J. of the Korean Sensors Society
Vol. 16, No. 4 (2007) pp. 277 - 285

A wireless sensor network approach to enable location awareness in ubiquitous healthcare applications

Vinay Kumar Singh, Hyotaek Lim*, and Wan-Young Chung*†

Abstract

In this paper, we outline the research issues that we are pursuing towards building of location aware environments for mainly ubiquitous healthcare applications. Such location aware application can provide what is happening in this space. To locate an object, such as patient or elderly person, 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.
The cost of the system was reduced while the accuracy in our experiments was fairly good and fine grained between 7 and 12 cm for location awareness in indoor environments by using only the sensor nodes and wireless sensor network technology. 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.

Key Words : indoor location, position, ubiquitous healthcare, wireless sensor network, context awareness, base station

1. Introduction

In pervasive computing age, one of the key features that distinguishes pervasive applications from non-pervasive ones is context-awareness[1-3]. 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 (Global Positioning System)[4] does not work well. Outdoor context aware information has enabled applications as diverse as locating people, tracking vehicles, logistical planning and resource discovery due to the development of GPS.

Where is the patient now in the hospital? How much distance user's moves in this particular day? Typical indoor applications require different types of location information such as physical space, position and orientation. Location is one of the important parameter of context. The location of the objects further can be utilized in developing the context aware applications like activity monitoring, resource discovery and location dependent ubiquitous healthcare application and determining location in he indoor environments presents special engineering challenges.

The coordinate system and the measurement precision supported by the indoor location often differ from outdoor environment. Therefore, there is a need of good location precision for developing the indoor location aware system. There are many indoor location aware systems available like RADAR[5], Active Bat[6], Active Badge[7] etc. User privacy, accuracy, architecture cost etc. determine how much the location aware system is effective in practical aspects.

Our goal is to develop an low cost and privacy aware indoor tracking architecture using wireless sensor network technology mainly for ubiquitous home healthcare applications.

Until now most of existing active indoor location system like Active Badge or Active Bat use passive ceiling mounted receivers to obtain information from active transmitters carried by users. Instead of the active architecture our system uses passive architecture in which

Department of Ubiquitous and Network Eng., Graduate School of Design & IT, Dongseo University
*Division of Computer & Information Engineering, Dongseo University
†Corresponding author: wychung@dongseo.ac.kr
(Received : January 22, 2007, Accepted : May 28, 2007)

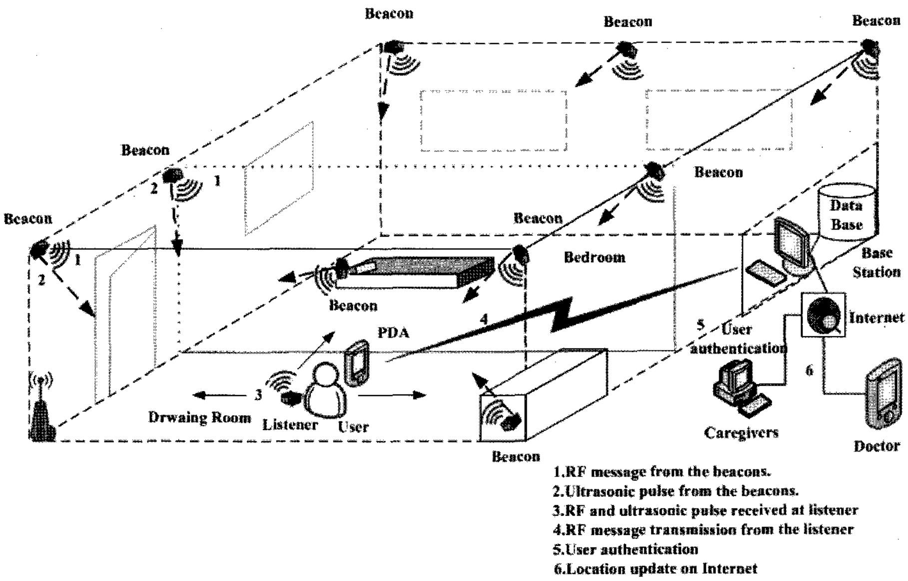


Fig. 1. Visualization of the location awareness using Indoor location aware system.

the reference beacons works as an active transmitters while the listener carried by the user works as a passive device. By employing passive architecture we have added several advantages such as privacy concern and cost reduction. 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.

2. System Design

2.1. System Structure

An significant aspect of building an aware environment is to explore easily accessible and more context aware services than available via the traditional desktop computing. Building of a computing infrastructure that supports all the need of context aware systems is therefore our primary goal. 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 Fig. 1.

This indoor location aware system uses sensor nodes with an ultrasonic transmitter and a receiver, MCS410 CA Cricket Sensor node (Crossbow Technology Inc. USA)[8]. 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 structure embedded is different. The beacons work as reference devices and send their location information 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 locating the user position at the base station. User position at the base station is shown on the GUI (Graphic User Interface) 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. In ubiquitous home healthcare applications, the caregiver and the doctor can got the information about the user position on their handheld devices.

2.2. Location Calculation

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 is ($>=10^6$) 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[9]. 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[9] as shown in Fig. 2. 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 $b_1, b_2 \ldots b_n$. 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 € the measurement error. If n=3, and the distance measurement errors are not too

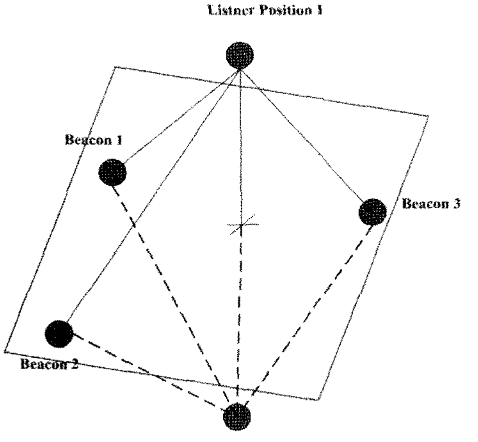


Fig. 2. Location of the object based on the beacons position.

large, a reasonable estimate of the listener position can be obtained by solving the three simultaneous equations.

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

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, residual e (i) is defined as follows.

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

We define sum squared error Ess as

$$Ess=\Sigma_{i=1}{}^{n}\ e(i)^2 \quad (3)$$

The optimization problem is to find the listener coordinates (x_0, y_0, z_0) that minimizes Ess. 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 was reduced by using the Kalman filter approach[10] taking the consideration of the temperature effect on velocity of sound.

3. Software Architecture

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

3.1. Software Architecture for the Sensor Node

The sensor nodes were programmed using nesC (network embedded C)[11] on TinyOS[12] platform. TinyOS is component based small size operating system for

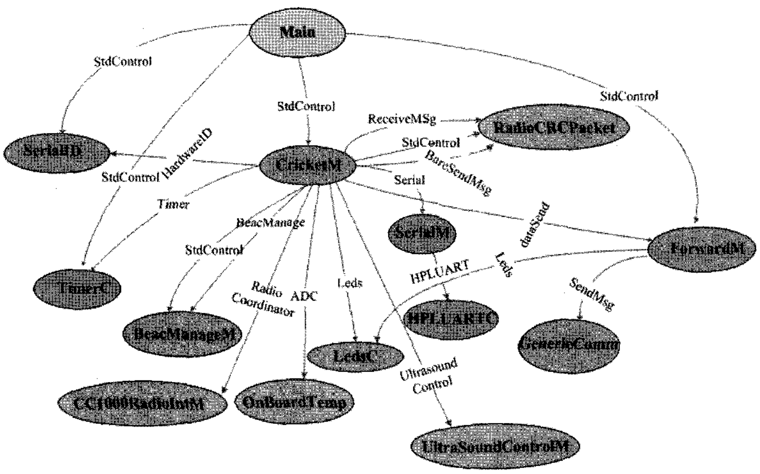


Fig. 3. Component graph of TinyOS for the beacon and listener node application.

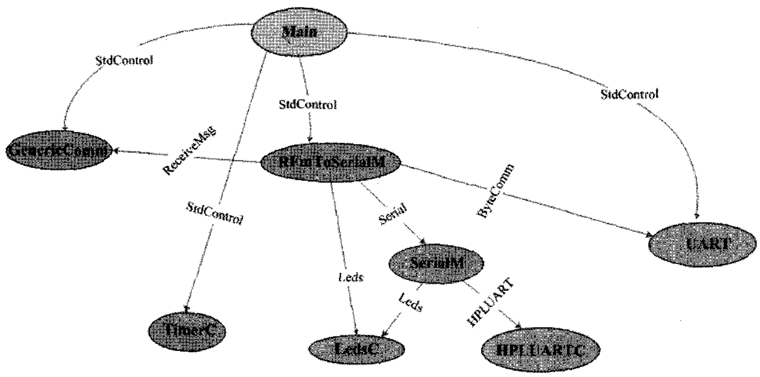


Fig. 4. Component graph for the base station node application.

wireless sensor network developed in University of California, Berkely. The component graphs of two application programs are shown in the Fig. 3 and Fig. 4, separately. First application in Fig. 3 shows the connection of the components for the beacons and the listener program. This is the modified version of cricket code from MIT[13]. Several components are added to forward the beacon message from the listener towards the base station. By adding these component only sensor node 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 the in distance calculation the speed of ultrasonic signals plays an important role but there is still the effect of temperature variation on speed of ultrasonic sound. So to remove the effect of temperature we have added one component called 'OnBoardTemp' which is used to read the temperature 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

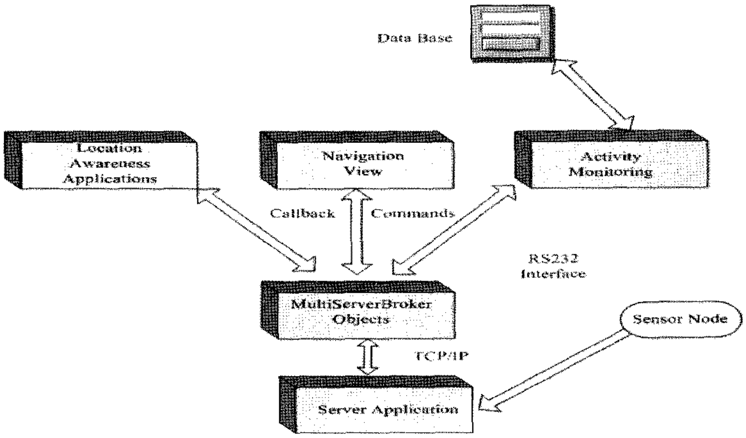


Fig. 5. Software architecture for the base station.

and debugging features. As shown in Fig. 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.

3.2. Software Architecture for the Base Station

The application programs at the server are implemented using Java 1.6 API. As shown in the Fig. 5 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[14] 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 Fig. 5. The description of each application is described in the next section.

4. Results and Discussion

4.1. Experimental Deployment for Accuracy Measurement

Experiments have been carried out to examine the integration between indoor location tracking system and 2-D navigation view as well as the accuracy of real-time user location positioning in 2-D indoor environment based on user's spatial information in physical world. The testing was done by putting the beacons 300 cm apart from each others as shown in Fig. 6. 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 exact measurement. To conduct this, four formerly configured beacons is mounted on the ceiling of a room at our laboratory with dimension of 5 m by 7 m, as shown in Fig. 6. User is required to carry the passive listener in order to receive and transmit spatial information messages from beacons to base station where user's current position is computed and determined. The spaces ID are also assigned as per the user convenience, such that we

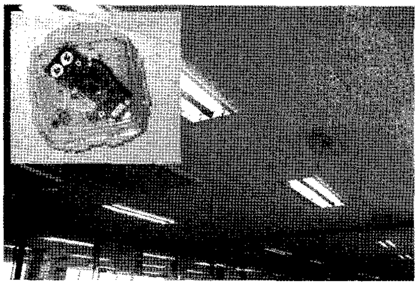


Fig. 6. Experimental deployment of the sensor nodes for performance evaluation.

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.

For measuring accuracy of the indoor tracking system, we compared the observed moving path obtained by the system and the actual path traveled by the target in 4×4 m^2 rectangular path. The accuracy of the position calculation in the rectangular path was tested between 7 and 12 cm. 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 on the ceilings.

4.2. Performances Analysis

At this stage of development, performance of this application was described in terms of its accuracy and precision. As per our experiments that are conducted in our laboratory the user's location is estimated by placing beacons 300 cm apart. As user moves, 2-D navigation view displays user's current position and viewpoint in 2-D indoor environment based on extracted space and coordinate information from indoor location support system.

The location positioning is proved to be sufficiently accurate after a comparison between locations in 2-D environment with the one in the physical world. The indoor location support system is known to affect positioning accuracy in 2-D environment. This is one of the factors that we should take into consideration. As a result, the desired positioning can be obtained only if the provided location information from indoor location support system is sufficiently accurate and fine-grained. In case of only context information the space id is sufficient to tell about the room, area or space where the person is there. In this case the deployment of sensor is limited in each room. We have to deploy one sensor node per room and these sensor node are sufficient to tell about the space of the user. So for application which utilizes the three dimensions coordinate location information it should be ensured that the deployment of the beacons should be done not more than 400 meters. While for the application that utilize the space id it can be deployed at more distance.

4.3. Development of Context Awareness Applications

We are interested in developing several smart and aware environments. Location awareness could be used to trigger information specific to the users, providing users with a more informed decision space and aiding user decisions. The applying this concept to ubiquitous healthcare is a potentially promised approach to be taken. Several applications have been enabled by this system to provide useful service for the emerging ubiquitous healthcare applications. Among these applications, activity monitoring and interaction with computer on move were developed in our indoor tracking system using wireless sensor network technology. However these are not the limited, further improved and addition of features can be done as per the requirement and feasibility. Following are a few aspects of perceptual processing of the location information that can lead to awareness.

4.3.1. 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[15] 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 may be like the visit frequencies per room, the lapses of time the resident spend in every room and the last motion events. One application which has been developed that stores the motion history of the person in terms of space and time and shows the current position on GUI is shown in Fig. 7. This interactive GUI is the map of our USN laboratory (Ubiquitous Sensor

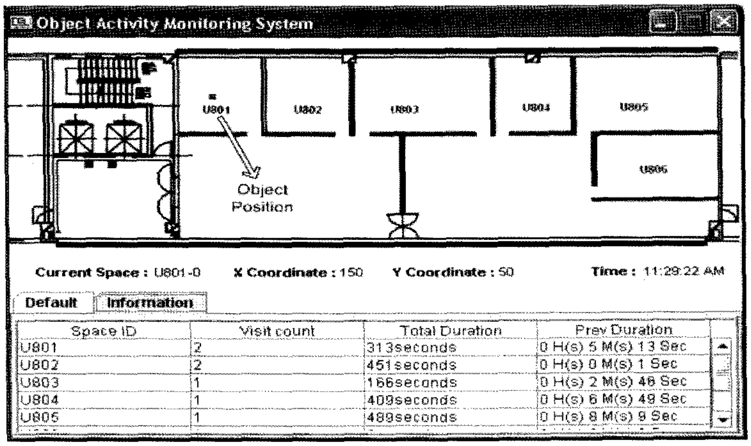


Fig. 7. Object activity monitoring mapped with real environment.

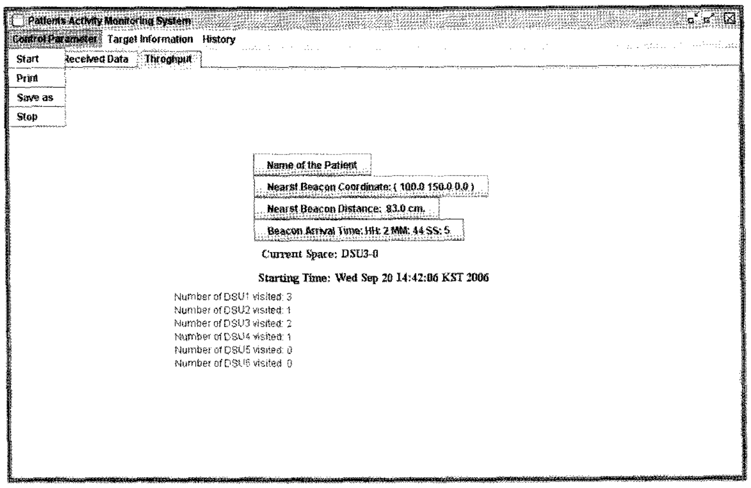


Fig. 8. User identity for context aware application.

Network Laboratory, Dongseo University)[16] and rooms are shown too. The position of the user is shown by red dot and the current space and coordinate information are also shown. 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. 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. This activity information is quite useful for remote monitoring of the person.

4.3.2. User Identity

User identity is a very important factor to be considered in context awareness. Using the listener node id, the user name and other information can be identified. Every sensor node user carry is given the name and the id. At the base station this id and name can be extracted from the packets send by the listener node. In this way by using only small sensor node the user context can be determined. As shown in the Fig. 8 the name of the user can be obtained by clicking on the name button as shown in the GUI.

4.3.3. Context awareness Information using Voice

The location information and the context aware information are quite useful for the home healthcare in home

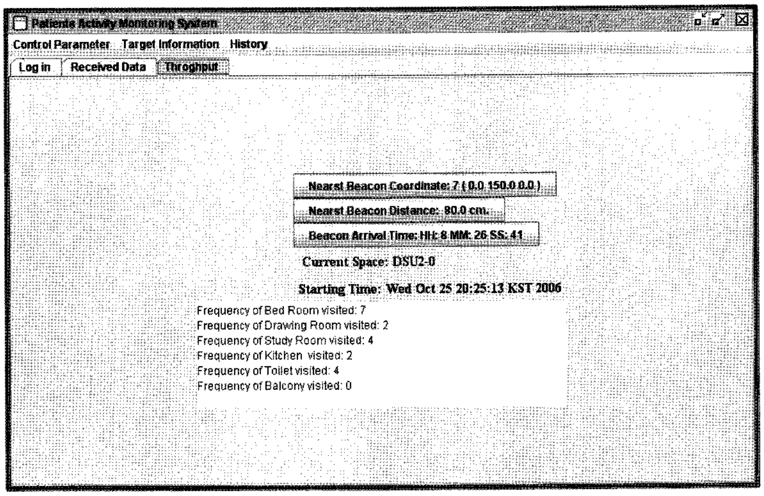


Fig. 9. Context information using voice.

environment. Generally the location information is displayed on the monitor, display etc. If we can provide the information using the voice it will be quite useful for the users. In this application we have provided the voice facility for context aware information. For increasing the granularity we have deployed one beacon each room. This application considers only the space information for giving the context aware information. As the user enters the room the base station determines the nearest beacon and the space id assigned to the beacon gives the user's context. As the user enters the room the base station started giving information about that room and the near by context. The message delivered by the base station can be the welcome message, object information in that room and the context information. As the user changes the space the nearest beacon also changes and the nearest beacon id gives the space associated with the user. So in this way we can provide the context information to various users.

Figure 9 shows the nearest beacon and also the current room. If the user need the location in precise form, the beacon should be deployed more granularity. How ever in the future we will try to add the coordinate information too along with space information. It was our initial effort for designing some application.

5. Conclusions

The indoor location support system using time difference of arrival between RF and ultrasonic signals in wireless sensor network was designed and its applications in context awareness for ubiquitous healthcare was proposed. This system is the result of several design goals like user privacy, low cost, decentralized architecture and portion-of-a-room granularity. We are actively pursuing efforts in deploying experimental infrastructure and applications in our existing work environment.

The widespread deployment of location-dependent applications inside hospitals and home has the potential to fundamentally change the way we interact with our immediate environment. The activity monitoring of the object is a first step towards enabling a rich class of application that object our research goals. Rapid user acceptance and usage of existing location based services are encouraging the development of more extensive and accurate systems with the focus on improving internal positioning technologies

Acknowledgement

This work was supported by the Korea Science and Engineering Foundation (KOSEF) grant funded by the Korea government (MOST) (F01-2005-000-10362-0).

References

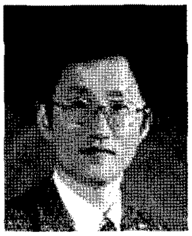
[1] B. Schilit, N. Adams, and R. Want, "Context-aware computing applications", Proc. Workshop on Mobile Computing System Applications, pp. 85-90, Santa Cruz, CA, 1994.

[2] 이대석, 정완영, "유비쿼터스 헬스케어를 위한 센서

네트워크 기반의 심전도 및 체온 측정시스템-1. 생체신호 모니터링 소프트웨어 시스템", 센서학회지, 제15권, 제6호, pp. 417-424, 2006.
[3] 신광식, 권준달, 이영동, 정완영, "무선 센서네트워크 기술을 활용한 Ad-hoc 홈 네트워크 시스템", 센서학회지, 제16권, 제2호, pp. 142-149, 2007.
[4] P. Enge and P. Misra, "Special issue on GPS: The global positioning system", Proc. of the IEEE, vol. 87, no. 1, pp. 3-15, 1999.
[5] P. Bahl and V. N. Padmanabhan, "RADAR: An in-building RF based user location and tracking system", Proc. IEEE INFOCOM 2000, Tel-Aviv, Israel, vol. 2, pp. 775-784, 2000.
[6] A. Ward and A. Jones, "A new location technique for the active office", IEEE Personal Communications, vol. 4, no. 5, pp. 42-47.
[7] R. Want, A. Hopper, V. Falcao, and J. Gibbons, "The active badge location system", ACM Transactions on Information System, vol. 10, no. 1, pp. 91-102, 1992.
[8] MCS410 CA Cricket Sensor node www.xbow.com
[9] J. Hightower and G. Borriello, "Location systems for ubiquitous computing", Computer, vol. 34, no. 8, pp. 57-66, 2001.
[10] A. Smith, H. Balakrishnan, M. Goraczko, and N. Priyantha, "Tracking moving devices with the cricket location system", Proc. 2nd International Conference on Mobile Systems, Applications and Services (Mobisys), pp. 190-202, 2004.
[11] D. Gay, P. Levis, D. Culler, and E. Brewer, nesC 1.1 Language Reference Manual, 2003.
[12] TinyOS at www.tinyos.net
[13] N. Priyantha, A. Chakraborty and H. Balakrishnan, "The cricket location-support system", Proc. 6th ACM MOBICOM 2000, Boston, MA, 2000.
[14] Geographic Location/Privacy (Geopriv) Charter. http://www.ietf.org/html.charters/geoprivchater.html.
[15] G. Virone, A. Wood, L. Selavo, Q. Cao, L. Fang, T. Doan, Z. He, R. Stoleru, S. Lin, J. A. Stankovic, L. Fang, T. Doan, Z. He, R. Stoleru, S. Lin, and J. A. Stankovic, "ALARM-NET: An assisted living-centered and testbed-oriented in-formation system based on a residential wireless sensor network", Proc. Transdisciplinary Conference on Distributed Diagnosis and Home Healthcare (D2H2) 2006, Arlington, VA, 2006.
[16] Ubiquitous Sensor Network Laboratory. www.dsu-nano.net

Vinay Kumar Singh

- 2004년 인도 UP 기술대학교 전자통신공학과 졸업(공학사)
- 2007년 동서대학교 컴퓨터네트워크공학과 졸업(공학석사)
- 주관심 분야 : u-헬스케어, USN, 디지털 이미지프로세싱



임 효 택(Hyotaek Lim)

- 1992년 포항공과대학교 전자계산학과 졸업(공학석사)
- 1997년 연세대학교 컴퓨터과학과 졸업(공학박사)
- 2006년 현재 동서대학교 컴퓨터정보공학부 부교수
- 주관심 분야 : 컴퓨터통신, 스토리지, 모바일 응용

정 완 영(Wan-Young Chung)

- 1989년 경북대학교 전자공학과 졸업(공학석사)
- 1998년 일본 규슈대학 총합이공학연구과(공학박사)
- 2006년 현재 동서대학교 컴퓨터정보공학부 부교수
- 유비쿼터스 IT전문인력양성사업단 단장
- BK21 USN기반 u-헬스케어사업팀 팀장
- 주관심분야 : USN, u-헬스케어, MEMS 센서 등