Drishti: An Integrated Indoor/Outdoor Blind Navigation System and Service

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Abstract

There are many navigation systems for visually impaired people but few can provide dynamic interactions and adaptability to changes. None of these systems work seamlessly both indoors and outdoors. Drishti uses a precise position measurement system, a wireless connection, a wearable computer, and a vocal communication interface to guide blind users and help them travel in familiar and unfamiliar environments independently and safely. Outdoors, it uses DGPS as its location system to keep the user as close as possible to the central line of sidewalks of campus and downtown areas; it provides the user with an optimal route by means of its dynamic routing and rerouting ability. The user can switch the system from an outdoor to an indoor environment with a simple vocal command. An OEM ultrasound positioning system is used to provide precise indoor location measurements. Experiments show an in-door accuracy of 22 cm. The user can get vocal prompts to avoid possible obstacles and step-by-step walking guidance to move about in an indoor environment. This paper describes the Drishti system and focuses on the indoor navigation design and lessons learned in integrating the indoor with the outdoor system.

1. Introduction

Studies [2] indicate that there are approximately 10 to 11 million blind and visually impaired people in North America, and this number is growing at an alarming rate. As many of these people have difficulty knowing where they are or where they are going, frequently feeling totally disorientated or even isolated, supplemental navigational guidance is very important for them. Navigation involves updating one's position and orientation while he or she is traveling an intended route, and in the event the person becomes lost, reorienting and reestablishing a route to the destination. Guiding people is about augmenting them with contextual information, which usually includes obstacle prompting and optimal routing.

In this paper, the Drishti outdoor navigation system for blind pedestrians [1] is extended to seamlessly support indoor navigation as well. The outdoor version of Drishti uses DGPS to locate the user in campus or downtown areas, answers the user's various requests and gives information about routing and rerouting dynamically according to changes in the environment. In an indoor environment, traveling is even more difficult because the space is relatively small and there are many narrow hallways, stairs, doors and pieces of furniture. As such visually impaired people may encounter more and closer obstacles. If they are new to the environment (e.g. in an hotel room or a convention or trade show floor), it is very dangerous for them to walk alone. This system conveys to its user the layout of the indoor facility, and gives him/her a broad picture of what the environment is like. The user may also get distance and navigation information between destinations. As the user walks around, the system guarantees travel safety by employing timely obstacle prompting. The system can also communicate with the user and answer different contextual awareness questions on demand.

Because GPS is not available indoors, and because the requirements of measurement error change, the Drishti system switches to a different location tracking technology: ultrasound positioning service, which provides a high precision measurement scale, for indoor use and prompts the user with the indoor room layout.

Our prototype is designed to enhance the user's real world navigation experience by augmenting their reality through vocal interfaces with contextual information about their surrounding environment. Advances in wearable computing, voice recognition, wireless communication, GIS, GPS, and ultrasound positioning devices have made our goal possible. Because we employ Commercial-Off-The-Shelf (COTS) hardware and software, design issues like hardware miniaturization and voice interface are not addressed here. In the reminder of this paper we will give a brief review of related work in section 2. In section 3 we discuss the problem domain and in section 4 we present the system architecture and expose important implementation issues, tradeoffs and lessons learnt. We talk about trial runs and data analyses in section 5 and limitations in Section 6. We present our summary and future work in section 7.

2. Related work

Blind and visually impaired people are at a disadvantage when they travel because they do not receive enough information about their location and orientation with respect to traffic and obstacles on the way and things that can easily be seen by people without visual disabilities. The conventional ways of guide dog and long cane only help to avoid obstacles, not to know what they are. Navigation systems usually consist of three parts to help people travel with a greater degree of psychological comfort and independence: sensing the immediate environment for obstacles and hazards, providing information about location and orientation during travel and providing optimal routes towards the desired destination.

Sunita Ram and Jennie Sharf [3] designed the “People sensor,” which uses pyroelectric and ultrasound sensors to locate and differentiate between animate (human) and inanimate (non-human) obstructions in the detection path. Thus, it reduces the possibility of embarrassment by helping the user avoid inadvertent cane contact with other pedestrians. The system also measures the distance between the user and obstacles. John Zelek [4] is working on a technology, “the logical extension of the walking cane,” which provides visually impaired individuals with tactile feedback about their immediate environment. Two small, webcam-sized video cameras wired to a portable computer feed information into a special glove worn by the user. The glove has vibrating buzzers sewn into each finger that send impulses to the user warning of terrain fluctuations up to 30 feet ahead.

There are many ways to determine the location and orientation of the user and provide routes. Metranaut [5], developed by Asim Smailagic and Richard Martin, is a novel wearable computer system that employees a bar code reader for information input and position from a series of bar code labels placed at strategic locations to assist visitors of CMU’s campus. A. R. Golding and N. Lesh [6] detect the user’s current information by using a set of cheap, wearable sensors that include a 3D accelerometer, a 3D magnetometer, a fluorescent light detector and a temperature sensor, that do not modify the environment at all. Loomis was one of the first to propose the idea of a navigation system for the blind using DGPS with an FM correction data receiver for the stable determination of the location of the traveler [7]. A similar approach is taken by Hideo Makino[8] et al. Other systems that exploit GPS to find the user’s location are MoBic [9] BrailleNote GPS from the Sendero Group [10] and the work done by Bruce Thomas, etc [11]. BrailleNote GPS is commercially available and provides the user with nearby location names and the distance to destination along the journey. Computer vision techniques are also used to locate the user. Sequential images are first geo-referenced manually and registered in a database. Then from the registered images the landmark lines are transferred onto an unregistered image by image-to-image matching based on straight-line features to get accurate position and orientation for real world images taken by the camera later [12,13]. This approach is more applicable to natural terrain environments. Since GPS does not work in indoors, relative positioning systems using sensors such as infrared transceivers, active badges, or accelerometers are exploited [6, 14, 15, 16].

One major limitation of these systems discussed so far is that they merely deal with navigation service in outdoor or indoor but not in the actual combined traveling environment. Imagine a visually impaired person needs to travel from his home to his office. He has to use at least two systems to guide him while walking indoors and traveling outdoors. His life will be much easier if one single system could guide him all the way to the destination. Drishti is such a kind of integrated navigation system that the user can employ while traveling from an outdoor environment to an indoor environment or vise versa by switching modes using a simple vocal command. Dynamic interactions and adaptability to changes are also the emphasis of Drishti.

3. Problem domain

While the visually impaired person travels, he lacks many useful inputs that can be seen by the sighted traveler such as the orientation, the location, possible obstacles ahead and building signs, so he would rely very much on repetitive and predefined routes with minimum obstacles. At times these routes may be subject to change: a sidewalk may be blocked for roadwork, a fallen branch or temporary puddle of water after a heavy rain on the route can be dangerous to those who could not see it. A guide dog or long cane may help detect the problem, but blind people need more information to find detours or rearrange routes. In order to augment a visually impaired person's pedestrian experience and help them travel comfortably in known and unknown environments, the navigation system should provide enough information to give him a whole picture of the environment and deliver the information along the visually impaired person's path in real time through auditory cues.

The prototype was designed based on Dr. Theral Moore's input and reviewing literature on user requirements for the blind. Dr. Theral Moore who became blind at a young age is father of one of the authors. To evaluate the efficiency of the prototype, the study area of the University of Florida campus is selected as the outdoor environment to include various scenarios such as crowded walkways, close buildings, services etc. The "elder's smart house" in the Pervasive Computing laboratory (www.icta.ufl.edu) is chosen as the sample indoor environment that consists of a kitchen, a living room, a bedroom and a bathroom. Figure 1 shows how to use voice command to switch from outdoor navigation to indoor navigation when the visually impaired person first enters the smart house and illustrates the sample communication between the user and the system.

User > "Indoor"
Drishti > "OK, indoor navigation"
User > " How are you"
Drishti > " How are you! Welcome to smart house! What can I do for you?"
User > " What we have?"
Drishti > " Refrigerator and stove in the kitchen, sofa and TV in the living room, bed in the bedroom, bath and toilet in the bathroom."
User > " Where am I?"
Drishti > "You are in the living room facing south."
User > " Sofa"
Drishti > " The distance to the sofa is 5 feet. Turn left 30 degrees and walk ahead."
User > " prompt"
Drishti > "Watch out for the TV. It is to your right beside the west wall."

Figure 1. User interface: the environment switch and walking instructions

The system introduces the indoor facility to give the user a broad picture of the indoor environment. While the user is walking, he may request the current location and ask for the optimal route to get to a destination. With the user's current position a step-by-step guidance is provided with the orientation and angles the user should turn. The user should also be aided in his quest along the way with vocal prompts, such as the possible obstacles, how far away the destination is and the new route if reroute is requested. The optimal route does not necessarily mean the shortest path. The system should provide the route with the least hazards. Warnings about possible obstacles are given in requests. The communication interface is user-friendly. It adopts many expressions that are widely used in daily life for each command. A vocal command list is also available upon request at anytime. 5 minutes of training is needed for the first time user. This current system only supports interface in English.

4. System design

Drishti is made up of COTS hardware and software. Our prototype weighs approximately 8 lbs. Drishti outdoor version [1] uses DGPS to locate the visually impaired user in the outdoor environment and provides him/her with dynamic route and reroute service.

Figure 2. Outdoor mobile client

This paper extends the previous work seamlessly to an integrated indoor and outdoor navigation system so that the user can travel in any place without changing services. He or she can go from an outdoor environment to an indoor environment or vice versa by speaking a simple command. This work gives the user extensive convenience and independence. Figure 2 depicts an author (Steve Moore) using the Drishti outdoor prototype on a test run and Figure 3 is another of the authors (Lisa Ran) using the integrated Drishti prototype on a test run at the indoor environment (an experimental Smart House).

Figure 3. Indoor mobile client

4.1. Hardware components

The following describes the hardware components used in the integrated Drishti system.

- **Wearable computer.** The wearable computer, as shown in Figure 2 and Figure 3, is a Xybernaut MA IV with a Pentium 200MHz processor, 64 MB main memory.

- **Differential GPS receiver.** We are using a Trimble PROXRS, 12 channel integrated GPS/Beacon/Satellite receiver with multi-path rejection technology. It has a rated horizontal differential correction accuracy of 50 cm + 1 ppm on a second-by-second basis. The system including the antenna weighs approximately 2 lbs. DGPS positions are provided to the wearable via a dual serial I/O pcmcia card using NMEA-0183 protocol. Reading from the pcmcia serial ports on the wearable is done using the Java Communications API.

- **Wireless network.** We use a campus-wide wireless network utilizing the 802.11b technology.

- **Ultrasound positioning device and location algorithms.** The ultrasound positioning device is offered by an OEM company, Hexamite, from Australia [17]. It harnesses ultrasound for high resolution high repeatability positioning. The best resolution can be within 0.3 mm. It can consist of an indefinite number of pilots and beacons to form a large system with the customized software. The device utilized in our system includes 4 HE900M pilots, 2 HE900T beacons and a RS485/RS232 converter. The two beacons are attached to the shoulders of the user using Velcro, as shown in Figure 3, to easily receive the ultrasound signals sent from the pilots and to provide not only position but also orientation. Figure 4 shows how the ultrasound positioning device covers the "smart house". In this system we choose to use 4 pilots that are mounted on the four corners of the "smart house" ceiling to provide full coverage of the house. The beacons on the user's shoulders can always receive ultrasound signals from at least two pilots at different positions. The flight time difference of the ultrasound signals is used to calculate the distance between the beacons and the two closest pilots.

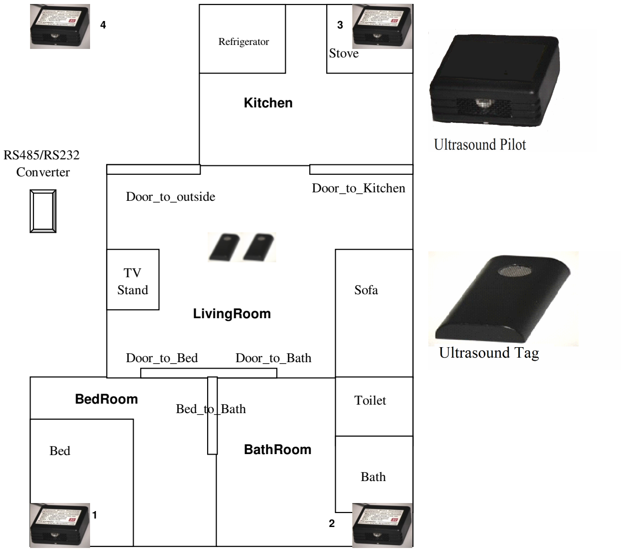

Figure 4. Ultrasound location system coverage of the Smart House

4.2. Software components

The software components of Drishti are briefly described below.

- **Spatial database.** ESRI's ArcSDE is a spatial database engine that acts as a gateway to manage GIS datasets on a relational database management system. We use Oracle 8i standard edition object RDBMS for Sun Solaris 2.8.

- **Route store.** Uses ESRI's NetEngine to define, traverse and analyze complex networks through a C API. We have wrapped the C API with Java Native Interface to access it from our mobile client that is implemented in Java.

- **Mapserver.** Uses ESRI's ArcIMS to serve the GIS datasets over the internet.

- **IBM ViaVoice.** The runtime and IBM's implementation of the Java Speech API are being used to provide spoken dialogue user interface.

- **Indoor location service.** The customized indoor location service software communicates with the ultrasound positioning devices using the Java communications API to get a distance string, parse the string to obtain the shortest distance between beacons and pilots, and then do some geometric analysis to provide the user with their location coordinates and orientation. The location error is within 22 cm, with the majority of position reads being within 10 cm of true location. The software files that perform this service are packaged into an Open Service Gateway Initiative (OSGI) bundle [18] to provide a generic service for location information so that multiple users can share the information simultaneously by registering to the service.

4.3. Indoor positioning algorithms

As stated earlier we use 4 pilots mounted at the four corners of the "Smart house" ceiling and two beacons attached on top of the user's shoulders. We get the person's location coordinates according to the simple geometric algorithm described in Figure 5, which is one of the eight cases of this algorithm to calculate the location.

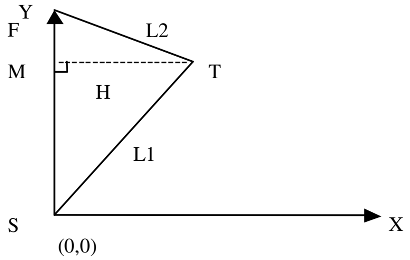

Figure 5. Location algorithm

For each beacon, we choose the shortest and next shortest distances, which identify the closest and next closest pilots to the beacon. Because a signal without any reflection always results in a shorter distance, the algorithm eliminates most of the reflection error. The other reason we choose 4 pilots is that even though at some positions, because of furniture or walls, the beacons might not receive signals from one pilot; there are always direct signals from at least two pilots to calculate the user's location.

In Figure 5, pilot S is located at the southeast corner of the smart house and is designed as the origin of ordinates. T represents one beacon that is attached to one of the cloth shoulders of the user. The shortest distance L2 is the distance from beacon T to the closest pilot F, the next shortest distance L1 is the distance from T to pilot S. We can get (TM, MS) as the location coordinates for beacon T. The middle point between the two beacons represents the location coordinates of the person. Because there are two beacons with their own IDs to identify the left and right shoulder, the user's orientation can also be calculated.

4.4. GIS database

The GIS database for our prototype consists of two parts. Part one consists of the AutoCAD data files for the campus obtained from University of Florida's physical plant division, which includes building locations, streets, walkways, parking, building plans, location of trees, fire hydrants, traffic lights and bike racks etc, and part two consists of the layers representing the centerline of walkways and layout of the smart house made using ArcView. These layers are used by the Route Store to generate optimal routes. AutoCAD data files were converted into GIS format before being loaded into the GIS database. The indoor layers are overlaid on the buildings that contain them in order to seamlessly track the user on the campus as they move between indoors and outdoors. Since the ultrasound positioning system is a relative positioning system with the southeast corner of the house as the origin of ordinates, an affine transformation is used to project the users location coordinates into the indoor layers. All the furniture and walls are pre-mapped out in the database. Non-stationary obstacles can be located at real time by attaching beacons on them, but this is part of our future work. For this current system we assume the furniture is stationary.

4.5. System architecture

We have developed an architecture to extend the outdoor version of Drishti [1] to a complete navigation system by integrating it with the indoor position tracking system. An indoor ultrasound positioning device is used to locate the user in the indoor environment. The only thing added on to the wearable load of the user is two ultrasound transceivers that are smaller than a credit card and can be tagged on to the user's shoulder using Velcro as depicted in Figure 3.

The architecture is displayed in Figure 6. The user communicates with the mobile client via the headphone and microphone using the commands defined in the system grammar, making queries about his/her location, asking for route and obstacle prompts.

The mobile client is implemented using Java 1.4 running on the Windows 98 wearable computer with the IBM ViaVoice runtime and the Java communications API installed. The Java COMM API is used to read the latitude/longitude locations of the user through the RS-232 serial port. When the user launches the mobile client, it creates a synthesizer object, a recognizer object and loads its customized grammar. The client contacts the server that supplies the client with a dedicated server-side proxy known as the client manager, which manages requests for information like optimal routes, current locations and spatial queries made on the database. The database can also be accessed by the various campus services such as the Police Department, the Traffic Department and the Physical Plants to provide them with the ability to insert and remove dynamic obstacles and monitor the campus for inputs added by individual users to maintain its veracity. When the indoor service is launched by a vocal command, for example, "indoor", the server will communicate with the *IndoorLocationService* to look for the user's current location.

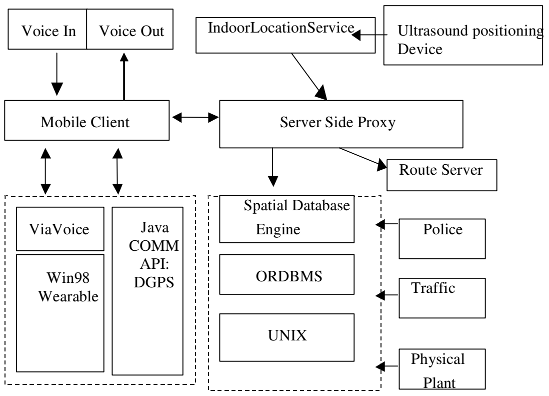

Figure 6. Integrated indoor/outdoor client/proxy/location server architecture

Let's look closer to understand how the *IndoorLocationService* works. Figure 7 illustrates the scheme of this service. The customized indoor location service software communicates with the ultrasound positioning device hardware through the RS232 serial port to get the distance string, parses the string to obtain the shortest distance between the beacons and the two closest pilots in *the Location.java*, then does some geometric analysis to provide the user with the location coordinates and orientation in *the Person.java*, which are the user's relative position information in the "smart house." These software files are packaged into the *LocationBundle*. The Person object is thrown as an Event with the coordinates and orientation twice every second to the *EventBroker* [18] bundle that has a thread listening to the event continuously once the Framework user starts the bundles. This *EventBroker* bundle acts like a middleman that receives the event and throws it out to its receivers. Any bundle that has registered to the *EventBroker* can be a receiver to grab this event. In our case the *LocationServerBundle* gets the location information and communicates with the Drishti server that we talked about above in Figure 6 using UDP. Then the Drishti server will manage the user's request or go to the database if needed. Multiple users can share the information simultaneously by registering to the *EventBroker*. This is the beauty of this location service.

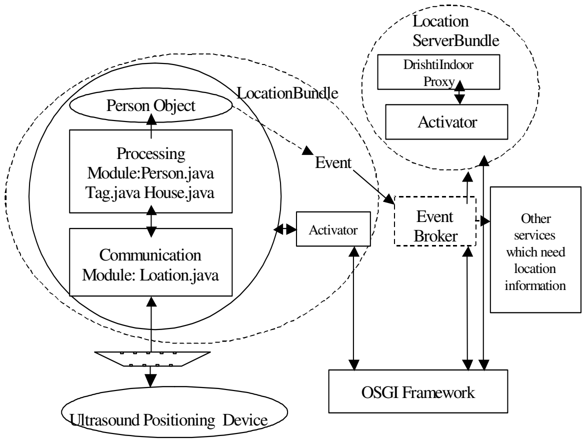

Figure 7. Indoor location service consists of three bundles: Location bundle, Location Server bundle, and Event Broker

5. Data analyses

We have made many test runs with this integrated system. To avoid reading errors we use a stationary model "Matilda" for the location error testing. Marking the ground directly below the beacon positions on the user's shoulders and measuring these positions with a metric tape we derive the actual X and

Y positions of Matilda. Different locations are chosen for multiple tests that are thought to produce the least accurate results, for example, a place close to furniture, walls or pilots. The actual error of 22 test cases is within 22 cm with 12 cases falling within 10 cm of true position as depicted in Figure 8 [19].

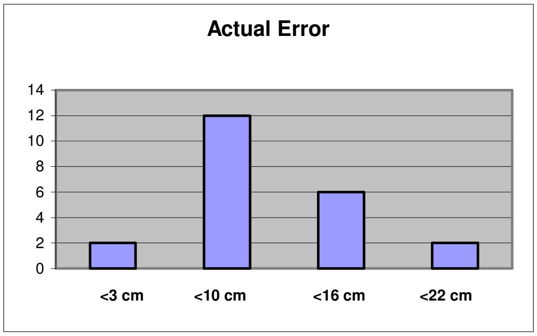

Figure 8. Actual error of indoor location tests

Ultrasound pulses are subject to environmental influences. We did several tests under normal indoor disruptive sound producing activities such as talking, yelling, radios playing, keys jingling, etc. Keys' jingling is the only case that makes the system unstable because it produces the highest frequency sound that can interfere with the ultrasonic signal produced by the system. Although our location algorithm relies on the shortest and next shortest distance between pilots and target beacon that are calculated according to the signal travel time, there are still some cases such as signal reflection from walls or furniture that cause the distance to be calculated longer than actual and may result in a larger error.

6. Limitations

The current system has two limitations. Because there are only two beacons attached to the user's shoulder, it is impossible to get the height information of the user. The algorithm we used to calculate the location is for two-dimension using the average height of a person, which results in bigger error if the user sits or lies down. Another issue is that we only use 4 pilots to cover the "Smart House." Because the signal may be reflected or blocked by furniture and walls, there are some "dead spots" that have bad data reads. This problem can be fixed by adding more pilots in each room to provide better coverage. The small cost of adding more pilots and beacons makes this expansion very practical.

7. Summary and future work

We developed an integrated indoor/outdoor navigation system for the visually impaired. Our design exploits some COTS software and all COTS hardware and provides a hands-free travel and living convenience to the blind and visually impaired user. Most systems that have been developed so far lack the dynamic interaction, the adaptability to changes and the comprehensive service coverage (both indoor and outdoor) that Drishti provides to the user. We emphasize the functionality of this navigation system to augment a visually impaired pedestrian's experience with sufficient information to make him/her feel comfortable traveling in both familiar and unfamiliar environments, both indoor and outdoor. In the indoor mode, because this system is bundled as an OSGI service, the location information can be shared by Drishti as well as by other services.

The working range of this system depends on the coverage of the wireless network. To give the user a greater traveling range without the cost of wireless network installation, we plan to employ a mobile phone as a substitute for the wearable client computer to communicate with the server. This will also ease the burden of the user by replacing the wearable computer and headset with a small cellular phone. This system may also be augmented to 3D measurement in the indoor environment by adding more pilots at the different height level of the house and putting more beacons at different part of the user's body to get the more information about the position of the user, including standing, sitting, bending, and lying to detect falls and provide emergency assistance. Also we are implementing the system so that Drishti is aware of when the user is indoors or outdoors based on the available positioning service so that the user does not have to explicitly switch modes.

8. Acknowledgment

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