DEVELOPMENT OF LOCATION-BASED INDOOR FACILITIES MANAGEMENT SYSTEM

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Abstract: Many facilities management systems depend on location information for identifying facilities of interest. However, obtaining location information in a large open space is not sometimes easy due to lack of landmarks. Although Global Positioning System (GPS) is well known for its ability to provide accurate positioning when used outdoor, it was seldom intended for indoor environment because the satellite signal tends to be week or deflected inside the building. Several indoor location identification systems therefore have been developed. This paper presents how a prototype location-based indoor facilities management system was developed and tested using the indoor location system.

Keywords: Facilities Management, Indoor Location System.

1 INTRODUCTION

Location of facilities is one of the key elements in facilities management. Many facilities management systems depend on room numbers or signboards for identifying location of facilities. However, location of facilities in a huge open space such as the lobby of an international airport terminal may not be easily identified due to lack of landmarks to be utilized.

Global Positioning System (GPS), which is a technology designed to identify the user's location in the globe utilizing electronic waves transmitted from artificial satellites, has a great potential in outdoor facilities managements. However, it may not be effectively utilized for indoor facilities managements because the strength of the GPS signal tends to be reduced significantly inside the building by the external walls and roof.

Recently, several indoor user location identification systems have emerged. Most of these systems are utilizing GPS technology to identify the user's location. The transmitter sends signals of its location using electronic wave and/or ultrasonic wave. Signals transmitted to the receiver are then analyzed by trigonometric function to identify the user's location. Some indoor location identification systems are designed for mobile devices such as Pocket PC. The process of manipulating location information of indoor facilities is therefore expected to be improved if the mobile-based indoor location identification system is applied for indoor facilities management.

2 MOBILE COMPUTING

Mobile computing is expected to improve facilities management in field by reducing laborious and redundant work. A facilities management system loaded on a mobile device would enable facilities managers acquire inspection data and update them in field without going back and forth to the office. These data would be synchronized with the main database later whey they come back to the office. Facilities managers therefore would avoid the process of entering inspection data in the main facilities management system, which often causes data duplication or omission.

The Texas department of Mental Health and Mental Retardation (TDMHMR) recently decided to use mobile devices to improve its facility management system. Instead of paper work orders, the TDMHMR use a Personal Data Assistant (PDA) to assign and track work orders. Through this process, work orders are downloaded to the technician's PDA and can be filtered and resorted by location, priority, and work type. When workers arrive at the site, they can cross check the procedure checklist stored in the PDA. Once they've completed the tasks, they can record the time spent and materials used in each task before moving on to the next assignment. At their convenience, workers can upload and synchronize the PDA with the database, closing completed work orders and recording time and materials automatically [1].

Some mobile devices, such as Intermec 5020 and Symbol MC9000-G, are even armed with bar code scanners. Facilities managers can acquire information on any items simply by scanning their bar codes. Hence, they can easily add/edit/delete related information pertaining to that item on-the-spot without the usual hassles of manual data entry and paper work routines. Both Intermec 5020 and Symbol MC9000-G use Microsoft Windows CE as the operating system and include the standard-based wireless network (802.11b or Bluetooth) that enables real-time communication [2].

At Northwestern Memorial Hospital (NMH), facilities management department uses PDA to manipulate Life Safety Systems, which have over 2,000 fire and smoke dampers scattered throughout its main facility unit. The PDA-based Life Safety Systems Management (LSM) is comprised of a PDA, a bar code reader, LSM software, and a Microsoft Access database on a host desktop PC. The process begins with a field survey to locate and barcode the desired devices. Inspectors then enter all the relevant information and results from the inspection of each device into the PDA. After the completion of the survey, data is synchronized with a host PC and linked to the facility's CAD files. The system's web-based front end allows authorized users to access the location and maintenance history of the devices via the Internet. With this new technology, NMH staffs are no longer burdened by tedious tasks of storing and filing heaps of outdated, hard copy inspection reports but can now easily access and update them via the Internet [3].

At West Coast Airport, Tablet PCs have been utilized mainly for security purposes. Autodesk, Inc. set up a pilot project to extend its security application, Homeland Security Initiative. The Autodesk Homeland Security Initiative is an application that delivers a suite of design and mapping applications that give first responders and emergency personnel quick access to data that are crucial to the safeguarding of infrastructure, enhancement of public safety, and management of emergencies. With the capabilities of the Tablet PC, emergency responders can access critical information on scene using live spatial data, maps, aerial imagery, and situation planning. Among the units and departments that participated in the pilot test included Airfield Operations, Terminal Operations, IT, Project Management, Facility Management, Environmental, and the Airport Managers Office. The pilot test was proven a success. Tablet PCs offered the management the flexibility to react with greater speed, efficiency, and accuracy, especially at times when public safety is at stake [4].

Computerized Maintenance Management Systems (CMMS) loaded on a mobile device enables facilities managers open or close work orders while conducting building inspection. Information on work orders is transferred to the central database via a wireless network that allows other managers or technicians to access up-to-minute information. Moreover, CMMS is connected to a web-based information system and allows customers to request maintenance services via a web browser [5].

Wearable computer is another mobile device that can be applied for facilities management. Mobile Inspection Assistance (MIA) is a good example. It consists of a portable pen-based computer that can be worn on the hip or chest; a Head Mounted Display (HMD) with audio device that allows inspectors to record exactly what they see; and a durable battery set that powers the system [6]. The software application of this MIA system usually consists of five functions: a graphic user interface that presents the previous inspection reports, current inspection form, collection of sketch templates, and photo album; a speech recognition tool that allows inspectors to invoke commands via speech; a database for storing information; a tool for sketching; and a tool for viewing/editing photos [7].

3 LOCATION INFORMATION

Often times, location information is critical for facilities management or construction management. Global Positioning System (GPS), which calculates the position in the globe using satellite signals, has been actively utilized to obtain outdoor location information.

When Mt. Fugen volcano in Japan erupted in 1994, two canals were constructed to guide lava flows into near sea. Since the construction was carried under the constant threat of lava flows, unmanned backhoes, bulldozers, and dump trucks were employed at the job site and were operated by a remote controller from a safe distance. Operators monitored several screens showing images from cameras on the vehicles or at the job site. However, the lack of true visual and depth perception increased the collisions between equipment involved in the operation. In order to solve this problem, a system to sense and warn vehicles of impending collisions was developed using Global Positioning System (GPS). The collision detection system calculated the distance from the potential collision point to each vehicle location using location information obtained from GPS [8].

GPS is sometime applied to monitor deformation of super structures. The KOMTAR building, the tallest building in Malaysia, is equipped with GPS-based stations to monitor the building's movement for preventive safety assessments. These monitoring stations record basic coordinates of reference points at regular time intervals and analyze the stability of the building. With this GPS technology, the building's supervisor could have up-to-minute information of the deformation of the structure and could rescue many lives from the disaster [9].

After the terrorist attack on September 11, 2001, New York City's Department of Design and Construction (DDC) led the recovery effort for the World Trade Center disaster, the overwhelming task of removing more than 1.8 million tons of fallen tower debris at the site known as "Ground Zero". Handling more than two hundred trucks from multiple contractors delivering loads to five different dumpsites was an arduous task. The DDC therefore used a GPS-based automatic vehicle location system in managing debris removal. The system included a broadband communications network, a camera monitoring and time-lapse recording system, a GPS-based vehicle tracking system, and a high-speed Internet service to provide access to related data. The system provided a near real-time view, including graphically mapped presentations of trucking operations on a macro level. Users in the field could access information over the Internet to view vehicle location, history reports, and movement tracking. At the end of the project, they found that this GPS-based technology yielded greater efficiency than traditional paper tickets. [10].

4 INDOOR LOCATION INFORMATION

Although GPS is well known for its ability to provide accurate positioning when used outdoor, it was never intended for indoor environment. Besides the fact that the satellite signals are not strong enough to be used inside a building, RF noise and metallic objects positioned inside the building can cause interference and deflection of satellite signals that lead to miscalculated positioning. Nevertheless, many developers have tried to find a way to make GPS work inside buildings. A location support system that operates inside office buildings and homes has the potential to fundamentally change the way human interacts with their immediate environment.

The Active Badge system, one of the earliest indoor location tracking systems, was developed between 1989 and 1992 by the Olivetti Research Laboratory [11]. The Active Badge system provides individual locations within a building by determining the location of their Active Badge. This Active Badge has a globally unique code that is periodically broadcasted through an infrared interface every 10 seconds. Networked sensors placed around the building would detect these transmissions and relay information over a wired network to the central database. The location of the badge can thus be determined on the basis of information provided by these sensors. Privacy issues and its high maintenance costs of the wired network are disadvantages of this technology.

After the Active Badge was developed, AT&T Laboratories Cambridge found that some applications require 3D location and orientation information, which Active Badge cannot supply. In 1997, the new 3D ultrasonic location system, the Bat system, was thus developed for this purpose. The Bat system uses ultrasonic signals to identify the user's location. A short pulse of ultrasound is emitted from a transmitter attached to the object to be located. Each transmitter has a unique 48-bit code and is linked with the fixed location system infrastructure using a bidirectional 433MHz radio link. The receivers used to detect the ultrasonic signals are installed in a square grid, 1.2m apart, above the tiles ceiling and are connected by a high-speed serial network. These receivers would measure the times-of-flight of the pulse and calculate the distances from the transmitter to each receiver. With three or more distances, the system can compute the 3D position of the transmitter. By finding the transmitter's positions for multiple times, the system can calculate its orientation. One disadvantage of the Bat system is the expensive wiring infrastructure used to relay information collected by the receivers to a central computer for processing and back to the user's handheld device [12].

The UNC HiBall Tracker system uses relative ceiling panels housing infrared Light Emitting Diodes (LEDs). A miniature camera cluster called a HiBall looks upward to view infrared LEDs installed in ceiling panels and converts individual LED sightings into position and orientation data. Using known location of the LEDs, the system computes and reports the user's position and orientation. The HiBall Tracker system resolves linear motion of less than 0.2 mm and angular motions under 0.3 degrees without distortions. Although this system yields highly accurate readings, it requires extensive wiring, which makes it expensive and difficult to deploy [13].

RADAR, developed by Microsoft, uses a standard off-the-shelf wireless network technology (IEEE 802.11b) to locate and track user. The RADAR system works by installing access points overlapped throughout the building. The system's administrator then measures and collects the signals' strength in each reference point to create a Radio Map. The Radio Map is a database of locations in the building and the estimated signal strength at each location. To identify the user's location, the system compares the signal strength from the user's mobile device to the Radio Map. Therefore, the nearest point on the Radio Map is identified as the user's current location instead of the real user's current position [14].

As opposed to previous development, the Cricket system, developed by Networks and Mobile System (NMS) research group at the Massachusetts Institute of Technology (MIT), allows applications running on user devices to learn their physical location [15]. The Cricket system consists of beacons and a listener. The beacon is a wall and ceiling mounted unit that emits a radio frequency (RF) wave and ultrasonic pulse. The listener is a unit attached to a user's mobile device and listens for RF wave and ultrasonic signals that the beacon publishes through a building. When the listener hears the RF signal, it turns on its ultrasonic receiver to listen for the ultrasonic pulse. Because the speed of sound in air is much slower than the speed of electronic wave in air, the listener uses the time difference between RF wave and the ultrasonic signal to determine the distance of the beacon. The listener sends information to the mobile device through the serial port. To determine the user's current location using this application, the listener has to obtain at least three estimated distances. Through these values, the application that runs on the user's device will then calculate the user's current location by using the triangular rule.

However, it is also possible for the listener to misinterpret ultrasonic pulses that is radiated from different beacon sources, consequently causing a miscalculation in the distance [12].

5 DEVELOPMENT OF PROTOTYPE APPLICATION

Our group determined to use the Cricket technology to develop a prototype location-based indoor facilities management system. Using schematic drawings obtained from NMS research group at the MIT, our group has fabricated ten beacons (Fig. 1) and two listeners (Fig. 2).

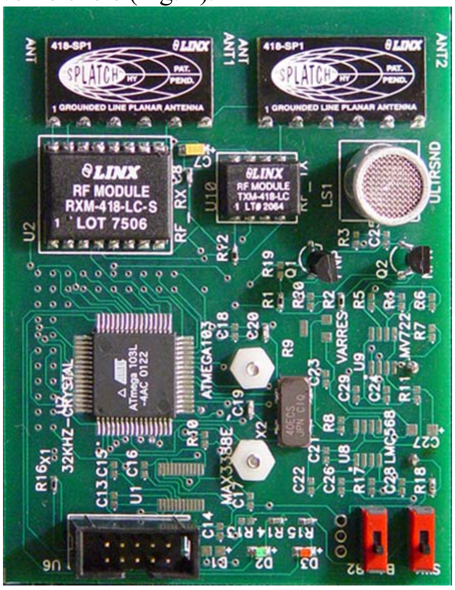

Figure 1. Cricket beacon

Figure 2. Cricket listener

Beacons and listeners were programmed for specifying their location names and ID numbers. Beacons were then mounted on the wall as shown in Fig. 3.

Figure 3. Beacon mounted on the wall

The prototype location-based indoor facilities management system consists of two computer applications. BeaconConfig, developed by the NMS group, is a Java application that retrieves data from the listener and calculates the time different between radio frequency wave and ultrasonic signal to determine the distance of the beacon. Once the listener detects signals emitted at least by three beacons, the BeaconConfig calculates user's current location using triangular rule. Our group added additional function, FMInfo, to BeaconConfig in order to transmit the listener's location information to the Web server. Fig. 4 and 5 show the user interface of BeaconCongif and FMInfo menu.

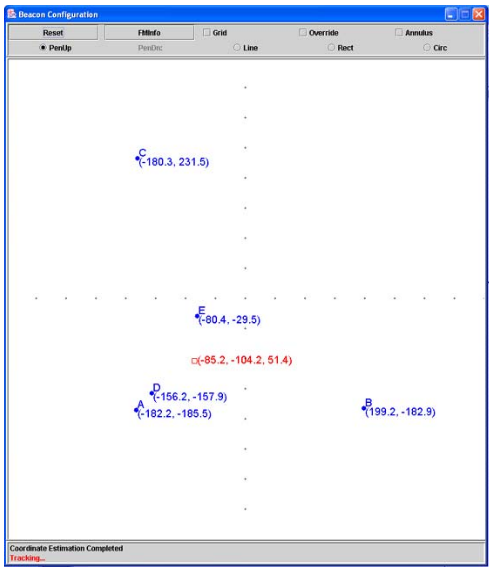

Figure 4. User interface of BeaconConfig

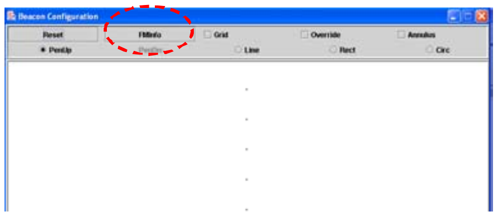

Figure 5. FMInfo button of BeaconConfig

Our group then developed a Web-based application, using Active Server Pages (ASP), to retrieve facilities management information from the database in the Web server. This Web-based application is called when the user clicks the FMInfo button in BeaconConfig. Once the user's location information is transmitted to the Web-based application, it searches database in the server, retrieves inspection data of facilities within a certain boundary, and displays them in the Web page as shown in Figure 6.

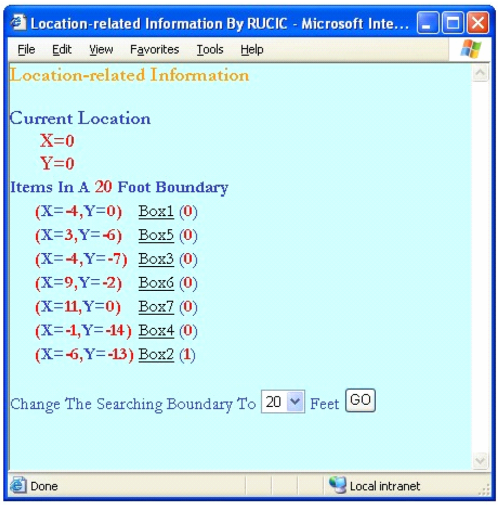

Figure 6. Inspection data retrieved

When the user clicks the object's hyper-linked name, detail object information including pending work order records and additional work order tasks are provided as shown in Figure 7.

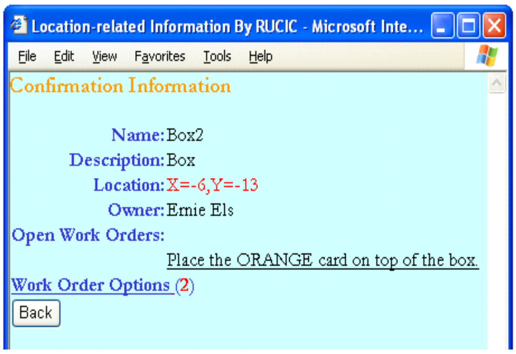

Figure 7. Work orders

If the user wishes to add work order to the object, one may click the hyper-linked "Work Order Options" menu to bring another page as shown Figure 8.

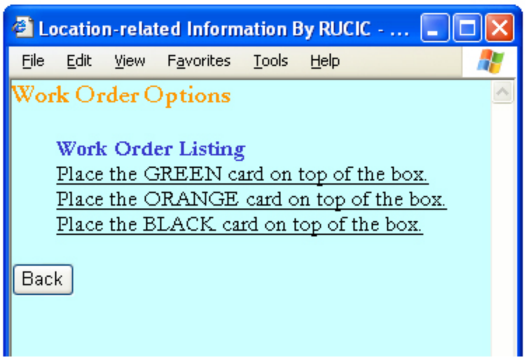

Figure 8. Work order list

This screen displays available work orders with associated links that provide further detailed information on that item of work. If the user clicks a hyper-linked open work order description, a detailed information page concerning that work order is displayed as shown in Figure 9. This page has a function to open or close the work order.

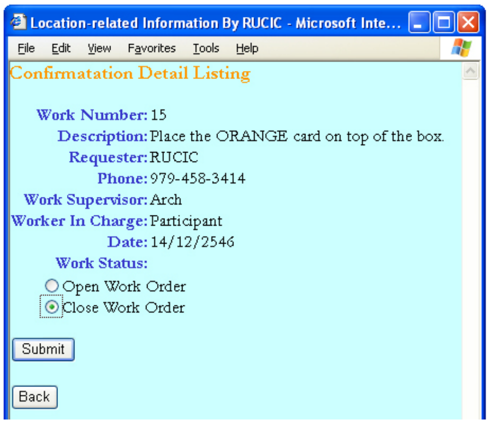

Figure 9. Detail work order

6 TEST OF PROTOTYPE APPLICATION

Our group tested the usefulness of the prototype location-based indoor facilities management system with 10 graduate students majoring construction management. Experiment participants were asked to locate a specific box among boxes scattered in a relatively large open space and conduct a simple task such as placing a magazine on the box using a paper-based instruction or our prototype location-based indoor facilities management system. Students finished given tasks almost 100% correctly when they used location-based system. However, when students were given paper-based instruction, only 40% of work orders were performed correctly. All experiment participants agreed that location-based indoor facilities management would improve facilities management inside a building. However, the test also revealed that the location information identified by the Cricket system was unstable, which made the process of collecting location information difficult. Our group also learned that the NMS group at MIT was developing the second version of the

Cricket system, which may produce more robust signals.

7 CONCLUSIONS

The prototype location-based indoor facilities management system presented in this paper has demonstrated the usefulness of indoor location information in facilities management. Although the Cricket system employed was not robust enough to produce consistent location information yet, indoor location information could be applied to many things such as punch list management. The new version of the Cricket system may prove to be more robust than the current version and will need to be tested again. Once the capacity of the system is enhanced, another experiment should be set up in a larger open space such as indoor stadium. This new experimental area would better mimic the true intent and usage of the technology as applied in the built environment.

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