LOCATION-BASED INFORMATION SYSTEM

FOR OPEN SPACES

A Thesis

by

KAMPANART TEJAVANIJA

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

August 2004

Major Subject: Construction Management

LOCATION-BASED INFORMATION SYSTEM

FOR OPEN SPACES

A Thesis

by

KAMPANART TEJAVANIJA

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

Approved as to style and content by:

Julian H. Kang (Co-Chair of Committee)	Kenneth C. Williamson, III (Co-Chair of Committee)
Robert E. Johnson (Member)	James C. Smith (Head of Department)

August 2004

Major Subject: Construction Management

ABSTRACT

Location-based Information System

for Open Spaces. (August 2004)

Kampanart Tejavanija, B.Arch., King Mongkut Institute

of Technology Ladkrabang, Thailand

Co-Chairs of Advisory Committee: Dr. Julian H. Kang

Dr. Kenneth C. Williamson, III

Problem solving for location is one of the most critical cognitive skills that can be utilized in deriving a naive location and/or finding a primed location in large open spaces of the built environment. Wayfinding or locating objects in large open spaces is not often easy for individuals due their limitations in building effective mental models of the open space or their lack of a correct procedure for determining the grid coordinates of an object within that space.

With the success of the global positioning system (GPS) in providing location information, it is expected that this technology could be utilized to control and improve building construction and facility management productivity within building interior spaces as well. However, GPS cannot perform robustly inside buildings due to the exterior walls or roofs, which weaken the signal. The Cricket indoor location support technology has been developed to respond to this limitation. Cricket uses a combination of radio frequency (RF), ultrasonic sound signals, and the triangular rule to calculate a user's current location.

This research investigated performances within the context of a work order system between a human-based system and a computer-based system. Thirty subjects participated in this study. The subjects were asked to derive, find and verify a target box's location. Locating time-on-task, accuracy, and attitudes were measured. The overwhelming results demonstrated the speed and accuracy of the computer-based system over the human-based system. In addition to longer procedural processing times, subject errors included: 1) an incorrect estimation of distance, 2) an inability to correctly locate and/or project the X-axis and Y-axis grid lines, and 3) an incorrect treatment of the positive and negative characteristics of these coordinates. Even though half of the subjects liked the human-based system more, they significantly believe the computer-based system to be more accurate. All but one subject preferred that the computer-based system be used in his or her own future business. Finally, results indicate that the computer-based system does relieve humans of cognitive dependency, which may be further evidence that the computer-based system developed and tested in this study achieved its purpose.

DEDICATION

I would like to dedicate this thesis to
all of my lovely family members
who always support me
with their love and endless concern

ACKNOWLEDGMENTS

This thesis would not have been completed if I did not receive help and support from the following persons:

I would like to begin by expressing my appreciation to all my family members, to whom I owe my undying gratitude. Thank you to my lovely Mom and Dad for all their love, concern, and support. Although at opposite ends of the world, the warmth in their hearts has not failed to always touch and comfort me. For this, they forever remain my role models and source of my strength. Thank you to my lovely Grandmother for all her care and concern; I am certain I have given her many causes of concern. Thanks to my beloved brother and sister for assuming my duties and responsibilities. Thanks to my lovely cousins, Chris and Jen, for always helping with my poor English without ever complaining, I know I gave them a number of headaches with my writing.

Thank you to my dearest girlfriend Krisanee Muendej for always standing by me. Thank you for the many good memories that we have created and shared at Texas A&M University (special thanks for the food that you always cooked for me too!). Thank you to all my Thai friends for making College Station such a special place in my memory. Special thanks must be given to Salilla Lertbannaphong who always gave her best when I was in need, and also fed me with her yummy food. A million thanks go to Peerapol Bhuaratnarunkon for his help and his knowledge about the computer programming. Things would be much harder if I didn't get help from him.

A million thanks go to Dr. Kenneth C. Williamson, III for always sharing his valuable time and showing such interest and care in my thesis. He has taught me so many things that transcend the ordinary classroom. I have learned how much one could really be in love with his work. I discovered that calling my professor at his office at 3 A.M. in the morning is possible! A million thanks also go to Dr. Julian H. Kang for his boundless knowledge in technology. Thanks for giving me the idea to develop this thesis and for opening my eyes to the world of technology. I also thank you for always opening your door to me when ever I was in need of help.

Special thanks must be given to my never-seen friend Allen Miu from MIT for replying to my every e-mail. Without his help, I would not have been able to run the Cricket system and solve its problems. Thanks for all the effort and valuable time that he has given me, even when we have never met each other in person. I also thank Steve Payne and his staff at the Department of Physics electronic shop for all their sincerely appreciated assistance.

So many facets of emotion, effort, and memories went into the process of producing this thesis. I will cherish all the joys of triumphs, disappointments in setbacks, and sincere gratitude to all that have contributed to the success of this project for the rest of my life. Thank you for all the good memories and meaningful time in the land of the Aggies. I will forever bear in mind that “once you are an Aggie, you are always an Aggie.”

TABLE OF CONTENTS

LIST OF TABLES

TABLE Page

LIST OF FIGURES

FIGURE Page

CHAPTER I

INTRODUCTION

1.1 Background

Problem solving for location is one of the most critical cognitive skills that can be utilized in deriving a specific location and/or finding a specific location in a large open space (Freksa 2004). Individuals need to have a spatial mental model, procedural knowledge, and various cognitive abilities to succeed in wayfinding (Piaget and Inhelder 1967; Hart and Moore 1973; Siegel and White 1975; Johnson-Laird 1983). Locating objects in a large open space is not often easy due to either the lack of identifiable reference points usable to the problem solver or the lack of a correct procedure for determining distance within an open space (Raubal and Worboys 1999).

Human-based procedures utilize a cognitive process to measure or estimate the distance from known points of reference to establish an object's location (Darken and Sibert 1996). These reference points could be, among others, visual queues or wave signal beacons. Distance information could be measured and described either by using a grid-coordinate procedure (route knowledge or X-axis and Y-axis), a relative procedure (configurational knowledge or line-of-sight), or an object procedure (landmark knowledge or object from or to object) (Siegel and White 1975; Lawton 2001). Both,

---

This thesis follows the style and format of the *Journal of Construction Engineering and Management*.

points of reference and distance information must be predictable for a problem solver to be able to accurately derive and find an object's location. Research in wayfinding identifies these two tasks as fundamental to spatial problem solving. Deriving a location is described as a naive search where the target location is unknown and finding a location is described as a primed search where the target location is known (Darken and Sibert 1996). The current study takes an additional step forward by adding the construct of verification as a fundamental requirement to spatial problem solving (Anderson 1990).

Johnson-Laird (1983) introduced the idea that on of the basic processes underlying problem solving and reasoning is the construction of mental models. He argued that individuals understand the world by construction mental models of their environment, which are based on general and specific knowledge. Individual problem solving is characterized by 1) construction finite models of explicit premises, 2) formulating commonly accepted conclusions based upon them, and 3) searching alternate models for counter examples. Individuals often fail at such problems solving because of a lack of a systematic search strategy or the lack of secure procedures for deriving solutions.

Individuals have equal access to incidental and explicitly perceived spatial queues. This means that when the locations of objects are encoded in coordinate space, the relations between their locations in the coordinate space represent spatial relations between objects in the models they construct. All conclusions are made as a consequence of placing objects in the same model of the environmental space (Bryant, 2004).

Cognitive problem solving methods requires an individual to either use an algorithmic or a heuristic procedure to reach a declarative solution. An algorithm identifies a series of sub-goals that, if correctly achieved, will always result in the correct solution to the problem. A heuristic is rules of thumb that will often, but not always, lead to an accurate declaration a problem's solution. Most individuals will first attempt the spatial solution using a heuristic procedure, which is a more rapid process than that required of an algorithmic procedure, but both require spatial knowledge (Car et al. 1999). This research considers the act of declaring a solution as the individual's verification that the procedural method has been utilized and that the individual believes they have preceded to a correct solution. Algorithms are procedures guaranteed to result in the accurate declaration of a problem's solution (Anderson 1990).

Computer location identification technologies, such as the global positioning system (GPS), have been utilized to solve object location problems in large open spaces, especially in the built environment. There are many ways to use GPS location information. For example, real-time positioning allows an operator to remotely control vehicles in dangerous areas without collisions, and aids in under-water construction by positioning objects that cannot be seen from the water’s surface. However, GPS itself is not an effective technology for use in the interior space of a building because the external walls and roofs reduce the strength of the GPS signal (Global Locate (GL) 2004).

With the success of GPS technology in many areas, it is expected that technologies similar to GPS will be developed that can advance those processes that require the manipulation of location information within building interior spaces. One such development comes from research in computer science and mechanical engineering at Massachusetts Institute of Technology (MIT). A new means of acquiring indoor location information by utilizing radio frequency waves and/or ultrasonic sound was developed and has been demonstrated with some success. It is, therefore, expected that making application of this new technology could improve many processes that involve locating objects in building interiors. This research concerns one such application of this new technology.

The central hypothesis of this current study is that the application of this new technology in the large open spaces of the built environment will enhance a person's ability to problem solve for either deriving or finding an object's location. The confirmation of this solution will allow the person to more quickly and more accurately verify and declare their solution with a higher level of confidence than that of the human-based system. The difference being that the computer-based system provides the solution with a minimum of human interaction and cognition.

1.2 Research question

The purpose of this study is to investigate differences in time-on-task and accuracy in deriving, finding, and verifying an object's location between the human-based system and a computer-based system. To accomplish this purpose this study will present, to its subjects, two spatial problems within the context of a work order system. The first naive spatial problem requires the subjects to accurately derive and verify an object's location, and the second primed spatial problem requires the subjects to find and verify an object's location. In both spatial problems the subject's must solve for the position of a target object in an experimental open space.

The algorithmic procedure, used in the current study, for solving for the targeted object's spatial location is the grid-coordinate method, which has been included in previous research on wayfinding in the large open spaces of buildings (Cornell et al. 2003). This procedure determines the center location of a target object by using two visual or signal reference points that allow for the projection of the X-axis and Y-axis grid lines. The visible references are a yellow pole on the X-axis and a red pole on the Y-axis. The signal reference points are electronic beacons, one on the X-axis, one on the Y-axis, and one on the upper X-axis, in that the Cricket technology requires a minimum of three locator beacons. Grid-coordinate measures above the red reference point are positive (+) and measures below the red reference point are negative (-). Grid-coordinate measures to the right of the yellow reference point are positive (+) and measures to the left of the yellow reference point are negative (-). The physical distance in feet represents measurements from the axis grid lines to the target object's central location. In all study administrations, (human-based deriving, human-based finding, computer-based deriving, and computer-based finding) this procedural algorithm is used for formulating a target object's location. According to this study's model, the relation between two points is determined by the measured position of the target object with respect to the projection lines established by the reference points to the coordinate axes (Freksa 1992; Papadias and Sellis 1994).

The study's application of this procedure is based within the context of a work order system. Whether a worker within the built environment is involved in construction punch listing or facility maintenance, object location and information must be reported and action must be taken. In the first case a worker must derive the object's location and verify the correct object was found by opening a work order for future action. In the second case an object's location is provided, the worker must find the object, execute the work, and verify that the work was completed on the correct object by closing the work order.

In the human-based system, object location is both derived or found utilizing human cognition, object information is accessed, presented, written and/or printed on paper documents, and changes are made by transcribing or writing down new information. In the current study, human grid-coordinate measures are established through a visual search of the open space for reference points, projecting lines to the coordinate axis, and measuring the physical distance from those lines to the center of the target object. In the computer-based system, object location both derived or found utilizes computer-programmed signal and listener technology, object information is accessed, displayed, and input through a programmed computer application, which uploads and downloads to and from a network information system's database. The computer grid-coordinate measures are established through a listener search of the open space for beacon signal reference points.

Of interest to this current investigation is if there will be differences in measures of accuracy and time-on-task between the human-based system and the computer-based system.

1.3 Goals of the study

The goal of this study is to test the usefulness of a computer-based indoor location identification system for buildings that have large open spaces. To achieve this goal this research will: 1) fabricate indoor location beacon and listener technology; 2) develop a prototype computer application that accesses, displays, and reports object information to and from a network database; and 3) test the usefulness of this system in deriving, finding, and verifying an object’s location within a building's open space.

1.4 Confirmatory (null) hypotheses

Hypothesis 1: There is no relationship between time-on-task and the system of deriving and verifying an object's location.

Hypothesis 2: There is no relationship between time-on-task and order of instrument administration in deriving and verifying an object's location.

Hypothesis 3: There is no relationship between time-on-task and the system of finding and verifying an object's location.

Hypothesis 4: There is no relationship between time-on-task and order of instrument administration in finding and verifying an object's location.

Hypothesis 5: There is no relationship between accuracy and the system of deriving and verifying an object's location.

Hypothesis 6: There is no relationship between accuracy and order of instrument administration in deriving and verifying an object's location.

Hypothesis 7: There is no relationship between accuracy and the system of finding and verifying an object's location.

Hypothesis 8: There is no relationship between accuracy and order of instrument administration in finding and verifying an object's location.

Hypothesis 9: There is no interaction between time-on-task and accuracy on the systems of deriving and finding an object's location and order of instrument administration.

Hypothesis 10: There is no relationship between sentiments and the type of location system.

Hypothesis 11: There is no relationship between preferences and the type of location system.

Hypothesis 12: There is no interaction between sentiments and preferences on the type of location system and order of instrument administration.

CHAPTER II

LITERATURE REVIEW

The following content serves to reflect upon problems of human sense of direction and their ability in wayfinding in large open spaces. The roles of global positioning system (GPS) technology in construction processes were reviewed, and case studies were cited to provide support for the use of GPS, its benefits, as well as its limitations. Existing indoor location support systems were also reviewed as solutions for resolving the limitation of GPS for indoor facilities management. Lastly, some selective case studies were used to illustrate the use of mobile computers and how its technology is incorporated in present day facility management system.

2.1 Wayfinding in buildings

Spatial memory and navigational ability play important rules for human in finding paths or locating objects in a built environment (Werner and Long 2004). Some salient reference design elements are built by using some basic measurements and geometric relations, such as straight lines and right angles, to embed this kind of information into the structures. The lack of perception where they are located in an environment may affect the ability of wayfinding in their mind. Therefore, architects design buildings with axes to guide the movement of the building's users. Axes inside a building could be represented by walls, corridors, or lighting. These elements would allow users to extract relevant spatial information into their minds. It does not mean that buildings have to be designed with a simple orthogonal grid as long as architects can achieve a common reference system by making common axes salient. However, individuals could remember objects' positions much better if they image themselves aligned with the room's two main parallel axes.

2.2 Location finding

Finding specific locations in the environment is one of the most necessary skills of agents like human beings, animals, and autonomous robots (Freksa 2004). Knowledge about the environment is required in order to find a location or a moving path. Exploring the environment and memorizing landmarks and their relationships usually gain this kind of knowledge. Cognitive maps are taken as mental representations that preserved survey knowledge of a familiar environment (Hart and Moore 1973). Survey knowledge includes the metric measurement and relational information about landmarks and paths (Siegel and White 1975). However, individuals who enter into a new environment usually use topological instead of metrical information (Piaget and Inhelder 1967).

Raubal and Worboys (1999) observed the movement of individuals in open spaces (Vienna International Airport) where the paths were not, if any, strongly presented. Individuals had to check-in, move through passport control, and move through security control at the gate. Raubal and Worboys found that individuals with imperfect observations of space usually derived incomplete and imprecise knowledge causing incorrect movement to them.

In order to identify objects' locations in open space, Darken and Sibert (1996) found that the grid coordinates system was superior in providing directional information and location in open spaces. In addition, Lawton (2001) found that women are more likely to say that they preferred to use the relationship between the specified landmarks along with "left" or "right" route while men preferred to report orienting to global reference points such as the cardinal directions (North, South, East, and West). Beside the grid coordinates system, hierarchical wayfinding algorithms are also important in querying the shortest paths in spatial wayfinding solution. However, this method is inefficient when using with larger area (Car et al. 1999).

To test the human sense of direction and wayfinding, Cornell et al. (2003) set up an experiment with variety of procedures, from a window-less room to the big city area scale. Cornell et al. asked participants to point target buildings, direction to go to buildings, etc., and recorded their performances to compare with results from questionnaire that participants were asked to rate themselves on how good they were with their senses of direction.

2.3 GPS technology

GPS stands for Global Positioning System which works as a worldwide satellite based radio-navigation system. The idea of developing a global, all-weather, continuously available, highly accurate positioning and navigation system began in the early 1960s. The U.S. Department of Defense's (U.S.-DoD) primary purposes in developing GPS were to use it in precision weapon delivery and to provide a capability that would reverse to proliferation of navigation systems in the military (Abrams 2003).

The beginning of GPS was the launch of the “Sputnik” in 1957. Scientists realized that they could track the satellite by its radio signal. That meant a person could obtain his position on the globe if he could read the signal from the satellite. In 1964, U.S. submarines began to use a satellite system, called TRANSIT, for positioning. This system required only one satellite to provide a rough reading every 35-45 minutes with the limitation that the submarine had to remain stagnant in order to be able to track its location. In 1967, the U.S. Navy launched the new system, TIMATION I, which included an atomic clock aboard the satellite. This development allowed for precise tracking despite the object being in motion. In 1973, the Navstar system was introduced. Navstar used several satellites instead of just one. The first four satellites of the Navstar constellation were launched in 1978. In the 1980s, U.S.-DoD made the system available for civilian use. Today, Navstar system is consisted of 24 satellites (the 24th satellite was launched in 1994) that now orbit the earth (Abrams 2003).

The GPS system has 21 operating navigational satellites and 3 active spares in orbit. GPS satellites are powered by solar energy and have backup batteries to keep them running in the event of a solar eclipse. This 24-satellite constellation orbits the earth at 10,900 nautical miles above the surface and takes 11 hours and 58 minutes to orbit the entire earth (Abrams 2003). This strategic pattern allows a receiver to receive a signal from at least four different satellites. Each satellite has an atomic clock, which allows satellites to emit a signal at regular intervals. This signal contains information of the satellite's position and time that it sends the signal. A GPS receiver compares the time a signal was transmitted by a satellite with the time it was received. The time difference tells the GPS receiver how far away the satellite is. Then, the GPS receiver uses triangulation to calculate the user's exact location. The GPS receiver must be locked on to the signal of at least three satellites to calculate a 2D position and four or more satellites for a 3D position.

2.4 GPS in construction

In 1994, Mount Fugen volcano erupted. Lava flowed downhill threatening the town of Shimabara. A project was pioneered to construct two canals to channel away future flows into the Sea of Japan (Oloufa et al. 2003). Since work was carried under the constant threat of lava flows, it was desirable to use in construction, an automated Tele-earthwork system, remotely controlled from a safe distance. The Fujita Corporation developed and implemented a Tele-earthwork system to control backhoes, bulldozers, trucks, and other vehicles and equipment. All of the construction equipment at the site was operated without on-board drivers. Backhoes, bulldozers, dump trucks were remotely controlled, each by a different operator. Operators had to monitor several screens showing images from cameras on the vehicles and another remotely controlled camera at the site. The lack of true visual and depth perception increases the collisions between equipment involved in the operation. GPS technology was applied to solve this problem. The company developed a system for sensing and warning vehicles of impending collisions. The collision detection algorithm worked by calculating the intersection point of the two vectors representing two moving vehicles. The GPS positions of the vehicle location and the vehicle bearing define each vector. After the intersection point was computed, and knowing the vehicles' speeds from GPS, the program then calculated the distance from the potential collision point to each vehicle location and the braking distance required for each vehicle. The project was successful. The system has been used for many projects in Japan such as the recovery missions from catastrophic landslides at Kumamoto, Nagano, and Akita, as well as the unmanned construction dam at Mt. Fugen.

Real Time Kinematic GPS is another development under the GPS technology that utilizes a static base station and remote rover unit(s) for real-time data collection. In 1997, Leica Geosystems Company installed an integrated high-precision Kinematic (RTK) GPS network that provides real-time accuracies of better than 3 cm for surveying and positioning applications in the construction of a bridge-tunnel connecting Denmark and Sweden (Leica Geosystems (LG) 1997). Leica established a network of five fixed reference stations, plus one mobile reference station that could be deployed as needed. The reference stations provided real-time messages for use by rovers throughout the construction area, and automatically logged data to bulletin boards for subsequent post-processing requirements. The five reference stations were carefully sited to provide overlapping coverage throughout the bridge construction project. Two were located in Denmark, two in Sweden and one on a makeshift island, which is located in the middle of the strait. A recorded number of constructors have remarkably benefited from the employment of Leica real-time network, especially for wide variety of survey, positioning and machine control applications.

Engineering structures such as dams, bridges and high rise buildings are subjects to deformation. GPS technology was applied to monitor these structures. For example, the KOMTAR building, the tallest building in Penang, Malaysia, is equipped with GPS-based stations to monitor the movement of its structure for the purpose of preventive safety assessments (Wan Aziz et al. 2004). The observation network consists of 2 base stations and 6 monitoring stations (four of them are located on top of the building, and the other two are located at the plaza). These monitoring stations would record basic coordinates of reference points at regular time intervals. If the system indicates that there is a significant movement at one station, it will automatically cross check other key reference points to see if this movement happens too. The GPSAD200 software is used to analyze the stability of all monitoring stations. 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.

The new positioning technology for river construction had been successfully tested at Lock and Dam 24, Mississippi River in Clarksville, Missouri (Surveying Engineering and Mapping Center of Expertise (SEMCE) 2004). The project aimed to erect a large steel protection cell to protect the downstream guide wall from collision by barge traffic. The cell was designed to be placed over 3 casings which were positioned by standard geodetic methods using a total station surveying instrument. The purpose of this test was to monitor the positioning of the casings and to verify that position by demonstrating the use of DGPS technology and high accuracy positioning software in placing large structure. Two small diameter GPS antennas were installed to monitor the position on the drill string and the drilling platform to calculate accurate heading information. Cables were attached at the antennas and connected to the geodetic receivers on the deck of the drilling barge. One radio antenna was connected to the two receivers to provide real-time kinematics (RTK) corrections. The software, Target: Structures, consisted of algorithms to compute the coordinates of the antenna and to give a graphic display of the location of the antenna. The actual position was compared to the desired position and was shown in real-time. The workers could see where the drill string was and could maneuver it to the desired location.

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" (Menard and Knieff 2002). Handling more than two hundred trucks from multiple contractors delivering loads to five different dumpsites had proven an arduous task. The DDC therefore summoned a meeting to acquire a technology that could best handle a project of such proportion and complexity. It was the first time that a GPS-based automatic vehicle location was used in managing debris removal in a disaster recovery setting. 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, spanning disaster areas, routes, and dumpsite locations. The operation involved sending track location information to the response center over a wireless network. The tracker server would then process the location information at the website server and notify users in the field of any exceptions dispatcher or email. Users in the field could then access tracker-server 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 more so than traditional paper tickets. The removal project, which was initially estimated by city officials at $7 billion ultimately, totaled to just around $750 million.

2.5 Indoor location support systems

GPS is well known for its ability to provide accurate positioning when used outdoor. However, GPS 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. One of the new approaches for indoor-capable GPS is a combination of an assisted GPS (A-GPS) and massive parallel correlation developed by Global Locate, Inc. (GL 2004). Assisted-GPS (A-GPS) was first proposed in 1981 by Ralph Taylor and Jim Sennott (Diggelen and Abraham 2001) to provide the GPS receiver with information which can be used to estimate the satellite location ahead of time provided faster GPS operation. However, A-GPS alone can’t make GPS work in indoor environment. It needs a very large number of correlators (massive parallel correlation) to measure the encoded signal. With massive parallel correlation, a GPS receiver can accumulate a thousand copies of the complete encoded GPS signal in matters of seconds, which allows the GPS receiver to acquire the encoded signal in indoor environment where the signal is hundreds to thousands of times weaker than outdoors. As evident in the test results, this new approach could provide robust indoor GPS performance (Diggelen and Abraham 2001). However, the system’s accuracy still ranges within 20-25 meters, which could act as hindrance in its successfully incorporation into indoor location applications.

The Active Badge system, one of the earliest indoor location tracking systems, was developed between 1989 and 1992 by the Olivetti Research Laboratory (AT&T Laboratories Cambridge in present) (Want et al. 1992). 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. The infrared signals reflect off walls and furniture to flood the surrounding area. 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.

However, 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 based on the principle of trilateration (positioning by degrees of angles). A short pulse of ultrasound is emitted from a transmitter (a Bat) attached to the object to be located. Each Bat 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 known position receivers would measure the times-of-flight of the pulse and calculate the distances from the Bat to each receiver. With three or more distances, the system can compute the 3D position of the Bat. By finding the relative positions of two or more Bats, the system can calculate the Bat's orientation (Ward, Jones and Hopper 1997). One disadvantage of the Bat system is the expensive wiring infrastructure used to relay information collected at the ceiling receivers to a central computer for processing and back to the user's handheld device (Miu 2002).

The UNC HiBall Tracker system was developed by the Tracker Research Group at the University of North Carolina in 1997 (UNC Tracker Research Group (UNC TRG) 2003). The UNC HiBall Tracker system uses relative ceiling panels housing infrared Light Emitting Diodes (LEDs), which were designed to substitute ordinary ceiling tiles in a standard acoustical grid (2'x2' panels), a miniature camera cluster called a HiBall, and the single-constraint-at-a-time (SCAAT) algorithm which converts individual LED sightings into position and orientation data. The HiBall is a cluster of 6 lenses and 6 photodiodes arranged so that each photodiodes can view LEDs through several of the 6 lenses. The UNC HiBall Tracker system works by mounting the HiBall to a user. This HiBall looks upward to view infrared LEDs installed in ceiling panels. 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.

RADAR User Location and Tracking System was developed by Microsoft in 2000. RADAR uses a standard off-the-shelf wireless network technology (IEEE 802.11b) to locate and track user by measuring the signal strength. 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 (Bahl and Padmanabhan 2000). The drawback of this system however, is the variation in signal patterns received between those recorded statically in the database and those recorded under dynamic environment where factors such as time and noise level come into play. Thus, RADAR may not operate powerfully in highly dynamic indoor settings (Miu 20002).

In 1999, the Cricket system was one among the many inventions pioneered by MIT Networks and Mobile System (MIT NMS) research group under Project Oxygen at the Massachusetts Institute of Technology (MIT) (NMS 2003). With the success of the location information support system like GPS, developers at MIT believed that 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. Therefore, Cricket was developed to be a location-support system for in-building, mobile, and location-dependent applications. The design goal was to develop a system that allows applications running on user devices and service nodes to learn their physical location (Priyantha 2000).

The Cricket system consists of two units: a beacon and a listener. The beacon is a wall- and ceiling-mounted unit that spreads signals through a building. The beacon publishes information on a radio frequency (RF) signal. With each RF advertisement, the beacon transmits a concurrent ultrasonic pulse. The listener is a unit attached to a user's mobile device and listens for RF and ultrasound 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 (about 1.13 ft/ms at room temperature) is much smaller than the speed of light (RF) in air, the listener is subjected to using the time difference between RF information and the ultrasonic signal to determine the distance of the beacon. The listener sends information to the mobile device through the serial port. However, it is also possible for the listener to misinterpret ultrasonic pulses that radiate from different beacon sources, consequently causing a miscalculation in the distance. To minimize these defaults, MIT soon developed an alternative application that uses statistics models (Majority, MinMean, and MinMode) to determine the distance. 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 (Miu 2002).

2.6 Mobile computers

Personal Digital Assistant (PDA) can be used as a stand alone mobile devices for facilities management. PDA, which is installed with some specific designed applications, helps facilities managers better maintain their facilities. Facilities managers can copy information from the main database before going out on field. While they walk through the facility, they can add/edit inspection data and send this information back to the main database when they come back to the office (Navarrete 1999). This technology helps facilities professionals avoid laborious and redundant work. Many facilities management systems also use PDA along with computerized maintenance management systems (CMMS) to maintain facilities (Thomas 2001). CMMS uses the central computer to perform three main tasks: maintenance schedule; requested work orders; and project follow-up. With mobile devices such as Palm or Pocket PC, facilities managers can 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. Customer can request maintenance services via a web browser. These requests will be recorded in the central database and are readily available to facilities managers or technicians. Evidently, the use of PDA together with CMMS has helped facility management system more effectively store and update information.

On the other hand, some mobile devices such as Intermec 5020 and Symbol MC9000-G integrated handheld PCs with bar code scanners. Facilities managers can acquire information on any item 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. New updated information will be transferred from handheld devices and stored directly in the main database system, a process which has proven both time efficient and effective (SYWARE 2003). 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. There are many database management programs that run on these handheld devices such as DDH Software HanDBase and Syware Visual CE. These mobile applications provide users with ease-of-use and customized functions as well as opportunity to create their own database templates.

Tablet PC—which boasts higher CPU speed and bigger screen than typical PDAs and lighter weight and more mobility than average laptop PCs—is the latest, up and coming technology in mobile devices. Facilities management systems capitalize on the potentials of wireless network by hooking up with web-based information technology such as XML and ASP to manipulate information directly from the main database system. This technology offers faster communication between on-site and in-office staffs. Moreover, this technology also boasts full-graphic support where information is no longer limited to only text-based displays. Drawing plans, color pictures and voice recording messages can be displayed thus allowing for better communication.

Wearable computers are another technology which are applied for facility and construction management. The term "Mobile Inspection Assistance" (MIA) is used for this wearable computer technology. This system consists of three parts: a portable-powerful-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 (Huang and Sethuraman 2002). The software application of this MIA system usually consists of five functions: a GUI that presents overlapping panels with taps for viewing 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 (Sunkpho and Garrett 2003). This system also integrates wireless network to transfer data between MIA and the database system through car (such as a van) equipment installations.

2.7 Applications of mobile computers in facility management

The Texas department of Mental Health and Mental Retardation (TDMHMR) recently discovered that the costs for its facility maintenance are demandingly high (TRIRIGA 2004). The director of Computer Aided Facility Management (CAFM) of

TDMHMR therefore decided to use PDAs to improve its facility management system. Instead of paper work orders, TDMHMR used PDAs (based on the Palm operating system) 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. In addition, PDAs with built-in bar code scanners can identify a piece of equipment by scanning a bar code instead of keying in an asset number, thus saving entry time and eliminating input errors.

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 (Advanced Technology Group (ATG) 2003). 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.

The IT-Port, an office building in Germany, was equipped with thousands of sun-blind motors, light units and switches, temperature sensors, and alarm contacts (VarIT (VIT) 2003). It uses a web-based application to control these devices by acting as an intelligent handler of information and dynamic software-update between networked devices and the user. The web-based application integrates with the mBedded Server, which is an open, modular and scalable Java-based software platform that is used for flexible dynamic adaptation of room constellations at field level. All installed devices are necessary for building automation and are grouped together in the so-called RCboxes. Operating together with the RCserver, these RCboxes form the IP based network that oversees facilities management tasks and the visual configuration of the system. The user can control and administer the automation system via web-interfaces that can be accessed from any place in the building with either a standard PC or a Pocket PC. The authorization for the web-interfaces can be customized for different rooms or persons.

Many warehouses use much more storage space than they really need. Morgan Integrated Technologies (MIT) has developed a rapid, accurate technique to optimize inventory space (SYWARE 2003). MIT uses handheld PCs equipped with build-in scanners to create an inventory database. The warehouse management software then works on the database to calculate how much space is needed for each part and where to store it. Creating the handheld application was performed utilizing Visual CE software, which allows non-programmers to quickly create customized databases and forms using an intuitive, drag-and-drop design. This Handheld technology eliminates both error and time factors typically associated with manual data entry associated and processing paper forms/reports.

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 (Autodesk Government (AG) 2004). 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.

2.8 Summary

Human sense of direction is a big key in the wayfinding. Geographers use topological to compare with reference landmarks to get a location. Architects try to put axes or salient objects in their buildings in order to give users movement paths inside a built environment. Within large spaces, the grid coordinates system play an important role to identify the location over hierarchical wayfinding algorithm. However, they both require spatial procedural knowledge, the knowledge that allows them to understand their surrounding environment. However, with open spaces inside large buildings, which sometimes are windows less, the sense of direction and/or the perception from building's axes are not possible to be acquired. As a result, building's users may have a hard time to locate and/or finding a specific location in large open spaces.

Based on the literature review, it is evident that location support systems such as the GPS has served as a critical element in the successful operations in the construction processes. However, it's been observed that the GPS cannot perform as effectively indoors, further preventing users from truly exhausting the system's full potential. Many research and test have been jumpstarted since to develop the ideal tool that could perform similar functions with enhanced precision and effectiveness.

With the inventions of mobile-based computers such as PDAs and Tablet PCs, facilities management system today is now ready to entertain the prospects of greater advancements, efficiency and effectiveness. Although many facilities professionals have managed to incorporate the unique functions of mobile computers into their management system, there is still no evidence that any have attempted to integrate the capabilities of indoor location support system into mobile-based computers for total facilities management. In conclusion, future facility management system may stand to benefit tremendously from the ideal, yet feasible integration the indoor location support system and mobile-based computers.

CHAPTER III

METHODOLOGY

3.1 Design of the experiment

The design of the study was a 2 x 2 x 2 factorial, which included two between subject factors (type of location system and order of instrument administration) by two within-subjects factors (problem-solving task). The type of location system had two levels (human-based system, and computer-based system), as did the order of instrument administration (human system first vs. computer system first). The differences in the problem-solving task factor included: deriving and verifying a target box's location and finding and verifying a target box's location.

3.2 Experiment subjects

The sample (N = 30) consisted students in the College of Architecture, at Texas A&M University, enrolled in COSC 351 Construction Equipment and Methods coursework. All subjects were in the Construction Science program's upper-level and all but one was male. Quiz credit was given for their participation in the experiments and honestly responding to the exit survey.

3.2.1 Human Subjects

Before proceeding with the experiment, both the proposal and list of interview questions were submitted to the University's Internal Review Board (IRB) for approval. This experiment was exempted from the full review and was approved under the code of federal regulations 46.101(b)(2). The IRB document could be found in appendix B. Once approved, the experiment and data collection processes were begun.

3.3 Experiment materials

The work order system in the built environment was chosen as the context for this study. To develop a realistic work order format current and existing formats were thoroughly investigated. This work order system was utilized to provide a record set of subject verification and confirmation actions necessary for study's data collection and analysis. To implement the investigation, indoor location support tools were fabricated. A prototype web-based application was developed to retrieve an object's location and descriptive information from a database on a server by utilizing the object's location acquired with the location support tools. Finally, an exit survey was developed to investigate subject sentiments and preferences.

3.3.1 The human-based system

Two paper work order forms were developed that mirrored the computer-based system. The first form was a blank work order form designed to report work order information for an object including, the object's location, the required work details, and that the work order is either opened or closed (see Fig. 3.1). On the back of this form was a listing of work options that must be accessed and transcribed to the work order (see Fig. 3.2). The second form was an assign work order form designed to provide all work order information previously assigned for an object including, the object 's location, the work required, and records what action was been taken, and if the work order is to remain open or is to be closed (see Fig. 3.3).

Work Order Form

Location Related Information

Current Location:

(X = ___________ , Y = ___________)

Items In A 2 Foot Boundary

Name: Description: Owner:

Work Details

Work Number: _____________

Description: ______________________________

Requester: ______________________________

Phone: ______________________________

Work Supervisor: ______________________________

Worker in Charge: ______________________________

Date: ______________________________

Work Order Status:

☐ Work Order Open

☐ Work Order Closed

Fig. 3.1. Blank work order form

Work Order Options	
Work Order Task	
Work Number:	1
Description:	Place the GREEN card on top of the box.
Requester:	RUCIC
Phone:	979.458.3414
Work Supervisor:	Arch
Worker in Charge:	Participants
Date:	7/1/2004
Work Order Task	
Work Number:	2
Description:	Place the ORANGE card on top of the box.
Requester:	RUCIC
Phone:	979.845.7052
Work Supervisor:	Archie
Worker in Charge:	Participant
Date:	7/3/2004
Work Order Task	
Work Number:	3
Description:	Place the PINK card on top of the box.
Requester:	RUCIC
Phone:	979.458.3414
Work Supervisor:	Arch
Worker in Charge:	Participants
Date:	7/2/2004

Fig. 3.2. Work order options list

Work Order Form

Location Related Information

Current Location:
(X = **-5** , Y = **7**)

Items In A 2 Foot Boundary

Name:	Description:	Owner:
Box7	**Box**	**Mike Wier**

Work Details

Work Number: **3**

Description: **Place the PINK card on the top of the box.**

Requester:	**RUCIC**
Phone:	**979.458.3414**
Work Supervisor:	**Arch**
Worker in Charge:	**Participant**
Date:	**06/02/2004**

Work Order Status:
- ☐ Work Order Open
- ☐ Work Order Closed

Fig. 3.3. Assigned work order form

3.3.2 The computer-based system

The computer system displayed a work order format that included simplified and easy-to-use functions that are generally included within currently marketed products and applications. Functions that provided object information were added into the application to enhance its capacity, these included providing: the locations of far and near-space objects with the ability to change the search boundary; the descriptive information on an target object, such as name, owner, etc.; and the ability to open and close work orders.

3.3.2.1 The Cricket technology

With its open-to-public information source, the Cricket technology was chosen as a study tool. The developer, Networks and Mobile System (NMS) research group at the Massachusetts Institute of Technology (MIT), provided Cricket's design drawings and the list of hardware that was needed for the fabrication through its website.

3.3.2.1.1 Fabrication

After gathering necessary information, the researcher contacted the Department of Physics' electronic shop at Texas A&M University to fabricate the Cricket technology, which included ten beacons (Fig. 3.4) and two listeners (Fig. 3.5). The electronic shop used approximately one hour and fifteen minutes to fabricate one beacon or one listener unit at a cost of approximately $60 per unit. However, the electronic shop stated that it would be much cheaper and faster if they produced it with an assemble line, and even faster with a machine. The total cost could be as low as $10 per unit.

Once the electronic shop completed the fabrication, the source code from NMS's website was used to program chips on both beacon and listener circuit boards. From the NMS's program, a location name and an ID number could be specified for each beacon. While, the name and the ID number establish the uniqueness of each beacon in the system, there is no difference in programming between each listener.

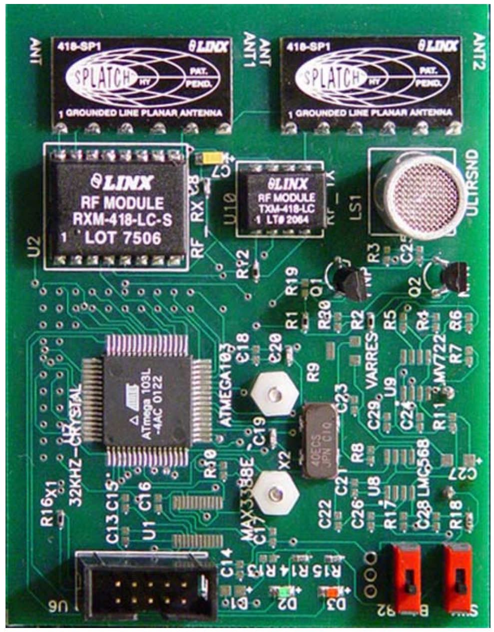


Fig. 3.4. The beacon unit

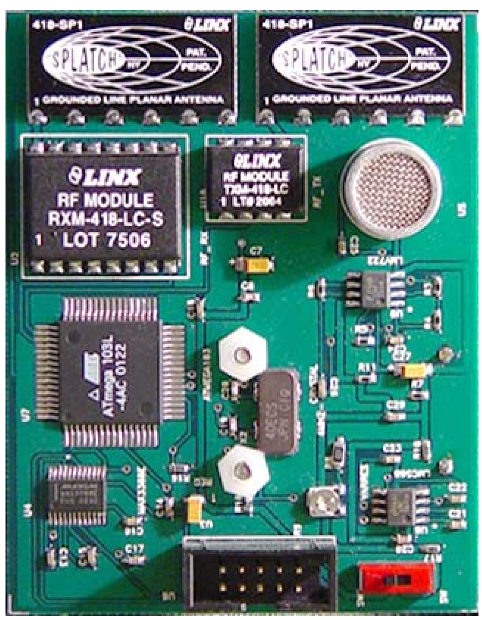


Fig. 3.5. The listener unit

3.3.2.1.2 Installation and calibration

The Cricket technology was installed in an experimental area for pilot testing. Fig. 3.6 shows the beacon installation and the housing unit that was developed to hold the beacon in place. Within a few pilot-test iterations, it was discovered that the Cricket technology could not receive signals consistently and therefore did not perform as efficiently as desired. This Cricket technology gave inconsistent X-axis and Y-axis coordinates that caused difficulty in the process of collecting an object's location. Consequently the NMS group at MIT was contacted concerning this consistency problem. It was found that this was a normal glitch in this version of Cricket (at the time the researcher wrote this conclusion, MIT was in the process of developing the second version of Cricket).

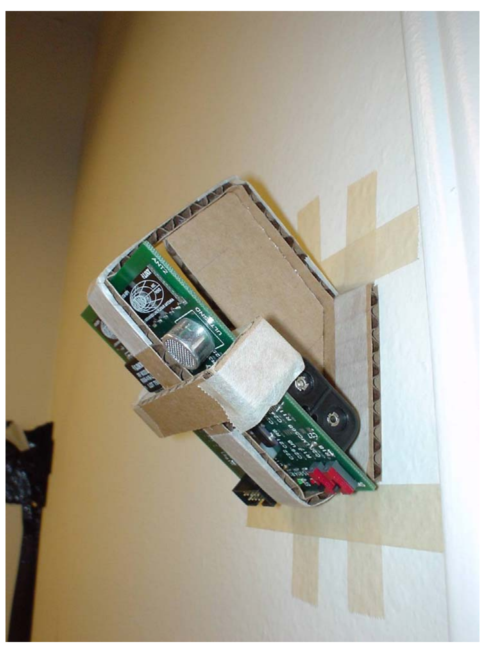


Fig. 3.6. The beacon housing unit

3.3.2.2 Prototype location applications

There are two parts of the prototype application. First, the prototype application provides the user's current position in terms of the grid-coordinates. This part of the process was adapted from the open source code Java application called "BeaconConfig" developed by the NMS group. Originally, the purpose of BeaconConfig was used to calibrate the Cricket technology and to track the user in the Cricket environment. BeaconConfig retrieves data from the listener through the serial port and calculate the time different between radio frequency and ultrasonic signal to determine the distance of the beacon. Once the listener hears at least three beacons, BeaconConfig calculate user's current location by using the triangular rule. The research then developed a new function into BeaconConfig to utilize this location information called "FMInfo". This function will call the web-browser, Internet Explorer, with a provided Uniform Resource Locator (URL) that contains the user's current location.

The second application, developed by using Active Server Page (ASP) executable scripts, runs on a database server and provides up-to-minute information to the user. This ASP application gets the user's current location from the Java application, searches through the database, gathers information that relates to that area, and displays a result page to the user via a web-browser. Fig. 3.7 shows the concept diagram of this prototype application.

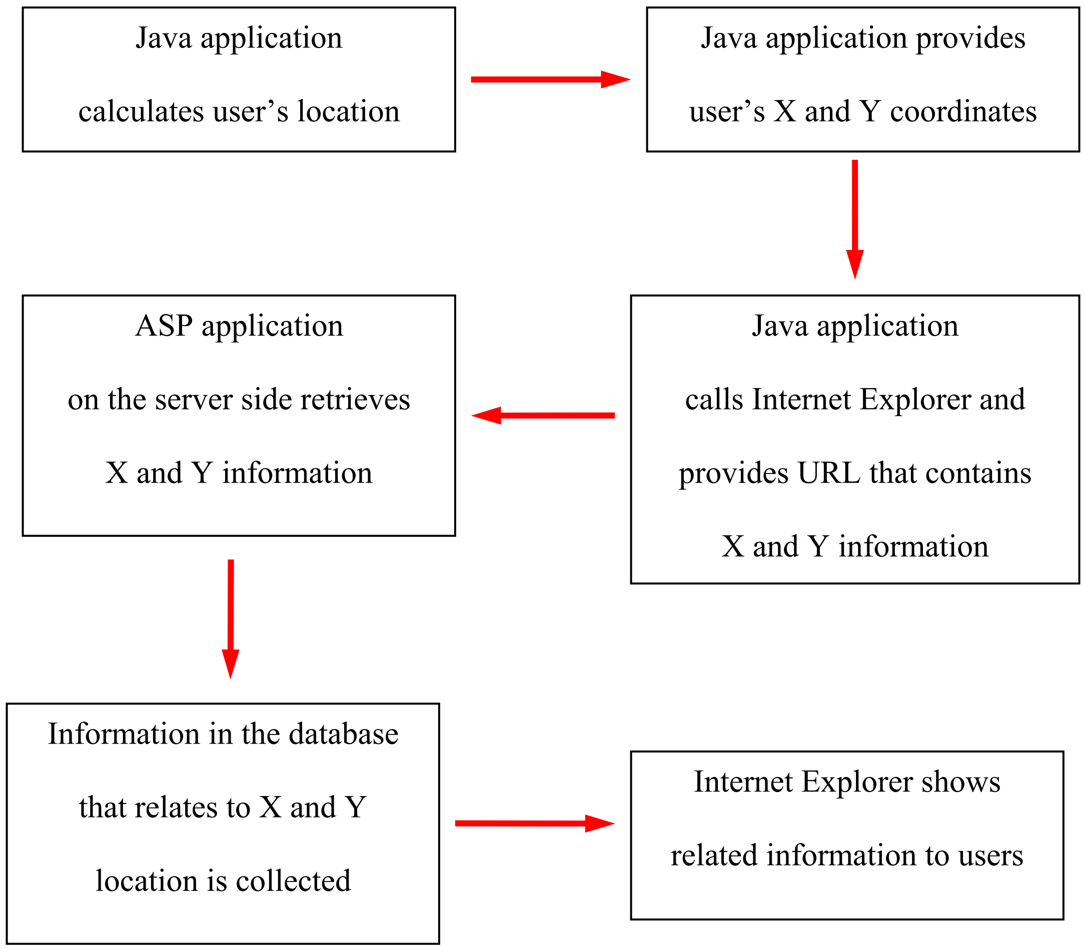


Fig. 3.7. The concept diagram of the prototype application

3.3.2.3 Programming language

This prototype application was developed with two programming languages: Java and Active Server Page (ASP). FMInfo function was written with Java to be added into original BeaconConfig application. BeaconConfig runs on the UNIX operation system, or Windows that contains the UNIX emulation. FMInfo provides user location information for a web-based application that executed on the database server. The ASP scripting language was chosen for this application. There are many advantages to using ASP such as:

- ASP is Windows NT based. Since Windows is the most popular operation system on the market, it is easy to run the ASP application on a computer or a server. ASP can also run on a UNIX server if some required files are installed.

- ASP works with open database connectivity (ODBC) compliant databases. ASP supports many database structures such as SQL, Access, Oracle, and Informix. The data can be inserted dynamically into the ASP pages.

- ASP runs the code on the server's side showing only results on the web page.

- ASP can enhance its capacity by integrating other programming languages such as Visual Basic, Visual C++ or Visual J++ (Saldanha 2003).

3.3.2.4 Object database

In this study the structural architecture of the database was simple. The database for object information was developed with Microsoft Access. There are three related tables in this structure: 1) the object details table, 2) the task order details table, and 3) the object coordinates table (see Fig. 3.8). The object details table is used to store object information such as names, owners, and descriptions. The task order details table is used to record both open work orders and work order archive information. These records are relationally link to the object details table enabling users to seek work orders by object. The object coordinates table is used to store objects' locations. Because some objects may contain more than one set of coordinates, it was decided to separate object coordinate information from the objects' details table giving more flexibility to the database structure.

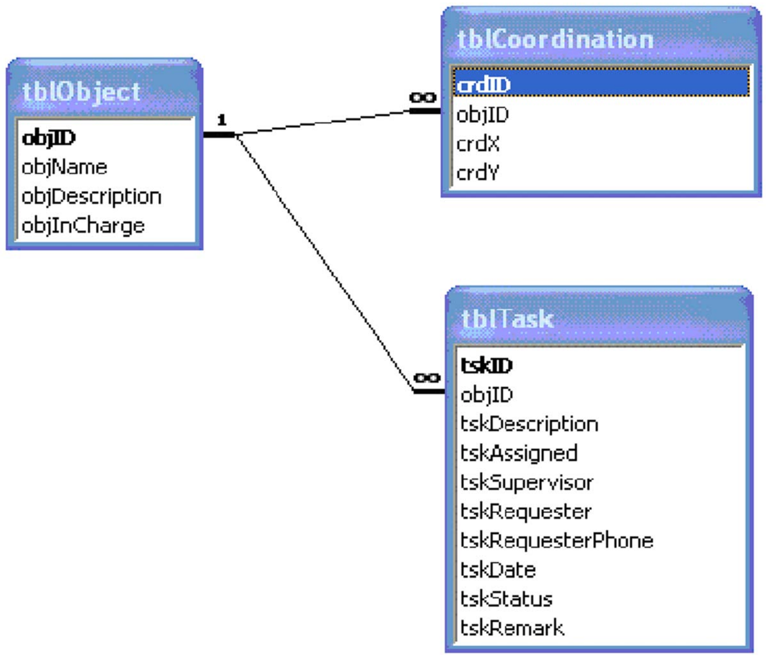


Fig. 3.8. The database structure

3.3.2.5 Prototype application interfaces

3.3.2.5.1 The Java interface

Before using the computer-based system, the Cricket technology has to be calibrated. To calibrate the Java interface, the listener has to be placed directly below each beacon. Once calibrated, the Java application will display blue points on the screen. Each blue point represents the beacons within Cricket environment (see Fig. 3.9). When the application is ready, the "tracking" status will be displayed. A red point is displayed representing the user's current location.

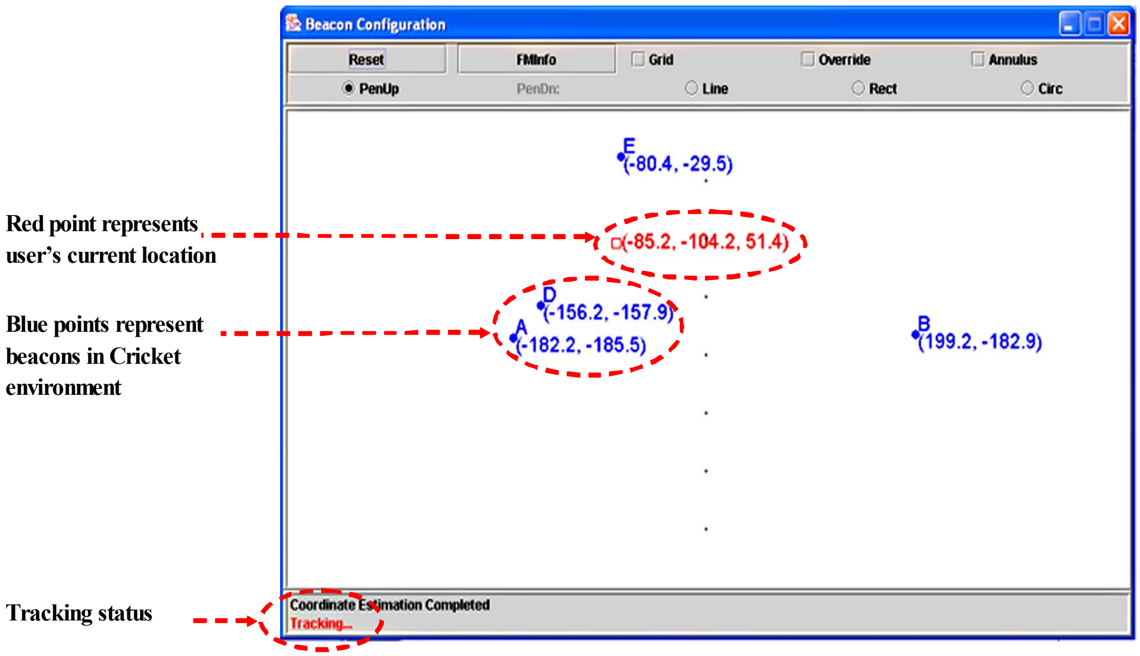


Fig. 3.9. Tracking status

The FMInfo function and button (shown in Fig. 3.10) was added into the existing BeaconConfig application (Fig. 3.11). With this application, users click the FMInfo button to identify objects within far and near space. This function calls Internet Explorer and provides an URL that contains all object location information. This function will only work when the "Tracking" status (Fig. 3.9) appears.

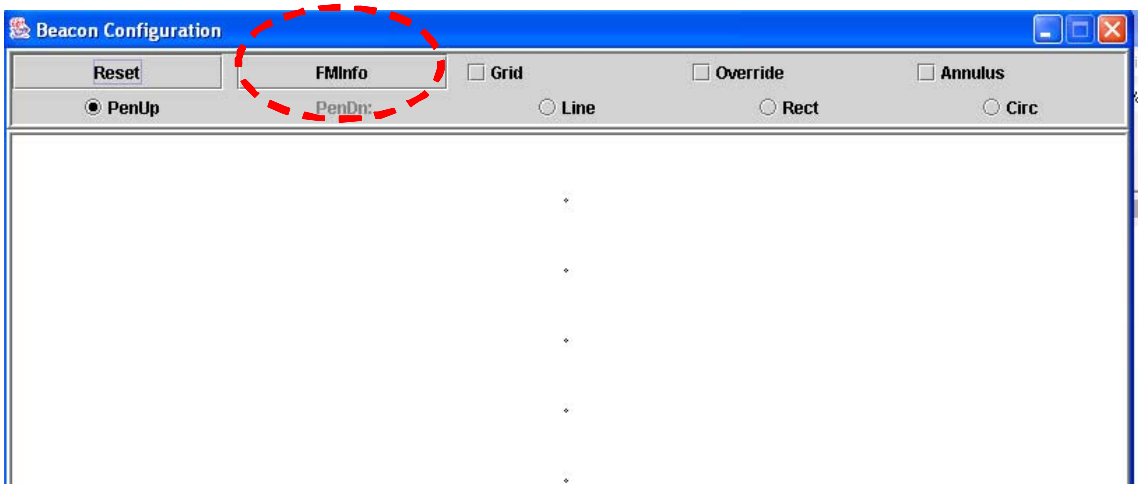


Fig. 3.10. FMInfo function button

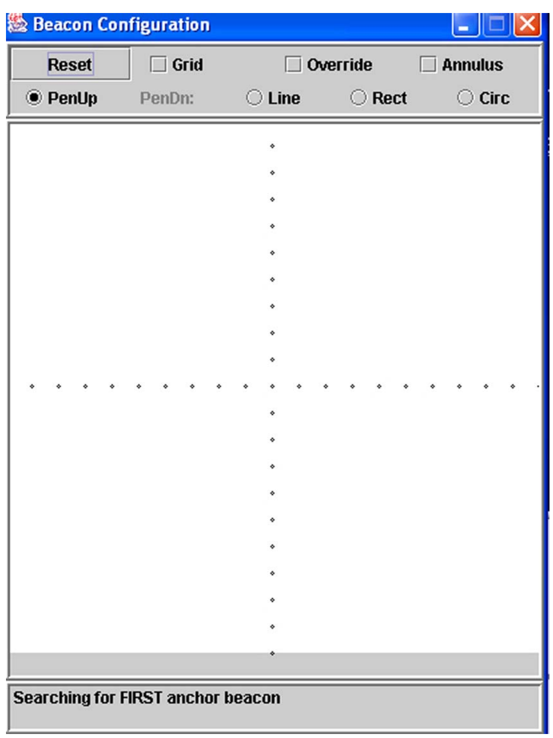


Fig. 3.11. Original BeaconConfig application

3.3.2.5.2 The ASP interface

Once the FMInfo sends the location information to the server, the ASP application gathers the related object information and reports the results to the user via Internet Explorer. There are four main screens within this ASP application. The initial screen (see Fig. 3.12) displays all objects that are in the current search boundary area (users may also change the searching boundary to greater or lesser distances). The number in parenthesis at the end of the object's name, such as (0) or (1), shows the count of pending work orders for that object.

When the user clicks the object's hyper-linked name, a confirmation information screen (see Fig. 3.13). This screen provides users with detail object information including two options: pending work order records and additional work order tasks that may be assigned to the object. If the user wishes to add work to the object they may click the hyper-linked "Work Order Options" to access the forth screen in Fig. 3.14. This screen displays the available work items list 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 (see Fig. 3.15) will be displayed. This page has a function to open or close the work order. Clicking this page's form submit button, uploads the data and returns a confirmation page. This confirmation page allows the user to verify that the information submitted was accurate.

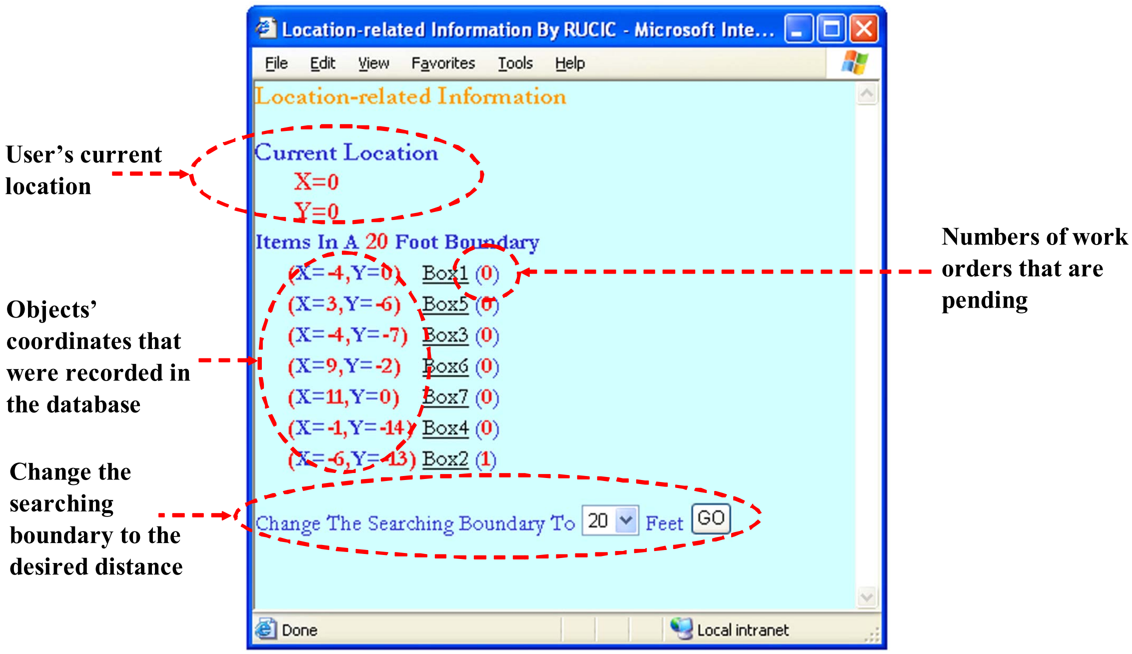


Fig. 3.12. The first ASP prototype application screen

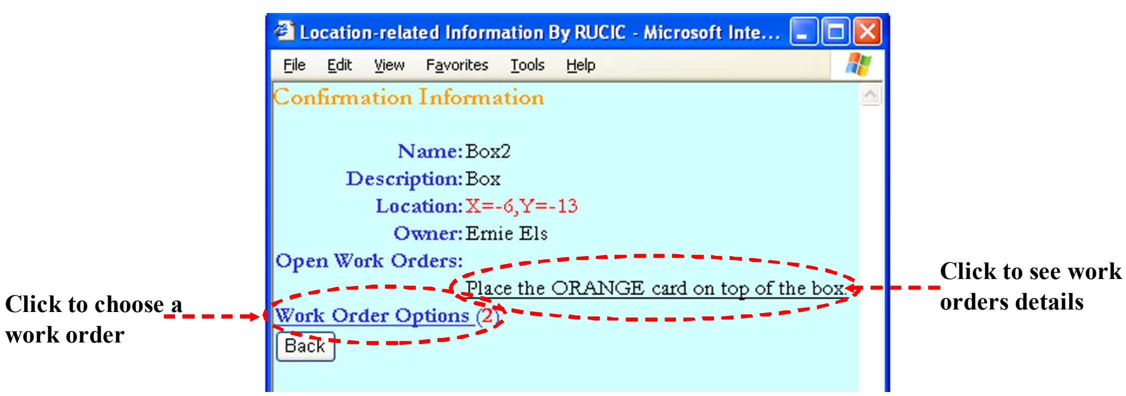


Fig. 3.13. Confirmation information screen

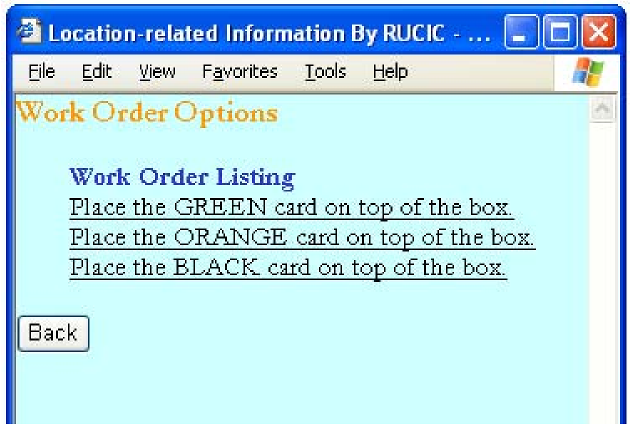


Fig. 3.14. Work order options screen

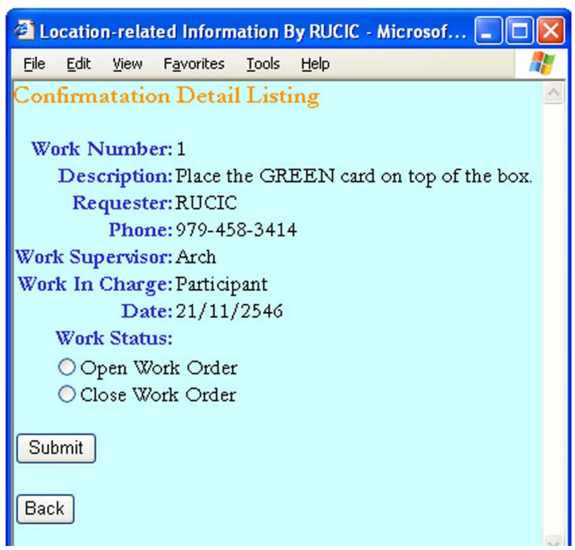


Fig. 3.15. Work order details screen

3.3.3 Exit survey

The exit survey was developed to investigate subject sentiments and attitudes concerning levels of comfort and accomplishment in writing out information and submitting information over a computer, and subject preferences for each of the location system types. The first section was based on a semantic-differential scale (from 1 to 5). On the second section subjects were required to choose between the human and computer systems followed immediately by open-end questions requesting a qualitative response as to why they favored the one they chose. The survey questionnaire is presented in Fig. 3.16.

Participant Survey ID: [/ /]

This is not a test. It is research instrument developed to assess methods of location problem solving. Once all data is collected and matched, quiz credit will be given for honestly responding to the items. This instrument could take you 5 minutes. Please answer to the best of your knowledge. Thank you for your participation.

"Circle" the value representing the strength of your responses.

1. I am uncomfortable writing out information on paper.
Agree **1** **2** **3** **4** **5** Disagree

2. I am comfortable submitting information on a computer network.
Agree **1** **2** **3** **4** **5** Disagree

3. I am accomplished at writing information on paper forms.
Agree **1** **2** **3** **4** **5** Disagree

4. I am not accomplished at submitting information on a computer network.
Agree **1** **2** **3** **4** **5** Disagree

5. I am familiar with the GPS system of measuring distances.
Agree **1** **2** **3** **4** **5** Disagree

6. I am not familiar with the Grid Coordinate system of measuring distances.
Agree **1** **2** **3** **4** **5** Disagree

"Circle" the question responses and "Write" your Why responses.

7. Which system of locating a box did you like best? **Written** **Computer**
Why? ____________________

8. Which system of locating a box do you believe is most accurate? **Written** **Computer**
Why? ____________________

9. Which system would you use in your own company? **Written** **Computer**
Why? ____________________

Fig. 3.16. Exit survey

3.4 Experiment protocol

The experimental protocol was divided into four instruments investigating the type of location system, two within the human-based system and two within the computer-based system: 1) deriving and verifying a location within the human system (H1), 2) finding and verifying a location within the human system (H2), 3) deriving and verifying a location with the computer system, and 4) finding and verifying a location with the computer system. In order to investigate and control for the learning effect, the thirty subjects were divided into two groups. The first group started the experiment with the human system first (human system first subjects) while the second group started the experiment with the computer system first (computer system first subjects). Integral to the data collection process was placing a queue card with the object's name, description, accurate location, and owner on the object (see Fig 3.17). This card was placed and taped face down so that the subject could not view the information until the appropriate time in the procedure. It not only provided the subjects with the target box's accurate location information for verification purposes but queued the time and process recording administrator when to take a time-on-task measurement.

NAME:

BOX 1

DESCRIPTION:

BOX

LOCATION:

X=5, Y=9

OWNER:

TIGER WOODS

Fig. 3.17. Information card

3.4.1 Experimental area location and set up

Experiment was conducted at the second floor, Langford Building A, College of Architecture, Texas A&M University. The open space on this floor was considered large enough to conduct the experiment. The experimental area was set up as the layout plan in Fig. 3.18. Two visible colored poles were provided, one yellow for the X-axis and one red for the Y-axis, as reference points. Three Cricket beacons (Fig. 3.19) were installed along the X-axis and Y-axis (Fig. 3.20 shows the beacon installed above the red pole). Seven boxes rotated in varied directions were arranged into the grid-coordinate system. A completed setup of the experimental area can be seen in Fig. 3.20. For the easier movement, the laptop mobile station in Fig. 3.21 was set up for the computer-based system.

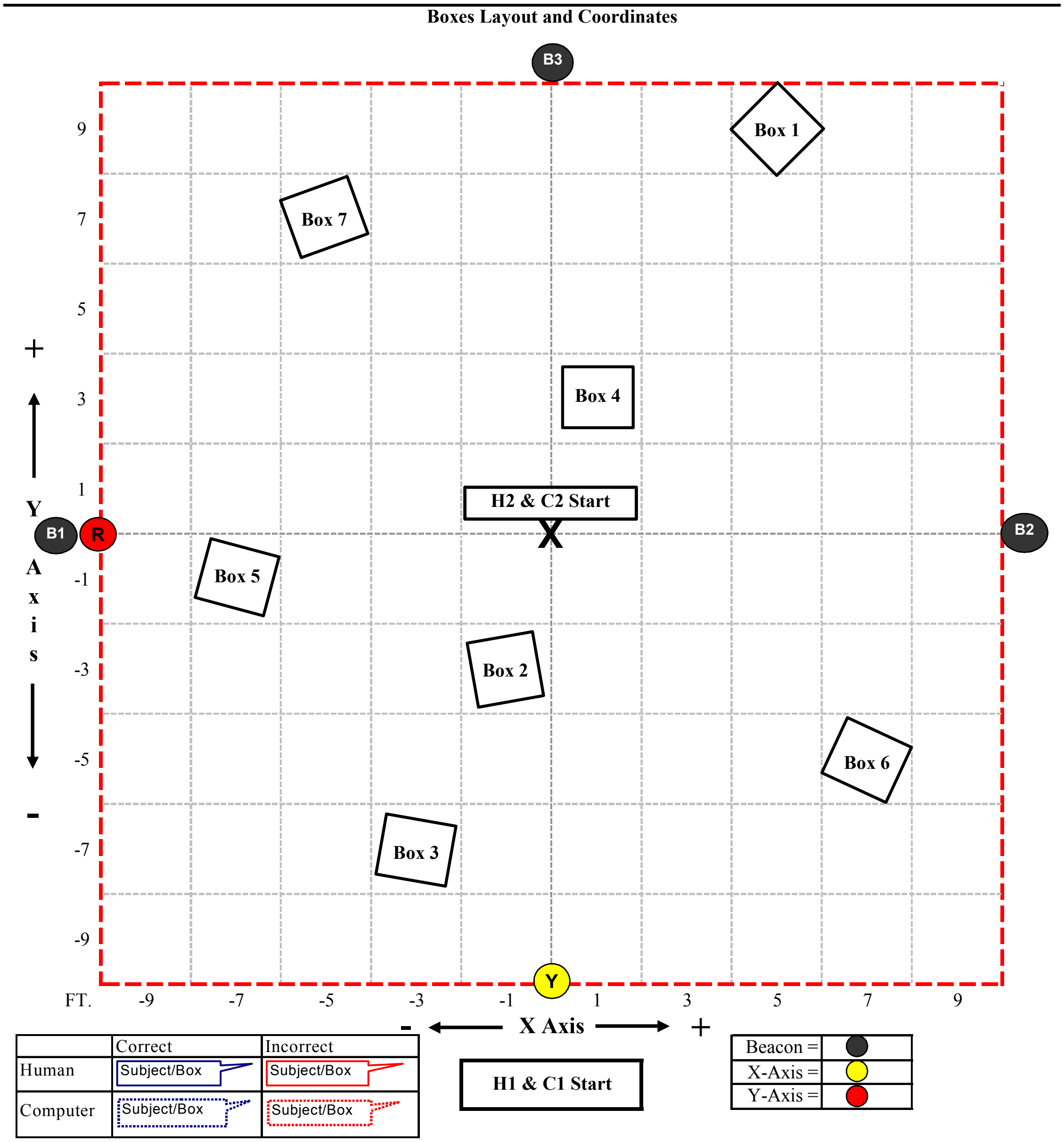


Fig. 3.18. The experimental area layout plan

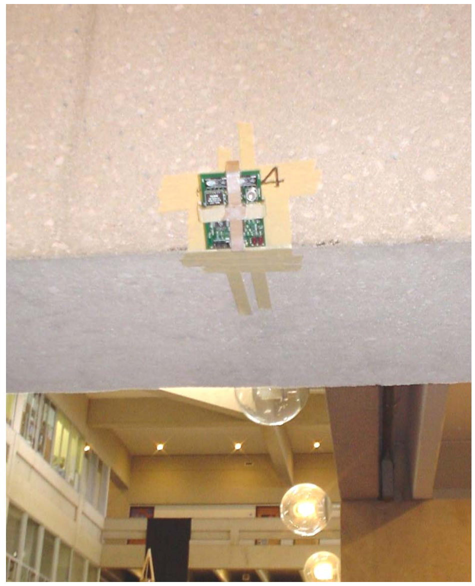


Fig. 3.19. The Cricket beacon's installation

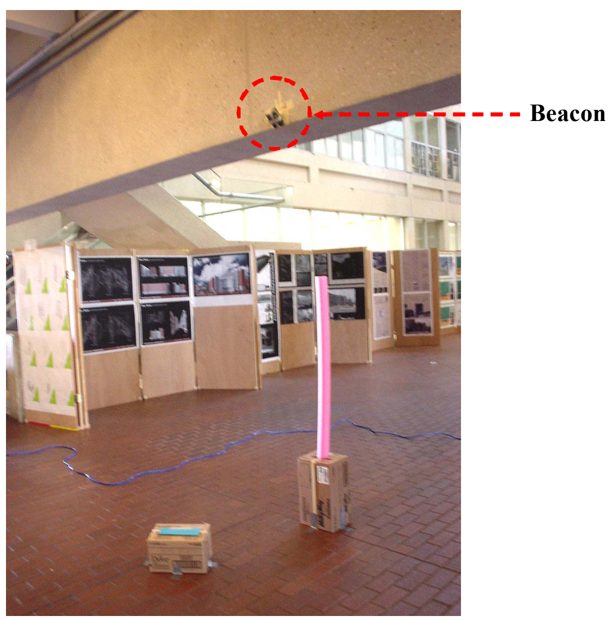


Fig. 3.20. The beacon installed above the red pole

Fig. 3.21. The complete set up of the experimental area

Fig. 3.22. The laptop mobile station

3.4.2 Experiment instructions

3.4.2.1 Human system - Deriving a location (H1)

Subjects were asked to request a work order with a blank work order form. The instruction sheet (see Appendix A.1) was given to the subjects. They were requested to read, verify their understanding of the assigned task, and to ask any questions they had before proceeding with the activity. Subjects began the activity from the starting point and moved to a predetermined target box with a clipboard containing the work order form. Placing a violet card on top of it identified the target box. Subjects were requested to derive the location of the center of the target box in term of the X-axis and Y-axis using the color poles as reference points, to turn to the blank work order form and record their grid-coordinate information in the spaces provided. Once they completed this task, they were requested to turn over the blue card and verify the box's actual grid-coordinates against the grid-coordinates they had recorded. If the subjects made an incorrect estimation, they would be queued as to where they erred in their application of the grid-coordinate procedure. The subjects were then requested to fill out the remainder of the work order form using the task option information on the back of the work order-form. They had three task options of work from which to choose. When they completed filling out the form, they were directed to check the form's box that indicated that the work order status was “Open”.

Time-on-task was measured follow these steps: 1) when the subjects stood at the target box, 2) when the subjects turned over the work order form, 3) when the subjects turned over the blue card, 4) when the subjects wrote on the work order form, and 5) when the subjects turned over the blue card. The derivation of location accuracy was collected from the subjects' estimations written on the work order form.

3.4.2.2 Human system - Finding a location (H2)

Subjects were asked to respond to an assigned work order with a paper form. The instruction sheet (see Appendix A.2) was given to the subjects. They were requested to read, verify their understanding of the assigned task, and to ask any questions they had before proceeding with the activity. Subjects started from the center of the experimental area marked by "X". They were provided with three colored cards (green, orange, and pink) attached to the clipboard. These three colored cards were used as directed in the work order to complete the work order task. This work order form provided the target box's true location, they were instructed to find the assigned target box, move next to it, turn over the blue card to verify they did in fact find the correct box, and then complete the assigned task. If they did not locate the correct target box they were directed to continue until they did locate the correct box. Once they completed the work requested the subjects were directed to check the box on the work order form indicating that the status was changed to "Closed".

Time-on-task was measured follow these steps: 1) when the subjects stood at the center of the experimental area, 2) when the subjects moved toward the assigned box, 3) when the subjects turned over the blue card, 4) when the subjects performed the required work, and 5) when the subjects turned over the blue card. The time and process recording administrator collected the derivation of location accuracy by counting how many times the subjects chose an incorrect box.

3.4.2.3 Computer system - Deriving a location (C1)

Subjects were asked to request a work order with the computer workstation. The instruction sheet (see Appendix A.3) was given to the subjects. They were requested to read, verify their understanding of the assigned task, and to ask any questions they had before proceeding with the activity. Subjects would start from the starting point and moved the mobile computer workstation to a predetermined target box. Placing a violet card on top of it identified the target box. Subjects would use the web-based application to get the target box's location. Once the computer application provided the target box’s grid-coordinate information, they were requested to verify its correctness by turning over the blue card on top of the target box. This task would reaffirm that they believe that the computer application had not erred in its application of the grid-coordinate procedure. Finally, the subjects were requested to use the computer application to assign and submit a work order to that box.

Time-on-task on the computer system was measured in two ways. First, the time and process recording administrator recorded the follow steps: 1) when the subjects stood at the target box, 2) when the subjects turned over the blue card, 3) when the subjects clicked the hyper-link, and 4) when the subjects turned over the blue card. The computer application's programming also recorded the time following these steps: 1) when the computer application popped-up, 2) when the subjects clicked the hyper-link, and 3) when the subjects clicked on the work order application's submit button. The time differential between these two measurements would be used to determine the exact time that subjects used to complete the activity. The deriving location accuracy was measured from the grid-coordinates that the computer application recorded.

3.4.2.4 Computer system - Finding a location (C2)

Subjects were asked to respond an assigned work order with the computer workstation. The instruction sheet (see Appendix A.4) was given to the subjects. They were requested to read, verify their understanding of the assigned task, and to ask any questions they had before proceeding with the activity. Subjects were requested to move the mobile computer workstation to the center of the experimental area marked by "X". They were provided three colored cards (green, orange, and pink) to complete the requested work order task. The computer application provided them the target box's true location assigned by work order. The subjects were directed to find the box that was assigned, move the computer workstation beside the target box, request the target box's location again, and turn over the blue card to verify if they had in fact found the correct box. This task would reaffirm that they believe that the computer application had not erred in its application of the grid-coordinate procedure. If they did not locate the correct box, they were directed to continue until they did locate the correct box. Once they completed the work requested they were directed to pick the radial button indicating that the status was changed to "Closed".

Time-on-task on the computer system was measured in two ways. First, the time and process recording administrator recorded the follow steps: 1) when the subjects stood at the center of the experimental area, 2) when the subjects moved toward the target box, 3) when the subjects stood at the target box, 4) when the subjects clicked the hyper-link, and 5) when the subjects turned over the blue card. The computer application's programming also recorded the time following these steps: 1) when the computer application popped-up, 2) when the subjects clicked the hyper-link, and 3) when the subjects clicked on the computer application's submit button. The time differential between these two measurements would be used to determine the exact time that subjects used to complete the activity. The time and process recording administrator collected the finding location accuracy by counting how many times they chose an incorrect box.

3.5 Data analysis

Examination of the data used a T-test for an analysis of variance between-subjects and sorted by order. Dependent measure will be deriving location and finding location across type of location system. That is, for example, the amount of change in time-on-task per type of location system used. Additional analysis of variance within-subject used the ANOVA test where further investigation of variable interactions was warranted. Each subject received both levels of location system type and both levels of problem-solving task. Administering the human system first to half the population and the computer system to the remaining half first controlled for order. The data will be matched to determine the change in time-on-task and accuracy. The examination of the exit survey data used a Chi-Square test for a frequency analysis of variance for nominal variables between-subjects and sorted by order.

CHAPTER IV

RESULTS

This chapter reports the results of an analysis on information obtained by the experiment conducted on the ability of subjects to not only derive and verify a location but also find and verify a location in an open space within the interior of a building. This discussion includes six major data analysis sets. The first set is a qualitative description of the human location errors found when subjects derived grid-coordinates in human system. The next two sets of analysis were conducted to examine the effects of deriving and verifying, and finding and verifying an object's location on time-on-task. The next two sets of analysis were conducted to examine the effects of deriving and verifying and finding and verifying an object's location on accuracy. Finally, the results of the exit survey analysis are presented. In each of the time and accuracy sets, tests of mixed within-subject and between-subject analysis of variance are presented. Statistical tests were conducted examining Type III sums of squares using a α <+ .05.

4.1 Human location errors

In the deriving and verifying a location experiments within the human system, subjects' estimated grid-coordinates were collected and are presented in Table 4.1. As in Fig. 4.1, the level of the successful estimations was computed by using the distance from the target box to the nearest box. At the middle of that distance, the level of confidence is equal to zero. Fifty percent of that middle distance was used to determine if the subject's were successful in deriving the correct grid-coordinates of the target box.

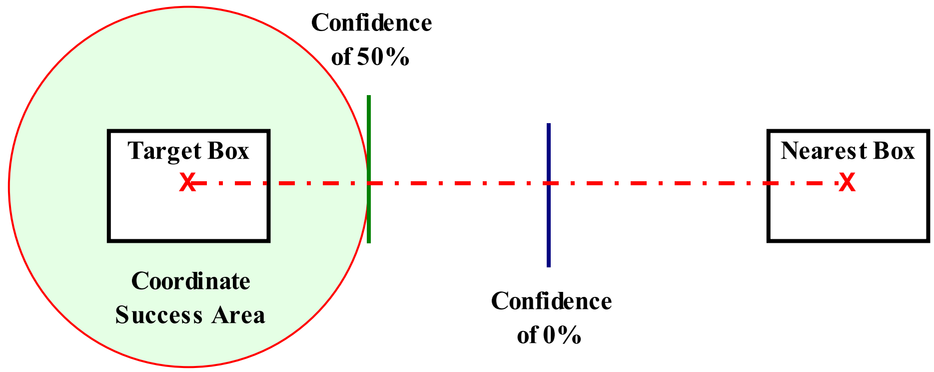


Fig. 4.1. Successful grid-coordinate scoring

Subjects' estimated grid-coordinates were plotted into the box layout map and are shown in Fig. 4.2. The time and process recording administrator made a record of the type of strategy used by the subject's in measuring the distance from the X-axis and Y-axis grid lines. It was found that 46.7% of the subject's used a step-off strategy in which they used their feet as equaling a foot of length. Results show that 13 out of 30, or 43% percent, of the subjects did not accurately estimate the target box's grid-coordinates. In analyzing the data for procedural errors three common algorithmic errors were found: 1) erroneous assignment of the X-axis and Y-axis ($_{nN=4,30}$ 13.3%); 2) erroneous assignment of the positive and negative nature of the coordinates ($_{nN=3,30}$ 10%); and 3) erroneous measurements of distance ($_{nN=11,30}$ 36.7%). Of those subjects who used the step-off strategy $_{nN=3,11}$ 27.3% did not provide accurate measurement of distances.

Table 4.1. Subject responses.

H1 Box Location					Responses			
STID	**Order**	**Box Name**	**Box Coordinates**		**Coordinates**		**Method**	**Error**
152	**1**	**7**	-5.0	7.0	-8.0	4.0	S	D
154	**1**	**7**	-5.0	7.0	-5.5	6.5	S	
104	**1**	**5**	-7.0	-1.0	-7.0	-1.0	S	
342	**1**	**1**	5.0	9.0	6.0	9.0	V	
294	**1**	**5**	-7.0	-1.0	-0.8	-7.5	V	X , +
912	**1**	**3**	-3.0	-7.0	-3.0	-7.0	S	
714	**1**	**7**	-5.0	7.0	4.0	-4.0	V	D, +
146	**1**	**5**	-7.0	-1.0	-5.0	-0.5	V	D
744	**1**	**4**	1.0	3.0	1.5	4.0	S	
270	**1**	**2**	-1.0	-3.0	8.0	6.0	S	X , D , +
500	**1**	**1**	5.0	9.0	8.0	5.0	V	X
123	**1**	**1**	5.0	9.0	5.0	8.0	S	
166	**1**	**4**	1.0	3.0	1.0	5.0	V	D
812	**1**	**1**	5.0	9.0	5.0	9.0	S	
78	**1**	**2**	-1.0	-3.0	-0.3	-2.5	V	
575	**2**	**7**	-5.0	7.0	-3.0	7.0	V	D
471	**2**	**6**	7.0	-5.0	6.0	-3.0	V	D
655	**2**	**6**	7.0	-5.0	7.0	-4.0	S	
231	**2**	**4**	1.0	3.0	1.0	3.0	S	
299	**2**	**2**	-1.0	-3.0	-1.0	-2.0	V	
237	**2**	**5**	-7.0	-1.0	-5.0	-0.5	V	D
965	**2**	**3**	-3.0	-7.0	-3.0	-6.0	V	
257	**2**	**4**	1.0	3.0	1.0	2.0	V	
475	**2**	**3**	-3.0	-7.0	-4.0	-6.0	V	D
781	**2**	**1**	5.0	9.0	5.0	8.0	V	
289	**2**	**2**	-1.0	-3.0	-1.0	-3.0	V	
991	**2**	**4**	1.0	3.0	1.0	3.0	V	
53	**2**	**6**	7.0	-5.0	7.0	-5.0	V	
431	**2**	**6**	7.0	-5.0	10.0	8.0	V	D , +
177	**2**	**3**	-3.0	-7.0	-4.0	-9.0	S	D
V=Visual, S=Step Off					X = X Y axis error, + = + & - error, D = Distance error			

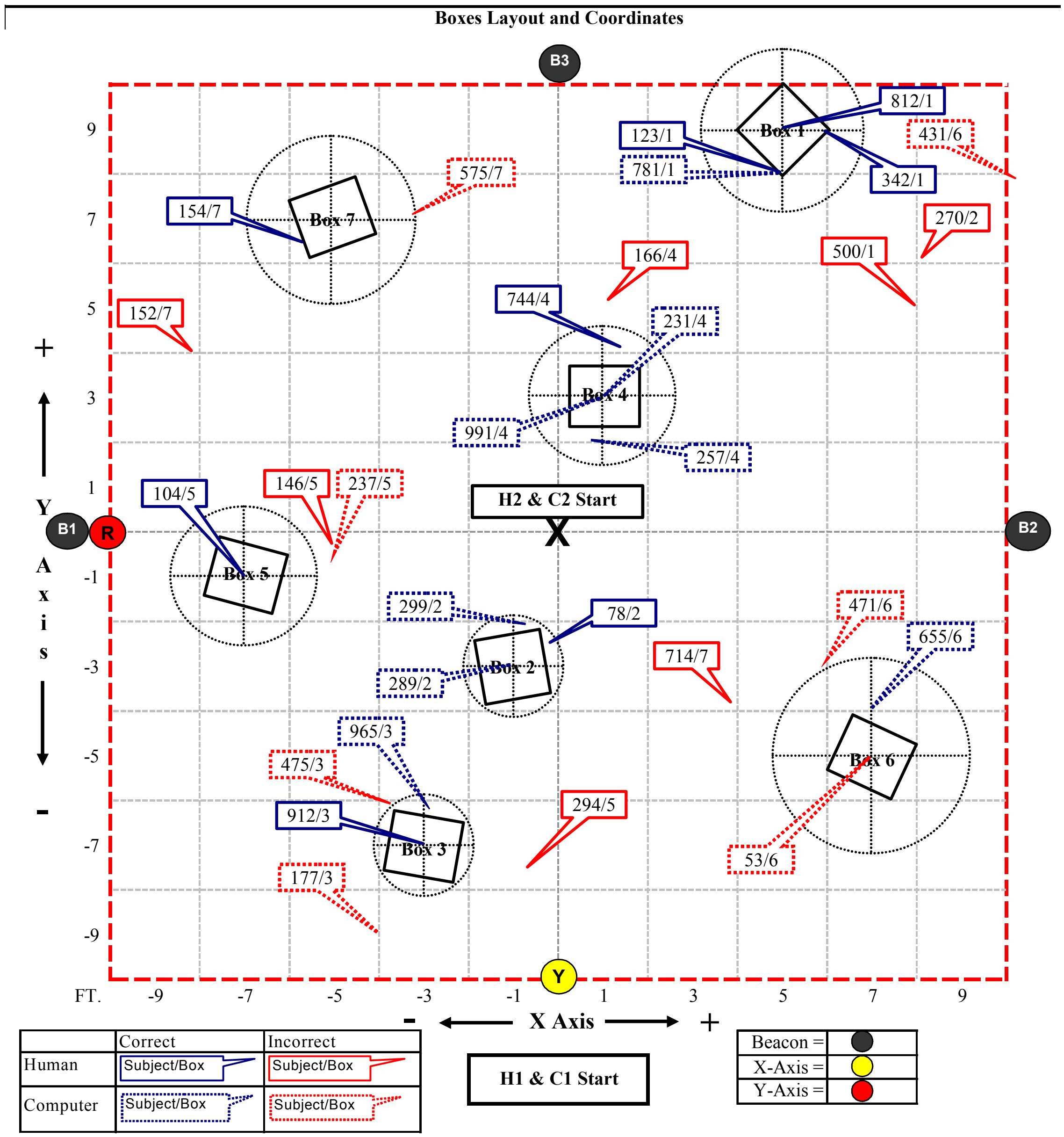


Fig. 4.2. Plotted responses

4.2 Deriving location time-on-task

Time measures were taken within both the human system and computer system administrations of deriving and verifying an object's location. These values served as the dependent measures. A between subjects by within-subjects *t*-test of system times and the interaction of order was computed. The results of the *t*-test are presented in Fig. 4.3.

Results indicate that the mean time value for deriving and verifying a target box's location in the human system was 1.1 (M= 1.14, SD = .698), whereas the time value for deriving and verifying a target box's location in the computer system was 0.3 (M = 0.323, SD = .289). A two-tailed *t*-test performed on these differences indicated that the combined difference between these two means was significant $t(29) = 7.23$, $p < .05$. The results indicate that the null hypothesis of no difference should be rejected. Since lower time values imply a faster location derivation and verification system, using the computer system appears to be associated with a faster system if identifying a target box's location. When these mean time values were split by order, the mean for human system first was 0.98 (M= 0.983, SD = .789), and the mean for computer system first was 0.48 (M= 0.481, SD = .402). Results show order of instrument administration was significant for both computer system first subjects $t = 5.166$, $p = .0001$ and human system first subjects $t = 5.971$, $p = <.0001$.

To further investigate the effects between type of location system groups by within-administrations an ANOVA of system times and the interaction of orders were computed. The results of the ANOVA are presented in Fig. 4.4. Results show that the mean time values for the human system group are: human system first 1.5 (M= 1.52, SD

= .747) and computer system first 0.76 (M= 0.764, SD = .384). The difference between these two means was significant df 1, 28= 12.036, p = .0017. Additionally, results show that the mean time values for the computer system group are: human system first .45 (M= 0.449, SD = .352) and computer system first 0.2 (M= 0.198, SD = .125). The difference between these two means was significant df 1, 28= 6.786, p = .0145. These results and the previous t-test results indicate that the null hypothesis of no difference by order should be rejected. In all analysis the computer system first subjects were able to provide the target box's location faster than human system first subjects when deriving an object's location.

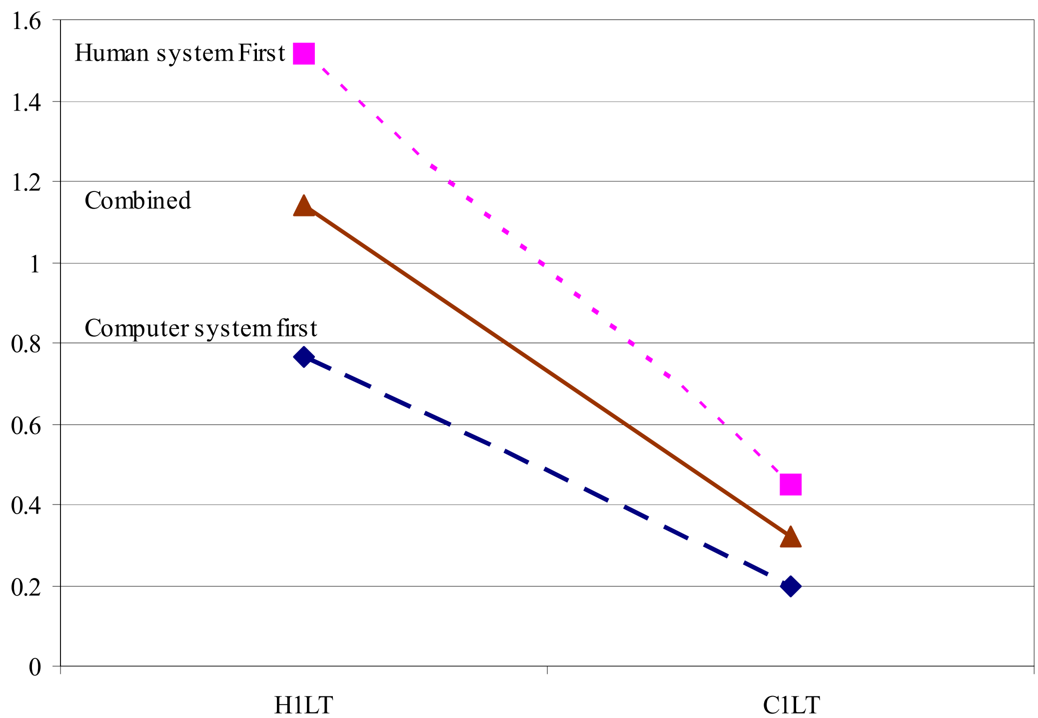


Fig. 4.3. Deriving and verifying a location time-on-task by order of administration

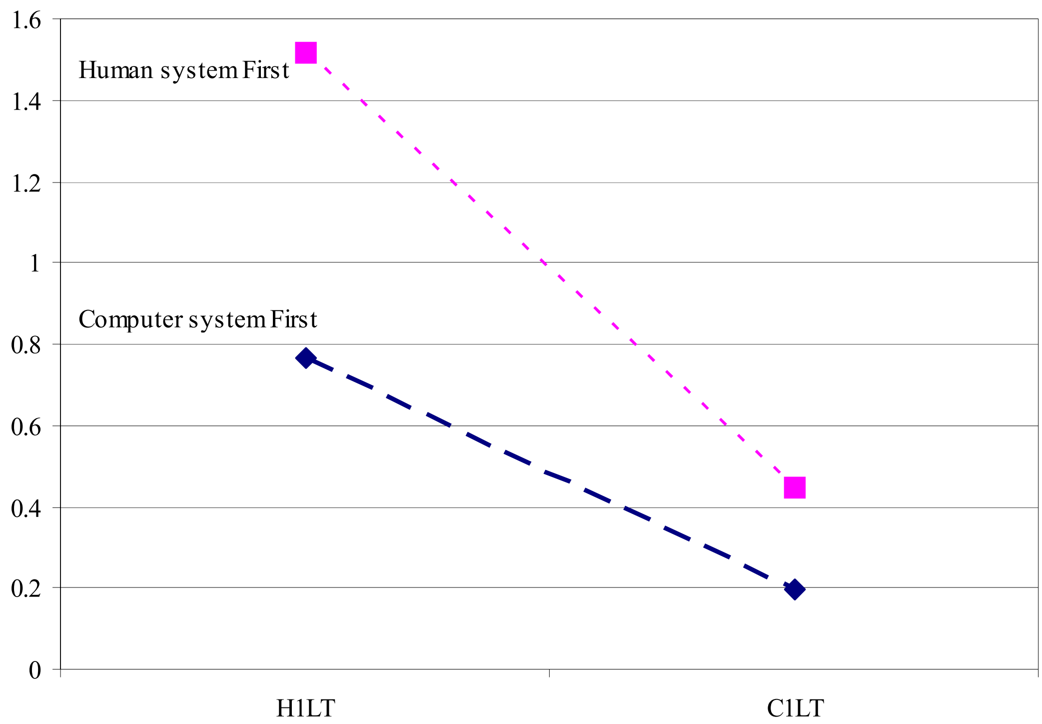


Fig. 4.4. Deriving and verifying a location time-on-task by order within administration

---

4.3 Finding location time-on-task

Time measures were taken within both instrument administrations of the system of finding and verifying an object's location. These values served as the dependent measures. A between subjects by within-subjects *t*-test of system times and the interaction of order of administration was computed. The results of the *t*-test are presented in Fig. 4.5.

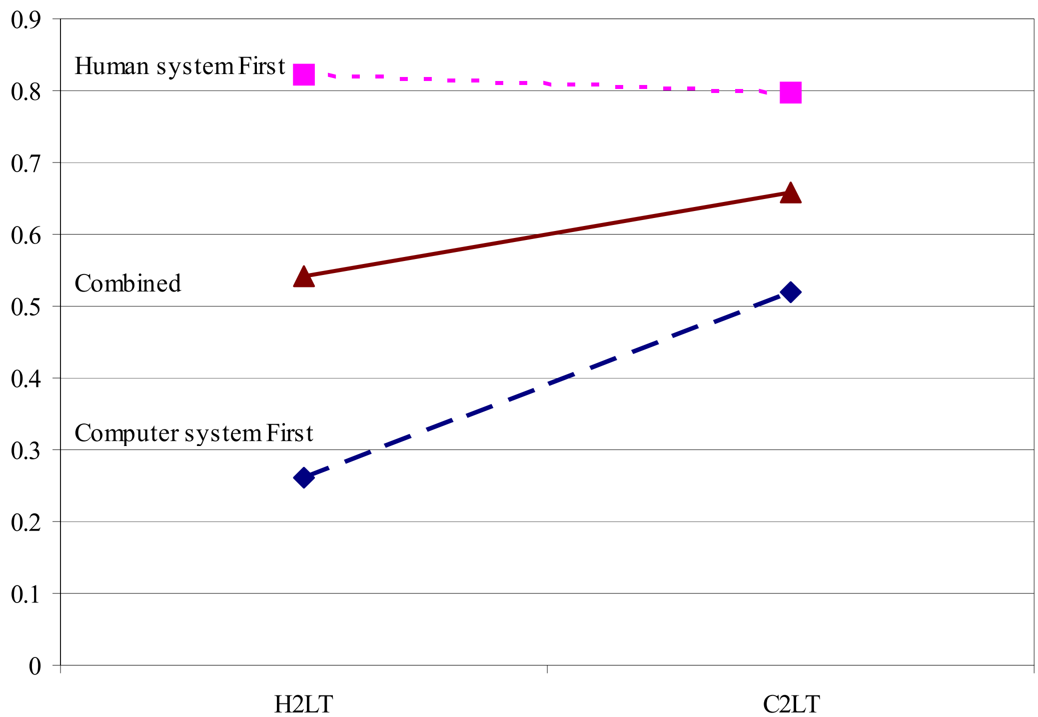


Fig. 4.5. Finding and verifying a location time-on-task by order of administration

---

Results indicate that the mean time value for finding a target box's location in the human system was 0.54 (M= 0.541, SD = .827), whereas the time value for finding a target box's location in the computer system was 0.66 (M = 0.658, SD = .449). A two-tailed *t*-test performed on these differences indicated that the combined difference between these two means was not significant $t(29) = -.722$, $p > .05$. The results indicate that the null hypothesis of no difference should be accepted. Since lower time values imply a faster finding and verification system, using the human system or computer system appears not to be associated with a faster system if finding a target box's location. When these mean time values were split by order, the mean for human system first was

0.81 (M= 0.808, SD = .838), and the mean for computer system first was 0.39 (M= 0.39, SD = .316). Results show order of instrument administration was significant for the computer system first subjects t = -2.527, p = .0242. All other interactions were not significant. The results indicate that the null hypothesis of no difference by order should be rejected in the case of the human system first administration. Human system first subjects were able to provide the target box's location faster than computer system first subjects when finding an object's location.

4.4 Deriving location accuracy

Deriving and verifying location accuracies were taken within both the human system and computer system administrations. These values served as the dependent measures. A between subjects by within-subjects t-test of system times and the interaction of order was computed. The results of the t-test are presented in Fig. 4.6.

Results indicate that the mean accuracy value for deriving and verifying a target box's location in the human system was 0.57 (M= .567, SD = .504), whereas the mean accuracy value for deriving and verifying a box location in the computer system was 0 (M = 0, SD = 0). A two-tailed t-test performed on these differences indicated that the combined difference between these two means was significant $t(29) = 6.158$, $p < .05$. The results indicate that the null hypothesis of no difference should be rejected.

Since lower accuracy values imply a more accurate derivation and verification system, using the computer system appears to be associated with a more accurate system if identifying a target box's location. When these mean accuracy values were split by order, the mean for human system first was 0.27 (M= 0.267, SD = .450), and the mean for computer system first was 0.30 (M= 0.300, SD = .466). Results show order of instrument administration was significant for both computer system first subjects *t* = 4.583, *p* = .0004 and human system first subjects *t* = 4.000, *p* = .0013. The results indicate that the null hypothesis of no difference by order of administration should be rejected. In all analysis the computer system first was able to provide the target box's location more accurately than human system first when finding an object's location.

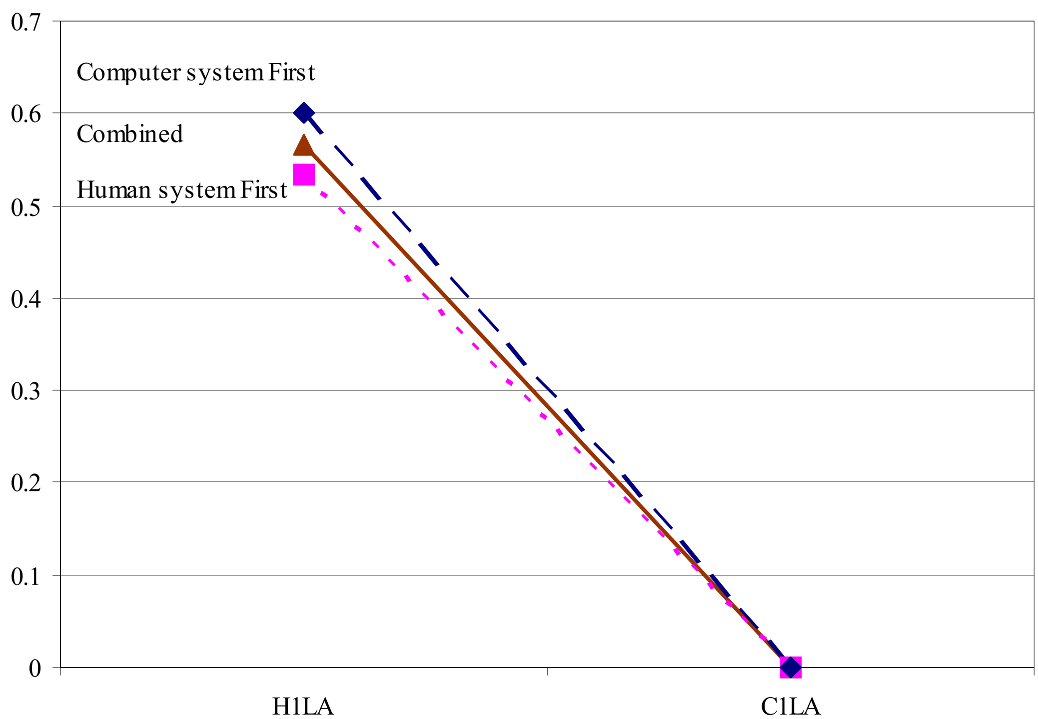


Fig. 4.6. Deriving and verifying location accuracy by order of administration

4.5 Finding location accuracy

Finding and verifying location accuracies were taken within both type of location system administrations. These values served as the dependent measures. A between subjects by within-subjects *t*-test of system times and the interaction of order of administration was computed. The results of the *t*-test are presented in Fig. 4.7.

Results indicate that the mean accuracy value for finding a target box's location in the human system was 0.13 (M= 0.133, SD = .434), whereas the accuracy value for finding a target box's location in the computer system was 0.17 (M = 0.167, SD = .379). A two-tailed *t*-test performed on these differences indicated that the combined difference between these two means was not significant $t(29) = -.372$, $p > .05$. The results indicate that the null hypothesis of no difference should be accepted. Since lower accuracy values imply a more accurate location finding and verification system, using the human system or computer system appears not to be associated with a more accurate system if finding a target box's location. When these mean accuracy values were split by order, the mean for human system first was 0.17 (M= 0.167, SD = .461), and the mean for computer system first was 0.13 (M= 0.133, SD = .346). Results show order of administration was significant for the computer system first subjects $t = -2.256$, $p = .0406$. The results indicate that the null hypothesis of no difference by order should be rejected in the case of the computer system first administration. Computer system first subjects were more accurate than human system first subjects when finding an object's location.

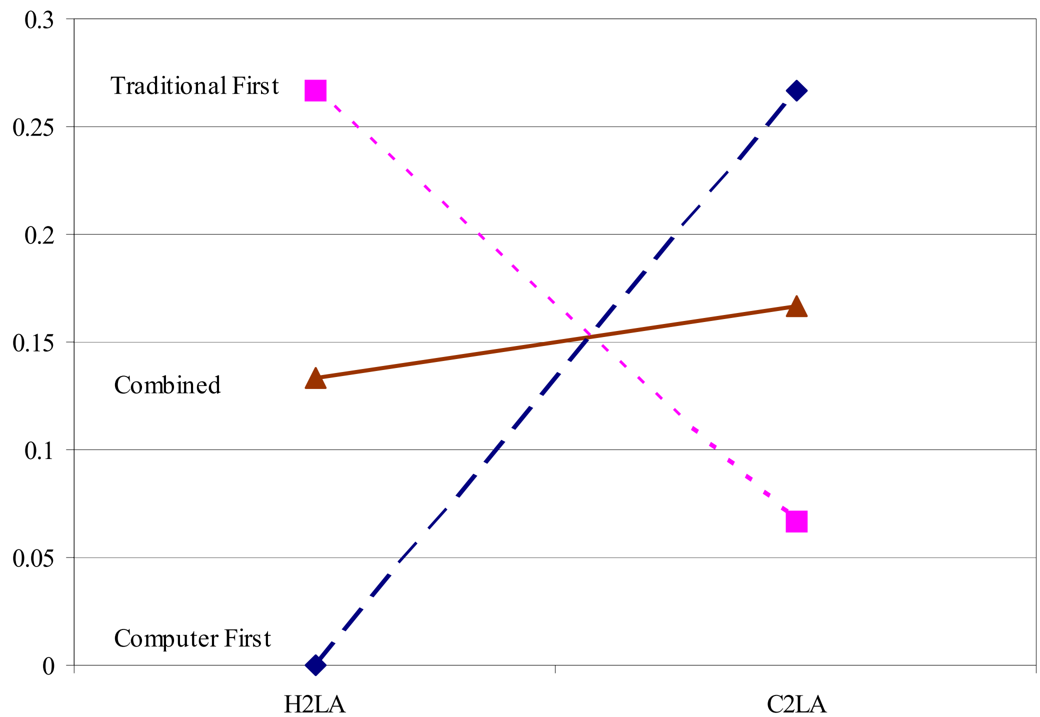


Fig. 4.7. Finding and verifying location accuracy by order of administration

4.6 Exit survey

An exit survey questionnaire was given that first investigated subject sentiments of comfort, accomplishment, and familiarity, and second investigated subject preferences toward the two types of location systems examined in this study. In the first part two investigations were conducted using a semantic differential scale and the second part asked subjects to indicate their preference for one location system type over the other and to explain the reasons for their choice. The frequencies of these questions served as the nominal measures, and a between subjects by within-subjects chi-square test of these question groups and the interaction of order were computed.

4.6.1 Sentiments

Results on the first part concerning their sentiments of comfort and accomplishment in writing out information on paper, in submitting information over a computer network, and their familiarity with both the GPS system and the Grid system are presented in Table 4.2. Questions 1, 4 and 6 were reversed in the questionnaire given the subjects, but for analysis all question responses were fit to the agree direction of the scale.

Table 4.2. Subject sentiment responses.

Question		Mean	SD
1.	I am comfortable writing out information on paper.	2.00	1.39
2.	I am comfortable submitting information on a computer network.	2.07	1.17
3.	I am accomplished at writing information on paper forms.	1.83	0.87
4.	I am accomplished at submitting information on a computer network.	1.93	0.98
5.	I am familiar with the GPS system of measuring distances.	2.53	1.22
6.	I am familiar with the Grid Coordinate system of measuring distances.	1.50	1.11
			Scale: 1 = Agree; 5 = Disagree

As illustrated above, subjects scored themselves as relatively in agreement with each of the survey sentiment questions. Results show that participants felt comfortable writing out information on paper (M = 2.00, SD = 1.39) and felt comfortable submitting information on a computer network (M = 2.07, SD = 1.17). Participants believed that they were fairly accomplished at writing information on paper forms (M = 1.83, SD = 0.87) and submitting information on a computer network (M = 1.93, SD = 0.98). Participants were closer to the middle of the scale when asked how familiar they were with the GPS system of measuring distances (M=2.53, SD = 1.22) while they were more strongly familiar with the grid coordinate system of measuring distances (M=1.50, SD = 1.11).

Between-subject by question, interaction effects were investigated. Results show a significant interaction for the questions 2 and 6, questions 3 and 5, and questions 5 and 6. No other significant interactions were found. First, the interaction was significant between questions 2 and 6 $t = 2.248$, $p = .0191$. Subjects who felt more familiar with the grid-coordinate system of measuring distances were more likely to feel less comfortable submitting information on a computer network. Second, the interaction was significant between questions 3 and 5 $t = -2.704$, $p = .0113$. Subjects who felt more accomplished at writing information on paper forms were more likely to feel less familiar with the GPS system of measuring distances. When sorted by order, this interaction was significantly truer of the human system first group $t = -2.578$, $p = .0219$ than the computer system first group. Finally, the interaction was significant between questions 5 and 6 $t = 3.474$, $p = .0016$. Subjects who felt more familiar with the grid-coordinate system of measuring distances were more likely to feel less familiar with the GPS system of measuring distances. Again, when sorted by order, this interaction was significantly truer of the human system first group $t = 2.874$, $p = .0123$ than the computer system first group.

4.6.2 Preferences

Results on the second part concerning their preferences for either the written (human system) system or the computer system are presented in Table 4.3. As illustrated below, subjects were evenly distributed between preferences for the computer system as compared to the human system, like best (M = 1.53, SD = 0.51). Subjects were fairly sure of their preference for the computer system as compared to the human system most accurate (M = 1.93, SD = 0.25). Finally, subjects were fairly sure of their preference for the computer system to be used in their own company (M = 1.89, SD = 0.32).

Table 4.3. Subject preference responses.

Question		Mean	SD
7.	Which system of locating a box did you like best?	0.53	0.51
8.	Which system of locating a box do you believe is most accurate?	0.93	0.26
9.	Which system would you use in your own company?	0.89	0.32
	Scale: 0 = Written; 1 = Computer		

Between-subject by question, interaction effects were investigated. Results of a Chi-Square test using the frequencies for nominal the variables between-subjects show a significant difference between subjects' responses to questions 7 and 9. No other significant differences were found. The difference was significant between questions 7 and 9 chi-square = 14.00, df = 1, $p = .0002$. Subjects who liked the computer system best were more likely to prefer the computer system to be used in their own company.

An analysis of the qualitative data required a subjective categorization of the responses. For question seven, the data was fit to the following categories: 1) faster, 2) faster and less confusing, 3) less confusing, 4) more accurate, and 5) more enjoyable. Within the category of faster, subjects liked the human system best $_{\mathrm{nN}\,=\,3,4}$ 75% in that they could derive and verify and write the target box's location faster than the computer system. Within the category of faster and less confusing, subjects equally liked both the human system $_{nN\,=\,2,4}$ 50% and the computer system $_{nN\,=\,2,4}$ 50%. Within the category of less confusing, subjects liked the human system best $_{nN\,=\,6,9}$ 67% because it was more simplistic than the computer system. Within the category of more accurate, subjects liked the computer system best $_{nN\,=\,8,11}$ 73% in that they believed the human system would cause more errors. Within the category of more enjoyable, subjects liked the computer system best $_{nN\,=\,2,2}$ 100%.

Within question eight all responses were categorized as more accurate. Of the29 responses only two choose the human system. Subjects overwhelmingly believed that the computer system best $_{nN\,=\,27,29}$ 93% in that it would provide a more accurate location than the human system.

Finally, for question nine the data was fit to the following categories: 1) faster, 2) less confusing, 3) more accurate, and 4) more accurate and faster. Within the category of faster, subjects liked the computer system best $_{nN\,=\,3,3}$ 100% in that they believed that the computer system would increase productivity by being faster. Within the category of less confusing, subjects liked the computer system best $_{nN\,=\,2,3}$ 67% in that they believed that the computer system removed the guesswork from submitting location information. Within the category of more accurate, subjects liked the computer system best $_{nN\,=\,10,12}$ 83% in that they believed the computer system would not make transcription errors and that the location information would always be correct. Within the category of more accurate and faster, subjects liked the computer system best $_{nN\,=\,10,10}$ 100%, they not only believed the computer system would not make transcription errors and the location information would always be correct, but also that it would be much faster than the human system.

CHAPTER V

DISCUSSION AND CONCLUSIONS

The results of this investigation provide evidence that differing types of open space location systems affect problem solving in deriving (naive search), finding (primed search), and verifying an object's location. The study substantiates the assumption that subjects do have difficulty solving problems with grid-coordinate procedure and that some of the underlying bases for these difficulties include the measurements of distance, the projection of the X-axis and Y-axis grid lines, and the positive and negative nature of the coordinates. Further, this study substantiates the assumption that an explicit computer-based system improves accuracy and time-on-task performance in locating objects in large open spaces over the implicit human-based system. This chapter examines these relations in detail and then presents recommendations for future research.

5.1 Location time-on-task

5.1.1 Deriving location time-on-task

For the naive search of space, where the target box's location was unknown the computer system was expected to provide the fastest time-on-task, in that, subjects did not have to mentally model the open space or invoke the grid-coordinate procedure to verify that they did find the correct target box. The computer system provided confirmation. This also supports the previous accuracy results indicating that this group did not utilize the grid-coordinate procedure to verify the location information. In that the human system first subject's were required to utilize the grid-coordinate procedure they were slower than the computer system first subjects in derivation and verification times.

5.1.2 Finding location time-on-task

For the primed search of space, where the target box's location was known the computer system was expected to provide the fastest time-on-task, in that, subjects did not have to invoke the grid-coordinate procedure to verify that they did find the correct target box. However, the data did not substantiate this hypothesis. There was not significant difference between groups. However, the computer system required subjects to use the Cricket technology twice. The computer system subjects requested grid-coordinate information at the starting point and then again at the target box, where the human system subjects invoked the grid-coordinate procedure only at the starting point. This extra task did not seem to have an effect. The data analysis indicates that the interactions by order were significant for the human system first subjects. In this case there does seem to be a learning effect, in that, they may have learned from deriving the box location.

5.2 Location accuracy

The central hypothesis of this study concerns the interaction effect for type of location system and order of instrument administration upon the subject's accuracy of deriving and finding a location. It was expected that subjects provided with the computer-based system first would perform more accurately than those given the human-based system first. When faced with such explicit displays of location information it was expected that the computer system first subjects would become aware of the grid-coordinate procedure and therefore perform as well if not better when presented the human system problem second. Further, for those who received the human system first, the necessity of them having to invoke and use the grid-coordinate algorithm should reduce their performance in terms of accuracy.

5.2.1 Human location errors

Half of the subjects used a step-off method of determining distance in which they used their feet as equaling a foot of length, but of this group approximately half of them still erred when providing the distances. Obviously this is not an exact enough method for determining distance between objects and the errors would be only compounded in larger and more open spaces.

Errors in measuring distances from the X-axis and Y-axis grid lines accounted for approximately 37% of the errors when deriving a location in the human system. As the analysis results indicated there was no effect for order of instrument administration. Not only was the distance that caused them to misjudge the target box's location, the basic algorithm of X-axis and Y-axis was also a part of their errors. Although subjects were asked to start and face at the same direction (establish and initial spatial state), some of the subjects did not either understand or could not effectively utilize the provided grid-coordinate procedural algorithm. These types of errors would only be compounded if they were in a large open space, which could be accessed from many starting points.

5.2.2 Deriving location accuracy

The body of literature defines this task as a naive search of space where the target box's location is unknown. With the computer-based system, which used the Cricket technology and the ASP application, subjects should always be able to get the correct and exact target box location, every time, no matter if they had an effective understanding of the grid-coordinate procedure or not. In all analysis, as one would expect, the computer system was able to provide the box's location accurately as compared to the human-based system where errors were expected when finding an object's location. The importance of this finding is that computerized aids to spatial wayfinding are an important tool that will not only increase accuracy in naive situations, but also increase productivity. The results provided an additional finding that should be discussed. Subjects who took the computer system first were expected to be more accurate in this naive search task than the human-based system first subjects. This relation was not found. It would seem that there was no learning effect when subjects use the computer system, in that, even though they had to verify the computer-generated grid-coordinates when they were given the human system the same amount of errors were evidenced. The computer system's program did not require that they put the procedure into practice.

5.2.3 Finding location accuracy

The body of literature defines this task as a primed search of space where the target box's location is known. In all analysis there was no significant difference between the human and the computer systems on this primed task. The researcher observed that most of the computer system first subjects did not really try to understand or use the grid-coordinate procedure provided because the box location was provided automatically. However, it was expected that when interactions by order were investigated that there would be less errors in the human system first subjects on this task. This relation was not found. The human system subjects had three instrument administrations to practice the grid-coordinate algorithm (H1, H2, C1, C2), where the computer system subjects only one (C1, C2). This should have made the human system subjects more accurate that the computer system first subjects, which was not the case. Computer system first subjects were less likely to make errors than the human system first subjects. The importance of this finding is that learning in the computer system may not be a necessary factor, which seems to counter the previous findings on the naive task.

5.3 Exit survey attitudes

5.3.1 Sentiments

Subjects scored themselves as being comfortable with submitting the information both by writing and using a networked computer. They also believed that they were accomplished at writing out information and submitting information over a computer.

They indicated strong familiarity with using the grid-coordinate procedure to determine the distance. However, participants hesitated when they were asked if they were familiar with the GPS system in measurements of distance. It seems, subjects who were more comfortable and accomplished with the human-based system of writing and submitting information felt significantly less familiar with the GPS system and using a computer in these tasks. Interestingly, the inverse of this was true of the subjects who were more comfortable and accomplished with the computer system.

5.3.2 Preferences

Subjects were evenly split between preference for the human system and the computer system. Their qualitative comments indicated that this was because the Cricket application didn't perform robustly during the experiment. For this reason, some of subjects thought that they could provide the location information faster than the computer system. Others indicated that inputting information by pencil requires a less complicated system than that of the computer application. However, when the accuracy was an issue, the majority of participants believed that the computer system could provide much more accuracy than what they could provide in writing.

Finally, when they were asked to choose the system for their future company, they saw benefits of using the computer system. Their responses indicated that it would provide them a faster, more reliable, and more accurate method of manipulating location information. They believed that using the computer system could eliminate input errors and reduce the time of redundant work, which would have a positive affect on overall productivity.

5.4 Conclusions

With the weight of all the evidence presented, the computer-based system seems to be better at both accuracy and time-on-task. There are many things that could be extended from this research. In terms of testing the technology, the indoor location support system has to be improved in order to more effectively support users. The new version of Cricket 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, this experiment of deriving and finding a location should be set up in a larger open space such as at an indoor stadium. This new experimental area would better mimic the true intent and usage of the technology as applied in the built environment. There seems to a learning affect that is yet undefined or measured. Future research should include a training session on using the computer applications prior to testing. This administration step may improve the quality of the investigation and provide more exact results that could be of better use in research on spatial problem solving. The next prototype application should run on handheld devices such as a Pocket PC or a Tablet PC to bring more mobility and more practicality to the user. Construction punch listing and facility maintenance applications are great options to be developed, however in that a majority of the research in this area deals with applying this technology to situations involving the visually impaired, this also should become an interest area of application development.

On the issues facing human cognition, the research should continue investigating wayfinding problem solving. Problems found in this current study include: 1) human system measurements of distance, projection of the X-axis and Y-axis grid lines, positive, negative nature of coordinates, and 2) computer application and the transfer of learning and practice. However, these errors could be somewhat justified in that applied technology does in fact relieve humans of cognitive responsibility. This may be further evidence that the computer-based system tested in this study achieved its purpose.

REFERENCES

Abrams, B. (2003). "What is GPS." <http://pigseye.kennesaw.edu/~bra5808/whatisgps.html> (December 2003).

Advanced Technology Group (ATG). (2003). "Northwestern Memorial Hospital: Life safety systems management at the touch of a screen." <http://www.atginc.com/(obiv2r55mmy3ieq3n0jkc255)/atginc/pdf/NMH%20LSM%20Case%20Study.pdf> (May 2003).

Anderson, J. R. (1990). *Cognitive psychology and its implications*, 3rd Ed., W. H. Freeman and Company, New York.

Autodesk Government (AG). (2004). "Autodesk extends homeland security initiative to Microsoft tablet PC with successful pilot program at major west coast airport." <http://www.autodeskgovernment.com/News/successstory1/2188572_Autodesk_Extends_Homeland_Security_Initiative_to_Microsoft_Tablet_PC.pdf> (February 2004).

Bahl, P. and Padmanabhan, V. (2000). "RADAR: An in-building RF-based user location and tracking system." *IEEE INFOCOM*, 2, 775-784.

Bryant, D. J. (2004). "A spatial representation system in humans." < http://psycprints.ecs.soton.ac.uk/archive/00000240/> (June 2004)

Car, A., Mehner, H., and Taylor, G. (1999). "Experimenting with hierarchical wayfinding." *Technical Rep. 011999, Department of Geomatics, University of Newcastle*, England.

Cornell, E. H., Sorenson, A., and Mio, T. (2003). "Human sense of direction and wayfinding." *Annals of the Association of American Geographers*, 93(2), 399-425.

Darken, R. P., and Sibert, J. L. (1996). "Navigating large virtual spaces." *The International Journal of Human-Computer Interaction*, 8(1), 49-71.

Diggelen, F. V. and Abraham, C. (2001). "Indoor GPS: The no-chip challenge." *GPS World*, 12(9), 50-54.

Freksa, C. (1992). "Using orientation information for qualitative spatial reasoning." *Theories and Methods of Spatio-Temporal Reasoning in Geographic Space*, Frank, A., Campari, I. and Formentini, U., eds., SpringerVerlag, Heidelberg, Germany, 162-178.

Freksa, C. (2004). "Spatial aspects of task-specific wayfinding maps." <http://www.arch.usyd.edu.au/kcdc/books/VR99/Freksa.html> (June 2004).

Global Locate (GL). (2004). "Global locate: IndoorGPS." <http:// www.globallocate.com/tech_over_main.shtml> (February 2004).

Hart, R. A. and Moore, G. T. (1973). "The development of spatial cognition." *Image and environment*, Down, R. M. and Stea, D., eds., Aldine, Chicago, 256-288.

Huang, P. and Sethuraman, S. (2002). "Reshaping the construction industry." <http://courses.washington.edu/cm505/FT.pdf> (February 2004).

Lawton, C. A. (2001). "Gender and regional differences in spatial referents used in direction giving sex roles." *Sex Roles: A Journal of Research*, 44(5), 321-337.

Johnson-Laird, P.N. (1983). *Mental models: Towards a cognitive science of language, inference, and consciousness*, Cambridge University Press, Cambridge, England.

Leica Geosystems (LG). (1997). "Leica installs real-time GPS network for resund bridge construction project." <http://www.leica-geosystems.com/news/1997/pr-july2-97.htm> (February 2004).

Menard, R. J. and Knieff, J. L. (2002). "GPS at ground zero: Tracking world trade center recovery." *GPS World*, 13(9), 16-26**.**

MIT Networks and Mobile Systems (MIT NMS). (2003). "The Cricket indoor location system." <http://nms.lcs.mit.edu/projects/cricket/> (February 2003).

Miu, A. K. L. (2002). "Design and implementation of an indoor mobile navigation system." M.S. thesis, Massachusetts Institute of Technology, Cambridge, MA.

Navarrete, G. (1999). "In the palm of your hand: Digital assistants aid in data collection." *Journal of Management in Engineering*, 15(4), 43-45.

Nogueras, J. R. (2001). "A stream redirection architecture for pervasive computing environments." M.S. thesis, Massachusetts Institute of Technology, Cambridge, MA.

Oloufa, A.A., Ikeda, M., and Oda, H. (2003). "Situational awareness of construction equipment using GPS, wireless and web technologies." *Automation in Construction*, 12, 737-748.

Papadias, D., and Sellis, T. (1994). "On the qualitative representation of spatial knowledge in two-dimensional space." *Very Large Data Bases Journal*, 3, 479-516.

Piaget, J. and Inhelder, B. (1967). *The child's conception of space*, Norton, New York.

Priyantha, N. B., Chakraborty, A. and Balakrishnan, H. (2000). “The cricket location-support system.” *Proc. 6th ACM International Conference on Mobile Computing and Network*, Boston, MA, 32-43.

Raubal, M., and Worboys, M. F. (1999). “A formal model of the process of wayfinding in built environments.” *Spatial Information Theory: Cognitive and Computational Foundations of Geographic Information Science,* Freksa, C., and Mark, D., eds., International Conference COSIT'99, SpringerVerlag, Heidelberg, Germany, 1661, 381-399.

Saldanha, A. (2003). “Ten reasons to choose ASP.” <http://www.15seconds.com/faq/IIS%203.0/471.htm> (December 2003).

Siegel, A. W., and White, S. H. (1975). “The development of spatial representations of large-scale environments.” *Advances in child development and behavior*, Reese, H., eds., Academic Press, New York, 10, 9-55.

Sunkpho, J. and Garrett, J. (2003). “Java inspection framework: Developing field inspection support system for civil systems inspection.” *Journal of Computing in Civil Engineering*, October, 209-218.

Surveying Engineering and Mapping Center of Expertise (SEMCE). (2004). “Monitoring steel cell placement using differential GPS at lock and dam 24, Mississippi River.”<http://crunch.tec.army.mil/information/publications/Lock_Dam24/cell.htm> (February 2004).

SYWARE. (2003). “Handhelds improve warehouse management with integrated bar code scanning.” <http://www.syware.com/reflib/hanimp.htm> (March 2004).

Thomas, G. L. (2001). “Operations and maintenance.” *Facility design and management handbook*, Teicholz, E., eds., McGraw-Hill, New York, Chapter 22, 22.1-22.42.

TRIRIGA. (2004). “State of Texas uses TRIRIGA Maintenance Management to rein in rising costs of facilities maintenance.” <http://www.tririga.com/solutions/pdfs/texas.pdf> (February 2004).

UNC Tracker Research Group (UNC TRG). (2003). “UNC HiBall Tracker.” <http://www.cs.unc.edu/~tracker/media/html/hiball.html> (July 2003).

VarIT (VIT). (2002). “Handheld solution for facility management.” <http://www.varit.com/varit/facilitymgmt.pdf> (July 2003).

Wan Aziz, W. A., Othman, Z., and Najib, H. (2004). "Monitoring high-rise building deformation using Global Positioning System." <http://www.gisdevelopment.net/technology/gps/techgp0024pf.htm> (February 2004).

Want, R., Hopper, A., Falcao, V., and Gibbons, J. (1992). "The active badge location system." *ACM Transactions on Information Systems*, 10(1), 91-102.

Ward, A., Jones, A., and Hopper A. (1997). "A new location technique for the active office." *IEEE Personal Communication*, 4(5), 42-47.

Werner, S., and Long, P. (2004). "Cognition meets Le Corbusier – cognitive principles of architectural design." <http://www.geog.ucsb.edu/~sara/teaching/int200/werner.pdf> (June 2004).

APPENDIX A

INSTRUCTION SHEET

A.1 Deriving a location with the human system instrument (H1)

Participant Instruction Sheet

ID: / /H1

Reporting a Work Order

1. Prior to starting this task please read these instructions carefully and completely. You may ask the investigator questions concerning the procedure required to accomplish this task. There are limitations on the amount of information that the investigator can provide you.

2. In this task you are being asked to report a work order on a box. Please enter into the study area, identify the target box with the "VIOLET" card on top, and move yourself and the clipboard to the side of that box.

3. You are being asked to determine the center location of this box. Two visible reference points are provided, one RED (Y Axis) and the other YELLOW (X Axis). Values above the RED reference point are positive (+) and values below the RED reference point are negative (-). Values to the right of the YELLOW reference point are positive (+) and values to the left of the YELLOW reference point are negative (-). Determine the estimated X and Y distances from each of these reference points to the center of the target box. Once you have completed your distance estimates, turn to the work order form and write these values into the spaces provided under the heading "Current Location".

4. Now turn the "BLUE" card over. The card provides you with the target box's correct location, name, description and owner. Verify that you understand how the X and Y coordinates represent the target box's location. You may not change your first location estimate.

5. Write the target box's name, description, and owner under the heading "Items In A 2 Foot Boundary" on the work order form.

6. Behind the work order form you will find a listing of possible work order task options. Choose only one work order task out of the possible options listed and copy its information onto the spaces provided on the work order form.

7. Confirm the final submission details of the work order report. If the information is correct then under the heading "Word Order Status" check the "Open Work Order" box.

8. You have now completed reporting a work order on the target box. Turn the "BLUE" card over so that the box's information is face down. Please return the clipboard to the investigator.

Work Order Form

Location Related Information

Current Location:

(X = ___________ , Y = ___________)

Items In A 2 Foot Boundary

Name:	Description:	Owner:
______________	__________________________	_______________

Work Details

Work Number: ___________

Description: ____

____

Requester: ___________________________

Phone: ___________________________

Work Supervisor: ___________________________

Worker in Charge: ___________________________

Date: ___________________________

Work Order Status:

- ☐ Work Order Open
- ☐ Work Order Closed

Work Order Options	
Work Order Task	
Work Number:	1
Description:	Place the GREEN card on top of the box.
Requester:	RUCIC
Phone:	979.458.3414
Work Supervisor:	Arch
Worker in Charge:	Participants
Date:	7/1/2004
Work Order Task	
Work Number:	2
Description:	Place the ORANGE card on top of the box.
Requester:	RUCIC
Phone:	979.845.7052
Work Supervisor:	Archie
Worker in Charge:	Participant
Date:	7/3/2004
Work Order Task	
Work Number:	3
Description:	Place the PINK card on top of the box.
Requester:	RUCIC
Phone:	979.458.3414
Work Supervisor:	Arch
Worker in Charge:	Participants
Date:	7/2/2004

A.2 Finding a location with the human system instrument (H2)

Participant Instruction Sheet

ID: / /H2

Responding to a Work Order

9. Prior to starting this task please read these instructions carefully and completely. You may ask the investigator questions concerning the procedure required to accomplish this task. There are limitations on the amount of information that the investigator can provide you.

10. In this task you are being asked to respond to a work order on a target box. Please enter into the study area and move yourself and the clipboard to the center of the experiment area indicated by the white X taped on the floor. You have been provided with an open work order form and cards that are colored GREEN, ORANGE and PINK. Turn to the work order form. On the form you will find the X and Y distances to the center of the target box under the heading "Current Location". Two visible reference points are provided, one RED (Y Axis) and the other YELLOW (X Axis). Values above the RED reference point are positive (+) and values below the RED reference point are negative (-). Values to the right of the YELLOW reference point are positive (+) and values to the left of the YELLOW reference point are negative (-). Using the X and Y location information provided determine which box is the target box. If needed, on the back of the work order form you will find a complete listing of all boxes within a 20-foot boundary.

11. Move yourself and the clipboard to the side of the box you have determined is the target box. Turn the "BLUE" card over to confirm that you have found the correct target box. If it is not the correct target box you will need to repeat step 2 and repeat this step.

12. Once you have located the correct target box, turn to the work order form and review the details of the work order. Do the work required by the work order. Finally, under the heading "Word Order Status", check the "Close Work Order".

13. You have now completed the responding to a work order on the target box. Turn the "BLUE" card over so that the box's information is face down. Please return the clipboard to the investigator.

Work Order Form

Location Related Information

Current Location:

(X = **-5**, Y = **7**)

Items In A 2 Foot Boundary

Name:	Description:	Owner:
Box7	**Box**	**Mike Wier**

Work Details

Work Number: **3**

Description: **Place the PINK card on the top of the box.**

Requester:	**RUCIC**
Phone:	**979.458.3414**
Work Supervisor:	**Arch**
Worker in Charge:	**Participant**
Date:	**06/02/2004**

Work Order Status:

- ☐ Work Order Open
- ☐ Work Order Closed

Location-related Information	
Location Related Information	
Current Location:	
(X = **0**, Y = **0**)	
Items In A 20 Foot Boundary	
(X= 1 , Y= 3)	**Box4 (0)**
(X= -1 , Y= -3)	**Box2 (0)**
(X= -7 , Y= -1)	**Box5 (0)**
(X= -3 , Y= -7)	**Box3 (0)**
(X= -5 , Y= 7)	**Box7 (0)**
(X= 7 , Y= -5)	**Box6 (0)**
(X= 5 , Y= 9)	**Box1 (0)**

A.3 Deriving a location with the computer system instrument (C1)

Participant Instruction Sheet

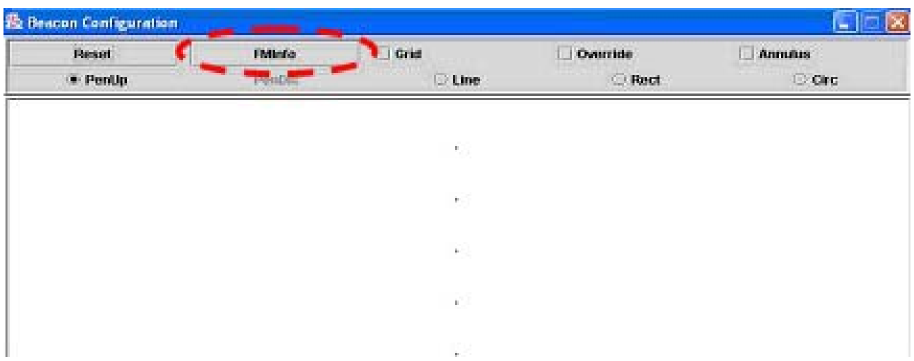
ID: / /C1

Reporting a Work Order

14. Prior to starting this task please read these instructions carefully and completely. You may ask the investigator questions concerning the procedure required to accomplish this task. There are limitations on the amount of information that the investigator can provide you.

15. In this task you are being asked to report a work order on a box. Please enter into the study area, identify the target box with the "VIOLET" card on top, and move yourself and the mobile computer to the side of that box.

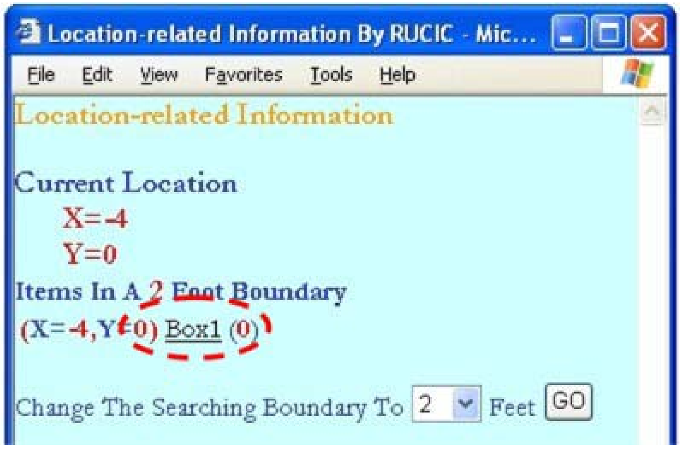
16. Once the computer is positioned and still click the "FMInfo" button displayed on the computer screen and wait until you see the application web page open.



The computer application provides you with the center location of the target box that is within 2 feet of you under the heading " Items In A 2 Foot Boundary". Two visible reference points are provided, one RED (Y Axis) and the other YELLOW (X Axis). Values above the RED reference point are positive (+) and values below the RED reference point are negative (-). Values to the right of the YELLOW reference point are positive (+) and values to the left of the YELLOW reference point are negative (-). It will also provide you with locating X and Y distances under the heading "Current Location". These distances are the location of the computer not the target box.

17. Now turn the "BLUE" card over. The card provides you with the target box's correct location, name, description and owner. Verify that you understand how the X and Y coordinates represent the target box's location.

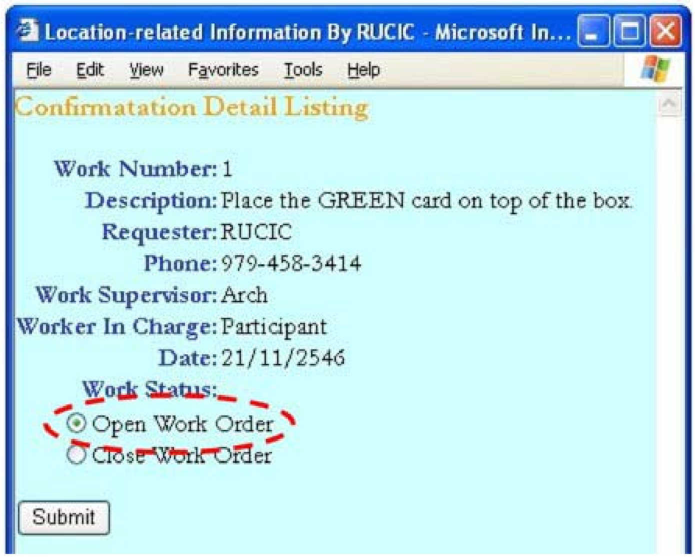
18. Click the hyper-link for the target box to confirm your acceptance of the target box's location.



19. Notice under the heading "Open Work Orders:" that you are informed that there are no work orders. Now click on the "Work Order Options" hyper-link to open a listing of work order options.

20. Choose only one work order task from the options listed by clicking on its hyper-link.

21. A display of submission details on the work order will appear. If the displayed information is correct then click on the "Open Work Order" radio button and then pick the "Submit" button.



22. A confirmation page will be displayed. Notice now under the heading "Open Work Orders:" that you are informed that there is an open work order. Click on the application's "Close" button.

23. You have now completed reporting a work order on the target box. Turn the "BLUE" card over so that the box's information is face down. Please return the mobile computer to the investigator.

A.4 Finding a location with the computer system instrument (C2)

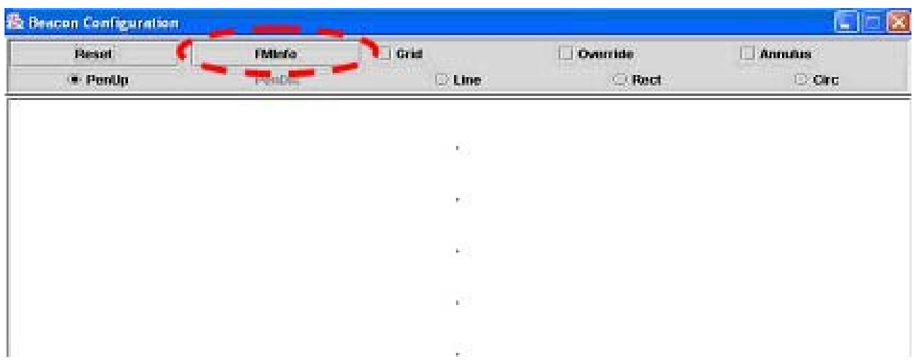
Participant Instruction Sheet

ID: / /C2

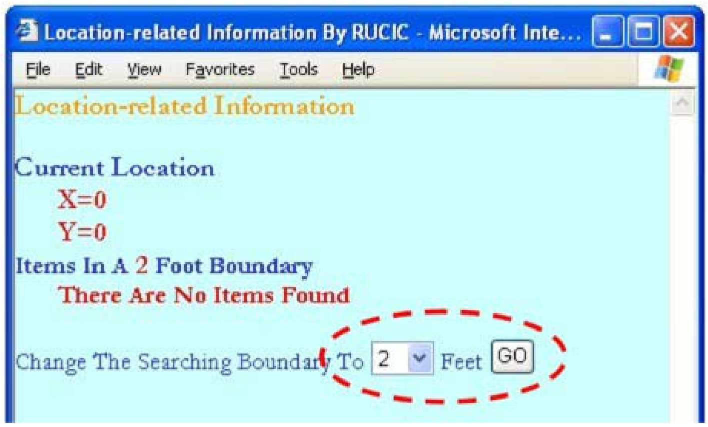
Responding to a Work Order

24. Prior to starting this task please read these instructions carefully and completely. You may ask the investigator questions concerning the procedure required to accomplish this task. There are limitations on the amount of information that the investigator can provide you.

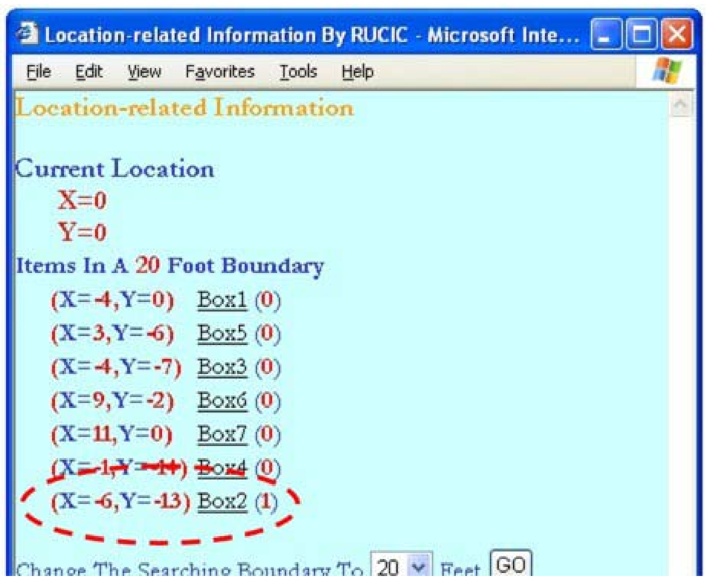
25. In this task you are being asked to respond to a work order on a target box. Please enter into the study area and move yourself and the mobile computer to the center of the experiment area indicated by the white X taped on the floor. Once the computer is positioned and still click the "FMInfo" button displayed on the computer screen and wait until you see the application web page open.



The computer application provides you with the center location of any boxes that are within 2 feet of you under the heading " Items In A 2 Foot Boundary". Two visible reference points are provided, one RED (Y Axis) and the other YELLOW (X Axis). Values above the RED reference point are positive (+) and values below the RED reference point are negative (-). Values to the right of the YELLOW reference point are positive (+) and values to the left of the YELLOW reference point are negative (-). It will also provide you with locating X and Y distances under the heading "Current Location". These distances are the location of the computer not the target box. Notice under the heading "Items In A 2 Foot Boundary" that you are informed that there are no items found.



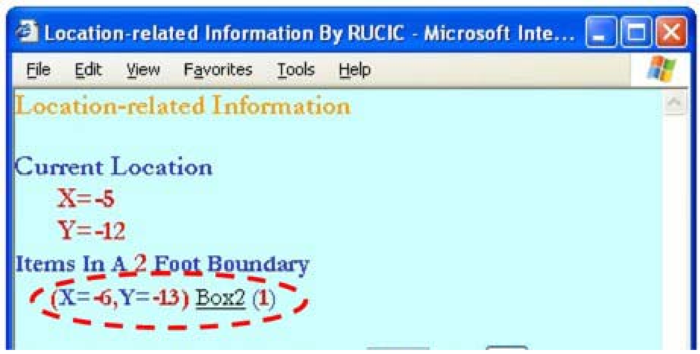
26. Now click on the drop-down menu besides the "Change the Searching Boundary" and select 20 Feet from the menu listing then click on the "GO" button.



The next page a listing of all boxes and their X and Y coordinates that are within a 20 foot boundary. Identify the box that has an open work order. It is represented by a value greater than (0) after the box name. Using the X and Y location information provided determine which box is the target box.

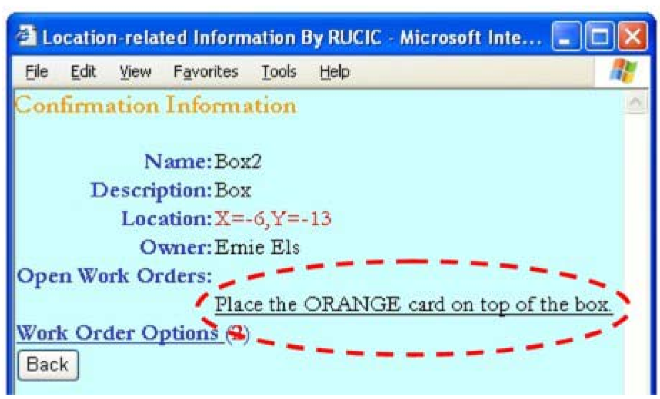
27. Move yourself and the mobile computer to the side of the box you have determined is the target box. Once the computer is positioned and still, click on the application's "Close" button.

28. Once again, click the "FMInfo" button displayed on the computer screen and wait until you see the application web page open.

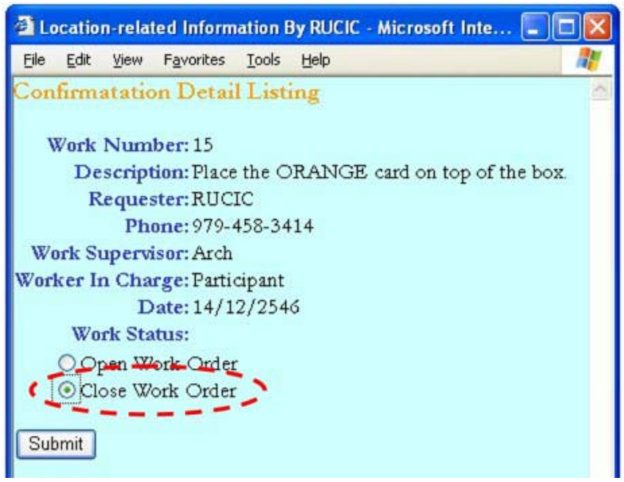


The next page displays the box that is within 2 feet of the computer under the heading "Items In A 2 Foot Boundary". Turn the "BLUE" card over to confirm that you have found the correct target box. If it is not the correct box you will need to repeat step 3 through 5. Once you have located the correct target box, click on the target box's hyper-link.

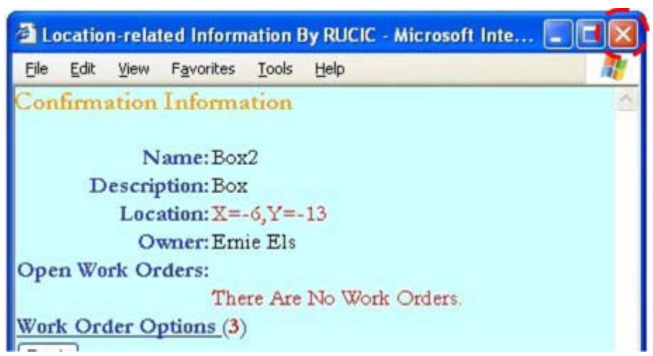
29. Under the heading "Open Work Orders:" there is a hyper-linked work order. Click on that work order's hyper-link.



30. Review the details of the work order page. You have been provided with cards that are colored GREEN, ORANGE and BLACK. Do the work required by the work order, then under the heading "Work Status", click on the "Close Work Order" radio button, and then pick the "Submit" button.



31. A confirmation page is displayed. Under the heading "Open Work Orders:" you will see that there are no work orders. Click on the application's "Close" button.



32. You have now completed the responding to a work order on the target box. Turn the "BLUE" card over so that the box's information is face down. Please return the mobile computer to the investigator.

APPENDIX B

INTERNAL REVIEW BOARDS APPROVAL DOCUMENT

Office of the Vice President for Research

Office of Research Compliance

Administration and
Special Programs

Academy for
Advanced
Telecommunication
and Learning
Technologies

Institute for
Scientific Computation

Laboratory Animal
Resources and Research

Microscopy and
Imaging Center

Office of
Business Administration

Office of Graduate Studies

Office of Sponsored Projects

Texas A&M University
Research Park

Texas A&M
University

1112 TAMU
318 Administration Building
College Station, Texas
77843-1112

979.845.8585
FAX 979.862.3176

Date February 18, 2004

MEMORANDUM

TO: Kampanart Tejavanija
Construction Science
MS 3137

FROM: Dr. E. Murl Bailey, CIP, Advisor
Institutional Review Board
MS 1112

SUBJECT: IRB Protocol Review

Title: "Location-Based Information System for Indoor Facilities Management"

Protocol Number: 2004-0045
Review Category: Exempt from Full Review
Approval Date: February 18, 2004 **to** February 17, 2005

The approval determination was based on the following Code of Federal Regulations
http://ohrp.osophs.dhhs.gov/humansubjects/guidance/45cfr46.htm

________	**46.101(b)(1)**	________	**46.101(b)(4)**
✓	**46.101(b)(2)**	________	**46.101(b)(5)**
________	**46.101(b)(3)**	________	**46.101(b)(6)**

Remarks:

The Institutional Review Board – Human Subjects in Research, Texas A&M University has reviewed and approved the above referenced protocol. Your study has been approved for one year. As the principal investigator of this study, you assume the following responsibilities:

Renewal: Your protocol must be re-approved each year in order to continue the research. You must also complete the proper renewal forms in order to continue the study after the initial approval period.

Adverse events: Any adverse events or reactions must be reported to the IRB immediately.

Amendments: Any changes to the protocol, such as procedures, consent/assent forms, addition of subjects, or study design must be reported to and approved by the IRB.

Informed Consent/Assent: All subjects should be given a copy of the consent document approved by the IRB for use in your study.

Completion: When the study is complete, you must notify the IRB office and complete the required forms.

Page 1 of 2

CONSENT FORM
Location-based Information System for Indoor Facilities Management

I have been asked to participate in this research study to test an indoor location support system for facilities management. I was selected to be a possible participant because I am a student or a faculty of the College of Architecture, Texas A&M University. A total of 10 people have been asked to participate in this study. The purpose of this study is to investigate the usefulness of the integration between an indoor location support system and an information database system for indoor facilities management.

If I agree to be in this study, I will be asked to participates with two experiments, one with a traditional paper-based process and the other with a new integrated tool for facilities management. I will be interviewed for my attitude toward these two processes. I have rights to accept or refuse to be audio taped during the interview section and rights to withdraw from these experiments at any time. This study will only take 30 minutes. There will be no risk associated with this study. I understand that there will be no compensation or other benefits for my participation in this study.

This study is anonymous. The records of this study will be kept private. No identifiers linking me to the study will be included in any sort of report that might be published. The audio recording tape will be used only to conduct the result of this study and will be stored securely and only Kampanart Tejavanija will have access to the records. The audio recorded tape will be erased after 30 days of my participation of this study.

My decision whether of not to participate will not affect my current or future relations with Texas A&M University. If I decide to participate, I am free to refuse to answer any of the questions that may make me uncomfortable. I can withdraw at any time without my relations with the university, job, benefits, etc., being affected. I can contact persons below with any questions about this study:

Kampanart Tejavanija
RUCIC lab room124a
Building A, Langford Architecture
Texas A&M University
College Station, TX 77843-3137
Tel: (979) 458-3414 or (979) 260-4970
Email: kt_arch@tamu.edu

Dr. Julian H. Kang
Department of Construction Science
College of Architecture
Texas A&M University
College Station, TX 77843-3137
Tel: (979) 845-7055
Email: juliankang@tamu.edu

This research study has been reviewed by the Institutional Review Board- Human Subjects in Research, Texas A&M University. For research-related problems or questions regarding subjects' rights, I can contact the institutional Review Board through Dr. Michael W. Buckley, Director of Research Compliance, Office of Vice President for Research at (979) 845-8585 (mwbuckley@tamu.edu).

I have read the above information. I have asked questions and have received answers to my satisfaction. I have been given a copy of this consent document for my records. By signing this document, I consent to participate in the study.

Signature: ______________________ Date: ____________
( )

Signature of Investigator: ______________________ Date: FEB 03, 04
(Kampanart Tejavanija)

Approved by Texas A&M University IRB
FEB 18 2004
Expires 2-17-2005
Protocol #2004-0045

PAGE 13 of 14

APPENDIX C

DATA COLLECTION

C.1 Time-on-task recorded on deriving a box location with the human system instrument (H1LT)

H1 Administrator Timed						
STID	**Order**	**Stands at Box**	**Turns to Work Order**	**Turns over Blue Card**	**Writes on Work Order**	**Turns over Blue Card**
152	**1**	0:00:00	0:01:40	0:01:50	0:02:22	0:03:57
154	**1**	0:00:00	0:01:32	0:01:46	0:02:08	0:05:14
104	**1**	0:00:00	0:00:10	0:00:20	0:00:25	0:03:30
342	**1**	0:00:00	0:00:17	0:00:22	0:00:30	0:03:07
294	**1**	0:00:00	0:00:58	0:01:07	0:01:14	0:04:05
912	**1**	0:00:00	0:01:00	0:01:10	0:01:34	0:05:09
714	**1**	0:00:00	0:00:47	0:00:52	0:01:08	0:03:16
146	**1**	0:00:00	0:00:26	0:00:38	0:00:55	0:02:37
744	**1**	0:00:00	0:02:13	0:02:17	0:02:45	0:05:57
270	**1**	0:00:00	0:00:57	0:01:06	0:01:51	0:03:34
500	**1**	0:00:00	0:00:40	0:00:58	0:02:32	0:03:52
123	**1**	0:00:00	0:00:28	0:00:45	0:01:18	0:03:04
166	**1**	0:00:00	0:00:44	0:00:54	0:02:34	0:04:00
812	**1**	0:00:00	0:01:27	0:01:36	0:02:17	0:07:03
78	**1**	0:00:00	0:00:45	0:00:50	0:01:39	0:03:03
575	**2**	0:00:00	0:00:19	0:00:22	0:00:32	0:02:16
471	**2**	0:00:00	0:00:10	0:00:15	0:00:31	0:01:45
655	**2**	0:00:00	0:00:17	0:00:25	0:00:30	0:02:09
231	**2**	0:00:00	0:00:06	0:00:09	0:00:20	0:01:43
299	**2**	0:00:00	0:00:14	0:00:30	0:01:05	0:02:08
237	**2**	0:00:00	0:00:26	0:00:32	0:00:59	0:02:41
965	**2**	0:00:00	0:00:20	0:00:25	0:01:06	0:02:27
257	**2**	0:00:00	0:00:05	0:00:10	0:00:40	0:01:52
475	**2**	0:00:00	0:00:23	0:00:27	0:00:41	0:02:13
781	**2**	0:00:00	0:00:27	0:00:32	0:00:58	0:02:17
289	**2**	0:00:00	0:00:14	0:00:17	0:00:49	0:02:11
991	**2**	0:00:00	0:00:17	0:00:22	0:00:40	0:01:51
53	**2**	0:00:00	0:00:30	0:00:32	0:00:47	0:01:53
431	**2**	0:00:00	0:00:17	0:00:21	0:00:39	0:01:50
177	**2**	0:00:00	0:01:00	0:01:15	0:01:29	0:02:22

C.2 Time-on-task recorded on finding a box location with the human system instrument (H2LT)

H2 Administrator Timed						
STID	**Order**	**Stands at Center**	**Moves toward Box**	**Turns over Blue Card**	**Turns to Work Order**	**Turns over Blue Card**
152	**1**	0:00:00	0:00:30	0:00:38	0:00:43	0:01:22
154	**1**	0:00:00	0:00:17	0:00:23	0:00:28	0:01:00
104	**1**	0:00:00	0:00:08	0:00:13	0:00:19	0:00:40
342	**1**	0:00:00	0:00:24	0:00:30	0:00:35	0:00:39
294	**1**	0:00:00	0:00:34	0:00:38	0:00:42	0:01:08
912	**1**	0:00:00	0:00:20	0:00:44	0:00:52	0:01:18
714	**1**	0:00:00	0:04:43	0:04:47	0:04:52	0:05:16
146	**1**	0:00:00	0:00:34	0:00:42	0:00:48	0:01:18
744	**1**	0:00:00	0:00:18	0:00:24	0:00:54	0:02:05
270	**1**	0:00:00	0:00:40	0:00:43	0:00:50	0:01:09
500	**1**	0:00:00	0:00:37	0:00:42	0:00:55	0:01:23
123	**1**	0:00:00	0:00:13	0:00:19	0:00:24	0:00:43
166	**1**	0:00:00	0:00:20	0:00:26	0:00:30	0:00:43
812	**1**	0:00:00	0:00:30	0:00:40	0:00:45	0:01:20
78	**1**	0:00:00	0:00:19	0:00:24	0:00:28	0:00:40
575	**2**	0:00:00	0:00:09	0:00:15	0:00:27	0:00:49
471	**2**	0:00:00	0:00:06	0:00:10	0:00:15	0:00:20
655	**2**	0:00:00	0:00:07	0:00:12	0:00:20	0:00:36
231	**2**	0:00:00	0:00:06	0:00:08	0:00:12	0:00:23
299	**2**	0:00:00	0:00:10	0:00:13	0:00:20	0:00:57
237	**2**	0:00:00	0:00:10	0:00:19	0:00:23	0:00:50
965	**2**	0:00:00	0:00:16	0:00:19	0:00:25	0:00:43
257	**2**	0:00:00	0:00:06	0:00:12	0:00:15	0:00:31
475	**2**	0:00:00	0:00:07	0:00:12	0:00:21	0:00:40
781	**2**	0:00:00	0:00:07	0:00:10	0:00:18	0:00:30
289	**2**	0:00:00	0:00:11	0:00:19	0:00:25	0:00:31
991	**2**	0:00:00	0:00:08	0:00:14	0:00:21	0:00:24
53	**2**	0:00:00	0:00:14	0:00:18	0:00:25	0:00:40
431	**2**	0:00:00	0:00:08	0:00:14	0:00:22	0:00:45
177	**2**	0:00:00	0:00:12	0:00:18	0:00:22	0:00:26

C.3 Time-on-task recorded on deriving a box location with the computer system instrument (C1LT)

C1 Administrator Timed					
STID	**Order**	**Stands at Box**	**Turns over Blue Card**	**Clicks Hyper-link**	**Turns over Blue Card**
152	**1**	0.00	0.50	0.68	1.40
154	**1**	0.00	1.70	1.80	2.13
104	**1**	0.00	2.90	2.97	3.53
342	**1**	0.00	1.33	1.60	2.22
294	**1**	0.00	0.57	0.60	0.83
912	**1**	0.00	1.60	1.83	2.20
714	**1**	0.00	1.57	1.92	2.25
146	**1**	0.00	2.58	3.07	3.42
744	**1**	0.00	2.20	3.05	4.17
270	**1**	0.00	0.67	0.92	1.90
500	**1**	0.00	1.43	1.50	1.72
123	**1**	0.00	1.72	1.78	2.32
166	**1**	0.00	1.57	2.13	2.60
812	**1**	0.00	3.02	3.12	3.43
78	**1**	0.00	0.87	1.00	1.30
575	**2**	0.00	0.45	0.60	0.83
471	**2**	0.00	0.63	0.72	0.97
655	**2**	0.00	0.42	0.50	0.80
231	**2**	0.00	1.53	1.67	1.92
299	**2**	0.00	0.55	0.58	0.98
237	**2**	0.00	0.27	0.33	1.05
965	**2**	0.00	0.83	1.38	1.72
257	**2**	0.00	0.92	1.03	1.28
475	**2**	0.00	0.32	0.35	0.85
781	**2**	0.00	0.50	0.58	0.85
289	**2**	0.00	0.38	0.40	0.77
991	**2**	0.00	0.83	1.22	1.50
53	**2**	0.00	2.68	2.75	2.98
431	**2**	0.00	1.03	1.20	1.65
177	**2**	0.00	0.50	0.55	0.67

C.4 C.4 Time recorded on finding a box location with the computer system instrument (C2LT)

C2 Administrator Timed						
STID	**Order**	**Stands at Center**	**Moves toward Box**	**Stands at Box**	**Clicks Hyper-link**	**Turns over Blue Card**
152	**1**	0.00	1.88	2.37	2.50	2.67
154	**1**	0.00	1.67	1.92	2.00	2.33
104	**1**	0.00	0.65	0.77	0.87	1.00
342	**1**	0.00	1.72	1.82	2.03	2.17
294	**1**	0.00	1.08	1.22	1.28	1.68
912	**1**	0.00	2.48	2.65	2.72	3.12
714	**1**	0.00	1.67	1.83	2.08	2.75
146	**1**	0.00	1.65	1.73	2.00	2.37
744	**1**	0.00	1.45	1.53	2.17	3.88
270	**1**	0.00	1.07	1.13	1.60	2.30
500	**1**	0.00	0.68	0.78	0.92	1.20
123	**1**	0.00	1.05	1.30	1.37	1.82
166	**1**	0.00	3.17	3.33	3.60	4.30
812	**1**	0.00	2.77	2.88	3.00	3.65
78	**1**	0.00	1.35	1.50	1.88	2.12
575	**2**	0.00	0.83	0.92	1.05	1.37
471	**2**	0.00	0.43	0.47	0.58	0.67
655	**2**	0.00	1.92	2.17	2.33	2.83
231	**2**	0.00	2.92	3.12	3.58	3.93
299	**2**	0.00	1.22	1.28	1.40	1.85
237	**2**	0.00	2.28	2.90	3.02	3.60
965	**2**	0.00	1.83	2.00	2.13	2.32
257	**2**	0.00	1.47	1.77	1.83	2.08
475	**2**	0.00	0.33	0.83	0.93	1.10
781	**2**	0.00	0.53	0.62	0.88	1.23
289	**2**	0.00	0.58	0.63	0.82	1.07
991	**2**	0.00	0.97	1.30	1.60	1.73
53	**2**	0.00	1.53	1.63	1.83	1.97
431	**2**	0.00	1.50	2.43	2.83	3.33
177	**2**	0.00	0.35	0.48	0.58	0.67

C.5 Time-on-task recorded on deriving a box location with the computer system instrument by the ASP application

C1 Programed Time-on-task				
STID	**Order**	**Application Pop-up**	**Click Hyper-link**	**Hit Submit Button**
152	**1**	0.00	0.38	1.12
154	**1**	0.00	0.45	0.80
104	**1**	0.00	0.25	0.75
342	**1**	0.00	0.20	0.77
294	**1**	0.00	0.17	0.57
912	**1**	0.00	0.73	1.15
714	**1**	0.00	0.60	0.90
146	**1**	0.00	0.77	1.12
744	**1**	0.00	1.40	2.52
270	**1**	0.00	0.25	1.22
500	**1**	0.00	0.13	0.30
123	**1**	0.00	0.17	0.70
166	**1**	0.00	0.78	1.23
812	**1**	0.00	0.28	0.60
78	**1**	0.00	0.17	0.50
575	**2**	0.00	0.40	0.68
471	**2**	0.00	0.15	0.40
655	**2**	0.00	0.12	0.38
231	**2**	0.00	0.18	0.55
299	**2**	0.00	0.17	0.50
237	**2**	0.00	0.20	0.88
965	**2**	0.00	0.50	0.82
257	**2**	0.00	0.22	0.43
475	**2**	0.00	0.08	0.62
781	**2**	0.00	0.20	0.45
289	**2**	0.00	0.10	0.42
991	**2**	0.00	0.35	0.87
53	**2**	0.00	0.12	0.48
431	**2**	0.00	0.12	0.55
177	**2**	0.00	0.07	0.23

C.6 Time-on-task recorded on finding a box location with the computer system instrument by the ASP application

C2 Program Timed				
STID	**Order**	**Application Pop-up**	**Click Hyper-link**	**Hit Submit Button**
152	**1**	0.00	0.62	1.53
154	**1**	0.00	0.62	1.05
104	**1**	0.00	0.28	0.77
342	**1**	0.00	0.15	0.90
294	**1**	0.00	1.20	1.60
912	**1**	0.00	0.73	1.03
714	**1**	0.00	0.80	1.03
146	**1**	0.00	0.37	0.58
744	**1**	0.00	1.65	3.33
270	**1**	0.00	1.02	1.70
500	**1**	0.00	0.52	0.85
123	**1**	0.00	0.80	1.23
166	**1**	0.00	1.48	2.17
812	**1**	0.00	0.37	1.32
78	**1**	0.00	1.35	1.55
575	**2**	0.00	0.28	1.02
471	**2**	0.00	0.17	0.47
655	**2**	0.00	0.20	2.05
231	**2**	0.00	0.72	1.72
299	**2**	0.00	0.45	1.03
237	**2**	0.00	0.30	1.43
965	**2**	0.00	1.28	1.90
257	**2**	0.00	0.22	1.02
475	**2**	0.00	0.85	1.07
781	**2**	0.00	0.20	1.07
289	**2**	0.00	0.60	0.83
991	**2**	0.00	0.50	1.12
53	**2**	0.00	0.37	1.00
431	**2**	0.00	1.48	3.18
177	**2**	0.00	0.17	0.48

C.7 Task accuracy recorded on deriving a box location with the human system and the computer system instruments (H1LA and C1LA)

H1 Box Location Acc.		C1 Box Location Acc.	
Order	**Errors**	**Order**	**Errors**
1	0	**1**	0
1	1	**1**	0
1	1	**1**	0
1	1	**1**	0
1	0	**1**	0
1	1	**1**	0
1	0	**1**	0
1	0	**1**	0
1	1	**1**	0
1	0	**1**	0
1	0	**1**	0
1	1	**1**	0
1	0	**1**	0
1	1	**1**	0
1	1	**1**	0
2	0	**2**	0
2	0	**2**	0
2	1	**2**	0
2	1	**2**	0
2	1	**2**	0
2	0	**2**	0
2	1	**2**	0
2	1	**2**	0
2	0	**2**	0
2	1	**2**	0
2	1	**2**	0
2	1	**2**	0
2	1	**2**	0
2	0	**2**	0
2	0	**2**	0

C.8 Task accuracy recorded on finding a box location with the human system and the computer system instruments (H2LA and C2LA)

H2 Work Order Acc.		C2 Box Location	
Order	Errors	Order	Errors
1	0	1	0
1	0	1	0
1	0	1	0
1	1	1	0
1	0	1	0
1	0	1	0
1	0	1	1
1	0	1	0
1	0	1	0
1	0	1	0
1	0	1	0
1	0	1	0
1	0	1	0
1	0	1	0
1	0	1	0
2	0	2	0
2	0	2	0
2	0	2	0
2	0	2	1
2	0	2	0
2	0	2	0
2	1	2	0
2	0	2	0
2	0	2	1
2	0	2	0
2	0	2	0
2	0	2	1
2	0	2	0
2	0	2	1
2	0	2	0

C.9 Participants location estimations

H1 Box Location Acc.					Participant Response		Method	Bug
STID	**Order**	**Box Name**	**Box Coords**					
152	**1**	**7**	-5.0	7.0	-8.0	4.0	S	D
154	**1**	**7**	-5.0	7.0	-5.5	6.5	S	
104	**1**	**5**	-7.0	-1.0	-7.0	-1.0	S	
342	**1**	**1**	5.0	9.0	6.0	9.0	V	
294	**1**	**5**	-7.0	-1.0	-0.8	-7.5	V	X , +
912	**1**	**3**	-3.0	-7.0	-3.0	-7.0	S	
714	**1**	**7**	-5.0	7.0	4.0	-4.0	V	D, +
146	**1**	**5**	-7.0	-1.0	-5.0	-0.5	V	D
744	**1**	**4**	1.0	3.0	1.5	4.0	S	
270	**1**	**2**	-1.0	-3.0	8.0	6.0	S	X , D , +
500	**1**	**1**	5.0	9.0	8.0	5.0	V	X
123	**1**	**1**	5.0	9.0	5.0	8.0	S	
166	**1**	**4**	1.0	3.0	1.0	5.0	V	D
812	**1**	**1**	5.0	9.0	5.0	9.0	S	
78	**1**	**2**	-1.0	-3.0	-0.3	-2.5	V	
575	**2**	**7**	-5.0	7.0	-3.0	7.0	V	D
471	**2**	**6**	7.0	-5.0	6.0	-3.0	V	D
655	**2**	**6**	7.0	-5.0	7.0	-4.0	S	
231	**2**	**4**	1.0	3.0	1.0	3.0	S	
299	**2**	**2**	-1.0	-3.0	-1.0	-2.0	V	
237	**2**	**5**	-7.0	-1.0	-5.0	-0.5	V	D
965	**2**	**3**	-3.0	-7.0	-3.0	-6.0	V	
257	**2**	**4**	1.0	3.0	1.0	2.0	V	
475	**2**	**3**	-3.0	-7.0	-4.0	-6.0	V	D
781	**2**	**1**	5.0	9.0	5.0	8.0	V	
289	**2**	**2**	-1.0	-3.0	-1.0	-3.0	V	
991	**2**	**4**	1.0	3.0	1.0	3.0	V	
53	**2**	**6**	7.0	-5.0	7.0	-5.0	V	
431	**2**	**6**	7.0	-5.0	10.0	8.0	V	D , +
177	**2**	**3**	-3.0	-7.0	-4.0	-9.0	S	D
V=Visual, S=Step Off; X = X and Y axis problem, + = + and - problem, D = Distance problem								

C.10 Survey questionnaire part 1

Survey Part 1		1 = Agree	2 = Disagree	R = Reverse Order				
STID	**Order**	**1R**	**2**	**3**	**4R**	**5**	**6R**	**7**
152	**1**	5	1	1	4	1	5	3
154	**1**	3	2	2	2	3	5	4
104	**1**	5	2	2	4	2	5	4
342	**1**	5	2	1	5	2	5	2
294	**1**	5	5	3	3	3	5	1
912	**1**	5	1	1	4	1	5	2
714	**1**	1	1	1	5	2	4	2
146	**1**	5	5	2	4	3	1	5
744	**1**	1	3	4	4	4	3	5
270	**1**	5	3	1	4	2	5	4
500	**1**	5	1	3	4	3	5	2
123	**1**	5	2	1	4	4	5	4
166	**1**	4	1	2	5	1	5	1
812	**1**	5	3	1	5	5	5	2
78	**1**	2	1	2	5	4	3	3
575	**2**	5	2	1	5	2	5	1
471	**2**	5	1	2	2	1	5	2
655	**2**	5	2	2	4	3	5	3
231	**2**	2	2	1	3	3	5	3
299	**2**	5	1	2	5	1	5	2
237	**2**	5	1	1	5	1	5	3
965	**2**	3	3	1	4	2	4	3
257	**2**	5	1	2	5	1	5	1
475	**2**	3	2	2	3	3	5	5
781	**2**	1	1	2	5	3	5	2
289	**2**	4	3	3	2	1	1	1
991	**2**	5	3	2	3	4	5	3
53	**2**	4	1	1	5	5	5	4
431	**2**	4	4	4	4	3	5	3
177	**2**	3	2	2	5	3	4	2

C.11 Survey questionnaire part 2

Survey Part 2					1 = Written 2 = Computer	
STID	**Order**	**8**	**9**	**10**	**11**	**12**
152	**1**	2	2	2	2	2
154	**1**	2	2	2	2	2
104	**1**	2	2	1	1&2	1&2
342	**1**	1	2	2	2	2
294	**1**	1	2	2	2	1
912	**1**	2	2	2	2	2
714	**1**	2	2	2	2	2
146	**1**	2	2	2	2	2
144	**1**	1	2	2	2	2
270	**1**	1	2	2	2	2
500	**1**	2	2	2	1	2
123	**1**	1	2	2	2	2
166	**1**	1	2	2	2	1
812	**1**	1	2	2	2	2
78	**1**	2	2	2	2	2
575	**2**	2	2	2	2	2
471	**2**	2	2	2	2	2
655	**2**	1	2	2	2	2
231	**2**	1	2	2	2	2
299	**2**	1	2	2	2	2
237	**2**	1	2	2	2	2
965	**2**	1	1	2	2	1&2
257	**2**	2	2	2	2	2
475	**2**	2	2	2	2	2
781	**2**	2	2	2	2	2
289	**2**	2	2	2	1	2
991	**2**	1	1	2	2	1
53	**2**	2	2	2	2	2
431	**2**	1	2	2	2	2
177	**2**	2	2	2	2	2

C.12 Survey open-end questionnaire

8. Which system of locating a box did you like best and why?

Group 1

152	Computer	Using the computer eliminates guessing.
154	Computer	The written seems confusing.
104	Computer	When I could get a signal, aside from the program and setting up the beacons, it takes out human error.
342	Written	Easier to follow and takes less time.
294	Written	Written because I am much better at estimating distances and quicker than the computer.
912	Computer	It is more accurate than someone else's guess.
714	Computer	I thought the positioning system was interesting.
146	Computer	Computer system seemed more accurate than my guess.
744	Written	Computer method made the simple task more difficult.
270	Written	Less confusion.
500	Computer	I enjoying using computers.
123	Written	Written because it was less complicated, and I didn't have to rely on the computer.
166	Written	Faulty computer equipment.
812	Written	I could find the box faster than the computer.
78	Computer	More accurate.

Group 2

575	Computer	It automatically finds the correct location. I only had to make sure it was right.
471	Computer	It was quicker to fill in the change order.
655	Written	I like being able to visualize a grid to make a good estimate.
231	Written	It was easier for me to read and write than having to mess with the computer.
299	Written	It is very easy to see the location of the box by myself.
237	Written	It is faster for me.
965	Written	Faster, easier. No complications with mobile network.
257	Computer	Easy to do and understand.
475	Computer	Much easier.
781	Computer	Less manual work.
289	Computer	Computer systems seem more dependable and accurate compared to a person writing it down.
991	Written	It was faster, no need to wait for a signal.
53	Computer	Easier, and I think it is faster.
431	Written	It was much faster and easier to estimate it myself.
177	Computer	Faster and easier.

C.12 Survey open-end questionnaire (continued)

9. Which system of locating a box do you believe is most accurate and why?

Group 1

152	Computer	Accuracy.
154	Computer	Not much room left for human error.
104	Computer	So long as the beacons have been set up right.
342	Computer	Figures out location and with multiple transmitters.
294	Computer	The computer could be if it picked up the items better.
912	Computer	People can't always judge distance well.
714	Computer	I think the positioning system work well.
146	Computer	Computer seemed more accurate than my guess.
744	Computer	It has a more precise measuring system.
270	Computer	The computer lacks human error.
500	Computer	Because it uses a GPS type of system to locate the box.
123	Computer	The computer already knows the answer.
166	Computer	Human error is limited to the engineer that devised the program.
812	Computer	If it was a long distance, the computer would probably be more accurate, but in this experiment, we both were accurate.
78	Computer	Everyone has one's own measurement.

Group 2

575	Computer	No human errors. I could find the location on my own, but the computer found the exact location.
471	Computer	GPS systems are very accurate and proven.
655	Computer	I feel the computer gave a more precise reading.
231	Computer	A computer is only wrong when there is human error.
299	Computer	Over time less mistakes will occur using a program designed for location objects.
237	Computer	Provides location to the nearest decimal point.
965	Written	With precise instructions, written instructions are best.
257	Computer	Human error.
475	Computer	Has physical locator.
781	Computer	No space for manual errors in measurement of location.
289	Computer	I think the computer is the most accurate.
991	Written	I located the wrong one with the computer, and I was correct on the written. I think also because I had a better visual idea of the system by the time the written test was performed.
53	Both	Both way was good to find boxes.
431	Computer	It has the exact coordinates.
177	Computer	No way did mistakes once I checked from computer.

C.12 Survey open-end questionnaire (continued)

12. Which system would you use in your won company and why?

<u>Group 1</u>

152	Computer	The use of computers in today's world is a must.
154	Computer	Faster and more reliable.
104	Both	Both computer to locate and written to work reports.
342	Computer	Less mistakes and less time.
294	Written	Personally, I would rather not use the computer because if they fail you have no trail and I just don't like computers doing all the work.
912	Computer	It is faster and more accurate.
714	Computer	Easy to operate and easy to read.
146	Computer	Less chance for mistakes
744	Computer	Must advance with technology
270	Computer	I feel it provided more clear and accurate information.
500	Computer	The computer system seems to me to be more efficient.
123	Computer	I would not have to worry about one of my employers making errors by copying down wrong information.
166	Written	Computer equipment requires more skill and cost to operate and maintain.
812	Computer	I would probably use both, but using the computer for work orders is faster.
78	Computer	More accurate and comfortable for me. It needs to be faster than now.

<u>Group 2</u>

575	Computer	Faster, easier, and more accurate.
471	Computer	Faster and more reliable.
655	Computer	Computers are more precise and tend to make for less mistakes than people.
231	Computer	Time and money.
299	Computer	Computers can process much more data, quicker, and all data can be printed out anytime you needed it.
237	Computer	Less chance of human error.
965	Both	A mixture of both without knowing the details.
257	Computer	More efficient and effective.
475	Computer	Easier.
781	Computer	Better time management and effective utilization of resources like manpower.
289	Computer	I think when we start developing new products, they become more user friendly, and this solves the problem of the amount of people that can operate these systems which in turn makes productivity go up.

C.12 Survey open-end questionnaire (continued)

Group 2

991	Written	I prefer writing things down and handing them in person. I still don't trust computers.
53	Computer	Over all, this kind of tasks should be done with a help of computer.
431	Computer	More accurate and predictable.
177	Computer	Save time and accuracy.

VITA

Name:	Kampanart Tejavanija	
Nationality:	Thailand	
Permanent Address:	107 Onn-nuch 32 Suanluang Suanluang Bangkok, Thailand 10250	
Education:	M.S. Construction Management College of Architecture, Texas A&M University. B.Arch, College of Architecture, King Mongkok Institute of Technology Ladkrabang, Thailand	
Honors:	Vice President:	Thai Student Association, Texas A&M University, 2003-2004
	Scholarship Awards:	Greater Houston Builders Association, 2003-2004 Hoar Construction Co. LLC, 2003-2004 Greater Houston Builders Association, 2002-2003
	Outstanding Part Time Student Award:	English Language Institute, Texas A&M University, Fall 2001

Professional experience:

	Project manager:	Progressive Building Management Co., Ltd, Thailand (http://www.pbm.co.th).