Indoor User Localization for Rapid Information Access and Retrieval on Construction Sites

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Abstract. Manual search of project information on construction sites is a tedious and time-consuming process. Evolving technologies such as location-aware computing offer significant potential of improving such processes and supporting important decision-making tasks in the field. For example, rapid and convenient access to contextual project information, through continuous position tracking of engineers, managers and inspectors, can lead to significant cost and time savings due to the accuracy and immediacy with which relevant project information can be made available to field personnel . Considering the spatial expanse and dynamic nature of typical construction projects, mobile users need to be constantly tracked outdoors as well as indoors. The Global Positioning System (GPS) is an attractive option for outdoor applications, but is not suitable for indoor applications because it needs a clear line-of-sight to the satellites in order to track position. As a result, alternate means to detect users' location in indoor environments without relying on GPS are needed. This paper presents research that is studying indoor wireless technologies for dynamic user position tracking. Three technologies, Wireless Local Area Networks (WLAN), Ultra-Wide Band (UWB), and Indoor GPS position systems are evaluated and compared.

1 Introduction

Field construction tasks such as inspection, progress monitoring and others require access to a wealth of project information. Currently, site engineers, inspectors and other site personnel, while working on construction sites, have to spend a lot of time in manually searching into piles of papers, documents and drawings to access the information needed for important decision making tasks. Evolving technologies such as location-aware computing offer significant potential of improving such processes and supporting important decision-making tasks in the field. Instead of requiring browsing through detailed drawings and other paper based media, contextual project information can be automatically retrieved by continuously and accurately tracking the mobile users' spatial parameters (Khoury & Kamat, 2008). Therefore, the concept of context-aware information delivery (Aziz et. al., 2005) encompasses the creation of a user centered mobile dynamic indoor and outdoor work environment, which has the ability to deliver relevant information to on-site mobile users by intelligent interpretation of their spatial context so that they can make more informed decisions (Schilit et al., 1994). Global Positioning System (GPS), being a satellite-based navigation system, works satisfactorily outdoors but lacks support indoors and in congested areas. In addition, unlike outdoor areas, the indoor environment imposes different challenges on location discovery due to the dense multipath effect and building material dependent propagation effect (Tadakamadla 2006). There are many potential technologies and techniques that have been suggested to offer the same functionality as a GPS indoors, such as Wireless Local Area Networks (WLAN), Ultra-Wide Band (UWB) and Indoor GPS. By tagging users with appropriate receivers/tags and deploying a number of nodes (access points, receivers, transmitters, etc.) at fixed positions indoors, the location of tagged users can be determined and continuously tracked.

The objectives of the paper are to present three key positioning technologies applicable indoors, portray the features of these techniques through several conducted experiments, and highlight the extent to which each one can be used to accurately calculate the position of a user in congested harsh environments and situations such as those found on construction sites. The experimental results demonstrate the ability of Indoor GPS, in particular, to estimate a user's location with a high degree of accuracy (1 cm).

2 WLAN Based User Position Tracking

In the last few years, Wireless Local Area Network (WLAN) radio-signal-based positioning system, supported by underlying transmission technologies Radio Frequency (RF) and Infra Red (IR), has seen enormous expansion and it will continue this trend due to the fact that it is an economical solution providing convenient connectivity and high speed links, and can be implemented simply in software (Hightower & Borriello, 2001). Additionally, WLAN covers a large area and is not restricted to line of sight. Wireless networks can support large numbers of nodes and large physical areas by adding access points to extend coverage. Therefore, WLAN allow users to be truly mobile as long as the mobile terminal is under the network coverage area. Additionally, the distance over which RF and Infra Red IR waves can communicate depends on product design (including transmitted power and receiver design) and the propagation path, in particular in indoor environments. Interactions with typical building objects, such as walls, metal, and even people, can affect the propagation of energy, and thus also the range and coverage of the system. IR is blocked by solid objects, which provides additional limitations. For that reason, most wireless LAN systems use RF, because radio waves can penetrate many indoor walls and surfaces. The range of a typical WLAN node is about 100 m (Wang & Liu, 2005). Coverage can be extended, and true freedom of mobility achieved via roaming. This means using access points to cover an area in such a way that their coverages overlap each other. Thereby the users can navigate around and move from the coverage area of one access point to another without even knowing they have, and at the same time seamlessly maintain the connection between their node and an access point.

WLAN is appealing because it allows enhanced connectivity and is particularly useful when mobile access to data is necessary. Additionally, user flexibility and portability can easily be reconfigured while requiring no cable infrastructure (CISCO 2002). For the above reasons, it was studied for the purpose of the proposed methodology. A proper WLAN architecture framework provides a structure to develop, maintain and implement an acceptable operation environment and can support implementation of automated testbed experiments conducted to continuously track mobile users. One set of experiments to obtain location information in this study were based on a WLAN based position system called the Ekahau Positioning Engine (EPE) from the Finnish company Ekahau Inc. (Ekahau 2004).

Being the centerpiece of the Ekahau tracking system, EPE is a WLAN positioning system made for indoor and campus areas (Ekahau 2004) where GPS does not perform adequately. The solution requires no proprietary WLAN base stations and it does not need to know the location of the base stations. EPE uses a patented process called *SiteCalibration* to create a model of the desired space. The underlying approach used for the calibration process is the fingerprinting technique. Areas/rooms are scanned and Radio Frequency (RF) parameter measurements (power loss, multipath phase, etc.) are recorded. Then the measurements with their location are saved to a database/Ekahau engine (i.e. Received Signal Strengths indicate power loss and this loss is translated into location). When a mobile device moves in the area, it reports its RF parameter measurements to the EPE. Then the device location is estimated by

matching the RF parameters against the location fingerprints in the database. The software uses certain patented algorithms and scene analysis on the signals to compute a location estimate. The whole process results in a positioning estimate that can be as accurate as 1 to 2 meters under optimal conditions (LaMarca et.al. 2005).
Having the positioning model created and calibrated, the positioning engine tracks the real time position of a WLAN-enabled mobile device (Figure 1). It discovers all the WLAN-enabled devices using their IP addresses, and makes use of the signal strength measurements as detected by the access points to determine the actual position (Aziz et.al. 2005).

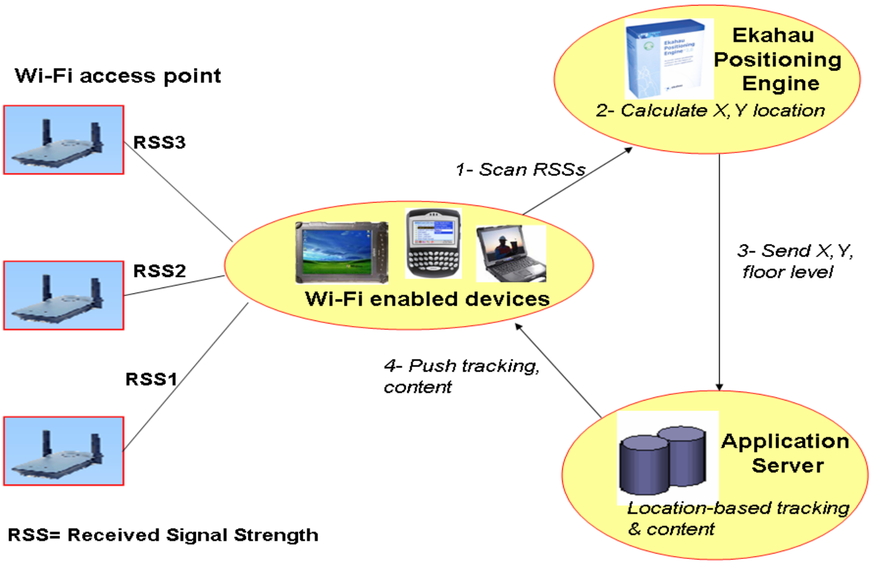


Fig. 1. Ekahau Positioning Engine Mechanism

2.1 WLAN-based Localization Experiment

Experiment: Construction Engineering Laboratory, University of Michigan

A testing application was conducted indoors at the Construction Engineering Laboratory located in the G.G. Brown building at the University of Michigan (Figure 2). The objective was to real-time track a mobile user's position and head orientation as s/he walked inside the laboratory. Three access points were used in this case.

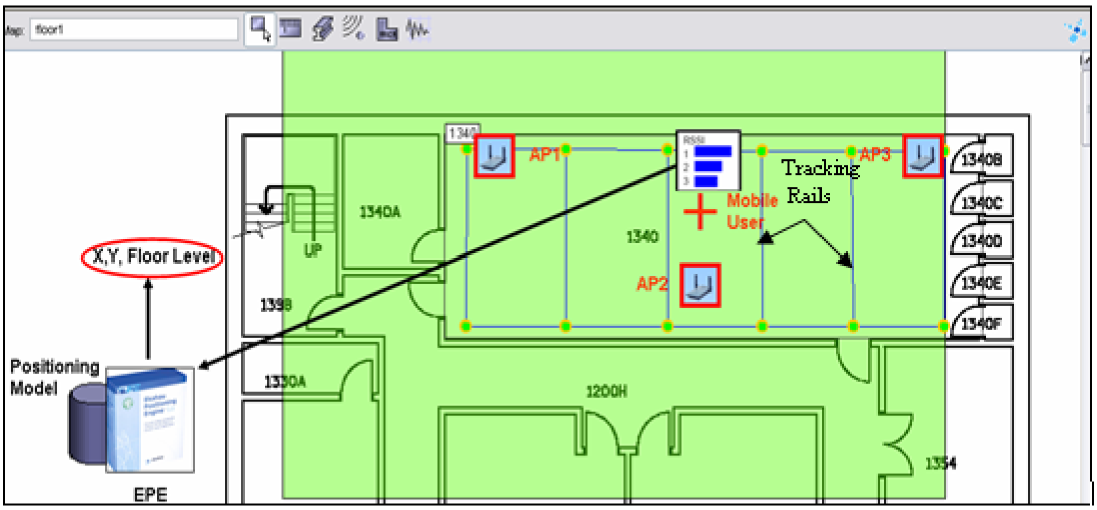


Fig.2. Ekahau Calibration and Testing inside the Construction Laboratory (University of Michigan)

For that purpose, positioning information (X, Y, floor level) obtained from Ekahau JAVA SDK (Ekahau 2004) and orientation information (roll, yaw, and pitch) obtained from a C++ TCM5 magnetic tracker-based application (Behzadan and Kamat 2006), were combined in a single C++ application as reflected through the pseudo code shown in Figure 3.

- Initialize C++ tracker application function to start obtaining head orientation values (roll , pitch and yaw)

- Get positioning values
    1. Open pipe to invoke Ekahau JAVA SDK& Return pointer to a stream using _popen ()
    2. Read output (X, Y, Floor level) of the invoked program using the reading access character string mode "r"

- Output all positioning and head orientation values (X,Y,Floor level and roll, pitch, yaw)
- Close pipe using _pclose()

Fig.3. Pseudo Code for creating a pipe between two tracking applications (JAVA and C++)

In order to virtually visualize how the mobile user (the first author in this experiment) is being continuously tracked in the laboratory using the obtained user's position and head orientation , a 3D environment that has sufficient underlying computer graphics support to allow the manipulation of entities in a 3D scene was needed. A computer graphics technology based on the concept of the *Scene Graph,* namely OpenSceneGraph (OSG) within Visual C++ .NET, was adopted (Kamat 2003). Selected snapshots of virtual views taken during the experiments, conducted on both the first floor (Construction Engineering Laboratory) as well as the second floor of G.G. Brown building are shown in Figure 4. The results of the experiments indicate that the Ekahau tracking system overall achieves a positioning accuracy that is on the order of 2m.

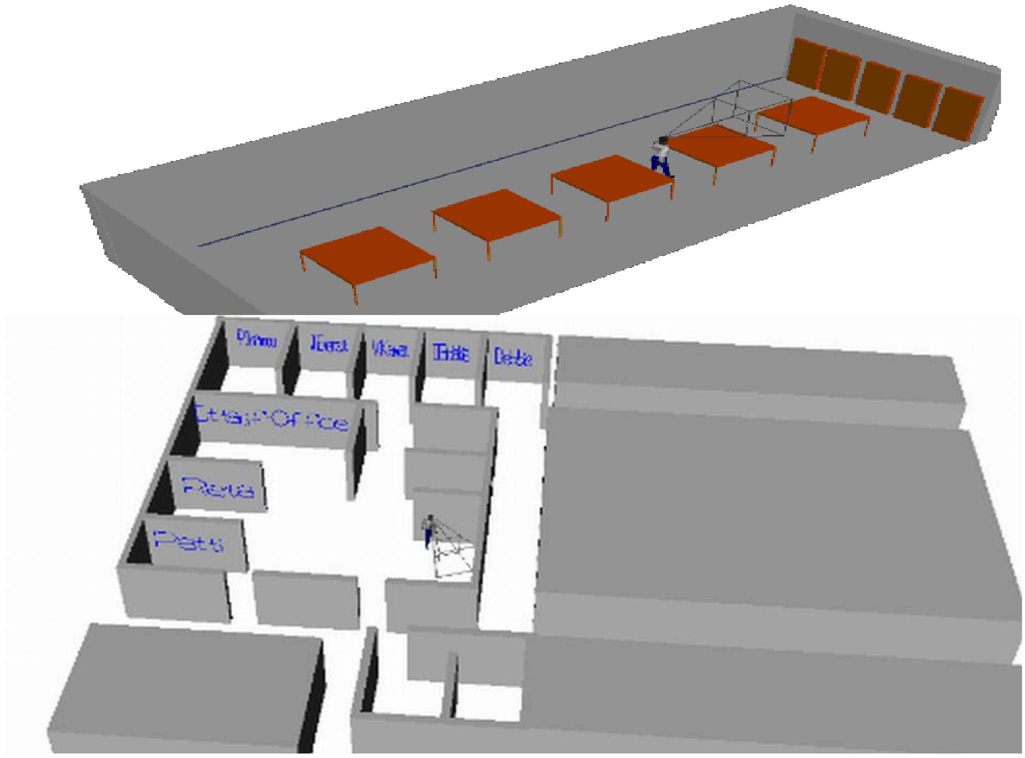


Fig.4. Virtual Representations for Indoor Tracking of a Mobile User in First floor (top) and Second Floor (bottom) of the G.G. Brown Building

3 UWB-Based User Position Tracking

The second tracking system evaluated in this research is the Sapphire *DART* Ultra Wideband *Digital Active Real Time Tracking* system (Multispectral Solutions 2008). It is designed for the tracking personnel and/or equipment. A system comprises of one processing hub, four or more receivers, one or more reference tags, and multiple tags for individual assets (Figure 5).

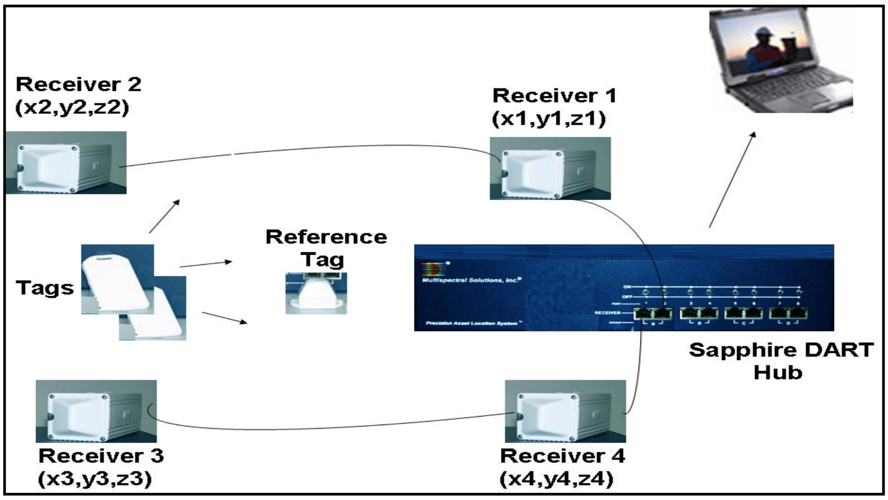


Fig.5. Sapphire UWB Tracking System

The system uses short pulse or UWB technology to determine the precise location of UWB radio frequency identification (RFID) tag and operates as follows:

Each tag repeatedly sends out a packet burst consisting of a short train of UWB pulses, each pulse having an instantaneous bandwidth of over 1 GHz. Since individual tags are not synchronous, and the packet bursts are of extremely short duration, the probability of tag packet collision is very small allowing for the simultaneous processing of hundreds to thousands of tags in a local area. These transmitted UWB pulse trains are received by one or more *Sapphire DART* UWB receivers which are typically located around the periphery of the area of coverage at known locations. Reception by three or more receivers permits accurate 2-D localization, while reception by four or more receivers allows for precise 3-D localization. If only one or two receivers can receive a tag transmission, proximity detection can also be readily accomplished. Each receiver uses a highly sensitive, very high speed, short pulse detector to measure the precise time at which a tag packet arrives at its antenna. The extremely wide bandwidth of the UWB pulses permits the receivers to measure these times-of-arrival to sub nanosecond precision. In order to determine the actual tag position from these measurements, the *Sapphire DART* Hub/Processor, using calibration data from the *Sapphire DART* UWB reference tag, determines the differential times-of-arrival between receiver pairs from these individual receiver measurements and implements an optimization algorithm to determine the location using a multilateration technique. Since the speed of light is approximately 0.98 feet per nanosecond, these differential times-of-arrival are readily converted into the appropriate measurement distances.

3.1 UWB-Based Localization Experiments

Experiments at Disaster City - Texas A&M University, and National Institute of Standards and Technology (NIST)

Disaster City is one of the most comprehensive emergency response training facility available today. It is a 52-acre training facility designed to deliver the full array of skills and techniques needed by urban search and rescue professionals. As part of the Texas Engineering Extension Service (TEEX) at Texas A&M University, the facility features full-size collapsible structures that replicate community infrastructure, including a strip mall, office building, industrial complex, assembly hall/theater, single family dwelling, train derailment and three rubble piles (TEEX 2004).

Many of the following indoor experiments were performed at Disaster City as part of the response robot evaluation exercises for Urban Search-and-Rescue (US&R) conducted by the National Institute of Standards and Technology (NIST) team, of which the first author was a member. These response robot evaluation exercises for US&R teams introduce emerging robotic capabilities to emergency responders within their own training facilities, while educating robot developers regarding the necessary performance requirements and operational constraints to be effective (NIST 2007). Several of those exercises were specifically performed at the maze in the assembly hall/theater (Figure 6).

Fig.6. Disaster City: a) Assembly Theater Location [TEEX 2007] and b) Maze

Six receivers were deployed in the hall as shown in Figure 7. Tags were placed on top of robots in order to track robot's 3D location.

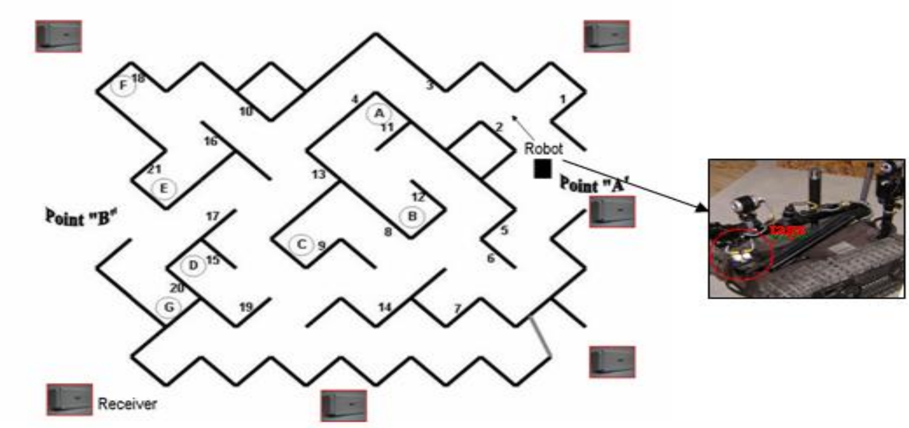
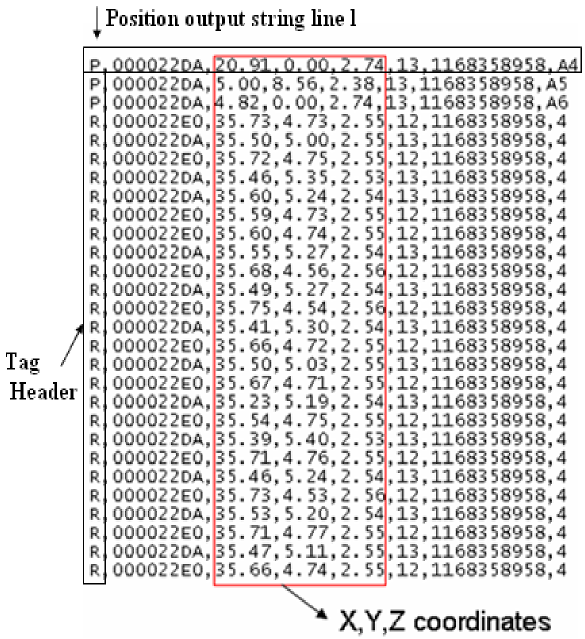


Fig.7. UWB tracking system at Maze (Disaster City)

TCP sockets were used to connect directly to the Hub and provide a quick and effective way for accessing location information from a local computer/laptop. This was achieved by opening a socket connection given the IP address of the hub and the port number, reading values and then performing a string manipulation on the values obtained (Figure 8a.) to obtain the X, Y, Z coordinates(Figure 8b.). Only values corresponding to a tag header **R** were extracted (n1, n2, & n3).



Open socket connection "s" to Sapphire HUB (IP address and port number)

- Receive each position output string l from s
- If (l contains tag header R meaning 3D readings X,Y,Z)
  - Do a string manipulation and extract array s[i], a set of 3 position coordinates from each string l
  - Convert the array of position strings s to array of position integers f & Assign n1, n2, n3 to each of the position integer values f

    for(i=0 → i=3)

    string s[i] → f[i]

    n1=f [1], n2=f [2] & n3= f [3]

Fig.8. a) Output Results from Sapphire HUB (top), b) Pseudo Code to extract UWB position coordinates (bottom)

The positioning values were then used together with orientation values received from the TCM5 magnetic tracker and both were integrated in the tracking OSG application to visualize (in 3D) how the robot is moving around the maze in real-time (Figure 9).

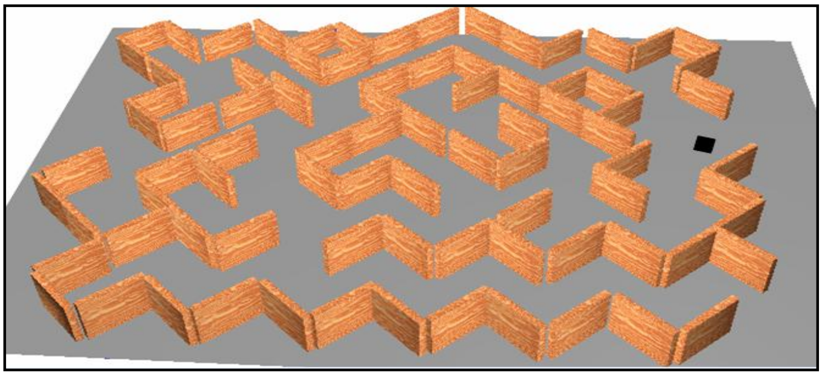


Fig.9. 3D OSG View of robot navigation inside the maze

The same experiment was carried out at NIST. Figure 10 is a 3D view of a mobile user walking inside the maze. The results of the experiments indicated that the UWB Tracking system overall achieves an accuracy of about 30 cm.

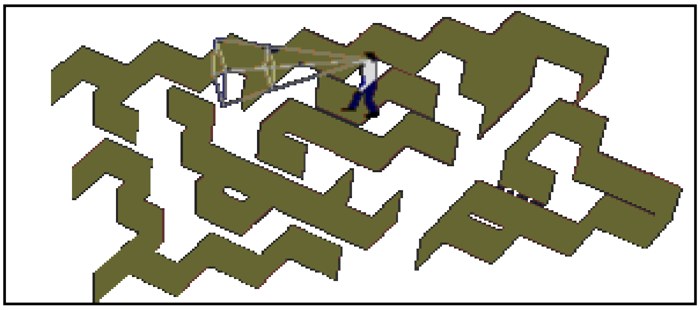


Fig.10. 3D OSG View of a Mobile User Path Inside the Maze (UWB)

4 Indoor GPS-Based User Position Tracking

Indoor GPS is the third tracking system studied in this research. The system is mainly defined by four or more transmitters and a receiver (Figure 11). A battery operated transmitter uses laser and infrared light to transmit one-way position information and elevation from the transmitter to the receiver. The receiver has photodiodes inside its module and senses the transmitted laser and infrared light signals. With the addition of a second transmitter of known location and orientation, users can calculate the position of the receiver in the base coordinate system. By adding two more transmitters, the system will have four laser transmitters having its accuracy maximized. The GPS-like navigation signal is transferred through a wireless network connection providing mobility to the operator (Kang and Tesar 2004). As in satellite-based GPS, this one-way signal path is created from transmitters to the receiver, allowing an unlimited number of receivers to continuously and independently calculate positions whenever two or more transmitters are in view. Basically, a receiver in the measurement volume detects and processes the signals from each visible transmitter. The 3D position of the optical receiver is then calculated by the process of triangulation. Triangulation (Lähteenmäki et al., 2001) is used, if the angles to known locations are given. With two known locations, the absolute position in 2D can be determined. The two angles are used to determine the line-of-sights to each of the known locations. With the position of the locations, these lines are unique in the two-dimensional space and intersect in the desired position. Therefore, given the angular information from at least two transmitters and provided with the position and orientation of each transmitter, a unique 3D position within the measurement volume can be calculated.

The indoor GPS eliminates the recurring problem of accidentally interrupting a laser beam during measurement action that requires the operator to begin the measurement again.

Fig. 11. Indoor GPS Transmitter (left) and Receiver (right)
[Source:http://www.indoorgps.com/Technology/Hardware.aspx]

4.1 Indoor GPS-Based Localization Experiment

The experiment using Indoor GPS was conducted at NIST, specifically inside the maze at the former NIKE missile base barracks building adjacent to the main NIST campus. The goal of this experiment was to simulate a mobile user such as a construction engineer or inspector moving around and surveying the building, and determine the extent to which user's position can be accurately and continuously tracked.

In this case, four transmitters were deployed inside and around the area of the maze as shown in Figure 12 and one receiver and the orientation tracker were held by the mobile user as s/he moved around. The user's position and orientation were continuously obtained from the Indoor GPS and magnetic tracker and the tracking values were used in the 3D OSG application to visualize the path of the user inside the maze (Figure 13). The results of the experiments indicate that the Indoor GPS tracking system consistently achieved a high accuracy of 1 to 2 cm.

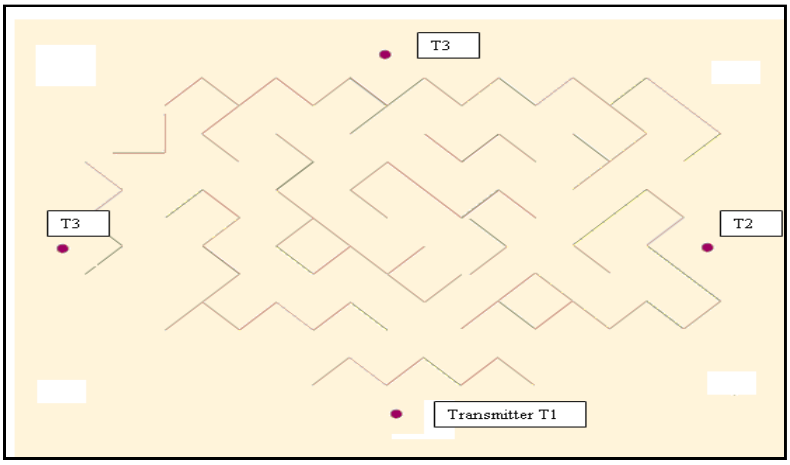


Fig.12. Deployment of laser transmitters around the maze

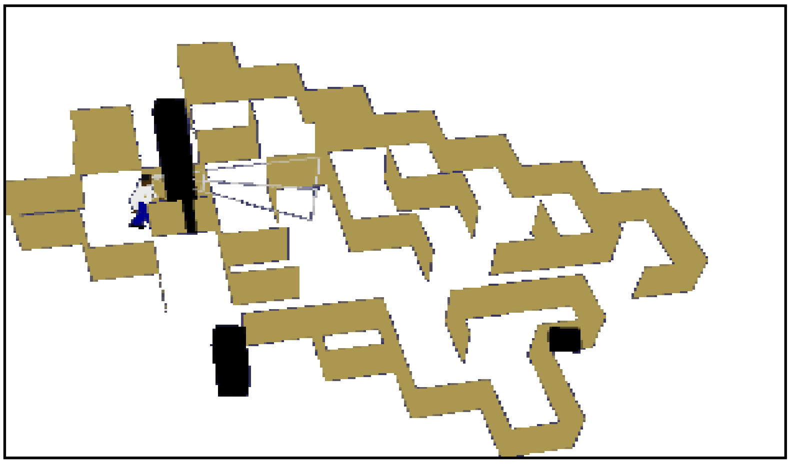


Fig.13. 3D OSG View of a Mobile User Path Inside the Maze (Indoor GPS)

5 Conclusion

The research presented in this paper compared three different wireless technologies (WLAN, UWB and Indoor GPS) that can be used for tracking mobile users on indoor construction sites. In order to evaluate the technical features of these technologies and their applicability in a context-aware information delivery framework, several validation experiments were conducted at the University of Michigan, Disaster City (Texas A&M University), and NIST.
It must be noted that the decision on using one technology or another is based on important technical criteria (calibration, line of sight, accuracy etc.) in addition to other logistic issues such as availability, the prevailing legal situation, and the associated implementation costs. Some of these criteria are summarized in Table 1.
However, in order to address the problem posed by the difficulties faced in the target operating construction environment, Indoor GPS positioning technologies provide the most promise due to the high level of accuracy it achieves (1-2 cm) compared to the accuracy of WLAN and UWB wireless technologies that provide a comparative accuracy of approximately 2m and 30 cm respectively (Table 1).

Table 1: Comparative Summary of Indoor Positioning Technologies

	Line of Sight	**Accuracy Requirement**	**Calibration**	**Deployment and Cost**
Indoor GPS	Needed (receiver-transmitter)	Very High (1-2 cm)	Needed (few sampling points)	Quite Easy but Expensive
UWB	Needed (receiver-reference tag)	High (10-50 cm)	Not needed	Quite Easy but Expensive
WLAN (Ekahau)	Not needed	Medium (1.5-2 meters)	Needed (time-consuming)	Easy and Economical

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