모바일 환경에서의 입체모델을 적용한 실시간, 고속 3D 실내 추적시스템

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Real Time 3D Indoor Tracking System with 3D Model on Mobile Device

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요 약

무선센서 네트워크 기술의 응용이 크게 증가함에 따라 저전력 IEEE 802.15.4 호환 무선방식을 활용하는 실내 위치추적기술이 최근에 큰 관심을 모으고 있다. 기존의 실내 위치감지 정보는 2D 영상 기준으로서 정보의 실질적인 전달에 제한적인 기능을 나타내었다. 본 논문에서는 PDA에 대화형 가상현실기술에 바탕을 둔 고정밀 3차원 RSSI 기반의 화면 구성에 초점을 두고있다. 개발된 시스템은 관심영역에서 RF신호의 감쇄를 계산하여 위치정보를 얻은 다음, 이를 3D 실내 가상맵에서의 사용자의 위치로 나타내도록 설계되었다. 이 연구에서는 3차원 모델링을 위해 개발된 VRML(가상현실 모델링 언어)이 3D 실내환경을 설계하는데 활용되었다.

ABSTRACT

Despite the increasing popularity of wireless sensor network, indoor positioning using low power IEEE 802.15.4 compliant radio had attracted an interest of many researchers in the last decade. Old fashionable indoor location sensing information has been presented in dull and unpleasant 2D image standard. This paper focused on visualizing high precision 3 dimensional RSSI-based (received signal strength indication) spatial sensing information in an interactive virtual reality on PDA. The developed system operates by capturing and extracting signal strength information at multiple pre-defined reference nodes to provide information in the area of interest, thus updating user's location in 3D indoor virtual map. VRML (Virtual Reality Modeling Language) which specifically developed for 3D objects modeling is utilized to design 3D indoor environment.

Keyword

Mobile healthcare, RSSI, Indoor Tracking, PDA, wireless sensor network

I. Introduction

Given current technology trends, indoor tracking system had gained its trust as new application for development of services for object location identification especially on mobile handheld. Various indoor tracking methods had been discovered and improved through different researches and experiments nowadays. Popular indoor tracking methods include Active Bat and Cricket used ultrasonic technology while Active Badge utilized the infrared technology. Meanwhile, received signal strength indicator (RSSI) identify user or object location based on radio frequency (RF) method. Due to its low cost implementation, many researchers focus on incrementing the accuracy the location sensing with RSSI method. Furthermore, representation of location sensing information is a critical issue in presenting user an understanding view of his current position. Therefore, three-dimensional virtual reality was utilized to provide user with interactive view, represent location sensing information in more systematic way, replaced traditional and dull 2D image standard.

Virtual reality had gained its trust as a representation of different spatial information in academic or industry areas recently. Visualization of 3D graphics on low processing, limited memory and resources constraint PDA presents a critical issue in modeling of 3D objects. One of the key technical elements specified the realization of this vision is be the construction, organization, and rendering processes of 3D databases to 3D pipeline to increase the visualization speed. Numbers of pioneers had started to exploit 3D in this area, but mostly are concentrated only on outdoor activities.

VRML offers faster high-level abstraction prior to its platform independent definition [1]. Therefore, 3D indoor maps modeling on PDA by VRML was the best choice.

The increasing miniaturization of electronic components leads to the development of extreme low power and small sensor nodes for indoor tracking application with RF-based signals method. RSSI exhibits favorable properties with respect to battery life-time, cost and size, eliminates the requirement of additional hardware. RSSI is able to estimate the distance between the transmitter and receiver and therefore predict the location of unknown device. Radiolocation device (CC2431 [2], Norway) is capable of estimating user location via RSSI. User relative position was estimated by using trilateration method, based on continuous range measurements from at least three known pre-defined position reference nodes.

The RSSI coordinate data is used to give location of the object; meanwhile, user's orientation plays an important role in deciding which 3D objects are to be viewed based on current direction faced by PDA user. Digital magnetic compass manufactured by OPCEL [3] was used to determine orientation, produce an output in digital format. TIP710GM sensor node (MAXFOR Technology Inc., Korea) is combined with the digital magnetic compass device for sending compass packets to base station via wireless communication where digital compass magnetic is interpolating on it.

II. Indoor Virtual Reality

This study focused on the development of indoor tracking system by RSSI method using wireless sensor nodes and digital magnetic compass device, and the implementation of 3 dimensional virtual viewers on PDA using the location and orientation data.

To give virtual reality in location tracking map, the VRML was used. VRML is an international standard for describing 3D objects and scenery on various applications [1]. VRML's technology has very broad applicability, extended to 3D collaborative environments, 3D user interfaces to remote web resources, distributed visualization, and more. VRML had different features that distinguish it from other 3D graphic tools including availability to access through internet at anytime, possibility to animate inside virtual scene at any viewpoint, and ability to interact with objects, move or change their state.

VRML could be constructed by using text editor or world builder application. VRMLPad [4] is used as a editor for VRML programming that used to model 3D indoor virtual environment in our experimented.

Indoor virtual reality is designed and modeled based on Ubiquitous Sensor Network Laboratory located at UIT-8 Floor in Dongseo University in limited the space of 27 x 11 meter. In order to ease the process of modeling, the laboratory was divided into eight spaces (cells).

2.1 VRML browser

Before outlining specifies of particular application developed, indoor virtual reality is to be stressed on for first priority in our development. Just as other 3D technologies, a dedicated browser is always required to explore and display virtual worlds. Famous products such as CosmoPlayer, WorldView, and Cortona3D Viewer are capable of viewing indoor virtual reality without additional software installed on PDA.

Cortona3D [5] and Pocket Cortona [6] offered by ParallelGraphics are used as VRML plug-in provide an ability to display 3D objects on

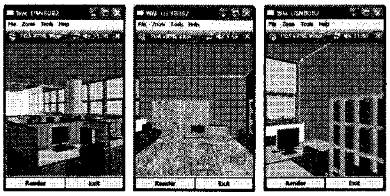


Fig. 1. Designed indoor virtual reality on PDA.

mobile environments in our study. Furthermore, extended applications developed using C# 2005 or Visual Basic 2005 could access the complexity of class libraries integrated in VRML via dynamic processes, updating user viewpoint in real-time environment by aid of Odyssey [7] CFCOM. Figure 1 demonstrates exploration of indoor virtual environment on PDA.

2.2 Culling Algorithm

Due to resources constraints, indoor virtual reality for PDA must be modeled to considerthe limited characteristic of device itself. Only essential and useful 3D objects should be included in consideration for indoor virtual reality displayed on PDA. Therefore, culling algorithm is introduced to reduce rendering time of the view on PDA to acceptable time range and thus increase the system performance.

Culling algorithm is used to reduce the load of 3D objects on well-designed system. Invisible object doesn't need to be fetched, transformed or shaded before entire 3D objects are loaded into rendering pipeline. View frustum culling discards the 3D objects that are outside of visible volume by user view point. Besides that, backface culling eliminates the rendering process of 3D objects that are not facing to user. Contribution culling throws away 3D objects that do not contribute significantly to the final image. Lastly, occlusion culling culled 3D objects that are entirely behind other opaque objects.

Portal rendering subdivided from occlusionculling algorithm is taking into consideration for indoor virtual reality environment. Both rendering and computational time for algorithm needed to take into consideration so that collaboration with positioning calculation time could be achieved within acceptable period of time. Therefore, according to our indoor virtual reality, only one of the eight cells is loaded into rendering pipeline based on user position.

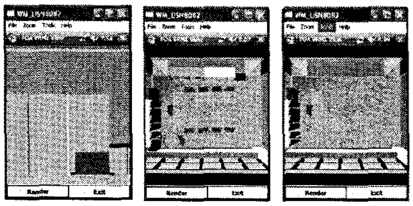
Following other three portal culling approaches are added to speed up the indoor virtual reality rendering time. First, cell-to-cell visibility eliminates other unseen cells from rendering into pipeline. Moreover, cell-to-objects visibility identifies 3D objects that occur inside a particular cell and finally eye-to-objects visibility renders only those visible 3D objects to be displayed on PDA screen.

Figure 2 illustrates the psuedocode of portal culling algorithm programmed using script available in VRML. The scripts are written in java-based thus collaboration with java program is possible to perform different type of processes. High speed of computation yet low complexity of portal culling algorithm are hardly to implement as many parts are required to keep in mind during the designation. Thus, only three basic culling approaches are integrated, but still reveal an ideal and satisfy result through experiment conducted.

```
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. 2. Psuedocode of portal culling algorithm.

By interpolating all the three culling approaches, 3D objects that visible to user view are sent to rendering pipeline and loaded to be displayed on PDA via VRML browser as shown in Fig. 3. Fig. 3(a) and (b) present the current user position in 3D and 2D view respectively with total of 27 3D objects in the map. By comparing both of the figures, the objects viewable to user include three big cupboards, one small cupboard, a chair as well as part of the desk. Thus, with the interpolating of culling approaches, only four 3D objects remain as shown in Fig. 3(c) based on the user front view. This implies that only 14.5% of 3D objects loaded into the 3D rendering pipeline, increment the rendering time of 3D scene. Each time the user position is updated, the event of culling algorithm is triggered for determine necessary 3D objects for user presenting location sensing information.



(a) (b) (c)

Fig, 3. Comparison of 3D scenes before and after portal culling algorithm (a) Current user view in 3D, (b) overall 2D view of the current room, (c) 3D objects remained in the current room based on user front view.

III. System Architecture

Our focus is aim to develop an interactive three-dimensional indoor world to represent location sensing information in dynamic real-time processing on PDA [8]. The developed application obtained spatial location sensing and orientation information in real-time from blind node and digital magnetic compass respectively. The architecture of the indoor monitoring system is as following. First, blind node held by tracking object broadcasts the signals to all reference nodes attached on the ceiling. Reference nodes reply by sending RSSI signals back to the blind node. Second, base station connected to PDA receives packets including RSSI data and their respective position data of reference nodes from blind node.

RS232 serial cable is connected between base station and PDA to transfer packets received from base station to PDA. The developed system extracts location sensing and orientation information from packets received and performs 3D culling and RSSI accuracy refinement algorithm accordingly. Moreover, 3D objects required are loaded into rendering pipeline and triggered events in VRML browser to render the final 3D images on PDA. Digital magnetic compass sends its signal to base station independently from CC2431 wireless communication devices. Structure of digital magnetic compass, base station and PDA are presented in Fig. 4.

Digital magnetic compass is integrated with

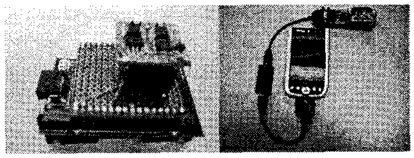


Fig. 4. Digital magnetic compass with TIP710GM attached (a), and base station connected to PDA via RS232 serial cable (b).

TIP710GM wireless sensor node to perform wireless communication with base station. The structure of digital compass module consists of microcontroller, two magnetic field sensors and amplifier. Different areas encounter different reading of orientation from compass in the same direction due to the true north affected by earth magnetic field. A deviation error of 11.5 degree is considered for variation correction had already been programmed inside the digital magnetic compass. Accuracy of ±1.5 degree is believed to be achieved by a series of experiments conducted during calibration process.

IV. Indoor Location Positioning

The CC2431 module can eliminate weak signal strength received from the sensor nodes [8]. However, signal strength received appears to be unstable due to multipath fading, shadowing and fluctuation in indoor environment. Therefore, RSSI signal received is hardly used for distance estimation. In addition, inaccurate evaluated distance between a reference node and a blind node results in wrong calculation in positioning as well. To reduce this error, accuracy refinement algorithm is used to estimate distance and position of the tracking object synchronized with real physical world using raw RSSI signals received[9].

The smoothing algorithm is divided into two phases which are RSSI estimation and prediction following by distance estimation. RSSI signals are computed within the blind node itself based on formula shown below.

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

The 'A' in equation (1)represents the received signal strength at 1 meter distance that approximate to 41 based on pre-processing calibration experiments conducted. 'n' is signal propagation constant and 'd' is estimated distances for each reference node to blind node. Thus, by reversing the RSSI formula, with A and n values known throughout the calibration model, distance between each reference node and blind node could be estimated. CC2431 location engine computes distance based on absolute RSSI signals; eliminate the negative sign as presented in formula (2).

$$d_i = 10^{\frac{(RSSI-A)}{10n}} \quad (2)$$

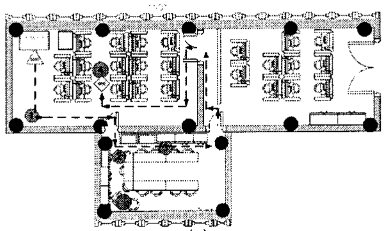
The user position is calculated by trilateration method according to simultaneous range measurement from at least three pre-defined location reference nodes. In our system, eight reference nodes with highest RSSI signals are selected for position estimation. In the case of absolute RSSI signals obtained, eight minimum instead of maximum RSSI signals are considered.

V. Experimental Results

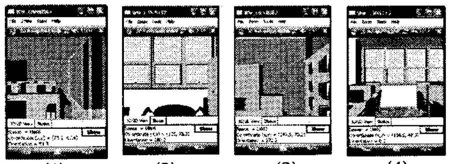
Experimental is conducted on one of the space in our laboratory. The main purpose of this experiment is to observe the precision of user's position based on raw RSSI signals received. In order to achieve a better result, experiment is conducted with less human activities within the space to reduce the interference that could affect the RSSI signals. Total fourteen nodes are configured as reference nodes and attached to the ceiling with position known to the user.

Figure 5(a) illustrates the routes walked by the user during experiment carrying a blind node on hand. The black circles denote the position of reference nodes. And the triangle and diamond shapes represent the user's starting and ending points respectively. Black dotted line drawn specify the route that to be walked by user during the experiment. Fig. 5(b) presents the view of user according to the position 1, 2, 3 and 4 from Fig. 5(a). Size of experiment at test bed is 27 x 11 meter in wideness.

Our implemented application provides user with several viewing options to ease user in understanding the location in more precise way as shown in Fig. 6 Display of 3D scenes is updated in the interval of 3 seconds based on the position calculated (Fig. 6(a)). Addition of mini 2D map along with 3D view allowed user to view in 2 different viewpoints at the same time (Fig. 6(b)). Furthermore, setting menu allowed user to change some of the options available such as serial com port, baud rates, type of views and etc. (Fig. 6(c)). Finally, changing of 3D view to only 2D view is also possible by just modify the setting in the application (Fig. 6(d)). Moreover, positions for mini map are available in top left, top right, bottom left and bottom right with size could be enlarge or set to be smaller depend on the user setting.



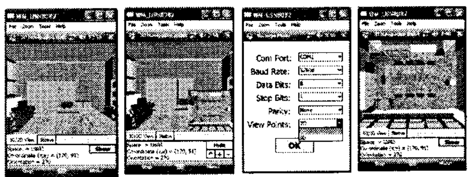
(a)



(1) (2) (3) (4)

(b)

Fig. 5. Experimental test route (a) and 3D virtual views from the objects position of (1), (2), (3) and (4) (b).



(a) (b) (c) (d)

Fig. 6. Three functions of the 3D virtual viewer on PDA; (a) 3D map view, (b) additional of 2D mini map, (c) setting menu for application, (d) change from full 3D to 2D view.

Pre-processing experiments are carried out to observe the rendering time for indoor virtual reality. Different cells are loaded continuously into PDA without culling algorithm integrated. Total time needed to render new cell from an old cell are recorded as well for comparison. Next, the experiments are repeated with culling algorithm integrated. Comparisons of render time for each cell with and without culling algorithm are illustrated in table 1. Experiments reveal an ideal result with rendering time for each cell is less than 1 second.

Table 1. Comparison of rendering time before and after portal culling algorithm is implemented

Space	Without culling algorithm	With culling algorithm
U801	1 sec	< 1 sec
U802	1 sec	< 1 sec
U803	2 sec	< 1 sec
U804	1 sec	< 1 sec
U805	1 sec	< 1 sec
U806	1 sec	< 1 sec
U807	2 sec	< 1 sec
U808	2 sec	< 1 sec

Ⅵ. Conclusions

The 3D indoor tracking viewing technology with digital magnetic compass is designed and implemented. The 3D indoor scenes were designed using VRML for location sensing representation. Furthermore digital magnetic compass provides user orientation in degree standard. User's position is updated in the interval of every 3 seconds. By interpolating culling algorithm, our application developed on low power processing PDA is managed to render the 3D view in acceptable time frame which is less than 1 second allowed other computations take place within 3 seconds.

Well-designed accuracy refinement algorithm increases our system performance by providing user with high accuracy location sensing information with average error of 2.1m. Low complexity, high flexible and scalable accuracy algorithm could perform RSSI smoothing, distance and position calculations in a short period of time. This not only provide user with interactive 3D way of location identification representation, but also high precision of user position.

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