Riehle, T.H., Lichter, P., & Giudice, N.A. (2008). An Indoor Navigation System to Support the Visually Impaired. *Proceedings of the 30th annual IEEE Engineering in Medicine and Biology conference.* V. 2008, PP. 4435-4438. August 20-24, Vancouver, Canada.

An Indoor Navigation System to Support the Visually Impaired

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***Abstract*— Indoor navigation technology is needed to support seamless mobility for the visually impaired. A small portable personal navigation device that provides current position, useful contextual wayfinding information about the indoor environment and directions to a destination would greatly improve access and independence for people with low vision. This paper describes the construction of such a device which utilizes a commercial Ultra-Wideband (UWB) asset tracking system to support real-time location and navigation information. Human trials were conducted to assess the efficacy of the system by comparing target-finding performance between blindfolded subjects using the navigation system for real-time guidance, and blindfolded subjects who only received speech information about their local surrounds but no route guidance information (similar to that available from a long cane or guide dog). A normal vision control condition was also run. The time and distance traveled was measured in each trial and a point-back test was performed after goal completion to assess cognitive map development. Statistically significant differences were observed between the three conditions in time and distance traveled; with the navigation system and the visual condition yielding the best results, and the navigation system dramatically outperforming the non-guided condition.**

I. INTRODUCTION

INDOOR navigation technology is needed to support seamless mobility for the visually impaired. Most people who are blind or have low vision can navigate effectively outdoors using a long cane, guide dog or their own vision as an aid, but indoor navigation in large or unfamiliar buildings without vision is often significantly more difficult as there is generally no access to orienting information such as signage, room numbers, building maps, and/or salient landmarks. A small, portable personal navigation device that provides current position, useful contextual wayfinding information about the indoor environment, and directions to a destination would greatly improve access and independence for people with low vision. Such a system would allow visually impaired persons the freedom of movement within public and commercial buildings.

All navigation systems have three functional components: an input device to determine position and orientation in space, a spatial database of the environment traversed, and an interface which provides information to the user. Navigation software utilizes data from input devices to determine the user's position and orientation and generates the geographic information system (GIS) for accessing and manipulating information in the spatial database through a user interface. These components have worked well for outdoor navigation systems. This research is aimed at creating equivalent components that work in an indoor environment

For outdoor navigation, visually impaired persons can use a global positioning system (GPS) based navigation device to solve navigation problems, but in a large office building, the standard GPS receiver is unreliable due to attenuation and fading of the RF signal. Recently, indoor location tracking systems have become commercially available based on a new wireless technology called Ultra-Wideband (UWB). This technology has several advantages over competing wireless technologies, such as its resistance to narrowband interference and its robustness in complex indoor multipath environments [1]. The primary application of this technology has been the tracking of assets within a facility. In this study UWB technology has been used to track a person's location and movement within a building as the foundation of an indoor navigation system. The system may be combined with GPS to provide continuous navigation for both indoor and outdoor environments.

II. METHODS

A. Real-Time Location System

In this study a commercial asset tracking system from Ubisense Corporation was used to provide real-time location tracking using UWB wireless technology. The Ubisense system is capable of position measurement accuracy of 15cm. Triangulated location information is transmitted from the Ubisense server to the wayfarer's handheld computer via a wireless Ethernet link. Software on the portable computer receives the position information and generates contextual wayfinding messages specific to the user's current location in the environment, as well as their desired destination, by means of a resident geometry database.

The indoor navigation system is comprised of several components shown in figure 1:

1) Tracking Tags – The tag is a small UWB transmitter that can be worn by a person. Their small size and weight (25g) makes them ideal for a body worn tracking application.

2) Sensors – Each sensor contains an UWB antenna array capable of measuring time- and angle-of-arrival of UWB pulses generated by the portable tracking tag. System

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Manuscript received April 15, 2008. This work was supported in part by the U.S. National Science Foundation under Grant 0712033.

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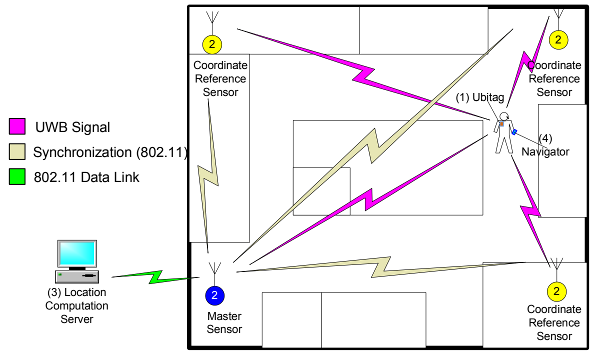

Figure 1. Location system block diagram showing (1) the body-worn Ubitag, (2) the coordinate sensors, (3) server, and (4) navigator.

location accuracy critically depends on a precise survey of sensor position and orientation. Each sensor device has a built-in Ethernet interface to enable the devices to be networked together to allow communication between the sensor nodes and the location server.

3) Server – Measurements from each sensor are collected and tag position is triangulated using Time Difference Of Arrival (TDOA) and Angle of Arrival (AOA). Precise 3D location of the tag is then communicated via wireless link to the handheld system.

4) Handheld Navigator – A small handheld computer runs custom navigation software which produces audio navigational cues based on real-time-position estimates received from the server. A Sony VAIO UX280P Micro PC was chosen as the handheld navigator for the trials described here. This computer was chosen because it was capable of running applications written using the full application framework supplied with the location system, and offers built-in wireless Ethernet networking and support for Bluetooth headsets.

Experiments were conducted with this apparatus using blindfolded sighted subjects. All subjects gave informed consent and IRB approval was obtained.

B. *Navigation System Design*

The design of the navigation system was influenced by research investigating language based spatial learning. It is generally accepted that language develops into an abstract spatial representation in memory referred to as a “cognitive map” [2] and these mental representations are not based on the preservation of the actual words in memory, but on spatial relations described by the texts [3]. Spatial learning is often measured using various techniques such as map reproduction and point-back-to-origin tests. Only a few studies have addressed the use of verbal descriptions during real-time spatial learning and navigation of indoor environments. This prototype navigator system design shares similar features with many existing studies [4][5] by providing static descriptions of the environment, in addition to dynamically updated directions [6] based on both real-time position and position history.

The design of navigational directions for the system was guided by the following principles:

- Provide directional information with respect to both a relative (right-left) and absolute (North, South, East, West) reference frame when feasible.
- Provide distance information in unambiguous units of paces versus feet or meters and use approximate “round” numerical measures such as “ten paces to your next turn.” These directions are used to increase the intelligibility of the message and reduce the cognitive load on the wayfarer.
- Provide frequent feedback to the wayfarer when they are proceeding on course between end-points or decision-points.

C. *System Integration*

Figure 6 shows a block diagram of the handheld navigator and tag. The navigation application contains the following components:

- RTLS queries. The Ubisense API provides a mechanism for the developer to write custom functions that will be called when (1) a new coordinate position has been triangulated, or (2) a tag has entered or exited a predefined region of the building, or (3) a tags button has been pressed.
- A route database which links predefined navigational cues to proximities within the test building for each test route.
- System calls to drive the audio system. This includes both a Text-to-Speech engine for generating audio from short sentences stored as STRING objects, and an object for playing prepared WAV files.
- Data logging system, to provide log files for each trial containing time-stamped position data and reports on when audio cues were provided.
- A graphical interface to allow experimenter control of trial condition, route and tag ID number. In our trials the GUI was controlled remotely via VNC, a remote-control desktop software package, while the PC was worn by the test subject.

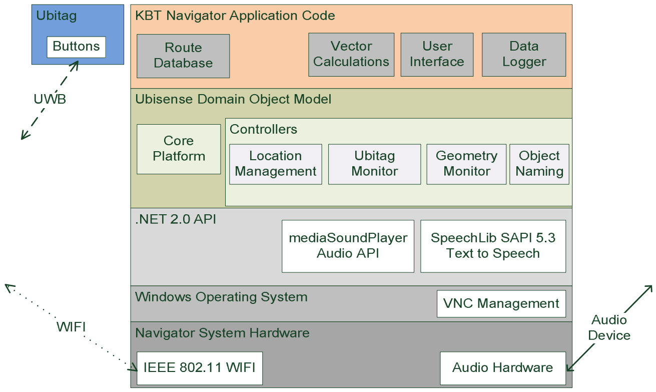

Figure 2. Navigator system block diagram.

D. *Human Trials*

The human study addresses the indoor navigation problem by comparing target-finding performance between several navigation conditions tested on routes in the test space. A suitable office space was chosen based on its size and internal layout complexity. Four distinct routes were chosen for the study, and together with reversed routes obtained by swapping origin and destination a total of eight routes were obtained. Each route presented the subject with several decision points at which they must choose a direction to follow. The number of decision points in each route is listed in Table 1 together with the length of each route and angular direction of the origin as seen from the destination, measured clockwise from North.

TABLE I
Summary of Route Parameters

Route	Decision Points	Route Length	Pointing Angle
1	3	118’	125°
2	4	141’	53°
3	4	128’	33°
4	2	115’	153°
5	3	118’	-55°
6	4	141’	-129°
7	4	128’	-149°
8	2	115’	-27°

Subjects were tested in two distinct blindfolded conditions as well as a normal vision control condition. Each subject was given a practice trial prior to testing in each blindfolded condition. During this learning phase, participants were started at one of eight origin locations within the test facility and asked to find a route to a destination target location (a specific room number). They were required to travel two routes in each of three navigation conditions (route by condition order was counterbalanced). Each route-finding task was the same for all of the conditions but the available information differed between each (described below).

Subjects in the blindfold navigation with guidance condition were guided along the route via the speech-based navigation system. As they walked, the room numbers and salient landmarks were spoken; the geometry of every intersection described and the direction of movement necessary for following the route was given. For instance, they might hear: “at a 3-way intersection, room 121 is ahead and hallways left, right and behind. Turn right and proceed 30 paces…” In the navigation without guidance condition, blindfolded subjects used the speech-based navigation system in a “non-guidance mode” which only provided descriptions about basic layout geometry and building features as they walked but they were not automatically given room numbers or told which direction to move in order to reach the goal, e.g. “at a 3-way intersection, there is a room ahead and hallways left, right and behind”. The information provided in this condition is similar to what is available to a blind person using a long cane or guide dog. To find the destination, subjects must explore the space at every decision point and approach every door before being told of the room number (much like the process of finding and reading a Braille sign). For the two blindfolded conditions, participants are aided by the experimenter. That is, the subject decided where to walk, e.g. “go left” and the experimenter ensured they didn't run into any obstructions during locomotion.

In the control condition, subjects navigated using normal vision. From the start position, they searched for the goal by walking through the space using whatever cues are normally available from visual perception, e.g. room numbers, landmarks, etc. The control condition was always run last to guarantee that information observed about the layout wouldn’t contaminate the two blindfolded conditions.

III. RESULTS

This experiment used a within subjects design to compare route navigation performance between three conditions: (1) guidance, where Subjects were directed along a route via a speech-enabled indoor navigation system, (2) non-guidance, where Subjects only received speech information about their local surrounds but no route information, and (3) visual control, where Subjects traveled the route using normal vision. Nine subjects were recruited ranging in ages from eighteen to fifty-two, composed of two men and seven women. The results were dramatically clear across the dependent measures of time and distance, with the non-guidance condition requiring the greatest time and distance to travel the routes. The guidance condition was also generally slower and less accurate than the visual control but these findings are partially offset by a potential bias which served to inflate performance in the visual condition. That is, early in the visual trials subjects discovered deviations within our prepared routes that provided short-cuts to the destination that were unavailable to subjects in the other experimental conditions. These data were retained to preserve the balance of our experimental design and to avoid the carryover bias that would occur if the trials were rerun.

TABLE II
Results

	Guidance		Non-Guidance		Visual	
Time (sec)	*M =*	*75.3*	*M =*	*331.5*	*M =*	*33.0*
	SE =	*16.4*	*SE =*	*182.6*	*SE =*	*17.9*
Distance (ft)	*M =*	*187.8*	*M =*	*606.8*	*M =*	*120.2*
	SE =	*61.0*	*SE =*	*355.4*	*SE =*	*84.3*
Pointing Error (octants)	*M =*	*0.94*	*M =*	*1.06*	*M =*	*0.69*
	SE =	*0.85*	*SE =*	*0.93*	*SE =*	*0.60*

A one way repeated measures ANOVA was conducted for each dependent measure with statistically significant results observed for time F(2,30) = 34.123, p<.001, $\eta^2 = 0.70$ and distance, F(2,30) = 22.407, p<.001, $\eta^2 = 0.59$. Post hoc pair wise comparisons revealed that all three conditions reliably differ from each other for both time and distance, all ps<.01. A similar numeric trend was evident for the pointing error, with the error in the point to origin task greatest in the non-guidance condition and least in the visual condition but these findings did not reach statistical significance in either the omnibus F test or subsequent pair wise comparisons.

IV. CONCLUSION

The observations reported in these experiments support the hypothesis that a small portable personal navigation device utilizing Ultra-Wideband technology that provides current position, useful contextual wayfinding information about the indoor environment, and directions to a destination would improve access and independence for people with low vision.

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