Indoor Passive Location Tracking and Activity Monitoring using WSN for Ubiquitous Healthcare

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Abstract—Indoor location system using wireless sensor network technology was applied for the status evaluation and activity monitoring of elderly person or chronic invalid at home. Location awareness application is transparent to the daily activities, while providing the embedded computing infrastructure with an awareness of what is happening in this space. To locate an object, the active ceiling-mounted reference beacons were placed throughout the building. Reference beacons periodically publish location information on RF and ultrasonic signals to allow application running on mobile or static nodes to study and determine their physical location. Once object-carried passive listener receives the information, it subsequently determines it's location from reference beacons. By using only the sensor nodes without any external network infrastructure the cost of the system was reduced while the accuracy in our experiments was fairly good and fine grained between 7 and 15 cm for location awareness in indoor environments. Passive architecture used here provides the security of the user privacy while at the server the privacy was secured by providing the authentication using Geopriv approach. This information from sensor nodes is further forwarded to base station where further computation is performed to determine the current position of object and several applications are enabled for context awareness.

Index Terms—Context-awareness, Indoor location, Wireless sensor network, ultrasonic, base-station.

I. INTRODUCTION

Sensor network are wireless networks that lack of predefined infrastructure and consist of many small, wireless devices called motes. These motes (sensors) gather information from the environment and communicate with the data back to a central unit called the base station. These networks have demonstrated their usefulness in many applications including health monitoring (Victor Shnayder *et al* 2005), data acquisition in hazardous environments, airborne plume detection and surveillance etc. Emerging mobile computing applications need to know the physical location of things so that they can record them and report them to us: What lab bench was I standing by when I prepared these samples? How should our search-and-rescue team move to quickly locate all the avalanche victims? Where is the patient now in the hospital? How much distance user's moves in this particular day? Where are the things in side the fashion mall?

More scenarios where such network may be deployed can be tracking patients at hospital, tracking elderly person at home, tracking the activities of the suspicious person, location discovery applications, context aware applications etc (Guanling Chen and David Kotz 2000). The importance and promise of context-aware applications has led to the design and implementation of systems for providing location information, particularly in indoor and urban environments where the GPS (P. Enge and P. Misra 1999) does not work well. There are many indoor locations tracking system available like RADAR (P. Bahl and V. Padmanabhan 2004), Active Bat (Andy Harter *et al* 2002), Active Badge (R.Want et al 1992) etc. User privacy, accuracy, architecture cost etc. determine how much the tracking system is effective in practical scenario.

Our goal is to develop an effective indoor location architecture that is different from existing active indoor location systems like the Active Badge or Active Bat that use passive ceiling mounted receivers to obtain information from active transmitters carried by users. Instead of the active architecture this system uses passive architecture in which the reference beacons works as an active transmitters while the listener carried by the user works as a passive device.

By employing passive architecture the feasibility of the tracking system for status evaluation or activity monitoring of elderly person at home was tested. The cost of the system is reduced by using sensor nodes on the ceiling without any wired infrastructure. The weight carried by the target also reduced which is one added advantage.

II. WIRELESS SENSOR NETWORK ISSUES FOR CONTEXT AWARENESS

In a wireless sensor network, although the sensors or motes are computationally capable of doing some local processing of the data and possibly exchange of information with their neighbors, aggregating data to more resourceful nodes or base stations remains a more feasible means of processing the information. Many pervious systems have used wireless sensor network approach for context awareness. In many context aware

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Manuscript received November 6, 2007.

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applications, context should be used to trigger information specific to the users, providing users with a more informed decision space and aiding user decision. The approach of wireless sensor network is more feasible if the information is transferred to the base station and the calculation should occur at the base station for the effective operation of sensor nodes. There are two types of architecture that are generally used in indoor location tracking which is active architecture and the other is passive architecture. In active architecture the users broadcast the signals such that the device installed at the ceilings can know the user context and this information can be transferred to make the context service available to the users. While in the later architecture, the scenario changes, the devices in the ceiling become active and they broadcast the information such that the static or moving nodes can determine their location. Active architec-ture provides good precision but external infrastructure is required for connecting each device whereas in passive there is no requirement of external infrastructure. Already existed systems have used active location architecture due to its good precision however there are several constrains like need of external infrastructure, privacy concerns and high cost of deployment. To achieve our design goal of low cost and privacy awareness we have used passive architecture by using only the sensor node. However for visualizing the object's location we have used base station where all the computation take place and further information can be provided to the third party.

III. SYSTEM ARCHITECTURE

The system considers a number of nodes that are deployed at the ceiling throughout the building and can send their location information by RF and ultrasonic signals. This architecture is used to determine the user position and space information at the base station. To implement the sensor network the sensor nodes are deployed in the configuration as illustrated in figure1. This indoor tracking system uses sensor nodes with an ultrasonic sensor and a receiver, MCS410CA (Crossbow Technology Inc. USA). These sensor nodes have the capability to process the data, send the RF and Ultrasonic signals after some time interval and can be easily configured, programmed. The devices installed at the ceiling are called beacons and the devices carried by the object are called listener. They are same sensor nodes however the program structures embedded are different. The beacons work as reference devices and send their location in the packets to the listener, the listener further forwarding these beacon signals towards the base station. At the base station the location of the target is calculated by using tracking algorithm and context aware applications are developed using this information. By carrying only the sensor nodes the weight of the device users' carry reduced. Perhaps, the cost of the system is also reduced. There is no need of any external infrastructure for tracking the user position at the base station. User position at the base station is shown on the GUI at the base station that we have developed. From the base station all the position and context aware information is provided to various applications using internet. The caregiver and the doctor got the information about the user position on their handheld devices.

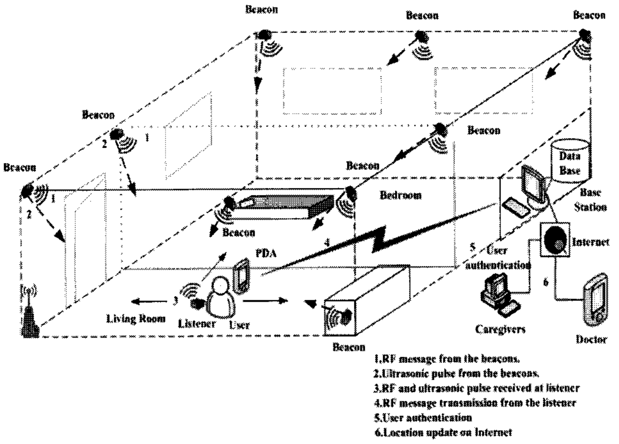


Fig. 1 System architecture of the developed indoor tracking system.

IV. LOCATION CALCULATION METHODD OLOGY

In this system the combination of RF and ultrasonic hardware is used to enable a listener to determine its distance with the beacons from which the nearest beacon can be identified. By measuring one way propagation time of ultrasonic signal emitted by a beacon taking advantage of the fact that the speed of light($=3\times10^8$ m/sec) is greater than the ultrasonic signal (speed of sound) in air. On each transmission, a beacon concurrently sends information about the space over RF, together with an ultrasonic pulse. When the listener hears the RF signal, it uses the first few bits as training information and turns on its ultrasonic receiver. It then listens for the ultrasonic pulse, which usually arrives a short time later because speed is slower if compared to RF. The listener uses the time difference of arrival (TDOA) between the receipt of the first bit of RF information and the ultrasonic signal to determine the distance to the beacon. The distance between a listener and the beacons can be determined by multiplying the speed of sound with the TDOA (Hightower and G Borriello 2001). Because the speed of the sound varies with temperature in distance determination the effect of temperature is also counted. The location of the static listener is determined by using the triangulation algorithm (Hightower and G Borriello 2001). Consider a listener located at (x, y, z) in the beacon coordinate system and assume that the listener can measure the distances to n beacons b_1, b_2….bn. Let d_i be the measured distance between b_i and the listener. Beacon b_i has coordinates (x_i, y_i, z_i). The true distance between the listener and b_i is given by d_i–€$_i$, where €$_i$ is the measurement error. If n=3, and the distance measurement errors are not too large, a reasonable estimate of the listener position can be obtained by solving the three simultaneous equations.

$$d_i^2 = (x - x_i)^2 + (y - y_i)^2 + (z - z_i)^2 \quad \text{for i = 1, 2, 3} \qquad (1)$$

Two possible solutions are calculated for these three equations, one with the listener located above the plane containing the three beacons and the other with the listener. Because the beacons are deployed on the ceiling, we can assume that the listener is always located below the plane containing the beacons. When n>=4, the following non-linear optimization used to compute listener coordinates. We assign some initial coordinates (x_0, y_0, z_0) to the listener. For each beacon b_i, residual e (i) is defined as follows.

$$e(i) = \sqrt{((x_0 - x_i)^2 + (y_0 - y_i)^2 + (z_0 - z_i)^2)} - d_i \qquad (2)$$

We define sum squared error E_{ss} as

$$E_{ss} = \sum_{i=1^n} e(i)^2 \qquad (3)$$

The optimization problem is to find the listener coordinates (x_0, y_0, z_0) that minimizes E_{ss}. If the number of beacons which gives the location information to the listener increases the accuracy of the system increases. When the listener is mobile, multiple beacons' distances are received at different instances of time, where the listener is at different positions. However, we can still compute a representative position for the listener by using these distance samples. The same technique used for mobile user, as for the static listener, the only difference is that the error now has two components; the measurement error, and error caused by the listener being at different positions when the different distance samples are obtained. These errors can be reduced by using the Kalman filter approach (A. Smith et al 2004) taking the consideration of the temperature effect on velocity of sound.

V. A QUICK INTRODUCTION TO TINYOS

TinyOS is a very popular operating system for embedded sensor network due to its small size, component based architecture and open source. Consequentially, it can optimize performance by implementing application-specific high-level networking and communications protocols, while controlling low-level hardware such as the radio and ADC. TinyOS is designed to be able to incorporate rapid innovation as well as to operate within the severe memory constraints inherent in sensor networks. TinyOS is an event driven operation system for the embedded sensor nodes that have very limited resources (core TinyOS requires 400 bytes of code and data memory, combined). TinyOS follows the components based architecture which can be used to make program convenient, easy to acquire events and process the data generated by the events. TinyOS can be described as an API interface which can interact with various sensors and the data is able to communicate with each other.

TinyOS system, libraries and application are written in nesC (network embedded C) (David Gay *et al* 2003), a new language for programming structured component-based applications. nesC is an extension to C programming language, designed to embed the structuring concepts and execution model of TinyOS. Some of the basic properties of TinyOS and nesC are as:

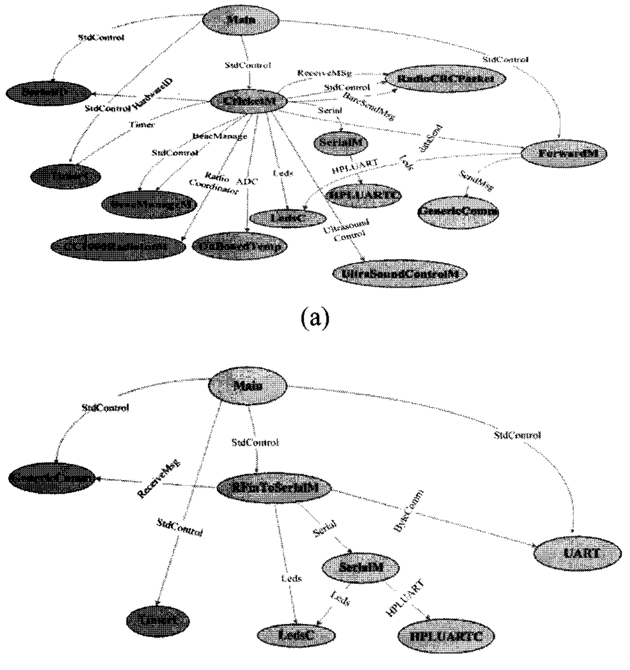
1. nesC has a C-like syntax, but supports the TinyOS concurrency model, as well as mechanisms for structuring, naming, and linking together software components into robust network embedded systems.
2. TinyOS executes only one program consisting of selected system components and custom components needed for a single application.
3. nesC applications are built out of components with well-defined, bidirectional interfaces; nesC defines a concurrency model, based on tasks and hardware event handlers, and detects data races at compile time

VI. SOFTWARE DESIGN

Software part is divides in two parts; in first part we describe the software development for sensor nodes while in second part server application program description is given.

A. Sensor Node Software Design

The sensor nodes were programmed using nesC (network embedded C) on TinyOS platform. The component graphs of two application programs are shown in the figure 2. First application in figure 2(a) shows the connection of the components for the beacons and the listener program. This is the modified version of cricket code from MIT (Nissanka B. Priyantha *et al* 2000). Several components are added to forward the beacon message from the listener towards the base station. By adding these components, sensor node itself can be sufficient to receive the beacon signals and forward them towards the base station. The cost of the system is reduced while only using the sensor node and without any external network infrastructure. In this application various components are attached, 'BeacManage' is used for beacon transmission, 'UltrasoundM 'component is responsible for ultrasonic signal and 'RadioCRCPacket' is responsible for sending the data through 'BareSendMsg' interface. 'ForwardM' component is used to forward the beacon message towards the base station using 'SendMsg' interface for 'GenericComm' component. However in distance calculation the speed of ultrasonic signals plays an important role because the speed is affected by temperature variation. So to remove the effect of temperature we have added one component called 'OnBoardTemp' which is used to read the temp from the onboard temperature sensor and provides the reading to the distance calculation. In the second application the components are used to receive the message from the RF channel and transfer them through UART. The UART interface is used to accept the signals from the sensor nodes and transferring them to towards the server. The Led interface is used to glow the led on the sensor nodes for interactive and debugging features. As shown in figure 2 (b) 'GenericComm' components is used for receiving the message through 'ReceiveMsg' interface, 'SerialM' component is used to send the message from main component to 'HPLUARTC' using 'HPLUART' interface and so on.



(a)

(b)

Fig. 2 Component graph; (a) for beacon and listener program, (b) for base station program.

B. Sensor Node Software Design

The application programs at the server are implemented using Java 1.6 API. As shown in the figure 3 the software is divided in to several steps. The server application receives the RF signal on RS232 port from the listener and calculates the position of the user based on the previously described technique. This RF signal contains various information in packets like the space ID of the beacon, distance from the listener and temp of the atmosphere etc. Therefore at the server side these fields are separated from the packets and by using the tracking algorithm the position and closest space ID of the listener is calculated at the server. Further, this position information is provided to the server broker component which acts as a server application whose work is to accept the connection from the third party and provide them the location information of the object. It accepts connection using TCP/IP sockets and at the same time many application can be connected. Because we are providing the object location information to third party possibility of this information to be accessed by unauthorized person exists and they can misuse the information in which this can play with the privacy of the user. Geopriv approach (Geographic Location/Privacy (Geopriv) Charter) is used to provide the security of the location information at server. For ensuring the user's privacy at server, confidently of the location information is achieved by using authentication. Once the connection is established user has to authenticate himself by providing user name and password. If the user is not authorized to access this information he will not be connected to the server program through sockets. Various applications are connected through the TCP/IP sockets as shown in figure 3. The description of each application is described in the next section.

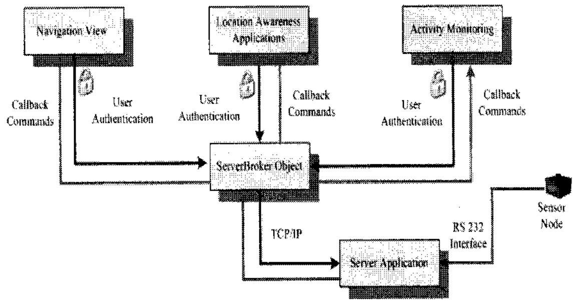


Fig. 3 Aucentification software architecture of the base station.

VII. EXPERIMENTAL DEPLOMENT

For the experimental evaluation of the developed system, the location of the object was tested by deploying beacons at the ceiling and measuring the coordinate and space information at the base station. The testing was done by putting the beacons in the Korean home environment. The experiment deployment is done in two ways, in first case the one sensor is placed in each room as shown in figure 4, while in the second way the deployment of the sensors is distributed only in two rooms. In the first case the activity monitoring of the person is determined by using the frequency visits per room, time spends per room and the room visited. However in the second case the main parameter of observation are the path traveled by the person and the accuracy measurement of the tracking system. The beacons are assigned the coordinate using reference coordinate system. Once we have assigned the reference coordinates to the beacons, the location information we have obtained from the system is compared with real coordinate values. The spaces ID are also assigned as per the user convenience, such that we can easily understand the position of the object by seeing the closest space ID. As the user moves around this testing environment, his 2D coordinate and space information are calculated at the base station from the beacon signals and displayed on GUI. The accuracy of the position calculation was between 7~15 cm in the test. The accuracy of the system that we have achieved is quite efficient compared to the other approach like radar, active bat and active Badge in which the accuracy of the tracking is in several meters. The accuracy of the system can be further improved by putting the beacons closely at the ceilings. One lesson to draw from these experiences with location tracking is the need to accurately describe the quality of the sensed information. For example, granularity and freshness of the location information are quality attributes. Providing this information to the application, and possibly to the user allows people to understand the limits of this technology, and use it with care.

VIII. APPLICATION FOR UBIQUITOUS HEALTHCARE

Location awareness could be used to trigger information specific to the users, providing users with a more informed decision space and aiding user decisions. Applying this concept to ubiquitous healthcare is a potentially promised approach to be taken. Several applications have been enabled by this tracking system to provide useful service for the emerging ubiquitous healthcare applications. Among these applications activity monitoring is one of them which tells about the state or action of the active target. Several other potential application scenarios are discussed that are beneficial in ubiquitous healthcare. However these are not the limited, further improved and addition of features can be done as per the requirement and feasibility.

A. Activity Monitoring

Activity is the term used to tell about the state, quality, and action of the active objects. The active object can be the elderly person at home or patient at the hospital etc. The states of the activity of the elderly persons (G. Virone *et al* 2006.) and the patients have a close relationship with their health and wellness. By utilizing the location awareness we can easily monitor the state and actions of the active object in their daily life. The activity of the person maybe much relationship with the visiting frequencies per room; the lapses of time the resident spend in every room and the last motion events. Using the sensors the space will be able to sense the activities of its occupants and learn their routines. Several applications have been tested to determine the activity of the person but in this experiment the emphasis has been given to the activity in terms of frequency visits per room, time spend per room and also the distance traveled during the observation time. One application which has been developed that stores the motion history of the person in terms of space and time. As shown in the Table 1 the activity of the person is observed from afternoon to evening time. For this observation we have placed one sensor node to each room like one in bedroom, one in toilet etc. The time spent by the person in each room also shown and the duration of the spent time is added in the previous spent time to know the total time spent in one room, space in a day or week. The name of the activity given is normal if the user visits per room is daily routine but if the user spends a lot of time in room like in toilet than the activity can be called abnormal. Privacy is of course a serious issue when applications, and thus colleagues, start tracking people's location. For this application, first of all user have to authenticate himself and if the authentication success, he can visualize these parameters. This can be one method to provide security to the privacy of the user. This application utilizes only the space information for increasing the granularity of the deployment of the sensor nodes. As soon as the user changes the space, his location information is updated and we can also calculate the duration of time the user spends in particular room.

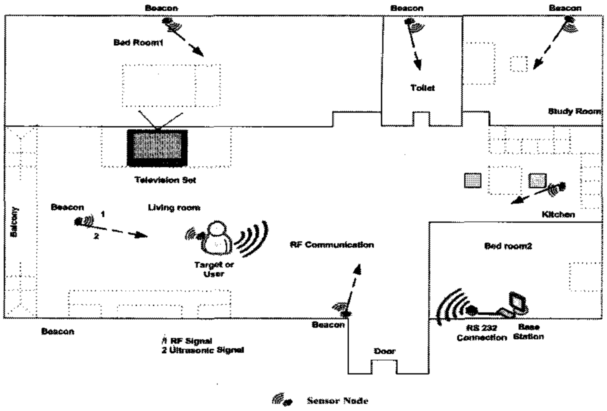


Fig. 4 Deployment of sensor nodes in a traditional Korean home environment for activity monitoring.

Table 1 Activity Monitoring of user from afternoon to evening in a traditional Korean home environment

Room Visited	Time Started	End Time	Total Duration Spend	Activity
Living Room	11:37 P.M.	11:45 P.M.	8 Minutes	Normal
Toilet	11:46 P.M.	11:49 P.M.	3 Minutes	Normal
Kitchen	11:50 P.M.	12:06 P.M.	16 Minutes	Normal
Bed Room	12:07 P.M.	13:00 P.M.	53 Minutes	Normal
Living Room	13:03 P.M.	13:30 P.M.	27 Minutes	Normal
Bed Room	13:31 P.M.	14:40 P.M.	59 Minutes	Normal
Toilet	14:41 P.M.	14:55 P.M.	14 Minutes	Normal
Study Room	14:56 P.M.	16:20 P.M.	84 Minutes	Normal

B. Estimation of Moving path

By processing the data obtained from the listener we can track the user as they move. These movements could be over short times (in minutes or seconds) or over long times (hours and days). Each type of moving path provides important cues about what is happening in a scene. Recognition of short time of activities could be used for determining about the status of the person while long term activities could be learned as routines and then deviations can be measured.

In the first scenario for measuring the accuracy and moving path, we have placed the sensor as shown in figure 5 and figure 6. As per our observation from the previous experiments we have observed that the most of the time user visited the particular rooms. So in this experiment the sensor nodes are deployed in two rooms one is the living room and other is the bed room. In figure 6 the comparison is done between the observed path and the actual path traveled by the target for accuracy measurement. The accuracy obtained was in between 7 to 15 cm. However, in the second scenario our main focus was to see the traveled path by the target. The placement of the sensor is same while the main observation was the movement paths that have been plotted on the graph as shown in figure 6. The path traveled shows the movement of the person inside the experimental test bed. While in second scenario as shown in the figure 7 our main observation was the distance traveled by the person in each hour duration. As shown in the graph, the distance traveled by the person who is carrying the listener node is shown. By visualizing this graph we can easily estimate the activity of the person as per the observation time. This monitoring graph tells about the distance traveled by the person as the observation time changes from afternoon to evening. This activity information is quite useful for remote monitoring of the person. For better visualization and understanding we have try to plot the experimental test bed on the plot by measuring the length and width of the test bed. The accuracy and the path observed are than mapped on this plot as shown in figures. These results tell about the experimental evaluation of this system and various application scenarios that can be developed by using this system.

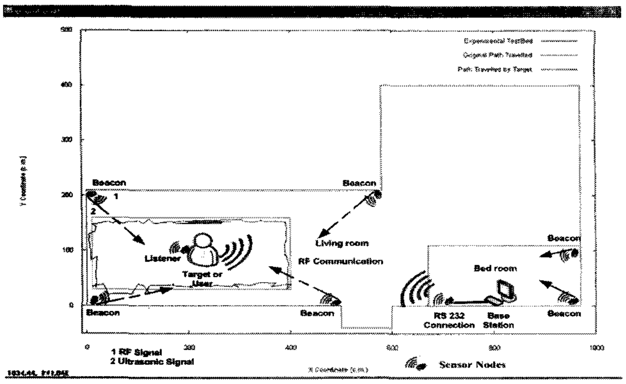


Fig. 5 Deployment of sensor nodes in a traditional home environment for accuracy measurement.

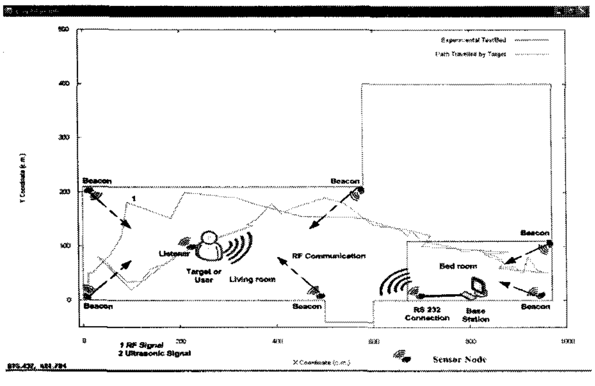


Fig. 6 Deployment of the sensor nodes in a traditional Korean home environment for evaluation of moving path scenario.

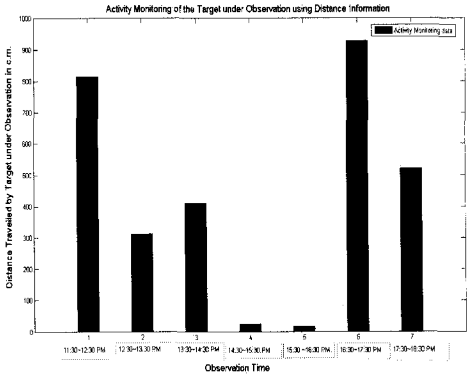


Fig. 7 Activity monitoring of the target under observation using distance information.

C. Other Application Scenarios

The usage of context information is still quite limited since it is very challenging and complex to capture, represent, and process contextual data. The most used types of context information are location, identity and time information. A user context can be quite rich, consisting of attributes such as physical location, physiological state (such as body temperature and heart rate), emotional state (such as angry, distraught, or calm), personal history and so on. Initially location context is the main consideration. We can develop various applications that are useful inside hospital, in shopping malls, and in big organization where the application utilize location context. Further context information can be used both in establishing ad-hoc networks, in routing protocols, as well as, on application level.

IX. CONCLUSIONS

The indoor location tracking system using flight time difference between RF and ultrasonic signals in wireless sensor network was designed and its applications in context awareness in ubiquitous home healthcare was tested. This system is the result of several design goals like user privacy, low cost and portion-of-a-room granularity. By using only the sensor nodes without any external network infrastructure the cost of the system is reduced while the accuracy in our experiments is fairly good and fine grained between 7 and 15 cm for tracking in indoor environments. Passive architecture used here provides the security of the user privacy while at the server the privacy is secured by providing the authenticcation using Geopriv approach.

The activity monitoring of elderly person or patient is a first step towards enabling a rich class of applications. Interaction with computer in limited area also can be one of important application area of the developed passive tracking system using wireless sensor network technology. The widespread deployment of location-dependent physiological applications inside hospitals and home has the potential to fundamentally change the way we interact with our environment.

ACKNOWLEDGMENT

This research was supported by the Program for the Training of Graduate Students in Regional Innovation which was conducted by the Ministry of Commerce Industry and Energy of the Korean Government.

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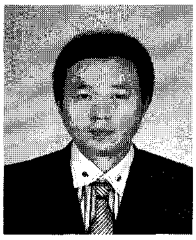

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