iWalker: Toward a Rollator-Mounted Wayfinding System for the Elderly

Vladimir Kulyukin, Ph.D., Aliasgar Kutiyanawala, M.S., Edmund LoPresti, Ph.D., Judith Matthews, Ph.D., and Richard Simpson, Ph.D.

Abstract—**Research on intelligent walkers aims at helping elderly individuals to maintain their independence in familiar and unfamiliar environments. Several walkers have been developed by researchers at Carnegie Mellon University and the University of Pittsburgh. This article contributes to this research venue by describing the design and initial evaluations of iWalker, a multi-sensor rollator-mounted wayfinding system for the elderly. The primary difference of the proposed navigation aid from other intelligent walkers is that iWalker is assumed to operate in a smart world (SW), a physical space equipped with embedded sensors. By integrating inexpensive sensors into the environment, the cost and complexity of the walker can be reduced.**

I. INTRODUCTION

It is projected that one in five Americans will be 65 years of age or older by the year 2030 [1]. Optimizing the functional independence of this growing population is of paramount importance, both for individual quality of life and for our society as a whole. Among the challenges posed by this changing demographic are the cognitive decline, physical impairment, and sensory degradation that may reduce older adults' ability to walk steadily and find their way in familiar and unfamiliar environments. Transforming a rollator — a mobility aid commonly used by older adults — into a navigation aid is one area of assistive technology where innovation is both needed and possible.

As people age, they experience changes in cognitive processes that affect their ability to acquire and use information about the spatial structure of their environment [2]. Compared with their younger counterparts, older adults are poorer at judging their wayfinding abilities and their perceptions of distance [3]. Such deficits contribute to reduced mobility and affect autonomy and self-esteem [4]. In particular, wayfinding difficulty can result from progressive neurodegeneration, such as Alzheimer's disease [5]. Among individuals with dementia of the Alzheimer type, the return trip from a destination can pose as much of a challenge as finding it in the first place from the original point of departure [6-8].

Several navigational mobility aids based on walkers are currently in development [9-15]. These devices provide assistance with obstacle detection and avoidance, combined with varying degrees of path planning and automated guidance. These projects are quite promising, but have largely focused on the needs of people with visual impairments. People with cognitive impairments may need a different user interface; one which can take advantage of the user's visual capabilities, but which provides instructions at a different level. People who have cognitive impairments but functional vision may not need obstacle avoidance capabilities, which can add significantly to the cost of a device.

Three robotic walkers were developed collaboratively by Carnegie Mellon University and the University of Pittsburgh [16, 19] in conjunction with the NurseBot project [17]. One robotic walker was a self-powered walker with an intuitive haptic interface. A software control system enabled data from force-sensing resistors to direct actuators in a mobile robotic platform to move in the user's intended walking direction. The base was equipped with a laser range finder and ringed at the top and bottom with sonar sensors for obstacle detection and avoidance.

The second walker was developed by modifying a wheeled walker (rollator) to include autonomous navigation capability, as well as self-parking and retrieval functionality actuated through a remote control mechanism. Feedback from elders was positive: during informal testing, users successfully navigated to a chosen destination within the retirement community by using the screen-based interface, and they also expressed enthusiasm for the device. Further modification of this walker has resulted in a third robotic walker that was used in a series of experiments to successfully predict people's walking activities [18].

The goal of the study reported in this paper was to develop a navigation aid, based on a four-wheeled rollator that provides navigation assistance to the user in the form of

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Vladimir Kulyukin is with the Department of Computer Science, Utah State University, Logan, Utah

Aliasgar Kutiyanawala is with the Department of Computer Science, Utah State University, Logan, Utah (phone: 435-512-0225; email: aliasgar@cc.usu.edu)

Edmund LoPresti is with AT Sciences, LLC, Pittsburgh, PA

Judith Matthews is with the School of Nursing, University of Pittsburgh, Pittsburgh, PA

Richard Simpson is with the Department of Rehabilitation Science, University of Pittsburgh, Pittsburgh, PA

verbal and visual instructions in order to guide the user to a desired location in an indoor environment. The primary difference of the proposed navigation aid, called iWalker, from other robotic walkers is that it does not make any attempt to assist the user in avoiding obstacles. Our belief is that such a system, while potentially useful, would be too expensive to deploy and maintain using current technology. Another important difference is that iWalker emphasizes a smart world (SW) perspective [20, 21]. A SW is a physical space equipped with embedded sensors. By integrating inexpensive sensors into the environment, the cost and complexity of the walker itself can be reduced.

The remainder of our article is organized as follows. We begin with findings from a focus group discussion with agency staff who work with frail older adults (Focus Group 1) that informed the design of the iWalker. We proceed to describe the actual hardware and software design, implementation, and technical evaluation. After discussing the system's software and hardware, we continue with two more focus groups: one with staff (Focus Group 2) and one with clients (Focus Group 3). User interface development informed by these focus groups is presented next, followed by user tests of the iWalker with four participants with histories of wayfinding difficulty. We describe the results of these tests and our observations. We conclude with the current status of the system and several thoughts on possible future research directions.

II. FOCUS GROUP 1: STAFF

To inform the design of the iWalker, a focus group was held with the staff from Community LIFE, Inc., a senior services agency in southwestern Pennsylvania that provides on-site and in-home supportive services to frail older adults in the community [22]. The focus group took place in a conference room at the Homestead, Pennsylvania site of Community LIFE. Written informed consent and socio-demographic information were obtained from participants prior to initiation of focus group activities. With participants' permission, all discussion during the two-hour session was audio-taped. A member of our team used a PowerPoint® presentation to provided a brief overview of current walker designs and asked seven participants to imagine a device that could be attached to a wheeled walker, or rollator, and be capable of guiding people from one place to another while keeping track of the path they take. Participants were asked to identify conditions affecting clients who might benefit from such a modified walker.

Four scenarios were presented depicting elderly individuals whose ability to navigate independently was impaired due to specific medical conditions (e.g., Alzheimer's disease, stroke, traumatic brain injury, skeletal deformity due to osteoporosis) and complicated by varying life circumstances (e.g., living alone but requiring a companion when venturing out, recently moving to a retirement community with a complex indoor and outdoor layout, needing constant vigilance from a family caregiver due to impulsive behavior and disorientation). These scenarios provided a springboard for discussion about who might benefit from such technology and what interface designs for offering guidance cues might be helpful.

Audio-taped discussion from the focus group session was transcribed verbatim and subjected to content analysis to identify recurring themes. Content analysis of transcripts revealed that the staff in Focus Group 1 endorsed our concept of a navigation assistant as potentially helpful to persons with stroke, traumatic brain injury, early- to mid-stage Alzheimer's disease, macular degeneration, cataracts, and other causes of visual impairment. Among the recurring themes were suggestions for walkers that could not only guide people but also prompt their safe use, inform them of hazards in their paths, and help pace their physical activity [22].

III. DESIGN IMPLEMENTATION AND TECHNICAL EVALUATION

Feedback from Focus Group 1 was integrated into the Phase I design of the system. The iWalker hardware was designed and assembled at the Computer Science Assistive Technology Laboratory of Utah State University (USU CSATL) [21, 23]. In designing the iWalker, we used a smart world perspective. We assumed that the iWalker would function in an indoor environment, e.g. a community center, instrumented with embedded sensors and computer systems to support various quality-of-life functions.

Several smart environments for people with disabilities have been investigated by researchers and are related to our work. The University of Washington Assisted Cognition Project [25] uses AI and ubiquitous computing to develop solutions that help people with cognitive limitations. Japan's Ministry of Land, Infrastructure, and Transport announced its support for the Autonomous Movement Support Project [26] whose objective is to place small electronic sensors into the pavement and street furniture to supply users with anytime location-specific information. Willis and Helal [27] propose an assisted navigation system where an RFID reader is embedded into a blind navigator's shoe and passive RFID sensors are placed in the floor. Hahnel et al. [28] use RFID to improve a probabilistic robotic mapping and localization system in office environments.

In designing the iWalker's hardware, we wanted to take advantage of passive radio frequency (PRF) exteroception. It has been our long-term research focus to investigate how PRF exteroception simplifies the onboard computing machinery required to accomplish localization tasks in indoor environments [20, 21, 23, 29, 30]. An important factor in assistive technology deployment is the difference between the cost of deployment and the cost of subsequent maintenance. Therefore, we would like to develop a device that does not require much maintenance after the required sensor infrastructure is put in place.

Fig. 1. iWalker Device.

The iWalker device is shown in Figure 1. The sensor suite consists of an encoder, a digital compass, two radio-frequency (RFID) readers, and two RFID antennas attached to the rear wheels. The encoder is a modified bicycle speedometer connected to an OOPIC microcontroller and the compass is a Revolution 2X digital compass from True North Technologies. The RFID readers (RI-STU-MB2A) and the RFID antenna (RI-ANT-S02C-00) and transponders (wedge shaped transponder RI-TRP-W9WK) are from Texas Instruments. All the sensors communicate with the laptop via serial to USB interfaces. In a production version of the system, the laptop can be easily replaced with a smaller computational unit.

The RFID reader, antenna, and transponder are low frequency (134.2 kHz range). The transponder was chosen for its small size (12 mm x 6mm x 3mm) and robust packaging. The transponder can be placed under carpets (or other surfaces) without producing noticeable bumps on the surface. One can walk, jump, and move carts over this tag without damaging it. While high frequency tags offer anti-collision protocols (where multiple tags can be read simultaneously), we could not find any off-the-shelf tags with sufficiently rugged packaging. The RFID reader and antenna were chosen so that the transmitted electromagnetic power would be low. Since the iWalker is designed primarily for nursing and assisted living homes, the electromagnetic radiation from the RFID system should not affect other medical devices present in the environment.

RFID tags are placed under carpet mats. Each RFID tag stores up to 64 bits of data which allows for 2^{64} (2 to the power of 64) unique tags in the environment. Each mat has 15 tags separated by a distance of 20 cm from each other. Such tags can be read through any non-metallic material, e.g., plastics, tiles, and carpets. Each tag costs about \$4 and one mat costs approximately \$70.

The mats (RF mats) can be placed anywhere in the environment (See Figure 3). The mats provide the iWalker with absolute location information whenever at least one antenna passes over a mat. Since the electromagnetic power transmitted by the antenna is low, the antenna has a small read area (the area where the antenna can read the tag successfully). The localization accuracy (difference between the position of the antenna and the position of the tag) is inversely proportional to the read area of the tag. Thus, a smaller read area translates to a higher localization accuracy, which is important in our application. It should be noted that these mats are used only for experimental purposes. In a production version of the system, virtual RFID strips that arrange tags into specific patterns can be placed directly under carpets at important strategic locations in the environment.

The dead reckoning module consists of an encoder and a digital compass and provides location information relative to the last mat. The encoder's resolution is 60 cm. The encoder is connected to an OOPIC microcontroller that provides a serial interface to the sensors. The sensors communicate with a laptop computer mounted on the rollator's seat. In a production version of the device, the laptop can be replaced with a smaller computational unit, e.g. an OQO [24]. All units are powered by rechargeable onboard batteries. The entire unit is mounted on a standard rollator without any modifications to the latter.

IV. PASSIVE RF SURFACES

Since many environments are composed of surfaces, we investigate how PRF sensors can be packed into those surfaces in order to improve the point-to-point navigation and localization of mobile units. In his book De Nive Sexangula (On the Six-Sided Snowflake), Kepler made a claim that face-centered cubic packing, e.g., apples on a fruit stand, was the tightest possible in 3D. Approximately 200 years later, Axel Thue proved the conjecture for 2D. Thue's theorem states that no packing of overlapping discs of equal size in the plane has density higher than that of the hexagonal packing [29].

Since the read area of a tag can be approximated as a disc, Thue's theorem is applicable. Thus, in each mat, tags are placed in a hexagonal pattern. The hexagonal placement of the tags ensures that the packing is the tightest possible and two rows of tags are used to maximize the localization probability [29, 30]. A total of twenty one tags were used to populate an eight feet wide mat.

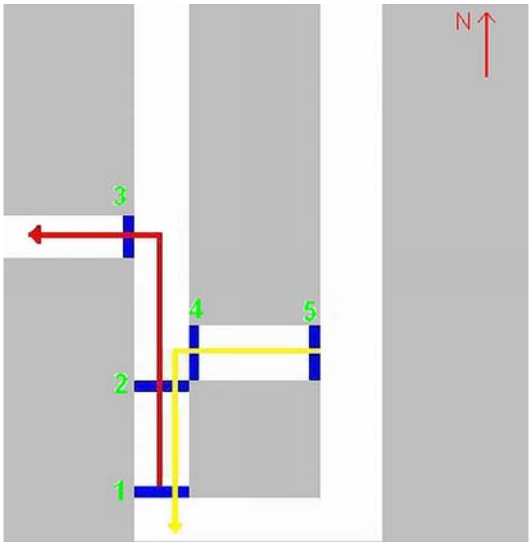

Fig. 2. Typical Office Environment.

The mats are also used to discretize the compass readings. Figure 2 shows a typical office environment. Hallways are shown in white, walls are shown in gray and RFID mats are shown as blue strips. A green colored number indicates the mat ID of each RFID mat. Consider that we are moving along the red colored route. As we start from the first mat, we can only move along the north-south direction. Now as we cross the second mat, we can continue north, turn back and go south, or turn right and go east. It is not possible to go west until the third mat is reached. Thus, the permitted directions are: north, south and east. Once the third mat is crossed, we can continue west or turn back and go east. It is not possible to go north or south unless the third mat is crossed again. Now consider that we are moving along the yellow colored route. As we start from the fifth mat, we can go only east or west direction until the fourth mat is reached. As soon as the fourth mat is reached, we can go only north or south. Thus, the permitted directions change depending on the direction we are facing while crossing each mat.

A discretization schema is associated with each mat at installation time and is activated at run time through a table lookup by the localization algorithm. The mat positions (x and y coordinates), spatial orientations, and connectivity are entered through a graphical user interface at installation time. This information can be edited if mats are moved or the environment's layout changes.

The localization algorithm on the laptop fuses readings from the encoder, the compass, and the RFID reader to localize the walker. At startup, the algorithm localizes the walker on the first strip it encounters. In between strips, the algorithm uses standard dead-reckoning from the compass and encoder readings. When a tag is detected, the encoder error is reset to 0 and the walker's position is reset to the x-y position of the tag's mat.

V. EVALUATION

The localization algorithm was tested at the USU Computer Science Assistive Technology Laboratory in a series of experiments performed on a 40 meter route in an office environment that consisted of four hallways that formed a square [23]. The route was divided into 40 one-meter segments marked with masking tape on the floor. Localization results were recorded and compared with the ground truth (the id of each segment) to generate the localization error every time the walker crossed one of these segments. The contribution of each sensor to the localization accuracy was measured as well.

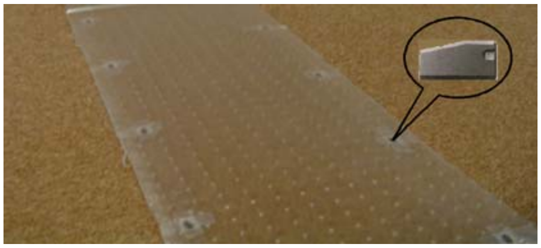

Fig. 3. RF Mat with Tags underneath.

The main research hypothesis was that the mats have a positive impact on the localization accuracy. The following configurations were tested: dead-reckoning alone, dead-reckoning and 1 mat, dead-reckoning and 2 mats, dead-reckoning and 3 mats, and dead-reckoning and 4 mats. Each configuration was tested on 30 runs along the route.

TABLE I
MEAN LOCALIZATION ERROR

Number of mats	Mean	Standard Deviation	Maximum	Minimum
0	4.2870	2.8550	8.8499	0.0185
1	3.0793	2.3772	8.6241	0
2	2.2643	1.7584	6.4840	0.0394
3	2.2150	1.8569	6.9585	0.0203
4	1.1124	0.5558	2.8616	0.2759

As shown in Table 1, the results showed that the average localization error drops from 4.3 meters (dead-reckoning only) to 1 meter (dead-reckoning and 4 RFID strips). This suggests that the average localization error is inversely proportional to the number of mats. The compass turns out to be the noisiest sensor. Thus, discretizing it at run time reduces the localization error by over a meter. Localization accuracy of 1 meter was found to be satisfactory given the encoder's resolution of 60 cm.

VI. FOCUS GROUPS 2 AND 3

After the technical evaluations, the iWalker was disassembled and shipped to Pittsburgh, PA along with 30 RF mats for the upcoming additional focus groups and user trials. A duplicate version of the device was built and mounted on a different rollator. This collaboration model allowed the investigators in Utah to reproduce software and hardware problems experienced by the investigators in Pennsylvania and address them in a timely fashion without being physically present on the site.

Two additional focus groups were conducted approximately six months after the initial focus group [22]. Focus Groups 2 and 3 also took place at the Homestead, Pennsylvania location of Community LIFE. Focus group 2 again involved center staff. The staff who took part in Focus Group 1 were permitted to take part in Focus Group 2. Focus Group 3 involved clients of Community LIFE. As with Focus Group 1, written informed consent and socio-demographic information were obtained from participants prior to initiation of focus group activities and, with participants' permission, all discussion during each two-hour session was audio-taped.

In preparation for these focus groups, a variety of user interface concepts were designed. Software concepts were implemented in a program, written in the Java programming language, which simply presented the screen designs (e.g. they were not integrated with the iWalker hardware). One of these concepts was integrated with the iWalker in order to illustrate how the final system would work in practice. The iWalker was then programmed for a short route in the Community LIFE facility. User interface concepts which require hardware (lighted arrows, a physical arrow, or vibrating handles) were presented as illustrations in a PowerPoint presentation. Screenshots of the software concepts were also included in the PowerPoint presentation for reference.

Preferences for interface options designed to provide navigational guidance to individuals with wayfinding difficulties varied considerably between staff who work with frail older adults and older adults themselves. Both groups frequently qualified their written responses with verbal anecdotes about how persons with certain conditions or functional characteristics (e.g., low vision, hearing impairment, easy distractibility, impulsiveness) might benefit or not from a particular interface.

We recognize that participants in Focus Group 2 and Focus Group 3 were asked to evaluate the potential helpfulness of each interface option separately and that they were asked to indicate their preferences for small, thematically-grouped sets of interface options rather than for each option in relation to all others. We took the former approach because we thought that the latter would be difficult, if not impossible, for staff to perform, and we anticipated that it would be even more difficult, if not impossible, for older adults, given the total number of interface options presented.

Though we knew neither the health history of any of our participants nor any clinical information regarding their cognitive and physical functional status, our casual observation of the verbal and non-verbal reactions of participants in Focus Group 3, in particular, led us to surmise that deficits in attention and memory, reading ability, and hearing and vision were present among several in this small group. In our judgment, it is likely that these deficits contributed to diminished ability among some of the clients to address the task at hand in a nuanced fashion.

Further, we recognize that since the number of participants in our focus groups was small, our findings may be unstable and should be interpreted with caution. Nevertheless, our findings suggest that the ideal navigation assistant should offer a variety of interface options that include simple text and arrows or other graphics, tonal alerts prior to cues, and voice prompts to help older adults compensate for wayfinding difficulty associated with brain disorders and sensory deficits more frequently experienced in old age.

VII. USER INTERFACE DEVELOPMENT

Based on the results of the focus groups, two user interface concepts were implemented. Both used audio cues with a preceding word that changed between cues; e.g. Please turn right, Now go straight. Visually, one interface displayed a text cue at the top of the screen which mirrored the audio cue; and a large green arrow in the center of the screen which indicated the direction to take. The second interface displayed a map of the immediate surroundings, showing walls and a smaller green arrow which indicated the iWalker's location and the direction to turn (if any). The first interface (text+arrows+voice) represents a combination of features popular to both focus groups; the second represented an alternative option popular in the client focus group. Note that tonal alerts were not played prior to auditory cues. The preceding word (please, now, etc.) serves a similar function – to attract the user's attention prior to presenting the important information.

Software was developed to determine the appropriate cue for a given route and location. Routes were defined as a sequence of nodes, where each node corresponds to an RF mat location. Nodes are removed from the route as the user arrives at a mat; and nodes are added if the user travels in an incorrect direction, in order to guide the user back to the intended route. For this prototype, routes were hardcoded in the system. In the future, the iWalker will be able to plan a route given a starting location and desired end location.

Whenever the iWalker arrives at an RF mat, it checks the route information for the next cue which should be delivered to the user. The cue is then presented based on the active user interface (arrows-and-text or map). In addition, when the map user interface is active, the software continually updates the map to indicate the user's current location and orientation as provided by the iWalker sensors.

VIII. USER TESTING

User trials with the iWalker were conducted via a series of single-subject case studies to evaluate whether users could understand the verbal/written instructions offered by the navigation assistant and whether they could successfully navigate to a target destination using the system. Four participants, each with a history of wayfinding difficulty, participated in the study. Participants were recruited from Homestead, PA and McKeesport, PA offices of Community LIFE. All four subjects currently used a cane, walker, or both. Two subjects had Mini-Mental Status scores of 23, one had an MMSE of 25, and one had an MMSE of 30.

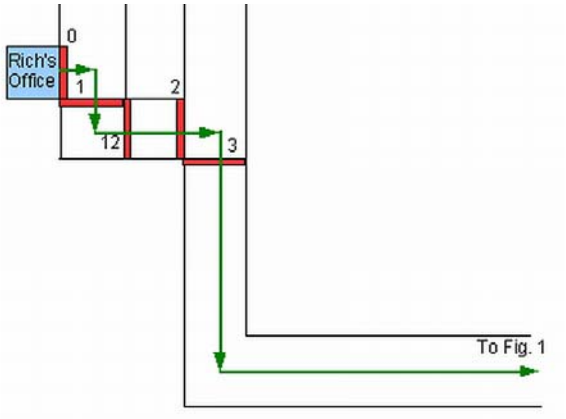

Fig. 4. Practice Route. Route 1 leads from Mat 0 to Mat 3; Route 2 leads from Mat 3 to Mat 0.

The iWalker was programmed with four routes within the Forbes Tower building on the University of Pittsburgh campus. In Figures 4 and 5, the arrows denote routes; the narrow blocks with numbers denote RF mats. Figure 4 shows two routes: 1) a 49.4 meter practice route from mat 0 to mat 3; and 2) a 49.4 meter practice route from mat 3 to mat 0 (reversing Route 1). Figures 5 and 6 show the other two routes: 3) a 79.9 meter test route from mat 4 to mat 28; and 4) a 79.9 meter test route from mat 28 to mat 4 (reversing Route 3). Note that routes 3 and 4 included a transition between floors by an elevator. The RF mats were placed at intersections and other key locations along these routes, and secured to the floor with duct tape to prevent tripping or slippage of the mats.

During a preliminary session at the participant's Community LIFE location, written informed consent was obtained and participant information was collected regarding their demographic characteristics and functional abilities, including their cognitive status, performance of physical and instrumental activities of daily living, mobility, and history of falls in the preceding year.

During a second session at the University of Pittsburgh, each participant was shown how to operate the navigation assistant and given the opportunity to practice using it on Routes 1 and 2 (see above). On each practice route the participant used a different user interface (text and large arrows or the map view), with the order of presentation randomized with counterbalancing across subjects. Once oriented to the Navigation Assistant's operation and capabilities, the participant was asked to choose a user interface to continue using on the test routes (Routes 3-4 above). The participant was then asked to complete three trial walks, with a resting period of at least five minutes between walks.

During the first and third walking trials, the participant used the Navigation Assistant and was asked to follow the cues it provided to reach the target destination. During the second walking trial, the participant walked without the navigation aid, instead using his or her usual assistive device (e.g., cane or walker), as needed, and accompanied by a member of our research team. The research team member offered the same scripted directions as those provided by the navigation aid. Participants' performance during the user trials and their comments made during and immediately after walks in the user trials were videotaped.

During each walking trial, data were collected regarding how long it took the participant to reach the destination, the route actually taken, the number of navigation mistakes (e.g., wrong turns) made before reaching the destination, and the participant's subjective evaluation of the navigation aid and its interface (e.g., ease of operation, his or her comfort level, sense of stability and security, level of frustration and fatigue, task load, and confidence in the navigation assistant's ability to provide guidance to a destination).

IX. RESULTS

Following the practice walks, three participants chose the user interface with the map, and one chose the text+arrows user interface. One participant was unable to use the map interface due to technical difficulties. Therefore, for the test routes with the walker, two participants used the map interface and two participants used the text+arrows interface. During the test routes, the participants who used the map interface stressed their preference for being able to see the walls along the route reflected in the map interface. One participant expressed that she liked the arrow that indicated the direction to turn. One participant (using the text+arrows interface) stated that she needed a better connection between what was on the screen and what was in her head. One participant stated liking the voice prompts (and that they seemed clearer on the second route with the walker). One stated that the auditory feedback was useful; but if she could not hear, the visual display would be useful.

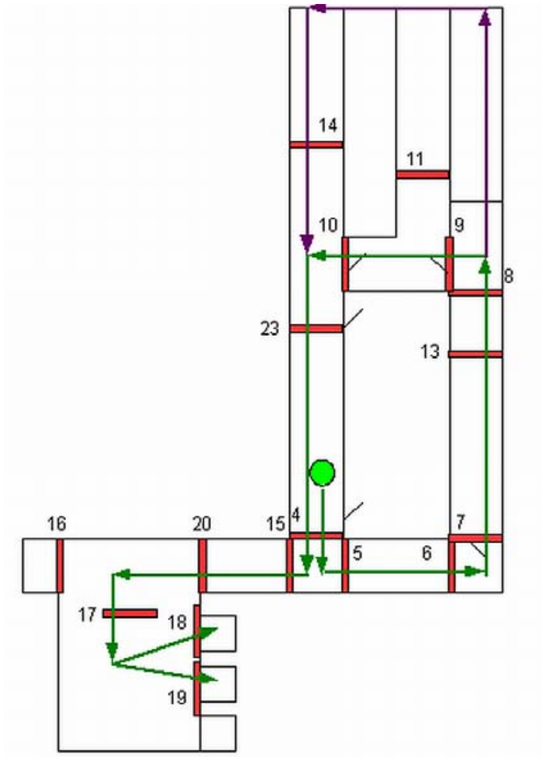

Fig. 5. Test route, section 1; mat 4 is the beginning of route 3 and the end of route 4.

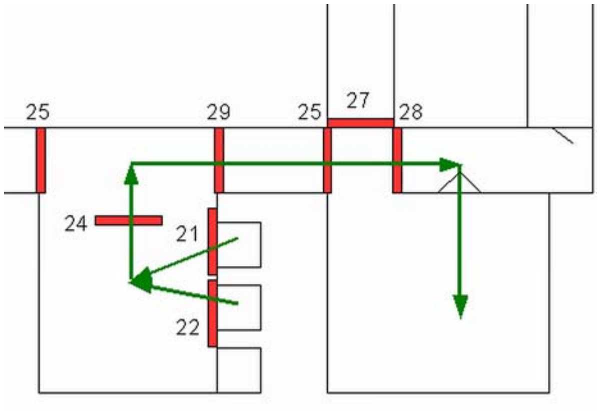

Fig. 6. Test route section 2; mat 28 is the end of route 3 and the beginning of route 4. Mats 21 and 22 are associated with elevators that connect with mats 18 and 19 in Figure 4.

In the discussion below, the phrases "first route with the walker" and "second route with the walker" refer to the test routes; e.g. following the practice routes. The hardware presented some difficulties in recognizing instrumented mats and direction of travel given the variation in walking speed among our participants. The first participant walked quite slowly, such that a given instrumented mat would register multiple times. Due to the unreliability of the digital compass, the system would occasionally give a false reading on the direction in which the mat was being traversed, and give an incorrect "turn around" direction, during these repeated recognitions of a single mat. To correct this, the software was adjusted to recognize a mat more slowly. However, the second participant walked quite quickly, so that the system would occasionally not detect a mat because the participant moved too quickly over it. The software was thus altered again, such that it recognized mats immediately, but would assume that any repeated identification of the same mat was a continuation of the previous identification (e.g. a slow mat traversal). As a result, this final software configuration would not recognize when a participant truly did cross a mat twice (e.g. once in the correct direction and then in the incorrect direction), and therefore the system could not provide a correcting instruction (e.g. "turn around") until another (incorrect) mat was traversed. In this final setting, the system gave correct instructions, but would be dependent on a dense distribution of mats to ensure that a user would not travel far in the wrong direction without correction.

The first participant frequently misheard the word "next" in instructions for the word "left." Therefore, an instruction such as "Next, go straight" would be heard as "Left, go straight" and interpreted as "Turn left, then go straight"; resulting in several incorrect left turns. As a result, the word "next" was removed from the list of possible "preceding" words for that participant during her second route, and for all remaining participants.

All participants reported that the directions were clear enough to follow; the voice was loud enough to hear; and the arrows were big enough to see (in both the text user interface with the large arrow, and the map user interface with the smaller arrow). The two participants who used the text user interface reported that the words were big enough to read.

When asked "Did the walker gave you directions like 'Turn right' or 'turn left' at the right time," following the first route with the walker, two participants said 'no', one said 'yes', and one did not respond. Following the second route with the walker, two participants responded 'yes', one still responded 'no', and one did not respond.

One participant expressed concern for what a system like this would cost, and whether people would be able to afford it. Two expressed concern about the weight, bulk, and/or height of the walker itself, but did not state concerns about the wayfinding user interface. One participant expressed frustration that the device would sometimes seem to contradict itself in subsequent instructions.

Although RF mats proved useful in this Phase I study, they had some limitations. There were problems with people moving too quickly over the mats: when a mat was crossed too quickly the antenna was unable to read any tags in it. The antenna used in the experiments is monopole. It has electromagnetic lobes on both sides. We conjectured that placing a metal plate near the antenna would cause the metal plate to act as a mirror and reflect the side lobes of the antenna to double in strength in one direction. This would cause the RF mat to be read at higher speeds.

Two experiments were performed to test this conjecture. The first experiment was performed using the Pioneer-2 robot from Activmedia, Inc. The robot was equipped with a RF reader and antenna. A RF mat was placed at a distance of five meters from the robot and the robot was programmed to move in a straight line at a specific velocity and stop on detecting the RF mat. The velocity of the robot was incrementally increased from 0.5 m/sec to 1.2 m/sec. The experiment was performed by placing the metal sheet above the antenna and then repeated without the metal sheet. The robot was able to detect the RF mats both with and without the mental sheet. Since 1.2 m/sec is the maximum speed of the robot, we could not automatically test higher speeds. Thus, it is still possible that the antenna cannot read tags at higher speeds.

The second experiment was performed using the iWalker. The RF mat was placed at a distance of seven meters from the iWalker. A point was marked at a distance of five meters from the RF mat. During a run performed by a researcher, a stopwatch would be started once the iWalker crossed this point and would be stopped when the iWalker would cross the RF mat. This speed of walking with the iWalker was measured by dividing the distance of five meters with the time taken to cover this distance. Runs were made at various speeds with and without the metal plate in front of the antenna and the maximum speed at which the RF mat could be detected for each run was noted. The RF mat could be detected at a maximum speed of around 1.5 m/sec in both cases. The RF mat could not be detected at higher speeds either with or without the metal sheet above the antenna. Thus, the hypothesis that the addition of the metal plate near the antenna causes the RF mat to be detected at higher speeds appears to be false.

X. DISCUSSION

The Phase I prototype indicated that elders with wayfinding difficulties were able to perform wayfinding tasks with cues from a computer-based system, and that a fusion of RFID, odometry, and directional sensing has promise for providing indoor location information. There were concerns among staff regarding the mats as potential trip hazards. Trip hazards, however, may not be an issue if the mats are placed not on the floor, as was done in our experiments, but are fit directly into the carpets, i.e., a strip of the carpet surface is cut out and replaced with an RF mat of the same color and texture. Another possibility is to explore longer-range RFID tags. However, long range RFID tags would result in lower localization accuracy, which, in turn would necessitate a much better odometry or some other means of compensating for RFID-based localization errors. Better odometry might also provide a substitute for the digital compass in providing pose information.

Although user feedback from the focus groups and user trials were valuable in designing the Phase I user interfaces, time constraints during Phase I did not allow for a formal user interface comparison. This will be performed in the future for the most promising user interface options from Phase I, to determine which user interface options are truly most promising, or which are most useful for different populations.

The Phase I prototype relied on hard-coded routes. The next prototype will need to address automated route planning to a user-selected destination from an arbitrary starting point. As route planning in an environment represented as a discrete graph has a variety of reliable solutions, we do not anticipate any difficulties in this respect. The user interface will also need to support selection of a destination. Once these changes are made, more extensive user trials will be needed for the final system.

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