A Survey of Indoor Positioning and Object Locating Systems

Hakan Koyuncu, Shuang Hua Yang

Computer Science Department, Loughborough University, Loughborough, UK

Abstract:
This paper investigated various indoor positioning techniques and presented a comprehensive study about their advantages and disadvantages. Infrared, Ultrasonic and RF technologies are used in different indoor positioning systems. RFID positioning systems based on RSSI technology are the most recent developments. Positioning accuracy was greatly improved by using integrated RFID technologies.

Keywords: *RFID, RSSI, GPS, Cricket, Active bat, WaveWLAN, triangulation*

1. Introduction

Indoor positioning systems locate and track objects within the buildings and closed enviroments. These systems uses wireless concepts, optical trackings or ultrasonic techniques. Object detection and tracking is the basis of many applications in survailance and activity recognition. There are many solutions developed for position estimation of indoor or outdoor objects [1,2].
Most of these solutions are based on triangulation and multi-lateration methods using light [3,4], ultrasound [5,6], or radio signals [7,8,9,10,11] and they provide positional information.
There are other techniques, which provide relative positioning such as, inertial methods [12,13]. Unfortunately they accumulate errors in time and require periodic recalibration.
In order to position or locate an indoor object; labels, tags, or tokens can be used.
Indoor positioning systems are used to locate people or required objects in large buildings and in closed areas. For example, locating patients in the hospital, finding people trapped in a burning building or finding workers in a large office block are a few applications of indoor positioning systems.
There are many positioning systems with different architectures to determine the location of objects. They have different accuracies, configurations, and reliabilities.
Some of the outstanding positioning systems are GPS [14], AT&T Cambridge Ultrasonic Bats [3], Microsoft Research's WaveLAN system [15], Active Badges [16] ,Smart Floor from Georgia Tech [17], Radio tags, Computer vision systems [18], and cellular phone based systems [19].

Manuscript received May 5, 2010
Manuscript revised May 20, 2010

In this study, initially a general overview of GPS system was given. Most popular Indoor positioning systems using infrared, ultrasonic and RSSI techniques are presented together with Computer vision, cell phone and Integrated RFID positioning systems. They are analysed and compared with each other. The results were tabulated for the readers.

2. Positioning systems :

2.1. The Global Positioning System (GPS)

GPS is the most popular system to find the location and the position of the objects [20]. The worldwide satellite network is used to measure the distances to a great accuracy, See Figure 1. Object locations can be computed to within 1 to 5 meters with this system. But it generally does not function when the receivers are indoors.
GPS is an outdoor positioning system. It receives signals from multiple satellites and employs a triangulation process to determine physical locations.
However High Sensitivity GPS can provide positioning in some indoor locations. Although the signals are heavily attenuated and reflected by the building materials, it was observed that High Sensitivity GPS receivers can track people through a 3 layers of brick wall. But the positioning accuracy is very low.

Figure 1 . Positioning Satellite in the orbit (Ref. 20)

GPS is made up of three parts: Space, Control and User. The Space part is composed of 24 to 32 satellites in medium earth orbit. The Control part is composed of a Master Control Station and many shared Ground Antennas and Monitor Stations. The User part is composed of hundreds of thousands of civil, commercial and scientific users.
GPS satellites broadcast signals from space to GPS receivers to provide 3-D location information (latitude, longitude, and altitude) and precise time. GPS can not provide location information for indoor use. This is because the Electromagnetic waves will be scattered and attenuated by the buildings and outdoor obstacles.

2.2. Infrared Positioning system:

Active badges is the first indoor location sensing system developed by AT&T Cambridge [3]. See Figure 2. A miniture infrared beacon , worn by every person , emits a unique code identifier every 15 seconds. Each location in a building covered with a network of IR sensors which detect these transmissions.
A central server collects this data from fixed IR sensors around the building, gathers into a central data bank, and the location of the badge (hence its wearer) can thus be determined.

Figure 2 : Active badges (Ref. 36)

2.3. Ultrasonic positioning systems:

a) Active bats :
AT&T Cambridge has developed an ultrasonic tracking technology which provided a better and more accurate indoor positioning then the previous Active Badges. Users and objects are tagged with ultrasonic tags identified as “bats”.The system was described in Reference [21]. These bats emitted periodic ultrasonic signals to receivers mounted across the ceiling. This system produced basic position data and additional orientation information. See Figure 3.
The problems of using this ultrasonic technique are the requirement of large number of receivers across the ceilings and their placements across the ceiling which needed quite sensitive alignments.

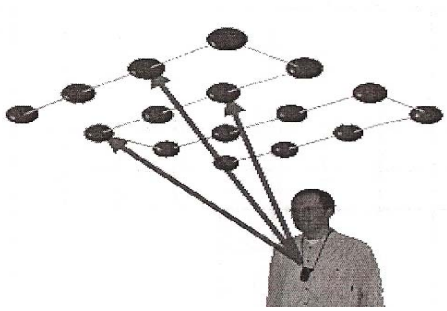

Figure 3: Active Bat system (Ref. 36)

b) Crickets
It is an ultrasonic positioning system. The Cricket nodes are small ultrasonic devices developed by the MIT Laboratories. A Cricket unit which is a transmitter/ receiver application board is shown in Figure 4. 3D positioning accuracy of 1–2 cm is claimed to be reached with this system in an indoor environment of 10m3.

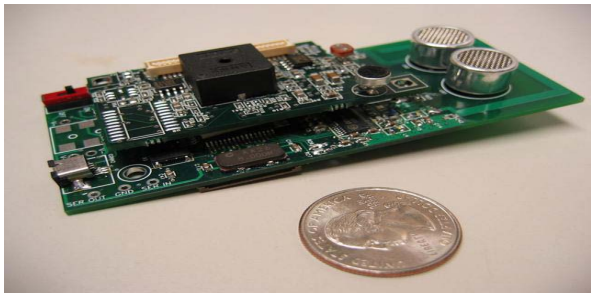

Figure 4: Cricket unit with sensorboard (ref. 22)

The Cricket unit can be programmed either as a beacon or listener. Real-time tracking can also be done with an update-rate of 1 Hz. The system details are given in [22].
c) Dolphin :
It is an ultrasonic positioning system. “ Distributed Object Locating System for Physical space Inter networking” (DOLPHIN) is explained in [23] and [24]. The DOLPIN system consists of distributed wireless sensor nodes See Figure 5.
They send and receive RF and ultrasonic signals. These nodes are attached to various indoor objects. Using a distributed positioning algorithm in the nodes, DOLPHIN enables positioning of the objects with minimal manual configuration. System claims an accuracy of 2 cm to be reached in a room of 3mx3m in size.

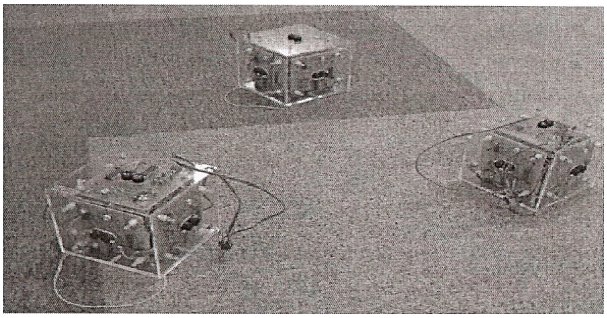

Figure 5 : Dolphin ultrasonic system (Ref. 23)

2.4. RSSI positioning systems :

Received Signal Strengh Information (RSSI) was employed to estimate the distances between transmitters and receivers. Usually RF signals are used [1]. The location of the objects are determined by calculating the distance of the object from the transmitters using triangulation or tri-lateration techniques. Initially a test run can be accomplished in indoors to determine the RSSI database for various transmitters [25].

The unknown RSSI data set was then compared with the test database and the best match was obtained.

One weakness is that the radio signals attenuates from the walls and the receivers perform poorly in indoor environment. Typical indoor environment have many walls and obstacles which are made of various materials. As a result, RSSI values changes and it becomes unreliable .

Many sensors are developed to measure signal strenghts and angles of signal orientations. Many algorithms are also developed for better signal acquisition and tracking.

There is a trend for integrating various sensors and data sources. They also use the triangulation, trilateration and data matching techniques.

RF signal based systems can be split into WaveLAN, UltraWide Band and RFID. ,

a) WaveLAN wireless networking technology

A tracking system in the buildings was developed by using WaveLAN wireless networking technology [15]. This system uses the signal strength and signal to noise ratio available from the WaveLAN network interface card (NIC). The system triangulates 2D position of an object within a building by using either empirical data or a mathematical model of indoor radio propagation. Advantages of this system are such that it requires few base stations and it uses the same general wireless networking in the buildings.

The disadvantage is that the tracked object must support a WaveLAN Network Interface Card (NIC) .Hence It is difficult to use this system in multi-floored buildings. The system claims an accuracy of finding objects to within 3 meters of their actual position .

b) Ultra Wide Band technology

UltraWide band (UWB) impulse radio signals are employed for indoor location and tracking [26][27]. The system platform was constructed using standard electronics components. Designed system allowed fast performance evaluation and estimated the time of arrivals (TOA) of received pulse signals . These sigtnals were transfered to a server computer where the location of the transmitter was calculated.

In this system an indoor object was equipped with an active tag and provided accurate position information even in multipath propagation environment. [28] The architecture of indoor location and tracking system is shown in Figure 6 .

The advantages of the UWB signals are to have high temporal resolution and to provide accurate TOA measurements in multi path environment.

Transmitted signal has a sequance of short pulses. They propagate in the media and received by the four receivers placed in know positions. Two network interconnect the receivers.

Clock network provides reference clock to all receivers. Data network is used for data communication between receivers and the PC. Data received is processed in the PC to analze the TOA of the receiver pulses and the position of the transmitter on the object is determined . The location error was below 30% for 95% of all the position estimations.

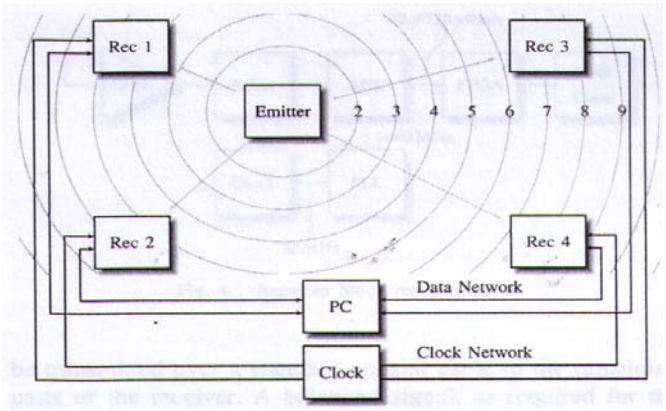

Figure 6: Architecture of network based location tracking system (Ref. 28)

c) RFID technology

Non contact and non-line-of-site characteristics are the advantages of this technology .They can work in high speeds and their RF tags can be read in any environment. See Figure 7. They are also very cost effective. Some popular RFID location finding sytems are called SPOT ON [8] and LAND-MARC[26]. They manage 3D location sensing based on RSSI. Tags are developed and they measured RSSI to calculate inter distance between the tags. An RFID system contains RFID readers and tags and a communication media between them

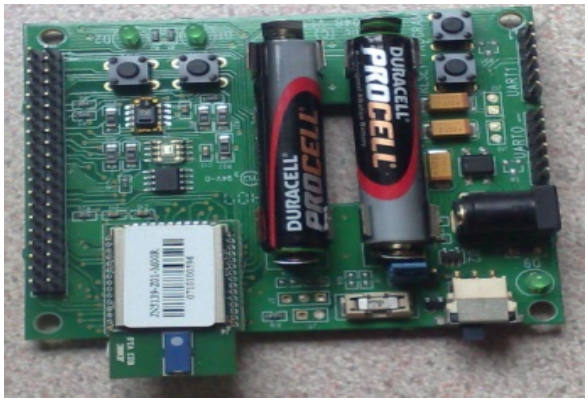

Figure 8: Jennic active RFID Tag (Ref. 29)

Figure 9 : Jennic active RFID reader (Ref. 29)

The signal strength drops with the square of the distance between the tag and the antenna if there is free space around them. In indoor environment the signal levels drops drastically.

LANDMARC is a succesfull RFID positioning system [26] where an RFID active tag is preprogrammed with an ID to be identified by the readers.See Figure 10. RFID reader has 8 power levels with level 1 is the shortest and level 8 is the longest range.

Each reader has a predetermined power level which corresponds to a certain range where it can detect RFID tags. The readers are placed in known positions dividing the region in sub regions.

The tags as they travel in these subregions can be associated with the sub regions. The accuracy of the system depends on the number of these readers and their placements. LANDMARC increased the accuracy without placing more readers by employing extra fixed location reference tags for location calibration. These reference tags become the reference points in the system .

Another indoor positioning system is called SPOT ON [8]. It is a new tagging technology for 3D location detection based on RSS . An embedded hardware system was developed named Hydra Microserver. See Figure 11.

Hydra has both ethernet and RS232 port and it is used for internetworking task .The interconnecting mixture of network and serially connected base stations are shown in Figure 12.

Figure 10 : RFID Tag and Reader used in LANDMARC system. (Ref. 26)

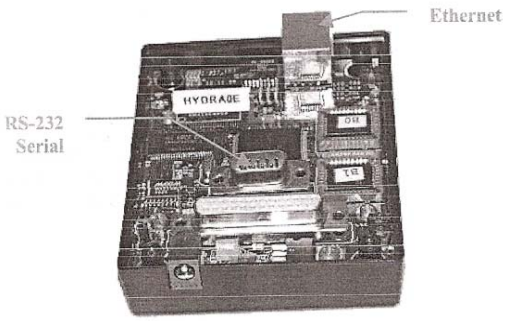

Figure 11: Hydra microserver (Ref. 8)

Multiple base stations are used in the system to provide RSS measurements. These measurements are sent through RS232 port via internet and stored in the server.

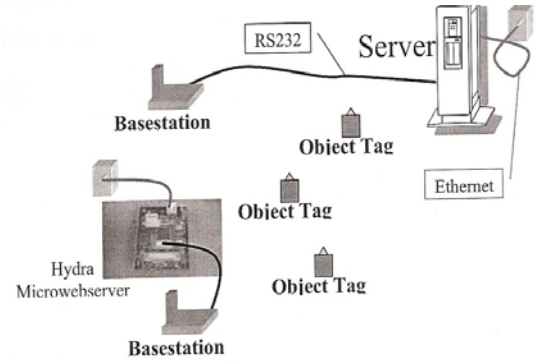

Figure 12: Internetwork architecture (Ref. 8)

The server processor maps the RSS values and using triangulation technique [30], determines the precise position of the objects.See Figure 13.

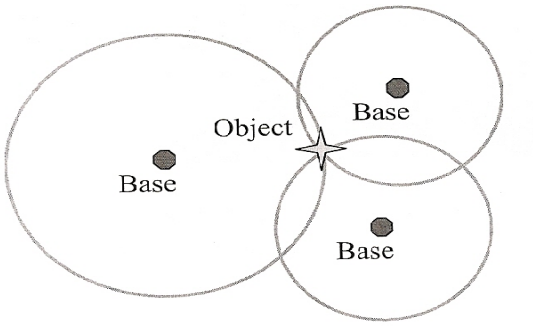

Figure 13 : Triangulation method (Ref. 8)

Once the position is known , A virtual 3D display of the indoor environment was constructed to show the location of the tags on the objects. This application was built with OpenGL.

RADAR is another RF based popular system used for locating and tracking objects or people in indoors [11]. The system records and processes the signal strength information received from base stations. These stations are positioned to provide overlapping coverage of the area of interest. It uses signal propagation modelling to estimate the object location to a great accuracy. Signal strength information collected at multiple receiver locations were triangulated to find the user coordinates. This triangulation was made using emperical approaches and computations of signal strength information. RADAR estimated the user's location within a few meters of his actual location .

2.5. Computer vision systems :

There are visual systems who track the people with multi cameras [18] and generate intelligent environment. The system uses two sets of stereo color cameras to track multi persons in living rooms.

Stereo images are used to locate the people and color images are used to maintain their identities. The system claims a location measurement accuracy of around 10 cm. A disadvantage of the system is that ıt uses multiple cameras to cover all the corners and oclusions of indoors. Hence it is expensive .

Another vision based localization system by two cameras is given in reference [35]. New feature initialization and feature matching techniques are used with two cameras to locate people. Experimental results show that the 3D positioning of the objects is more accurate than single camera cases. The work was aimed for the development of intelligent robots to increase their ability to recognize their environment and their position.

2.6. Cell Phone positioning system (E- 911)

Enhanced 911 is a North American based system which links the telephone calls with the callers' positions [19]. The caller's address and information is displayed for the call taker upon the arrival of the call. E-911 technology is used by wireless telephones. It will allow emergency dispatch centers to process emergency 911 calls and provide the number and geographic information from public safety service providers. Location of the wireless users are found by location pattern matching (LPM) and time difference of arrival (TDOA).

When a person makes a 911 call using a telephone via landlines, the service provider routes the call to the nearest public safety answering point (PSAP), which then distributes the emergency call to the appropriate service(s) with the geographical information

2.7. Integrated positioning systems :

In recent times the positional accuracy was greatly improved by using integrated systems. For example, Inertial technologies [13] where low cost gyros were used for position determination and error correction were included in positining systems.

Inertial navigation system (INS) and RFID positioning methods have been used together to calculate the position of the objects. User's position information is obtained by using RFID technique and RSS measurements .This position information is integrated with the information obtained from INS [31]. Integration of RFID and INS improve position determination since the inertial sensors are not effected by the signal propagation limitations such as obstructions and multipaths. The benefit of this system is such that more RSS information collected a higher resolution of positioning is produced. Hence a probabilistic method was used to determine the tag positions .The probabilities of the user tag's positions [32] are calculated and given in Figure 14.

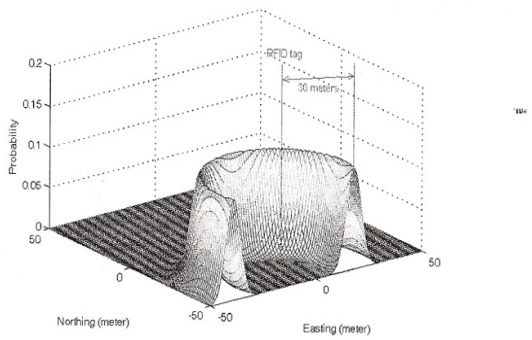

Figure 14: 3D graph of probabilistic positions of a user tag (Ref. 32)

Another technique called finger printing method [7] (FPM) is integrated with RFID technique. Best positioning was achieved in two stages . In first stage, identified as off–line stage. RSS values and physical coordinates are collected from RF transmitters at a reference point and stored in a

database which is called fingerprint. In second stage, identified as On-line stage, the mobile user samples the RSS pattern and searches for similar pattern in off-line database to find the best possible position [33]. The accuracy with this method is around 5m. It calculates the user position according to conditional probabilities of the location under certain RSS . The technique is quite accurate to deal with instabilities of RSS. This probabilistic method also finds the best user tag position with respect to RSS distribution as shown in Figure 14.

Finally, INS/RFID and the finger printing RFID methods were integrated to improve the position accuracy further. Kalman Filtering algorithm was used [34] to integrate these two systems. The accuracy recorded was under 1m.

3. Comparisons :

In this paper,variety of currently used indoor positioning systems were studied and their advantages and disadvantages were compared for the reader.

Table 1,below, was prepared to overview and compare various positional systems. It was aimed that the reader would have a comprehensive view of these systems and would decide which one to use for his/her purpose.

If the accuracy and the cost are the most important parameters , then the systems using ultrasonic techniques are the desirable systems according to

Table 1. Ultrasonic and infrared techniques used TOA (time of arrival) techniques while the techniques using RF signals employed RSS and triangulation / lateration .

All the systems were real time systems and the position information was produced in real time. The accuracies of the systems varied between 2 cm and a few meters .

data repetation rate was between 1 Hz to 70 Hz for the RF systems.

On the other hand ,the integrated systems are the most promising systems for the future. Their accuracies are around 1-2 meters. The technology is easy to apply.

Ultrasonic and Infrared techniques can be integrated with RFID techniques. Better indoor planning and positioning of the sensors can also coupled with these techniques to increase the accuracy levels.

Table 1: Overview of comparisons between various positioning systems

system	*outdoor*	*indoor*	*realtime*	*accuracy*	*range*	*signal*	*Data rate*	*principle*	*cost*
GPS	+		+	1-5m	global	RF	20Hz	TOA, lateration	High
Active badge		+	+	7cm	5m	Infra Red	0.1Hz	TOA, lateration	moderate
Active Bat		+	+	9cm	50m	Ultrasound	75Hz	TOA, lateration	moderate
Cricket		+	+	2cm	10m	Ultrasound	1Hz	TOA, lateration	Low
Dolphin		+	+	2cm	Room scale	Ultrasound	20 Hz	TOA, lateration	Moderate
Wave LAN		+	+	3m	Room Scale	RF	4Hz	RSS, triangulate	Moderate
UWB		+	+	10cm	15m	RF	1Hz	TOA,	Moderate
SPOT ON		+	+	3m	Room scale	RF	2Hz	RSS,triangulate	Low
Land Marc		+	+	1-2m	50m	RF	70Hz	RSS,triangulate	moderate
Radar		+	+	2-3m	Room scale	RF	4Hz	RSS,triangulate	moderate
Comp vision		+	+	10cm	Room scale	Camera images	3.5Hz	Image process	High
Cellphone	+		+	50m	outdoors	RF	Tel rate	Telephone trunk	moderate
INS/RFID		+	+	2m	indoors	RF	100Hz	RSS/INS	moderate
FPM/RFID		+	+	1.7m	indoors	RF	100Hz	RSS/INS	moderate

4. Conclusions :

The determination of 3D positions of people and objects in indoor enviroment is an hot topic . People would like to know their positions in large buildings to a great accuracy . As discussed in this paper there are many attemps to define the 2D and 3D positions of objects by using ultrasonic , infrared and RF technologies. Due to the reduction of the cost of RF devices, namely readers and tags, the positioning systems using RF technology became more attractive. Active transmitter tags are strategically placed in indoor environment. The receiver tags on the objects receive transmissions and calculate their positions in their processors. The calculated object coordinates were later transmitted to a base station database to be visually displayed.

The only problem was the irregular radiation patterns, hence the RSS values, due to obstacles along their path. These obstacles caused multiple radiation paths, radiation reflections and signal attenuations. The result was the generation of false signal receptions from the receivers. This in return degraded the accurate position detection..

RSS values, arriving from the trannsmitters, are used together with the fixed coordinates of the transmitters to determine the positional coordinates of the receiver . Triangulation technique was employed in these calculations.

It can be concluded that integrated systems are emerging as the most promising indoor positioning systems. RFID technologies will be integrated with other technologies ie. Infrared,ultrasonic etc.. and new more accurate systems will be developed in near future.

References

[1] Boon-Giin Lee, Young-Sook Lee, Wan-Young Chung; 3D Navigation Real Time RSSI-based Indoor Tracking Application, Journal of Ubiquitous Convergence Technology, Vol.2, No.2, November 2008, pages 67-77

[2] Cliff Randell Henk Muller; Low Cost Indoor Positioning System , report , Department of Computer Science, University of Bristol, UK.

[3] R.Want , A.Hopper,V.Falcao and J.Gibbons; The active Badge location system,ACM Transactions on Information systems Vol. 40, No. 1, pp. 91-102, January 1992

[4] R.Want, B.Schilit, N. Adams, R. Gold, D. Gold- berg, K.Petersen ,J.Ellis, M Weiser; The Parctab Ubiquitous Computing Experiment", Book Chapter: "Mobile Computing", Kluwer Publishing, Edited by Tomasz Imielinski, Chapter 2, pp 45-101, ISBN 0-7923-9697-9, February 1997.

[5] A.Ward, A.Jones, A.Hopper: A neq location technique for the active office , In IEEE personal Communication Magazine ,Volume 4 no 5,pages 42-47 ,October 1997

[6] A.Harter ,A.Hopper, P.Steggles, A.Ward, P. Webster; The anatomy of a context aware application, In proceedings of the 5th annual ACM/IEEE ınternational conference on Mobile Computing and Networking,pages 59-68,August 1999

[7] P. Bahl, V.N. Padmanabhan; RADAR: An in-building RF-based user location and tracking system, in: Proceedings of IEEE INFOCOM 2000, Tel-Aviv, Israel (March 2000), http://www.research.Microsoft .com/padmanab/papers/infocom2000.pdf

[8] J. Hightower, R. Want and G. Borriello; SpotON: An indoor 3D location sensing technology based on RF signal strength, UW CSE00-02-02, February 2000, http://www.cs.washington.edu/homes/jeffro/pubs/hightower2000indoor/hightower2000indoor.pdf

[9] RadioFrequencyIdentification (RFID) home page, http://www.aimglobal.org/technologies/rfid/

[10] Konrad Lorincz, Matt Welsh ; "MoteTrack: A Robust, Decentralized Approach to RF-Based Location Tracking," Proceedings of the International Workshop on Location and Context-Awareness (LoCA 2005) at Pervasive 2005, May 2005

[11] Bahl P. Padmanabhan VN; RADAR: An In-Building RF-based User Location and Tracking System, In, IEEE Infocom 2000. Volume, 2.pp.775-784, March 2000

[12] Kennedy, S. Hamilton, J. Martell; Architecture and System Performance of SPAN NovAtel's GPS/INS Solution, Proceedings of IEEE/ION PLANS 2006, San Diego, USA, April 23- 25, 2006.

[13] Jussi Collin, Oleg Mezentsev, Gérard Lachapelle Indoor positioning system using accelerometry and high accuracy heading sensors Proceedings of GPS/GNSS 2003 Conference (Session C3), Portland, OR, September 9-12, 2003,

[14] Starlink Incorporated. DGPS Explained, http://www.starlinkdgps.com/dgpsexp.htm. 1999

[15] P. Bahl, V. N. Padmanabhan; User Location and Tracking in an In-Building Radio Network, Microsoft Research Technical Report: MSR-TR-99-12, February 1999

[16] A. Harter and A. Hopper, A Distributed Location System for the Active Office, IEEE ,Network, January 1994

[17] Robert J. Orr, Gregory D. Abowd; The Smart Floor: A Mechanism for Natural User Identification and Tracking, GVU Technical Report GIT-GVU-00-02 (full paper). January 2000

[18] John Krumm, Steve Harris, Brian Meyers, Barry Brumitt, Michael Hale, Steve Shafer; Multi camera Multi-person tracking easy living , Third IEEE International Workshop on Visual Surveillance, 2000, Dublin, Ireland, p-1-8

[19] http://www.safecomprogram.gov/NR/ rdonlyres/D8BFF5A9-47A7-4496-AB93-611DD043C3E0/0/emerging_wireless_technologies_enhanced_911.pdf

[20] http://en.wikipedia.org/wiki/Global_Positioning System

[21] Hazas, M., Hopper, A; A Novel Broadband Ultrasonic Location System for Improved Indoor Positioning, IEEE Transactions on mobile Computing, Vol. 5, No. 5, May 2006.

[22] Priyantha, N. B; The cricket indoor location system: PhD Thesis, Massachusetts Institute of Technology. 199 p, June 2005

[23] Fukuju, Y.; Minami, M.; Morikawa, H.; Aoyama, T.; Dolphin. 2003. An autonomous indoor positioning system in ubiquitous computing environment, in Proc of the IEEE Workshop on Software Technologies for Future Embedded Systems.

[24] Minami,M.;Fukuju,Y.; Hirasawa, K.; Yokoyama, S.; Mizumachi,M.; Morikawa, H.; Aoyama, T.; 2004. Dolphin: A practical approach for implementing a fully distributed indoor ultrasonic positioning system, Ubicomp, 347–365.

[25] E.E.L. Lau, W.Y. Chung; Enhanced RSSI-based Real-Time User Location Tracking System for Indoor and OutdoorEnvironments, International Conference on Convergence Information Technology, pp. 1213-1218, November 2007.
[26] Lionel M.NI, Yunhao Liu, Iu Cho Lau, Abhıshek P. Patil; LANDMARC: Indoor Location Sensing Using Active RFID;
[27] D.Harmer; Ultra wide-band indoor positioning, Dec. 2004, online March 2008,http://esamultimedia.esa.int/docs/NavigationProjects
[28] R. Merz_, F. Chastellain_, C. Botteron_, A. Blatter, -A. Farine; An Experimental Platform for an Indoor Location and Tracking System; http://www.merz.li/documents/GNSS2008.pdf
[29] http://www.jennic.com/jennic_support/application_notes/jn-an-1052_home_sensor_demonstration_using_zigbee
[30] http://en.wikipedia.org/wiki/Triangulation
[31] Zhu M; Novel Positioning Algorithms for RFID-Assisted 2D MEMS INS Systems, 2008, Proceedings of the Institute of Navigation GNSS 2008 conference, Savannah, Georgia, US
[32] Ming Zhu, Kefei Zhang, William Cartwright , Günther Retscher, Qing Fu; Possibility studies of Integrated INS/RFID Positioning Methods for Personal Positioning Applications, International Global Navigation Satellite Systems IGNSS ,2009
[33] Retscher G,Fu Q; Using Active RFID for Positioning in Navigation Systems, Proceedings of the 4th International Symposium on Location Based Services and Telecartography, Hong Kong, 2007
[34] Brown RG, Hwang PYC; Introduction to Random Signals and Applied Kalman Filtering, 1997, (3rd edition), John Wiley & Sons, New York, 484pp
[35] Gab-Hoe Kim, Jong-Sung Kim, Ki-Sang Hong; Vision-based Simultaneous Localization and mapping with Two Cameras , RSJ Int conference on intelligent robots and systems p3401-3406
[36] http://www.uk.research.att.com/ab.html