3D Navigation Real Time RSSI-based Indoor Tracking Application

Boon-Giin Lee, Young-Sook Lee, Wan-Young Chung

Abstract—Representation of various types of information in an interactive virtual reality environment on mobile devices had been an attractive and valuable research in this new era. Our main focus is presenting spatial indoor location sensing information in 3D perception in mind to replace the traditional 2D floor map using handheld PDA. Designation of 3D virtual reality by Virtual Reality Modeling Language (VRML) demonstrates its powerful ability in providing lots of useful positioning information for PDA user in real-time situation. Furthermore, by interpolating portal culling algorithm would reduce the 3D graphics rendering time on low power processing PDA significantly. By fully utilizing the CC2420 chip-based sensor nodes, wireless sensor network was established to locate user position based on Received Signal Strength Indication (RSSI) signals. Implementation of RSSI-based indoor tracking method is low-cost solution. However, due to signal diffraction, shadowing and multipath fading, high accuracy of sensing information is unable to obtain even though with sophisticated indoor estimation methods. Therefore, low complexity and flexible accuracy refinement algorithm was proposed to obtain high precision indoor sensing information. User indoor position is updated synchronously in virtual reality to real physical world. Moreover, assignment of magnetic compass could provide dynamic orientation information of user current viewpoint in real-time.

Index Terms—magnetic compass, RSSI, virtual reality, VRML.

1 INTRODUCTION

RECENT researches for location sensing on mobile devices had received ample attention in various industries nowadays. In order to compete between mobile technologies throughout the whole world, location sensing had always been a critical issue in achieving context-awareness as well as ubiquitous computing purposes in our daily life. Virtual reality provides stronger point by extracting the mobile user location in a more specific and attractive way, providing better viewing and valuable information to mobile user. Various researches had been conducted especially in industries and academic fields.

This research aims to deliver a feasible and practical 3D-based indoor tracking system on PDA devices. Multiple issues and challenges related to indoor environment and designated 3D user interface on PDA had been investigated to optimize the system performances. Moreover, periodically of updating 3D world with minimum rendering time on limited memory and low power processing PDA addressed a crucial creation of complex virtual reality.

Based on mobile users' perceptive, our system is extremely beneficial for various applications such as internal building mobile tourist guide, monitoring of workers inside building construction, indoor routes viewable for mobile users as well as remote navigation for other mobile users. It is more economical if multiple users are able to be track at the same time in an indoor environment.

The standardized 3D objects modeling language, VRML designed specifically for distribution of 3D graphics on World Wide Web.

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VRML possesses the abilities to present 3D objects through animated dynamic processing, provided mobile user with 3D representation of real and nature behavior relative to real physical world. Moreover, multimedia objects such as sounds and videos are capable to be implemented in VRML to increase its performance in designing an interactive 3D world. Furthermore, VRML offers faster and more user friendly high-level abstraction prior to its platform independent definition. Thus, VRML is suitable for designing 3D indoor virtual reality with high rendering speed in our system.

Various methods had been proposed for location sensing to track and identity user's position either in outdoor or indoor environments. Wide-known famous tracking method such as GPS [1] had proved its ability as outdoor tracking services using mobile devices. However, due to its insufficient and high-cost implementation, GPS is not designed specifically for indoor tracking purpose. Apparently, RF-based system, one of the tracking technologies is developed to cater the solution for indoor environment.

Recently, there exists several works for positioning system considering using the information extracted from received signal. RSSI is one of the parameter used by many researchers nowadays. Radiolocation device (CC2431 [2], Norway) uses IEEE 802.15.4 standard is incorporated to locate user's position with minimal tracking error. The device is capable for estimating user's position via RSSI signals. Blind node embedded within CC2431 location engine received signal from all reference nodes, read out measured position from location engine and sends the position to PDA application system through the base station. Trilateration method calculates mobile user's position based on continuous range measurements from at least three known position reference nodes.

Digital magnetic compass, manufactured by OPCEL [3], is capable of orientation determination, implemented in various applications such as sensor development application, mobile system and navigation system. The compass module contains patented magnetic sensor to collect magnetic field sensing information generated by earth. Compass heading thus is determined through some mathematical calculation. Our system utilized digital magnetic compass by interpolating the compass with TIP710CM for wireless communication with base station.

In first section, we had introduced the emerging of wireless sensor network to track user in indoor environment and 3D indoor scenes visualization representing the location sensing information. Secondly, system architecture is illustrated in details in Section II, follow by designation of 3D indoor virtual reality by VRML in Section III. Next, RSSI-based indoor tracking method with accuracy refinement algorithm is discussed in details in Section IV. Digital magnetic compass is illustrated in Section V. Section VI illustrates the server program installed at the server side. Explanation of experiments conducted is described in Section VII and analysis is discussed in Section VIII. Lastly, conclusion and future work are presented in details in Section IX.

2 System Design and Architecture

Our developed system used RSSI-based indoor tracking method to locate user and visualize mobile user's viewpoint in 3D virtual reality [4]. Furthermore, orientation of mobile user is taking into account by interpolating digital magnetic compass into our system. For the recorded review by future used, all necessary information such as user coordinate and print screen of virtual reality are stored in a particular server installed at specific place as demonstrated in Fig. 1. CC2431 location engine device used RSSI-based location algorithm which can be configured as either reference or blind node. CC2431 device which configures as reference node with fixed position corresponding to real physical position is attached to the ceiling in our laboratory. Higher accuracy of mobile user position can be obtained with more reference nodes assigned into our system.

Mobile user is required to hold a CC2431 device which configured as blind node and a TIP710CM sensor node with digital magnetic compass attached on it. Blind node broadcasts signals to all reference nodes to request for RSSI values. Reference nodes response by

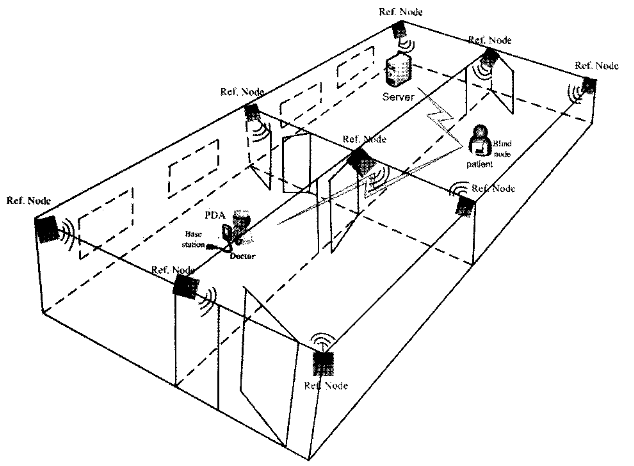

Fig. 1. System design

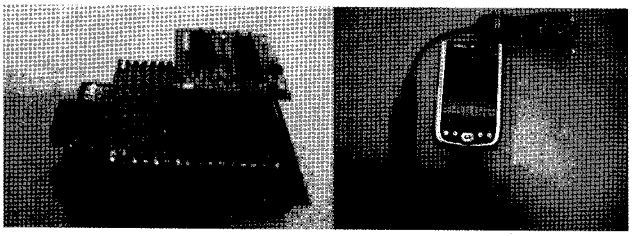

Fig. 2. Digital magnetic compass with TIP710CM attached and base station connected to PDA via RS232 serial cable

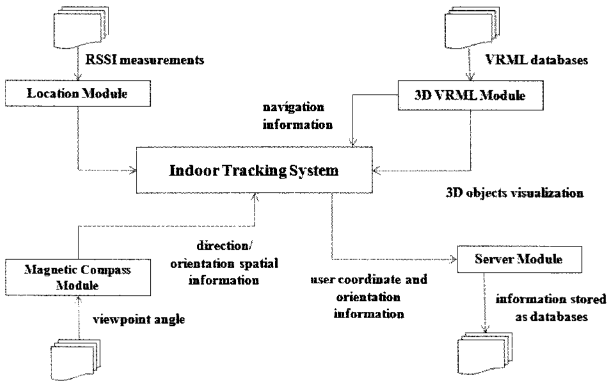

Fig. 3. System architecture

sending RSSI values along with their position back to the blind node. Blind node collects signals sent by reference nodes and selects 8 highest RSSI signals to be dispatched to base station. PDA received 8 highest RSSI signals and corresponding reference nodes position through base station connected by serial cable with RS232 interface. Digital magnetic compass sends its signal to base station independently from CC2431 devices as presented in Fig. 2.

Overview block diagram of system architecture is presented as shown in Fig. 3. Location module is devoted to manage and calculate estimated position extracted from the packet received from blind node. Meanwhile, 3D module handles VRML databases by updating 3D objects to be rendered. Next, magnetic compass module as stated is responsible to calculate user's direction. The server module is in charge of recording all the necessary information into an organized file structure to be stored in the database for future references. Lastly, indoor tracking system is in charge of collaboration between modules. In Fig. 3, by cooperation between these 5 modules, our system is able to manage large-scale of indoor environment efficiently and system performance is optimized with multiple functions provided to mobile user.

2.1 Location Module

Location module received raw data packet from blind node in a constant period. Packet is analyzed by filtering out 8 highest RSSI signals and its corresponding reference nodes. Accuracy refinement algorithm is proposed for estimating user's position based on smoothed RSSI values. The location module therefore sends the estimated position to application module to update the position in virtual reality.

2.2 Magnetic Compass Module

Magnetic compass analyzes the packets received from digital magnetic compass in real time environment. The magnetic compass reading is converted to readable values either in radian or degree format. User's orientation only been updated in 3D virtual reality periodically, to synchronize with the user's position even though magnetic compass module handles real-time updating of user orientation.

2.3 3D VRML Module

3D VRML databases are stored and managed by 3D VRML module. 3D VRML module is important as it presents the location information in virtual reality with respect to real physical environment. It has the highest responsibility to define a correct and unified virtual reality for mobile user based on the position and orientation received.

By aid of Pocket Cortona [5], our developed system is able to interact and manipulate VRML objects in VRML browser. CFCOM [6] provides an interface to allow mobile computing programming to handle VRML automation interfaces to access functionalities in VRML.

Moreover, 3D VRML module handles user request to present the location sensing information in 2D floor map or 3D virtual environment. Both 2D images and 3D graphics share the same VRML browser to utilize the resources available. 2D texture mapping will remove 3D scenes in VRML browser if user option had been changed and vice versa.

2.4 Server Module

All the user information such as position and orientation are send to the server installed at particular room through wireless sensor network.

2.5 Application Module

Application module collaborate the location, 3D VRML and magnetic compass modules to perform a high precision RSSI-based indoor tracking system with interactive 3D visualization of location sensing information using PDA.

Location and orientation spatial information received from location module and magnetic compass module respectively are passed to 3D VRML module to retrieve related 3D objects. 3D module will pass the information regarding of viewable 3D objects to application module, thus updating the VRML browser with latest mobile user's position and orientation.

3 3D Virtual Reality

First step in developing our system is to design an indoor virtual environment. Basically, 3D virtual scenes are divided into two main parts, which are portals and cells. VRML is proposed for our 3D indoor scenes modeling which accepted as the international standards by the International Organization for Standardization (ISO) together with its successor X3D.

3.1 Indoor Virtual Environment

In our application, 3D indoor scenes are modeling according to our ubiquitous sensor network laboratory in UIT-8 floor building, Dongseo University. In order to facilitate multiple perception design of indoor environment, 2D floor map is implemented as well to provide user with an overview of indoor building structures. 3D objects inside building such as desks, chairs, rooms, and etc. are designed independently. Modification of an object will not affect the entire 3D indoor structures. VRML provides function to import other 3D objects, thus combining all 3D objects together to design a complete virtual reality.

In addition, VRML manages to duplicate the same 3D objects with different translation and rotation in a portal, eliminating same 3D objects to be loaded into the system. The VRML model is also used to set up and run server based spatial analytical searches to identify and retrieve 3D objects on the basis of PDA user's position and direction with respect to the real physical world.

The origin point is located on the west top corner of whole 3D scenes constructed. 3D objects modeling basically build from six feature elements such as cube, cylinder, sphere, box and other appearance features, for the designer to choose from. However, shape of an object can be defined by coordinates of all points which attached the objects to the virtual environment. This is called as points modeling techniques. In order to reduce the file size and ease our work, we decided to use the basic six features element for the 3D scenes modeling.

Fig. 4 demonstrates the 3D visualization of indoor environment on PDA screen.

3.2 VRML Browser

The 3D scene model is hosted using the Pocket Cortona VRML browser ActiveX control from ParallelGraphics. Thus, Pocket Cortona was bought in order to display 3D modeling on

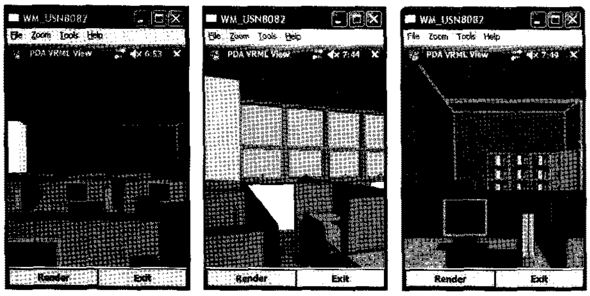

Fig. 4. Indoor virtual reality display on PDA screen

```
Culling_Algorithm (Cell, Pos)
    If IsCellVisible (Cell, Pos)
        LoadCell (Cell)
        For each (Child in Cell.Node)
            If IsObjectVisible (Cell.Node.Bbox, Pos)
                LoadNode (Node)
        End for
    Endif
```

Fig. 5. Pseudocodes for portal culling algorithm

PDA screen. The VRML browser is customized to enable comparative display within browser, provides PDA user with capability of orientate viewpoint to different angles as well as changing the position in 3D indoor environment manually.

The ActiveX uses Cortona VRML control objects and acts as container for 3D scenes. Moreover, Cortona control interface has multiple properties that allowed turning off the rendering features to minimize the rendering time. However, it is hard to detect whether an object is hidden by other objects with nodes function integrated in VRML.

Therefore, a good browser implementation is needed to carry out the work for detecting objects based on viewpoint orientation and view angle. Level of Details (LOD) specifies the complexity of 3D objects to be loaded based on range measurement from viewpoint position in virtual reality. Unfortunately, VRML databases increase dramatically due to multiple simplified or detailed 3D modeling for the same objects. We decided to proceed to a simpler implementation which we deploy portal culling algorithm to the 3D indoor virtual environment.

3.3 Portal Culling Algorithm

VRML performs badly on visualization for large scale 3D virtual reality as it is an interpreted language. Large amount of 3D objects needed to load into the VRML browser before any visualization takes place. This method performs somehow well for a static tracking process but not for dynamically changing process. Continuous of location tracking exploits portal culling algorithm in 3D objects rendering for VRML for rendering speed maximization.

In response to minimize rendering time, we had divided our laboratory into eight cells. New cell will be loaded only if user moves from current cell to another cell; otherwise, cell will not be replaced by VRML browser where user is remained. Meanwhile, objects that already loaded in the particular cell will be check first. New objects will be rendered to pipeline while unused objects will be removed to free up PDA memory spaces.

Three popular portal culling algorithms used nowadays are cell-to-cell geometry, cell-to-object geometry and eye-to-object geometry. 3 sub-functions had been implemented in VRML using java-based script for portal culling algorithm. In the first step, we utilized the cell-to-cell geometry which implies the rendering of visible cells which are only viewable to user. Next, objects in rendered visible cells are determined and finally cull those objects which are not viewable to user based on user's current location and orientation angle.

Pseudocodes for 3 sub-functions are illustrated in Fig. 5. Initial test is performed to load visible cell to rendering pipelines based on user's position. Then, objects for loaded cell are extracted from VRML databases. Finally, from the VRML databases; only objects which are viewable to user in this particular time will be loaded.

As shown in the Fig. 6, user is currently facing at 270 degrees with the position of (x, y) with respect to VRML specification. Instead of rendering all objects inside a cell, only viewable objects are rendered thus implied the efficiency

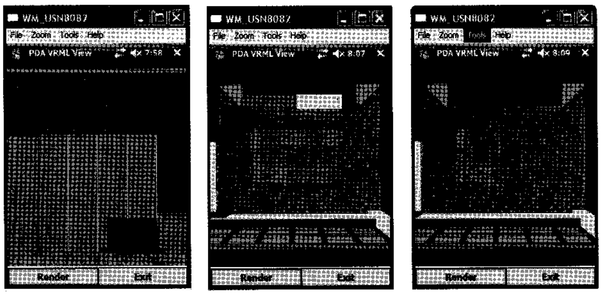

Fig. 6. Comparison of scenes with and without culling algorithm implemented

of culling algorithm. It does not make any differences for user from the view portion, but it does increase the rendering speed for 3D objects.

4 Indoor Location Sensing

Many researchers utilized existing WLAN in RSSI researchers. It is no doubt a low-cost implementation but suffered from elimination of rays. Weak signals are unable to contribute in distance and position calculation, thus they must be sacrificed by the system.

Therefore, CC2431 is selected as it provides capability to perform some signal elimination process on signal strength received from the sensor nodes [7]. Unfortunately, position calculated by CC2431 location engine is hardly to be trusted as accurate position for mobile user. Therefore, raw RSSI signals are received to estimate the user's position.

One of our major focuses is to achieve high accuracy of user's position as relative to real physical environment. So, accuracy refinement algorithm is proposed to obtain user's position in acceptable range. Fig. 7 represents accuracy refinement algorithm for distance and position estimations.

4.1 Distance Estimation

RSSI-based indoor tracking method must consider errors in the measured RSSI signals which would result from multi-path propagation, shadowing, reflection and other effects. Small changes on radio wavelength can cause different developments of fading effects caused

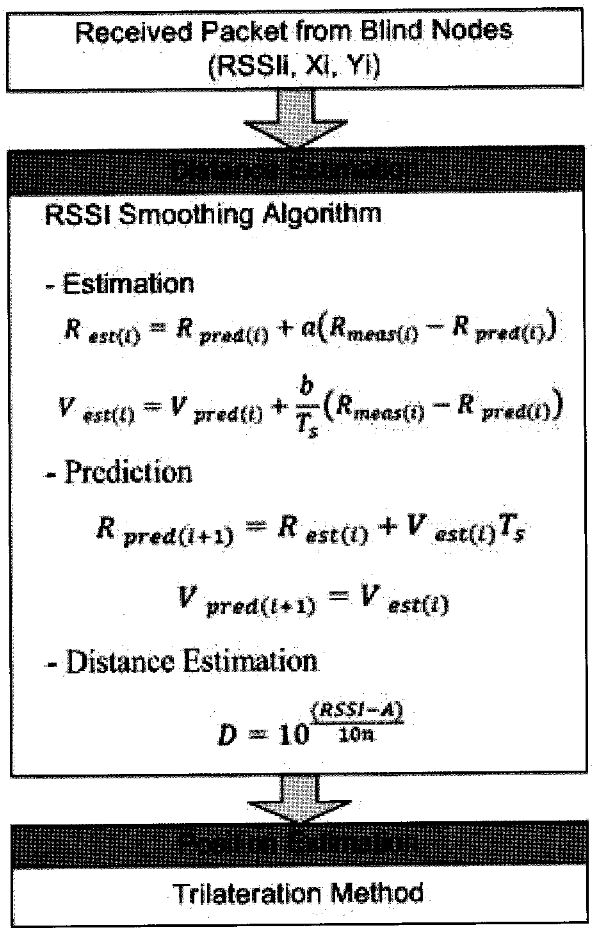

Fig. 7. Accuracy refinement algorithm

by reflection. Furthermore, the natural of signal's behavior implies signal strength varies over time although the mobile user remains on the same position.

Calibration process was conducted in each cell to capture RSSI signals behaviors. Different environments will exhibit different feature of non-isotropic path loss due to the various transmission medium and direction. Therefore, calibration process was carried out to cater such limitation and calibrated values are processed to obtain suitable propagation constant for each reference node. RSSI are computed based on the formula shown in (1).

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

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.

By reversing the linear RSSI equation as shown in (2), calibrated propagation constant which takes obstacles into consideration can be obtained.

$$n = \left(\frac{RSSI_i - A}{10\log_{10} d}\right) \quad (2)$$

Before distance estimation took place, RSSI signals received are being smoothed to obtain stable RSSI measurements. The basic assumption is constant velocity motion will result in constant data change rate and stationary noises processes.

The estimation stages for the smoothing algorithm used are shown as below.

$$R_{est(i)} = R_{pred(i)} + a(R_{meas(i)} - R_{pred(i)}) \quad (3)$$

$$V_{est(i)} = V_{pred(i)} + \frac{b}{T_s}(R_{meas(i)} - R_{pred(i)}) \quad (4)$$

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

$$R_{pred(i+1)} = R_{est(i)} + V_{est(i)}T_s \quad (5)$$

$$V_{pred(i+1)} = V_{est(i)} \quad (6)$$

Where $R_{est(i)}$ is the ith smoothed estimation range, $R_{pred(i)}$ is the ith predicted range while $R_{meas(i)}$ is the ith measured range. $V_{est(i)}$ and $V_{pred(i)}$ are the ith smoothed estimation range rate and the ith predicted range rate respectively. a and b is the gain constant and T_s is time segment upon the ith update.

Filtered RSSI values are used for distance calculation based on RSSI formula as presented in (1).

4.2 Position Estimation

Trilateration is used to estimate user's position based on simultaneous range measurement from at least three reference nodes. Blind node position is derived based on distance estimation from filtered RSSI and the calibrated constant. Minimum of three and maximum of eight reference nodes needed to compute user's location. Position estimated from Trilateration method based on filtered RSSI and position calculated on CC2431 location engine are analyzed to observe the improvement achieved.

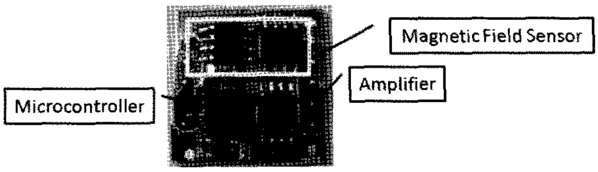

Fig. 8. Digital magnetic compass

5 Digital Magnetic Compass

Digital magnetic compass is used to identify user's direction based on the earth magnetic field. The digital compass consumes only 5V with the size of 20 mm x 20 mm x 2.8 mm, thus suitable to be collaborated with TIP710CM to perform wireless communication. User's orientation is converted into hexadecimal reading to be included inside the sensor node packet by TIP710CM. Packet is then dispatched to base station in wireless communication. There are basically 3 important modules build for digital magnetic compass as shown in Fig. 8 below.

Magnetic compass sensor gather earth magnetic field information while microcontroller computes the direction based on information received from the sensors. Amplifier strengthens the weak signals received so signals are strong enough to contribute in direction computation.

A deviation error of 11.5 degree is encounter in the magnetic compass due to true north based on earth magnetic field. Current magnetic compass provides a compensation scheme for variation correction for the output. Thus, accuracy of 1.5 degree could be obtained after the calibration process is performed.

6 Server

A dedicated server was installed at the server room where all the information are collected, organized and store systematically into the database for future review. Fig. 9 illustrates the program in server used to receive all related information.

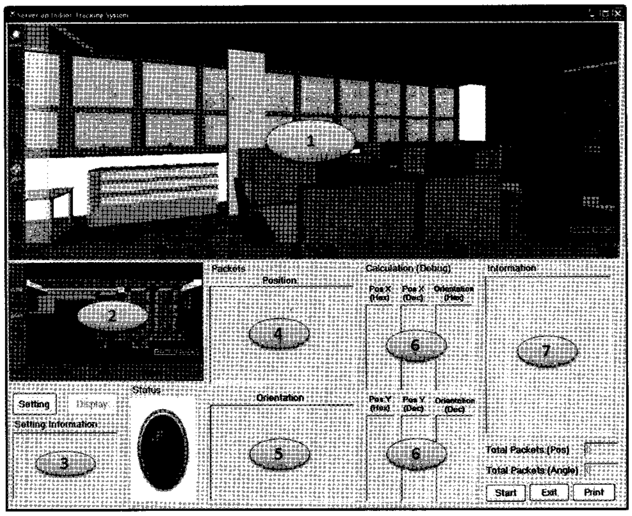

Fig. 9. Screenshot of program installed in Server

Part 1 shown in Fig. 9 displays the current location of user in virtual reality while part 2 demonstrates the user position in 2D standard floor map. Moreover, user could check the configuration used for receiving data packets such as serial com port, baud rate, and etc as view in part 3. Part 4 and 5 views the data packets received which are position and orientation data respectively. Furthermore, part 6 extracts the data from the packets and display the data converted from hexadecimal to decimal format for debug purpose follow by useful information include user position, orientation, and spaces in part 7.

All the data included print screen of will be stored automatically. Person in charge such as doctor and administrator could retrieve records from this program as well. This program provides multiple options for user to display the records based on user requirements.

7 Experiment Setup

Our system is developed in Visual C# Window Mobile 5.0 for application interface. Dell x51v Axim is used for conducting the experiments. VRML is used for 3D objects modeling to design indoor virtual reality. Moreover, VRML databases are stored in PDA itself, thus our system perform an independent system. Performance is improved as no internet communication needed to retrieve VRML databases online. Furthermore, a server had been set up to collect, organize and record all important information for future review.

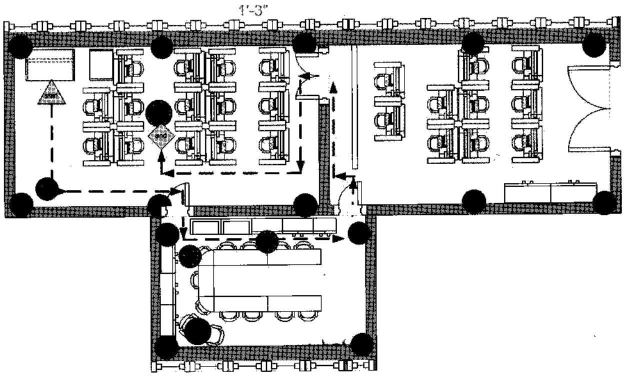

Fig. 10. Experiment path

A path had been identified for our experiment purpose as shown in Fig. 10. Antenna for each reference and blind node is set to the angle of 90 degrees at the mounting surface to reduce the reflection. In order to conduct a practical experiment, total 14 reference nodes are attached to the ceiling in our laboratory. The triangle and diamond shape defined the start and end position respectively during the experiment. The black circles with total of 14 denote the reference nodes attached to the ceiling in each room for experiment used.

The experiment was conducted with minimal human activities are around to minimize the interface. The signal propagation constant was calibrated through calibration process for each reference node in this experiment environment as mention in Section IV. Mobile user walked along the identified path with interval of 3 seconds in real-time processing. Moreover, mobile user walked in reserve direction too thus completing for 2 cycles for this experiment.

Total of 8 cells are constructed and group together as a complete indoor building structures for our laboratory. Before experiment takes place, rendering time for each cell is measured independently for the comparison in later experiment. Time for render new cell and update user's position in particular cell are measured to analyze the performance of the system. The final results of information calculated are sent to server for record purpose.

TABLE 1
Comparison of Rendering Time

Space	*With Culling*	*Without Culling*
*U*801	1*sec*	< 1*sec*
*U*802	1*sec*	< 1*sec*
*U*803	2*secs*	< 1*sec*
*U*804	1*sec*	< 1*sec*
*U*805	1*sec*	< 1*sec*
*U*806	1*sec*	< 1*sec*
*U*807	2*secs*	< 1*sec*
*U*808	2*secs*	< 1*sec*

8 RESULT AND DISCUSSION

Calibration still performs some drawbacks due to different calibrated constant for each reference nodes. Such drawbacks are due to the difference in attenuation of signal on the medium surrounding the reference point. Furthermore, different cells consist of different obstacles thus signal propagations are not similar for each cell. Position only can be retrieved and updated in an interval of 3 seconds but orientation is retrieved in almost real-time processing. Thus, in order to synchronize both position and orientation, we decided to update position and orientation every 3 seconds.

Table 1 shows the rendering time for each cell. Comparison is made before and after portal culling algorithm is implemented into the system. Portal culling algorithm aims to speed up the rendering time and cull any unused primitives to be loaded to the system. The performance is slightly increased with portal culling algorithm integrated in VRML. However, it sacrificed the size of VRML files, thus more memory is required to store the whole VRML databases in the system.

Fig. 11 illustrates comparison of RSSI signals with and without RSSI smoothing algorithm integrated. Based on the results given, signal fluctuations for each reference nodes are reduced significantly by integrating smoothing algorithm. However, fluctuation still exists, thus more suitable and sufficient algorithms are required to obtain a smooth RSSI signals.

In Fig. 12, actual position is compared with estimated position calculated from iterative trilateration method and measured position which read out from the CC2431 location engine. The results obtained reveal an effective-

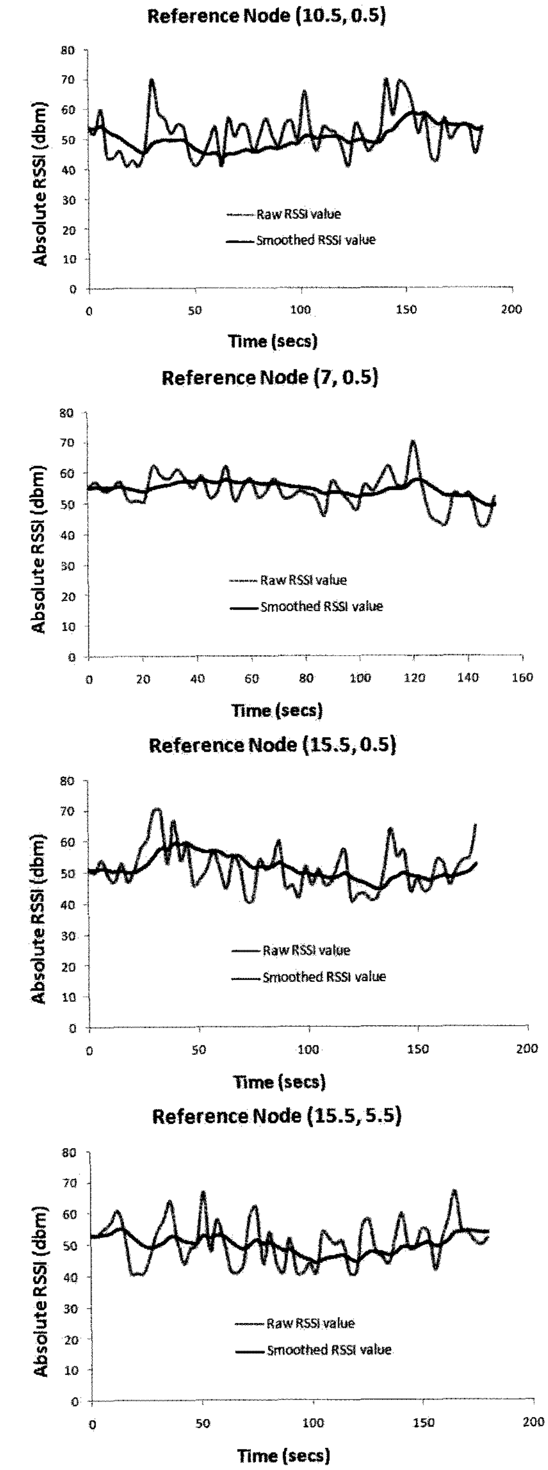

Fig. 11. RSSI smoothing algorithm for each reference nodes

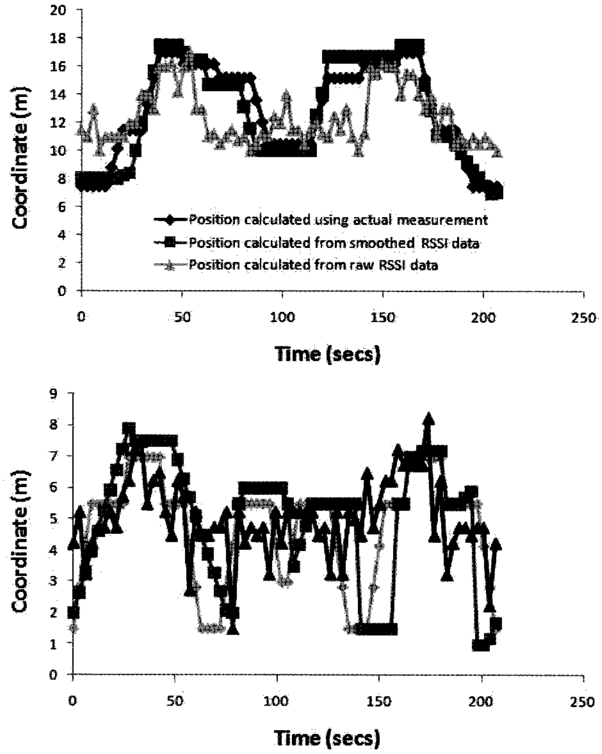

Fig. 12. Comparison of position calculated

ness of the proposed algorithm to be applied to indoor tracking system.

9 Conclusion and Future Work

In this research, 3D visualization real-time indoor tracking system on PDA is presented. 3D objects modeling by VRML perform higher rendering speed compare to other 3D modeling languages such as 3D Max. Virtual reality impresses mobile user by represent outstanding location sensing information in an interactive and effective way, replaced traditional dull 2D standard floor map. Through 3D viewing on PDA screen, mobile user is able to retrieve path guidance to identify his final destination in indoor environment. Portal culling algorithm is proposed and implemented to manage complex virtual reality thus optimized the system performance.

In addition, refinement algorithm is proposed to provide sufficient level of monitoring assistance to users by means of 3D representations. Experiment implied that high accuracy of location estimation could be obtained. Further studies to design an appropriate yet low complexity accuracy refinement algorithm are in progress. Besides that, current experiments only carried in small portions of laboratory where only 3 cells are utilized. More complicated experiments will be carried out in large-scale of indoor environment for further improvement in refinement algorithm.

Indoor tracking with multiple users are crucial to implement due to the signal propagation effects such as shadowing and multi-path effect. Our future research focuses on performing multi-user tracking and multi-3D visualization work simultaneously, synchronized with real physical indoor environment.

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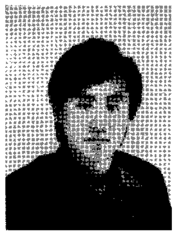

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