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ENHANCED RSSI-BASED HIGH ACCURACY REAL-TIME USER LOCATION TRACKING SYSTEM FOR INDOOR AND OUTDOOR ENVIRONMENTS

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Abstract- Existing researches on location tracking focus either entirely on indoor or entirely on outdoor by using different devices and techniques. Several solutions have been proposed to adopt a single location sensing technology that fits in both situations. This paper aims to track a user position in both indoor and outdoor environments by using a single wireless device with minimal tracking error. RSSI (Received Signal Strength Indication) technique together with enhancement algorithms is proposed to cater this solution. The proposed RSSI-based tracking technique is divided into two main phases, namely the calibration of RSSI coefficients (deterministic phase) and the distance along with position estimation of user location by iterative trilateration (probabilistic phase). A low complexity RSSI smoothing algorithm is implemented to minimize the dynamic fluctuation of radio signal received from each reference node when the target node is moving. Experiment measurements are carried out to analyze the sensitivity of RSSI. The results reveal the feasibility of these algorithms in designing a more accurate real-time position monitoring system.

Index terms: location sensing technology, Received Signal Strength Indication, deterministic phase, iterative trilateration, probabilistic phase, smoothing algorithm, dynamic fluctuation, real-time position.

I. INTRODUCTION

Due to the maturity in the wireless technology, location-tracking of objects and people in indoor or outdoor environments has received ample attention from researchers lately. There are various methods for identifying and tracking user position such as Cricket [1], Mote Track [2] or GPS [3]. GPS offers a scalable, efficient and cost effective location services that are available to the large public. However, the satellite emitted signals cannot be exploited indoor to effectively determine the location. Due to different environmental characteristics, none of the above methods is used for tracking user in both indoor and outdoor environment using the same sensor device and sensing method. Hence, accurate estimation of location in both environments remains a longstanding difficult task.

The aim of this research is to track a user position in both indoor and outdoor environments with a minimal tracking error by incorporating a radiolocation device (CC2431 [4], Chipcon, Norway) which uses IEEE802.15.4 standard. The device possesses a location estimation capability via Received Signal Strength Indicator (RSSI). This method computes distances based on the transmitted and received signal strengths between blind node and reference nodes. Blind node, which is embedded within CC2431 location engine, will collect signals from all reference nodes responding to a request, reads out the calculated position and sends the position information to a monitoring application.

Much of the researches on RSSI are done by utilizing existing WLAN infrastructure [5, 6]. This approach is no doubt a cost effective solution, however, the uses for this WLAN suffers from the elimination of rays. Some signals are too weak to contribute in the calculation of distance and therefore, they must be eliminated from the system. Such signal elimination process is done in this radiolocation device.

As the prototype has been designed and constructed, the objective behind this work is to improve the accuracy of the system. Accuracy of location tracking system which caters the solution for hybrid environments is obligatory to ensure the effectiveness in estimating a user position. Therefore, instead of capturing the position information sent from the blind node, raw RSSI values processed by blind node are captured and sent to the monitoring application. Several refining algorithms are proposed and developed in addition to the current radiolocation's algorithm so that the error is reduced to a more acceptable level.

From application perspective, this hybrid environment tracking scheme can be utilized for various applications such as locating in-demand personnel like doctors or patients with vital sign sensor in hospital environment. It can also serve as a basis for context-aware application.

II. SYSTEM DESIGN

Figure 1 depicts the system design for this real time location tracking system. The system consists of a set of static reference nodes at preset coordinates, and a blind node carried by the mobile target. Blind node broadcasts signal to the reference nodes nearby and reference nodes reply by sending their coordinates and RSSI values at that distance back to the blind node. Blind node then selects the best eight highest RSSI signals (from -40dBm to -95dBm) to be dispatched to the base station, which is connected to a laptop, using RF transmission from CC2420 radio chip. Refining algorithm and estimation of blind node's position are implemented in the base station after the reference nodes' RSSI data ($RSSI_i$) and position information (X_i, Y_i) are received. Estimated position is continuously updated and visually represented on a monitoring application. The position information can be accessed remotely from other personal computer (PC) via Wireless LAN.

a. Deterministic Phase

Deterministic phase involves calibrating RSSI values for each reference node. In the previous studies on radio propagation patterns [7, 8] in different environments exhibits the feature of non-isotropic path loss due to the various transmission medium and direction. Therefore, there is a need for the analysis of real radio propagation pattern to cater for this irregularity. Using a blind node, raw RSSI values are collected at several predefined distances from the respective reference node at the test area where it is implemented. The calibrated values are then processed to obtain a suitable propagation constant for each reference node. Chipcon [9] specifies the following formula to compute the RSSI.

$$RSSI = -(10n \, log_{10} \, d + A) \qquad (1)$$

where n is signal propagation constant or exponent, d is the distance from sender and A is the received signal strength at 1 meter distance.

A series of calibration shows that uniform computation of signal propagation constant in order to determine the distance according to signal strength exhibits some drawbacks. This verified that different mediums (free space, glass, and wall) surrounding the reference nodes affect the signal attenuation differently. Therefore, if only a single propagation constant is used for all reference nodes, miscalculation of the distance occurs. The calibrated propagation constant takes obstacles into account and it is calculated by reversing the linear RSSI equation as shown in (1).

$$n_i = -\left(\frac{RSSI_i - A}{10\log_{10} d_i}\right) \qquad (2)$$

The value A is obtained in a no-obstacle one-meter distance signal strength measurements from the reference nodes.

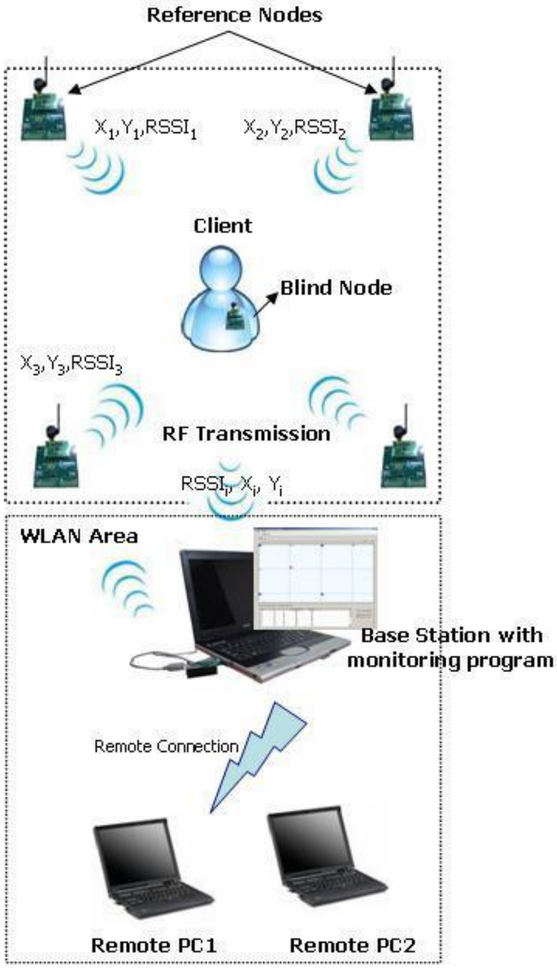


Figure 1. System architecture

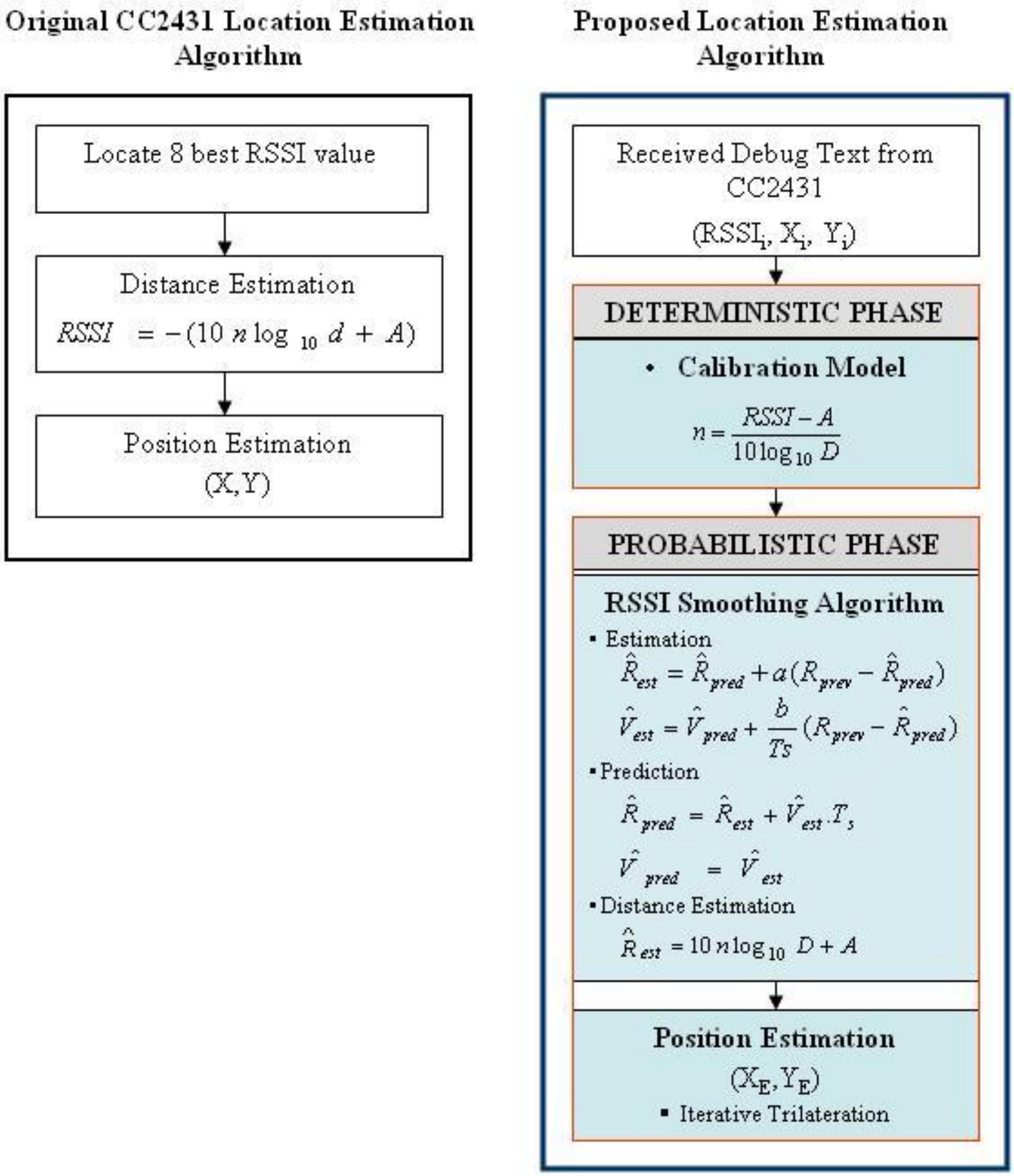


Figure 2. Refinement algorithm

b. Probabilistic Phase

Probabilistic phase involves two tasks, namely the distance estimation and the position estimation.

b.i. Distance Estimation

The main challenge in RSSI-based location tracking is its high sensitivity to the environmental changes. The vacillating nature of RSSI measurement limits the accuracy in the estimation. In other word, if the radio propagation signal strength is tightly correlated with the distance between emitter and receiver, location determination would be a trivial problem that could be solved easily. However, in practice, the relationship between signal strength and distance is not straightforward and is dynamic in nature. This happens even when the mobile target does not move and yet, signal strength varies over time. This is the nature of signal's behavior. Therefore, a low complexity smoothing algorithm is proposed to minimize the dynamic fluctuation of radio signal received from each reference node when the blind node is moving.

The method is based on the fact that the mobile user does not move arbitrarily within the testbed. There is a correlation between current positions with previous location. The basic assumption for this smoothing algorithm is that the constant velocity motion will result in constant data change rate and stationary noise processes. The selection of gains is based on the optimal trade-off between the filter coefficients and the blind node's motion change rate, so that the noise is reduced to an optimal value. The estimation stages for the smoothing algorithm used are shown as below

$$\hat{R}_{est\,(i)} = \hat{R}_{pred\,(i)} + a\left(R_{prev\,(i)} - \hat{R}_{pred\,(i)}\right) \qquad (3)$$

$$\hat{V}_{est\,(i)} = \hat{V}_{pred\,(i)} + \frac{b}{T_s}\left(R_{prev\,(i)} - \hat{R}_{pred\,(i)}\right) \qquad (4)$$

The prediction stages for the smoothing algorithm used are shown as below

$$\hat{R}_{pred\,(i+1)} = \hat{R}_{est\,(i)} + \hat{V}_{est\,(i)} T_s \qquad (5)$$

$$\hat{V}_{pred\,(i+1)} = \hat{V}_{est\,(i)} \qquad (6)$$

where $\hat{R}_{est\,(i)}$ is the *i*th smoothed estimation range, $\hat{R}_{pred\,(i)}$ is the *i*th predicted range while $R_{prev\,(i)}$ is the *i*th predicted range. $\hat{V}_{est\,(i)}$ and $\hat{V}_{pred\,(i)}$ are the *i*th smoothed estimation range rate and the *i*th predicted range rate respectively. a and b is the gain constant and T_s is time segment upon the *i*th update.

Filtered RSSI values obtained from the equations above are converted to distances using equation stated in (1) with calibrated propagation constant derived from previous phase.

b.ii. Position Estimation

To estimate the position of the blind node, at least three reference nodes in the network must be able to detect and measure the blind node's signal strength. Trilateration is a method to determine the position of an object based on simultaneous range measurements from three reference nodes at known location. Iterative method is applied to derive blind node position according to the estimated distance resolved from filtered RSSI and the calibrated constant. The algorithm requires the coordinates of at least three reference nodes (x_i,y_i) and the distances di between the blind node and the respective reference nodes, which are estimated in the previous subsection. A trivial estimated position (x_e ,y_e) is needed to start the algorithm. This estimated position represents the latest calculated position. The algorithm then calculates the difference between the measured and estimated distance by

$$|f_i = (x_e, y_e)| = \left| d_i - \sqrt{(x_i - x_e)^2 + (y_i - y_e)^2} \right| \qquad (7)$$

Applying the first degree Taylor series approximation, the adjustment (Δx, Δy) used in iteration of (x_e, y_e) can be determined using matrix calculation with the following equation

$$\Delta = (B^T B)^{-1} B^T f \qquad or \qquad \Delta = \begin{bmatrix} \Delta x \\ \Delta y \end{bmatrix} \qquad (8)$$

where B is given by

$$B = \begin{bmatrix} \frac{\partial F_1}{\partial x_e} & \frac{\partial F_1}{\partial y_e} \\ \vdots & \vdots \\ \frac{\partial F_i}{\partial x_e} & \frac{\partial F_i}{\partial y_e} \end{bmatrix} = \begin{bmatrix} \frac{(x_1 - x_e)}{\sqrt{(x_1 - x_e)^2 + (y_1 - y_e)^2}} & \frac{(y_1 - y_e)}{\sqrt{(x_1 - x_e)^2 + (y_1 - y_e)^2}} \\ \vdots & \vdots \\ \frac{(x_i - x_e)}{\sqrt{(x_i - x_e)^2 + (y_i - y_e)^2}} & \frac{(y_i - y_e)}{\sqrt{(x_i - x_e)^2 + (y_i - y_e)^2}} \end{bmatrix}$$

while f is calculated by

$$f = -\begin{bmatrix} d_1 - \sqrt{(x_1 - x_e)^2 + (y_1 - y_e)^2} \\ \vdots \\ d_i - \sqrt{(x_i - x_e)^2 + (y_i - y_e)^2} \end{bmatrix}$$

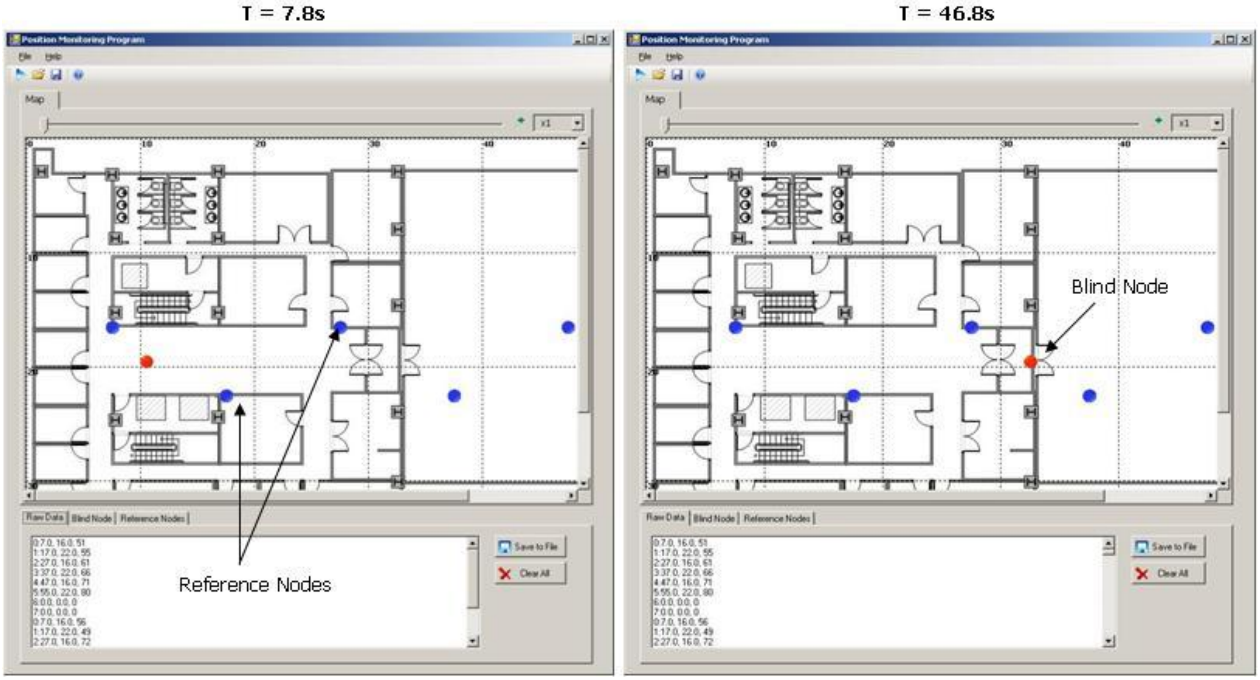
where

$$x_e = x_e + \Delta x, \qquad y_e = y_e + \Delta y \qquad (9)$$

New estimated position (x_e, y_e) is obtained by solving equation 9. The iteration continues until the error is acceptable. By calculating the mean value of the points, the final position is computed. Both CC2431 position estimation results and this iterative trilateration algorithm are analyzed to observe the improvement achieved.

III. EXPERIMENT SETUP

Experiments were carried out in a combined indoor and outdoor environment to test and validate the proposed model mentioned in previous section. Error caused by reflection due to the antenna diversity can be reduced by setting the antenna of each reference node and blind node at the angle of 90 degrees at the mounting surface. Different measurement campaigns pertinent to each parameter in the model are implemented to analyze the sensitivity of RSSI. TIP sensor node [9] which features the Chipcon CC2420 [10] radio for wireless communication is used as a base station to receive raw RSSI values from blind node. The base station is connected to a personal computer via USB serial port. In order to track the real-time position of the moving target, an application with Graphical User Interface (GUI) is developed in C# to depict the floor plan of the building. The position of the blind node is displayed as a red dot whilst the reference nodes are depicted as blue dots. A snapshot of the tracking system is shown in Figure 3. The monitoring application collects and processes the raw RSSI data received by the base station node.


T = 7.8s

T = 46.8s

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0:7.0, 16.0, 51
1:17.0, 22.0, 55
2:27.0, 16.0, 61
3:37.0, 22.0, 66
4:47.0, 16.0, 71
5:55.0, 22.0, 80
6:0.0, 0.0, 0
7:0.0, 0.0, 0
0:7.0, 16.0, 56
1:17.0, 22.0, 49
2:27.0, 16.0, 72
```

```
0:7.0, 16.0, 51
1:17.0, 22.0, 55
2:27.0, 16.0, 61
3:37.0, 22.0, 66
4:47.0, 16.0, 71
5:55.0, 22.0, 80
6:0.0, 0.0, 0
7:0.0, 0.0, 0
0:7.0, 16.0, 56
1:17.0, 22.0, 49
2:27.0, 16.0, 72
```

Figure 3. Real-time monitoring application GUI

The layout of the experiment test-bed is shown in Figure 4. The physical dimension of the indoor environment is 34m x 30m, with a corridor in the middle measuring 24.7m x 3m (see Figure 5). The outdoor environment (balcony) has a physical dimension of 29m x 27m (see Figure 6). A total of six reference nodes were placed from the corridor indoor to the balcony outdoor, in such a way that a distance of approximately 10m exists between the two nearest reference nodes. These reference nodes thus formed a rectangular test area with physical dimension of 47.5m x 3m (see Figure 4). The reference nodes in the corridor indoor were placed approximately 2.5m above the ground, whereas the reference nodes deployed in outdoor were raised at approximately 1.4m above the ground.

The experiment was conducted at a time when the interference from human activities was minimal. Before the experiment was carried out, several preparation steps were conducted. Firstly, the available radio frequency channels were scanned to avoid interference from Wireless LAN at the test area. Secondly, the blind node was rotated slowly in all orientations to examine the orientation effect. After that, the signal propagation constant was calibrated for each reference node in this experiment environment.

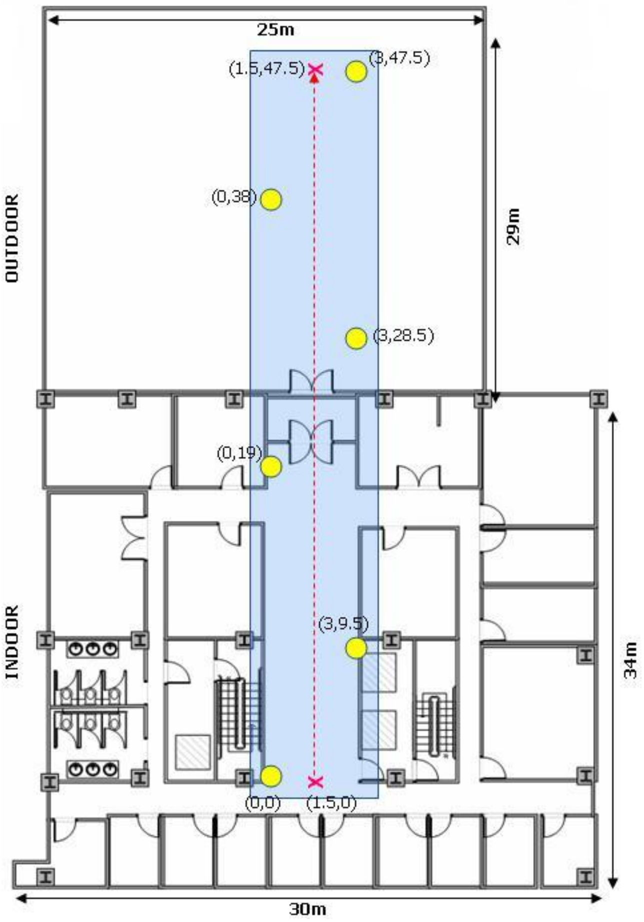

Figure 4. Layout plan of the experiment testbed

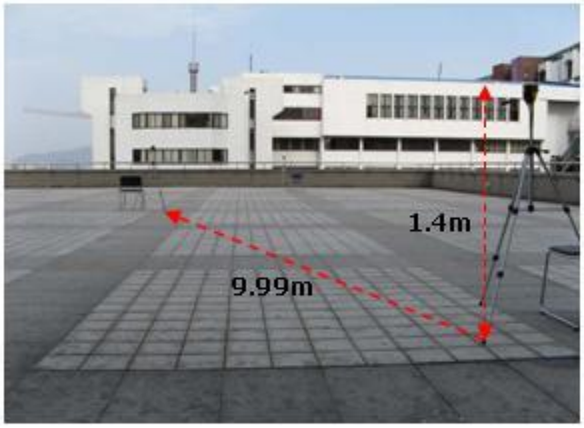

Figure 5. Outdoor testbed setup

During the experiment, a user carrying the blind node walked from an indoor starting point with coordinate (1.5, 0) to an outdoor ending point with coordinate (1.5, 47.5). The movement was tracked at real-time with 1.3 second of interval. The accuracy of the proposed system with refining algorithms was found by comparing the position estimated by this system with the predicted position calculated mathematically.

Figure 6. Indoor testbed setup

IV. RESULTS AND DISCUSSIONS

Calibration results based on several static locations reveal the drawback of uniform computation for propagation constant applied in CC2431, as the propagation constants are different for different reference nodes in the RSSI-distance conversion formula. The variation of signals is due to the difference in the attenuation of signal on the medium surrounding the reference point. In deterministic phase, RSSI values are collected at several static points in all orientation and the average data are processed to obtain the propagation constants via linear regression equation.

In Figure 7, the signal fluctuation exhibited by the blind node is significantly reduced after implementing the smoothing algorithm. Although the fluctuation still exist, the smoothing algorithm yields smoother linear curves with less extreme vacillation than before, which corresponds better with the actual blind node's motion. In the experiment, the total time spent by blind node's movement from coordinate (1.5, 0) to (1.5, 47.5) was 88.4s, in which the user was moving indoor from time 0s to 48.1s, and outdoor from 48.1s onwards.

Figure 8 shows a comparison of filtered and unfiltered distance with the predicted distance for reference node located at coordinate (0, 19) in the indoor environment and that for the reference node at coordinate (3, 28.5) in the outdoor environment. The predicted distance is computed by assuming blind node moves with a constant velocity. Result shows that the reduction of RSSI signal fluctuation corresponds more accurately with the actual blind node motion as the blind node does not change its motion rapidly The average variation of the filtered distance from the predicted distance is reduced, which implies that the accuracy is improved compared with the unfiltered data.

Figure 9 shows the comparison of position estimation for both CC2431and iterative trilateration with the predicted position. The average error of coordinates computed is around 1.7m, which is smaller than the average error of approximately 2.8m computed by CC2431. Iterative trilateration results in which the distances are computed according to the filtered signal strength reveals the effectiveness of this calculation in contributing a more accurate position.

The results obtained through the combined algorithms validate the feasibility of the proposed technique and algorithms to be applied in both indoor and outdoor environments.

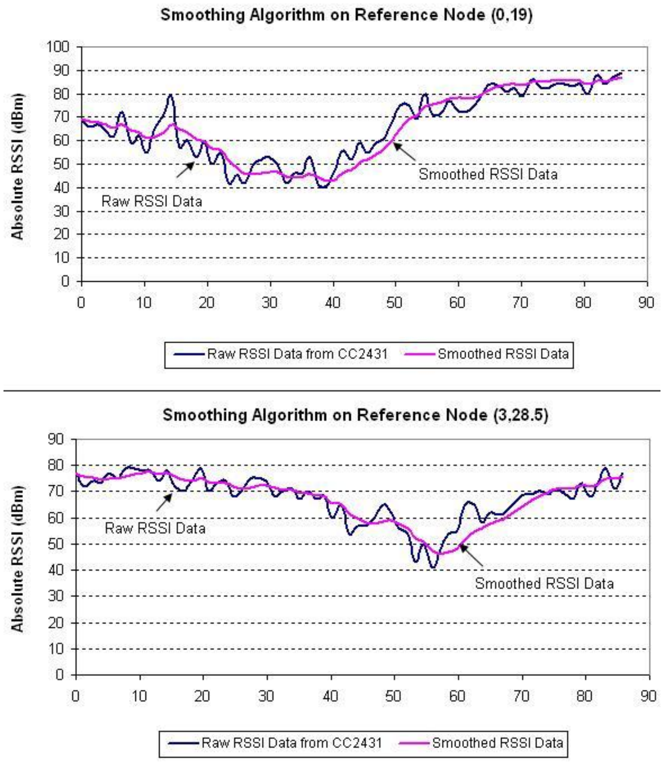

Figure 7. Smoothing algorithm applied on the raw RSSI data received from reference nodes

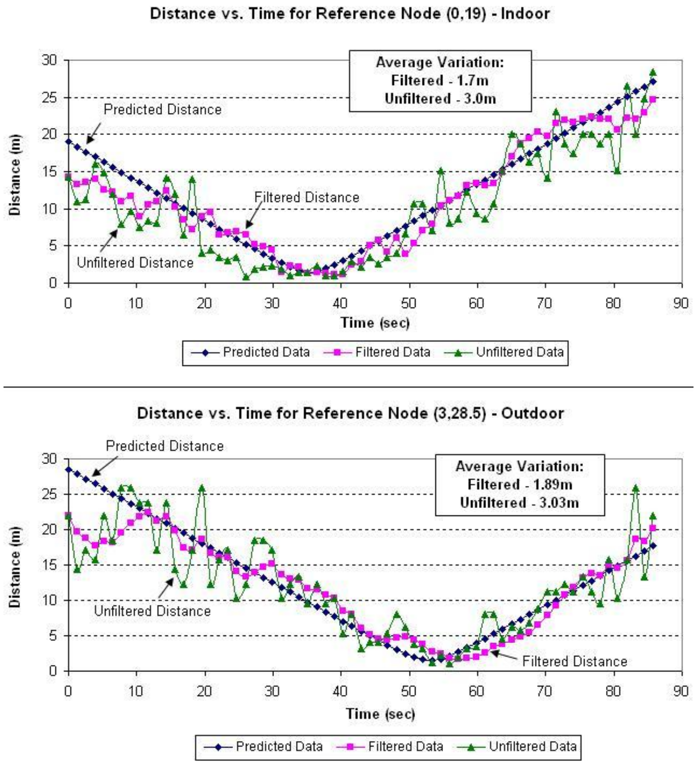

Figure 8. Comparison of distances between filtered RSSI and unfiltered data

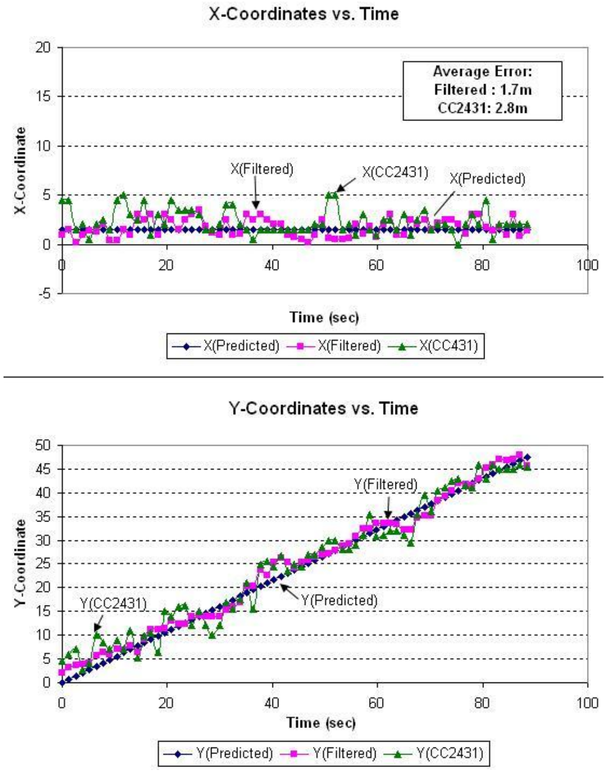

Figure 9. Comparison of location coordinates (X, Y) computed by iterative trilateration algorithm and CC2431

V. CONCLUSIONS AND FUTURE WORKS

In this paper, a real-time indoor and outdoor tracking application prototype is presented. RSSI technique is employed to estimate user's location in a hybrid of indoor and outdoor environments. Refining algorithms were proposed to improve the accuracy on tracking a mobile target and the results were evaluated. Several tests were conducted to show its improvements compared to the current CC2431 location estimation engine. Comparing with other existing RSSI-based location tracking systems [5, 11, 12], the system discussed in this paper exhibits similarity in terms of propagation constants calibration, but the smoothing algorithm is not proposed in other systems. Using this smoothing algorithm, it outperforms the other systems in terms of accuracy. Besides, due to the low complexity, the smoothing algorithm can be easily embedded in the microprocessor to filter the RSSI values. This prototype experiment is used as a proof-of-concept implementation of the proposed technique. In conclusion, the application implemented in this research provides an enhanced solution to track user position in both indoor and outdoor environments. Overall average accuracy is improved through the refining algorithms that combine the calibration of signal propagation constants, reduction of dynamic signal fluctuation and trilateration.

Experimental results from this paper indicate that good signal strength estimates can be achieved. However, considerable estimation errors at certain positions remain. A number of extensions can be studied to further improve the performance of the location estimation techniques. The study of the impact of using different propagation models such as to obtain the minimum, average and maximum RSSI signal propagation constant instead of considering only the average value and to apply the smoothing algorithm on distances instead of RSSI in location accuracy are in progress. Besides, current experiments are carried out along the hallways where all reference nodes are located at the line-of-sight to the target node. A more complicated experiment will be designed to verify the effectiveness of the proposed algorithm to be relocated to a different testbed with the same propagation model proposed in determining a user's location.

REFERENCES

[1] N. Priyantha, A. Chakaborty, H. Balakrishnan, “The Cricket Location-support System”, ACM Mobicom Conference, Boston, MA, August 2000.

[2] K. Lorincz, and M. Welsh, "MoteTrack: A Robust, Decentralized Approach to RF-Based Location Tracking", In Proceedings of the International Workshop on Location- and Context-Awareness (LoCA 2005) at Pervasive 2005, Oberpfaffenhofen, Germany, May 2005.

[3] Stoleru, R.; Tian He; Stankovic, J.A., "Walking GPS: a practical solution for localization in manually deployed wireless sensor networks," Local Computer Networks, 2004. 29th Annual IEEE International Conference on, vol., no.pp. 480- 489, 16-18 Nov. 2004.

[4] CC2431 Development Kit User Manual, http://www.chipcon.com/files/CC2431DK%20Development%20Kit%20User%20Manual_1_3.pdfhipcon.com

[5] F. Lassabe, P. Canalda, P. Chatonnay, F. Spies, “ A Friis-based Calibrated Model for WiFi Terminals Positioning”, In Proceedings of the Sixth IEEE International Symposium on a World of Wireless Mobile and Multimedia Network, 2005.

[6] Cesare Alippi, Giovanni Vanini, “A RSSI-based and Calibrated Localization Technique for Wireless Sensor Networks”, In Proceeding of the Fourth Annual IEEE International Conference on Pervasive Computing and Communications Workshops (PERCOMW’06),2006.

[7] Tereus Scott, Kui Wu, Daniel Hoffman, “Radio Propagation Patterns in Wireless Sensor Networks: New Experimental Resutls”, In Proceeding of the 2006 international conference on Communications and mobile computing IWCMC '06, July 2006.

[8] Saad Biaz, Yiming Ji, Bing Qi, Shaoen Wu, “Dynamic Signal Strength Estimates for Indoor Wireless Communications”, In Proceeding of 2005 International Conference on Wireless Communications, Networking and Mobile Computing, pp.602-605, Sept 2005.

[9] TIP Data Sheet, http://www.maxfor.co.kr

[10] Chipcon: CC2420 802.15.4 compliant radio, http://www.chipcon.com.

[11] Castano.J.G, Svensson.M, Esktrom.M, “Local Positioning for Wireless Sensors Based on Bluetooth”, In Proceeding of IEEE Radio and Wireless Conference, 2004.

[12] Ekahau Inc., http://www.ekahau.com