprinting positioning method outperforms the RSS triangular positioning method, but in order to use the fingerprinting positioning method one needs to build the RSS database in advance.

Figure 9 shows the positioning results combining with the developed indoor 3D GIS system. In Figure 9, the squares indicate the starting position and the end position of the user, and the circles represent the user positions in motion. From Figure 9, the trajectory of the user is similar to a straight line, and the positioning result is practically accurate. Moreover, users can quickly know where they are by the developed prototype LBS system. The virtual reality is capable to provide the information of the local environment as well. As a result, this paper successfully develops a prototype LBS system using the Department of Aeronautics and Astronautics building in National Cheng Kung University as an example.

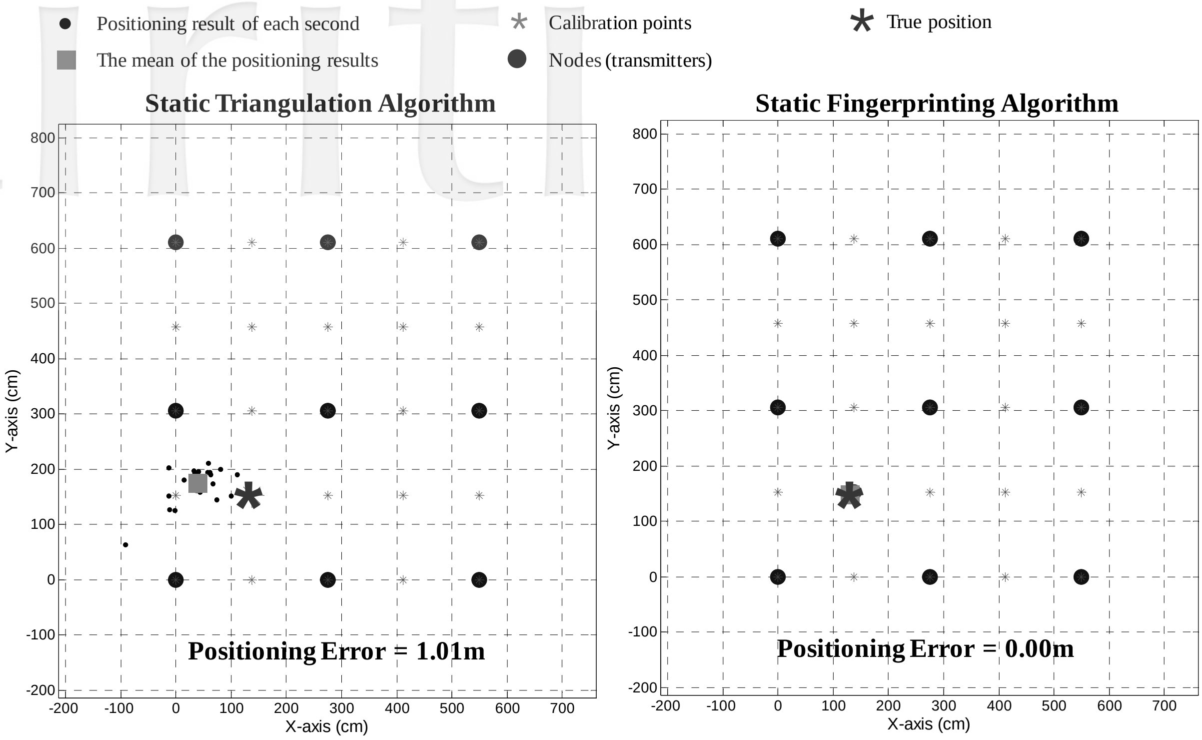

Figure 7 Increasing integration time method

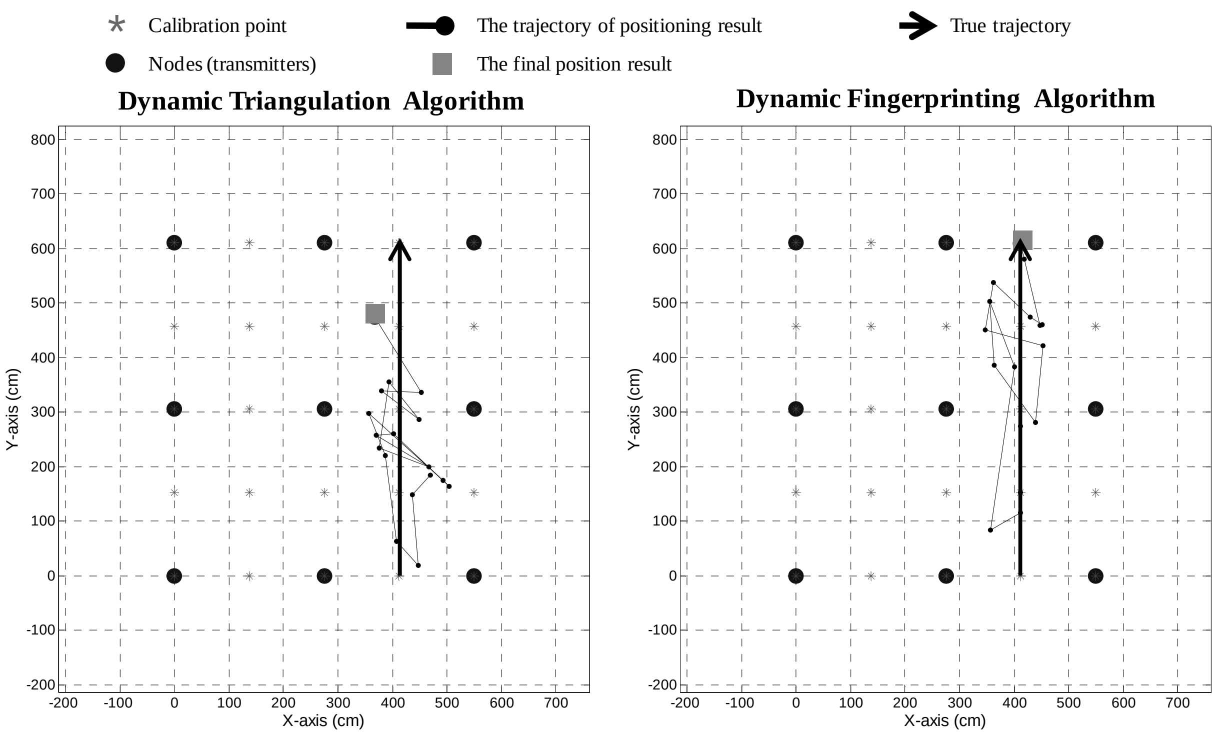

Figure 8 Increasing integration time with overlapping data method

V. CONCLUSIONS

This paper developed a prototype Location Based Service (LBS) system, and the development of this prototype LBS system included the indoor positioning system using the ZigBee Wireless Sensor Network (WSN) and the three-dimension (3D) indoor Geographic Information System (GIS). As shown in the experiment results, the WSN indoor positioning system implemented in this prototype LBS system adequately tracked the user

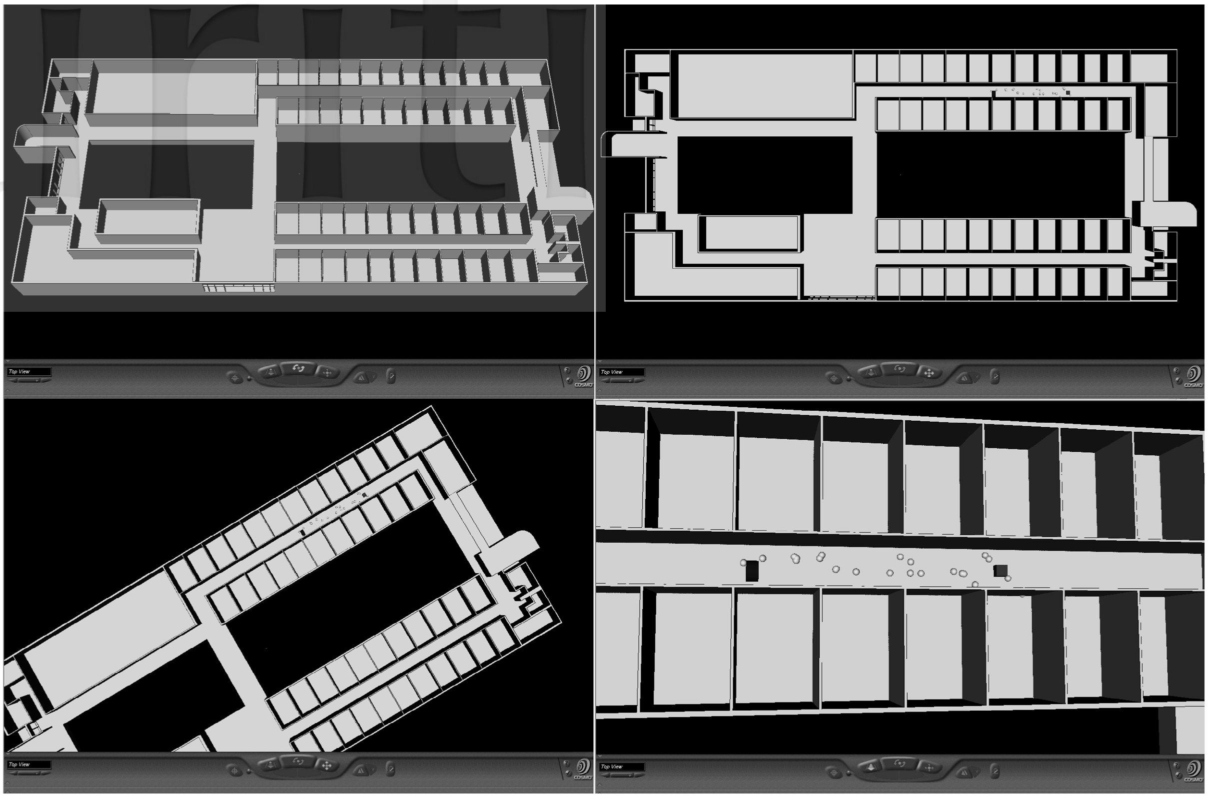

Figure 9 The outdoor signal tracking result by the standard tracking loop architecture

trajectories. This work included two positioning methods: the Received Signal Strength (RSS) triangular positioning method and the fingerprinting positioning method. This paper also applied the concept of the virtual reality to display the user position onto the developed 3D GIS. Therefore, users can interact with this prototype LBS system to obtain the local environment information.

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