Drishti: An Integrated Navigation System for Visually Impaired and Disabled[†]

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Abstract

Drishti is a wireless pedestrian navigation system. It integrates several technologies including wearable computers, voice recognition and synthesis, wireless networks, Geographic Information System (GIS) and Global positioning system (GPS). Drishti augments contextual information to the visually impaired and computes optimized routes based on user preference, temporal constraints (e.g. traffic congestion), and dynamic obstacles (e.g. ongoing ground work, road blockade for special events). The system constantly guides the blind user to navigate based on static and dynamic data. Environmental conditions and landmark information queried from a spatial database along their route are provided on the fly through detailed explanatory voice cues. The system also provides capability for the user to add intelligence, as perceived by the blind user, to the central server hosting the spatial database. Our system is supplementary to other navigational aids such as canes, blind guide dogs and wheel chairs.

1. Introduction

The main motivation behind this navigational system is one of the author's fathers; Dr. Theral Moore is blind from a young age. He is currently an Associate Professor in the department of Mathematics at the University of Florida. He specializes in Topology and Number Theory. He no longer has any sight and cannot even detect light. It is our belief that recent advances in technologies could help and facilitate in the day-to-day operations of visually impaired and disabled people.

The focus of this paper is navigation aid for the blind and disabled. Our work can be easily extended to support multiple applications such as routine building maintenance by physical plant crew, emergency response system and tourist campus guide. Commuting in a crowded environment for the blind is much more challenging than for a normal person. Even for the sighted person, navigating in an unknown environment requires some form of directional clues or maps to reach their destination. The blind person is at a disadvantage, as one does not have access to contextual information and spatial orientation of immediate proximity.

For navigation, the knowledge structure typically used by the blind is a mixture of declarative and route knowledge [11]. Often the blind has to rely on repetitive and regular routes with least obstructions for their daily movement in a predefined area of the campus. Still these routes are not free from unexpected hazard or obstacles such as puddle of water, wet walkway after a rain event, groundwork sign placed by work crew and broken tree limb. To a certain extent, traditional navigation aids like long canes and blind guide dogs provide assistance in such scenarios. Even such aids cannot detect overhanging broken tree branches to prevent from accidents occurring to the blind person. Further the biggest hurdle for blind and disabled is to travel distant unknown or dynamically changing environments. A school like UF with constant athletic and special events requiring detours and road blockades, can be characterized as a dynamically changing campus. The goal of our work is to provide adaptive navigation support in such environments.

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Advances in wearable computing, voice recognition, wireless communication, GIS and GPS have made possible to address the visually impaired and disabled navigation problem. Our work is closely related to augmented reality and user interfaces. In augmented reality, the user's real world experience is supplemented by virtual world [17]. In our case the virtual world is modeled through a GIS database. The user's context with respect to his current location, obtained by GPS, is provided dynamically from this spatial database. Most of the application interaction occurs through voice interface for the blind and visual interface for the disabled. The main emphasis in this project is functionality of the system. Currently design issues like hardware miniaturization and power consumption are not addressed. In the remainder of the paper we discuss related work in section 2. The problem domain is explained in detail in section 3. Section 4 describes the system architecture and implementation issues. Finally in section 5 we present our conclusions and future anticipated work.

2. Related Work

Initial efforts in augmented reality dealt with see-through head mounted display for assistance in applications like aviation, surgery, maintenance and repair; building restoration work and parts assembly [8, 18]. The common feature of all these applications is some sort of precise tracking. Further, such applications are usually restricted to small operating zones and tethered to a fixed network.

In 1991, Golledge et al; were the earliest to propose the use of GIS, GPS, speech, and sonic sensor components for blind navigation in a progress notes on the status of GIS [11]. MOBIC, is a GPS based travel aid for blind and elderly. It also uses a speech synthesizer to recite the predetermined travel journey plans [13]. This test prototype is implemented on a handheld computer with preloaded digital maps and limited wireless capabilities to get latest information from a remote database. A similar system was implemented by Golledge et al; using a wearable computer [10].

Other terrestrial navigation support using augmented reality is developed for the sighted people. Metronaut, is a CMU's campus visitor assistant that uses a bar code reader to infer its position information from a series of bar code labels placed at strategic locations of the campus [16]. Similar kind of systems are developed by researchers in which current position of the user is used to overlay textual annotation and relevant information from their web servers to coincide with the image captured through their head mounted display [8, 18]. Smart Sight, the tourist assistant developed by Yang et al; is a slight variation to this approach. It gives user multi-modal interface, which includes voice, handwriting and gesture recognition [20].

Attempts are also made to use computer vision techniques for outdoor augmented reality applications. Behringer et al; have developed a system based on the use of horizon silhouettes for precise orientation of camera to the user's view [2,3]. This approach is more applicable to natural terrain environments. Similar approach is used for registration in urban environment with the exception that the line of sight is registered by comparing the video frame or digital image with a 3D virtual GIS model [5, 6]. The main breakthrough of these augmented reality applications is that it covers larger footprint.

Indoor navigation systems are also developed using similar concepts. Since GPS does not work inside a building, most systems rely on relative positioning using sensors such as active badge, digital tags, accelerometer, temperature, photodiodes and beacons [7,9,12, 15]. The People Sensor, an electronic travel aid for the visually impaired, uses pyroelectric and ultrasound sensor to locate and differentiate between animate and inanimate obstruction in the detection path [14]. Image sequence matching methods are also used to give real-time positioning. This approach involves a set of trained images for each location. The image captured from the head mounted camera is compared against the trained set to give user context and location information [1].

Computer vision techniques show promise for real time positioning and tracking. However, in practice there are many constraints that must be satisfied for such systems to work. Image registration techniques work only in perfect environmental conditions. Most related work stated so far deals in situations with user having unobstructed view of the target object. Right amount of lighting and weather of the day are a prerequisite for such techniques to work in outdoor. In indoor navigation using such systems, very few have addressed issues such as what happens when a light bulb is fused, the intensity of bulb goes down or other people sharing the corridor partially obstructing the user's views. Most of them are standalone systems putting substantial amount of load over the network. Generating image training set for each location of the building and various conditions is a monumental task by itself. In applications using registration with virtual 3D models, accurate positioning and camera orientation is required, which is difficult to achieve. Also, it is observed that sensor-based approaches are more ideal for the indoor than for outdoor navigation.

One major limitation in all systems discussed so far is the lack of dynamic query capabilities and support for dynamically changing environment. Also, context awareness is not well supported. The term context awareness as applied to mobile location services is related to delivering location-specific information like building names, and traffic description within the vicinity, general weather reports for the area etc. [4]. In our view, contextual awareness is very important in navigating blind people. It provides the immersive experience needed to augment the "blank" reality of these users. Our main focus in this project is the development of a prototype that navigates blind and disabled people in dynamic outdoor environment, while providing contextual awareness during the navigation process.

3. Problem Domain

When people walk from one place to another, they make use of several different inputs. When a visually impaired person walks from one building to another on campus, he would lack many useful inputs. Our goal is to develop a system to augment a visually impaired person's pedestrian experience with enough information to make them feel comfortable on a walk from one location to another. A map of the study area of the University of Florida (UF) campus is shown in Figure 1. For brevity and clarity only major layers of our GIS database and only a portion of the study area are shown. The study area covers about one fourth of the actual campus. To evaluate the efficiency of the prototype, it was made sure to select an area to include various scenarios such as crowded walkways, close buildings, services etc.

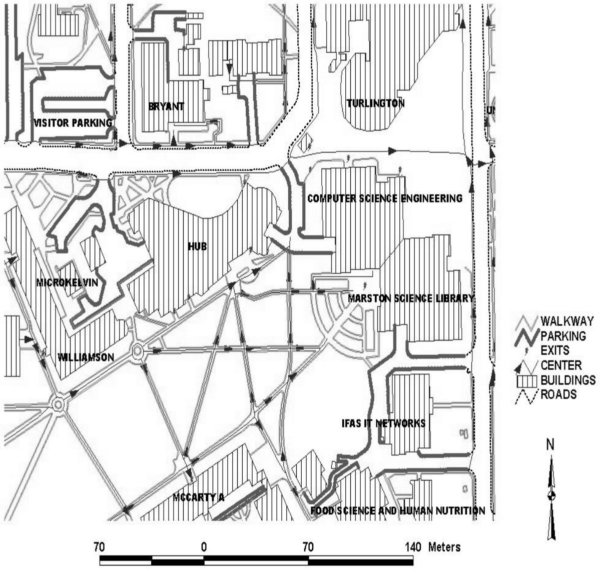


Figure 1. Spatial layout of the study area

The prototype was designed based on Dr. Theral Moore's input and reviewing literature on user requirements for blind. One of the key requirements is to deliver the information along the blind person's path in real time through auditory cues. For example, a visually impaired individual might like to be standing anywhere on campus and ask where is the mathematics department. With the user's current position a vocal map highlighting a route to get to the appropriate building should be presented. As the person travels along this route they could be aided in their quest. Further, such system should be capable of generating routes preferable to the user.

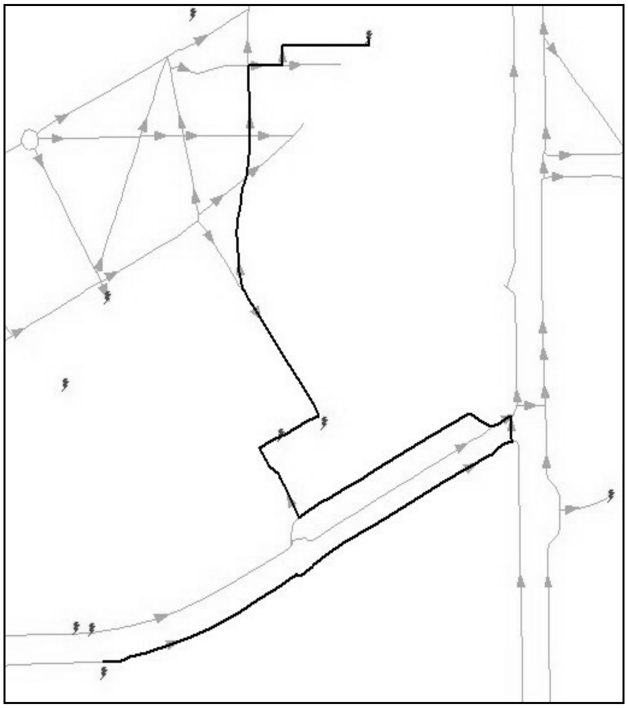


Figure 2. Path generated by route manager based on user's preference

Most route selection algorithms usually provide the shortest path. Often for a blind user shortest path to the destination is not the best route. The best route is the one with the least hazard. To illustrate further, in Figure 2, the best path generated by our prototype Route Manager (Refer to section 4 for details). The blind person is required to commute a segment of the path almost twice to avoid a crossover of a busy street and bike lanes. This may not be a major issue with the disabled person. The user should also have the preference of avoiding congested walkways at a particular time of the day. Figure 3 shows a sample voice prompt summarizing the journey. Such prompts include landmark information and warnings about potential hazards in their way. The system will warn the user when approaching a building whether a ramp or stairs need to be used to enter the building.

In addition to generating routes, the users need to be guided along the path within the walkway width. The path buffered to the walkway's width is as shown in Figure 4. There will be situations when the user changes his mind and needs to be re–routed. In such cases the system must be capable of taking user's current location and re-route to his new destination. A similar scenario is depicted in Figure 5. After a blockade for a special event, the user is re-routed to the same destination through an alternate path.

- **Starting from Computer Science**
- Turn left on to Hub Walkway 2
  - Travel on Hub Walkway 2 for 79 feet
- Turn left on to Stadium Road Walkway
  - Travel on Stadium Walkway for 225 feet
- **Turn left into stop #2**
- **Starting from stop #2**
- Turn right on to Stadium Road Walkway
  - Travel on Stadium Rd. Walkway for 225 feet
- Continue straight onto Hub Walkway
  - Travel on Hub Walkway for 81 feet
- Turn left onto Black Hall Walkway
  - Travel on Black Hall Walkway for 111 feet
- **Turn right into Mathematics**

Figure 3. Visual display of auditory cue

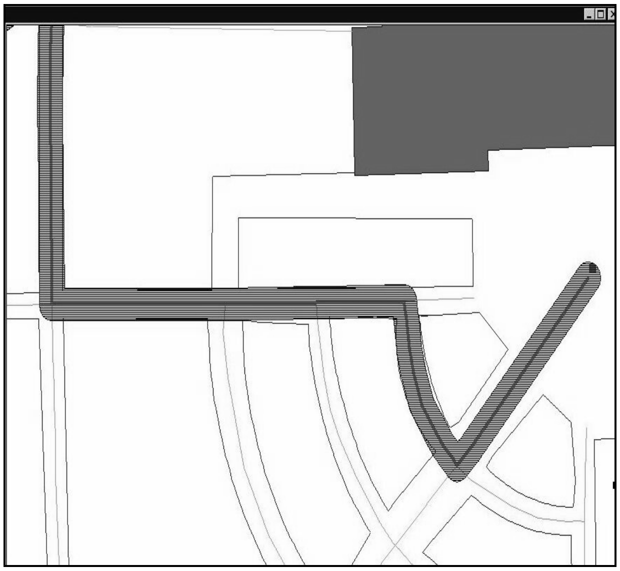
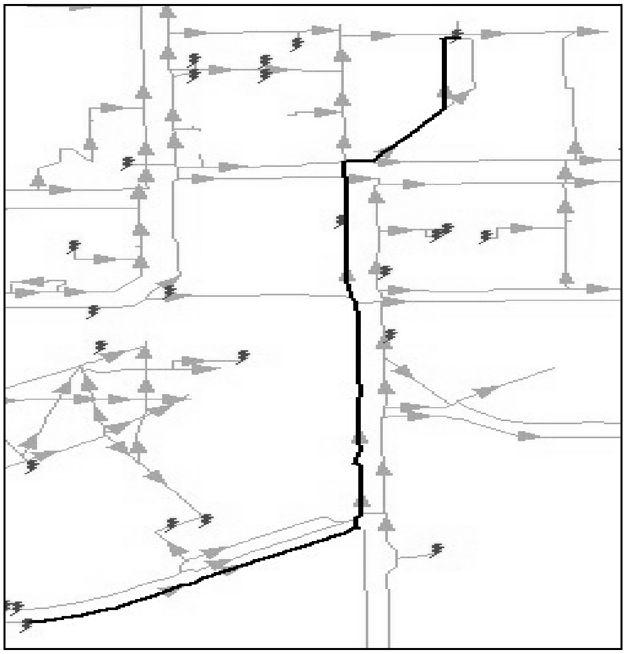
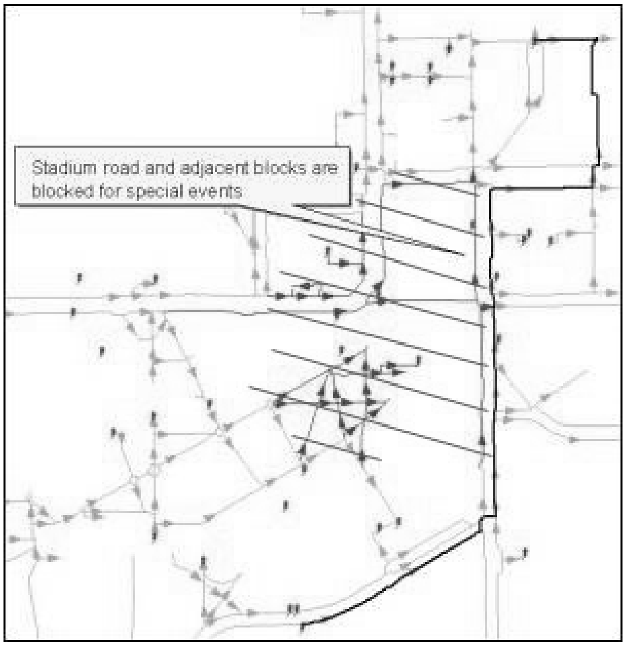


Figure 4. Path buffered to walkway width

In some situation the user prefers to add notes about certain conditions encountered. For example, the walkway has a pothole. This information should be used to warn the user appropriately next time when he uses the same path or the concerned authorities should fix the problem. In the same fashion the blind user when lost or has a sudden emergency need to be contacted by police and paramedics.



(a) A simple path without any obstacles



(b) The path re-routed after a special events blockade enforced to a portion of the campus

Figure 5. Dynamic path re-routing

4. System Design

In designing our prototype we made use of Commercial-Off-The-Shelf (COTS) hardware and software. This helped us in focusing on the functionality of the system. Our prototype weighs approximately 8 lbs, which we believe most blind and disabled persons can carry. The backpack is designed in a way to distribute the load evenly.

Figure 6 depicts a user (Steve) using the Drishti prototype on a test run. The wearable computer along with the GPS receiver and electronic compass are placed in the backpack. The user wears the head mounted display for visual tracking (disabled) and the integrated headset for speech I/O (blind).

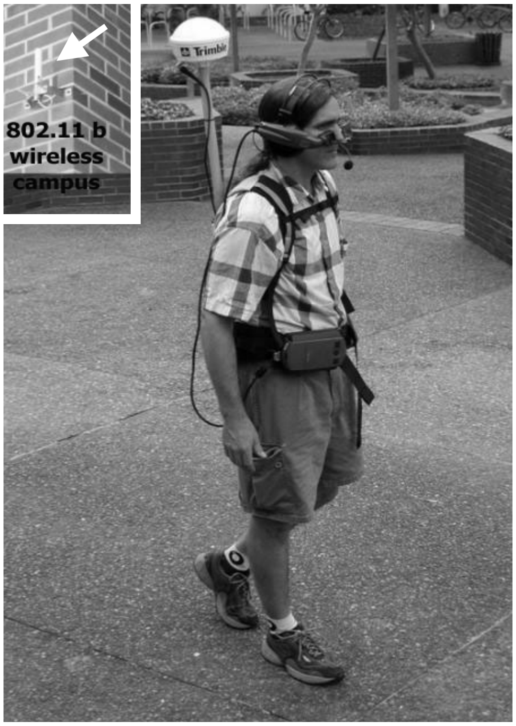


Figure 6. Wearable mobile client

We describe the hardware and software components of the system, and then we give the details of the system architecture.

4.1 Hardware Components

Wearable computer: Our wearable computer, which is shown in Figure 6, is a Xybernaut MA IV with a Pentium 200MHz processor, 64 MB main memory, 512 KB L2 cache, 1MB Video RAM, 2.12GB hard drive, 2 PCMCIA slots, 1USB port, Full duplex sound card, VGA Head mounted display, ANC 600 Pro monaural headset, two button built- in pointing device, MS Windows 98 operating system, and weighs 1.75 lbs. The built-in mouse option for tracking on display is retained for disabled client.

Differential GPS (DGPS) receivers: We are using 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 + 1ppm on a second-by-second basis. These values are applicable for environments with clear view of sky. It has RTCM SC – 104 standard format input for real time differential correction and NMEA-0183 output. The system including the antenna weighs approximately 2 lbs. An Electronic compass also provides input to the system via serial port using the same NMEA-0183 protocol. Using a dual serial I/O pcmcia card provides two serial ports. Reading from the serial ports is done using the Java Communications API.

Wireless network: We used several wireless network connections through the different test phases of this project. We used the 802.11b wireless LAN technology providing 11Mbps bandwidth. The advantage of 802.11b is that it is easy to port and setup for demo purposes (e.g. in conferences and similar meetings). We have used 9600 bps GSM circuit switched connections requiring an Ericsson phone and a PC-card. Of late, we acquired iDEN wireless packet data phones from Motorola offering 40 Kbps raw data rates. We will continue our development using the iDEN packet data technology. Eventually, a campus-wide, outdoor wireless network utilizing the 802.11b technology will be the network of choice for the users of our prototype. Omni antennas connected to 802.11b access points are currently being deployed in the UF campus (see Figure 6, upper-left corner).

4.2 Software Components

Spatial database: ESRI's ArcSDE, is a spatial database engine, which acts as a gateway to manage GIS datasets on a Relational Database Management Systems (RDBMS). In our case, we have used Oracle 8i standard edition object RDBMS for Sun Solaris 2.8. Until recently most GIS systems were file based systems with limited multi-user capabilities. ArcSDE has its own Java API, which came in handy for our development purposes.

Route Store: It uses ESRI's NetEngine to define, traverse and analyze complex networks through a C API. It provides a special memory management module to represent networks larger than the virtual memory available on a particular computer. We have wrapped the C API with Java Native Interface to access it from our mobile client, which is implemented in Java.

Mapserver: It uses ESRI's ArcIMS to serve the GIS datasets over the Internet. It has both client side and server side components. The user has the option of using an HTML or a Java client viewer.

IBM's ViaVoice: The runtime and IBM's implementation of the Java Speech API are being used to provide a spoken dialogue user interface. This involves text-to-speech synthesis, voice recognition and the design of a dynamic recognition grammar. Figure 7 shows a sample spoken dialogue interaction between the system and the user, Theral in this case.

Theral > "where can I go"
Drishti > "known buildings are", "Little", "Music", "Tigert"
Theral > "more"
Drishti > "Computer Science and Engineering", "Matherly"
Theral > "departments"
Drishti > "known departments are" , "Mathematics", "Journalism"
Theral > "more"
Drishti > "Computer Science", "Forestry", "end of list"
Theral > "Stop"
Drishti > "ok"
Theral> "from here to computer science"
Drishti > "ok from here to computer science"
Theral > "yes"
Drishti > "one moment please"

Figure 7. User browses list of available destinations

4.3 GIS Database

The GIS dataset for the campus was obtained from UF's physical plant division (UFPPD) [21]. The architecture and engineering department of UFPPD provides services for renovation, remodeling work and new constructions. Scale of the dataset is a critical factor in blind navigation. Datasets with detailed information is required. If possible, a scale of 1:1 is the most appropriate one. The scale of the datasets was 1: 1200. For most planning application it is a very good scale. In any GIS related project about 80 percent of the time is dedicated to data collection. So at the present time we are evaluating the UFPPD datasets and if deemed appropriate a new set will be created. The dataset included building location, streets, walkways, parking and building plans. AutoCad data files were converted into GIS format before being loaded into the GIS database. These layers became the base layers for our prototype. Other layers, which are vital to the project, to name a few, such as location of trees, fire hydrants, utility poles, bike racks, steps, traffic lights etc were mapped using DGPS.

We restrict navigation to be confined within walkways. For this purpose the centerline of walkways were digitized to create a new layer. This layer is our network layer used by the *Route Store* to generate travel paths. The datasets were ground truth for both descriptive and spatial accuracy. It was found that the GIS layers had a systematic error of 2m (6.5 ft.). We are accounting for the error while determining the user's current location. Traffic congestion at each walkway for various periods of time during the day of a semester is calculated by monitoring traffic volume. These values are used as weight functions in route generation.

4.4 System Architecture

Figure 8 describes the client/proxy/server architecture of our prototype. The server manages incoming requests from Mobile Clients, through a server-side proxy known as the client manager. Each client manager acts as a gateway between the client it supports and the GIS database. The server and client manager were developed using Java. The proxy shields the mobile clients from the details and software requirements of server. This was important to keep the mobile client simple and to control its footprint. Client managers make spatial queries and add new spatial information via ESRI's spatial database engine's Java API. The GIS database is exposed to various campus departments such as the University Police, Physical Plant and Special Events, to provide them with the ability to insert and remove dynamic obstacles, and monitor the campus for inputs added by individual user for its veracity.

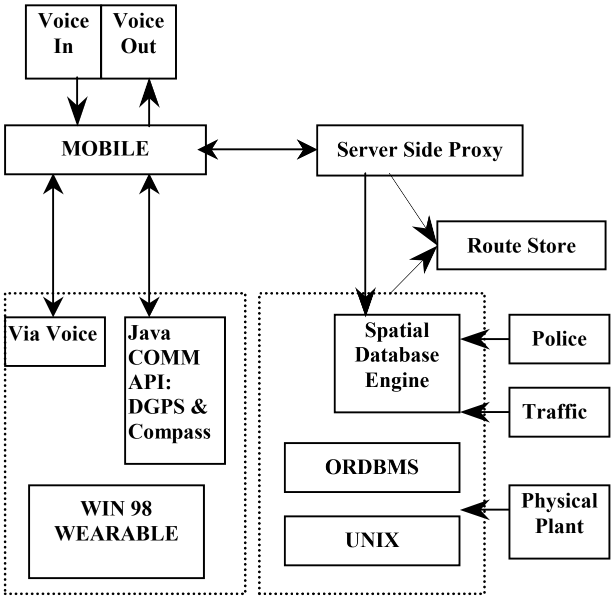


Figure 8. Client/Proxy/Server architecture

Taking a closer look at the architecture and component interaction on the mobile client in Figure 9, we see two inputs. Voice input is used to support a dialogue between the user and the system. The dialogue is controlled by a carefully designed rule grammar, parts of which change dynamically based on the contents of the GIS database. We say carefully designed since care needs to be taken not to commit to all matched rules without a subtle request for verification. Voice input results in requests that may be satisfied locally such as browsing the remaining part of a route or that will be satisfied by the server side client proxy such as computing and returning a new route, or adding personal feedback information about current location into the GIS. The result of query is returned to the user as voice using text to speech synthesis provided by ViaVoice. The other input shown in the figure is DGPS, latitude/longitude locations of the user that are read in through the RS-232 serial port. These coordinates are generated every second and represent an implicit query as to where the user is on their itinerary, what is upcoming, and if they have chosen, elements on their route such as buildings, trees will be augmented into their travel experience or memory by way of voice. This feature facilitates the user build in their mind a layout of the campus. In situations when GPS tracking is lost, we rely on dead reckoning techniques based on compass bearings and the users average speed of walking.

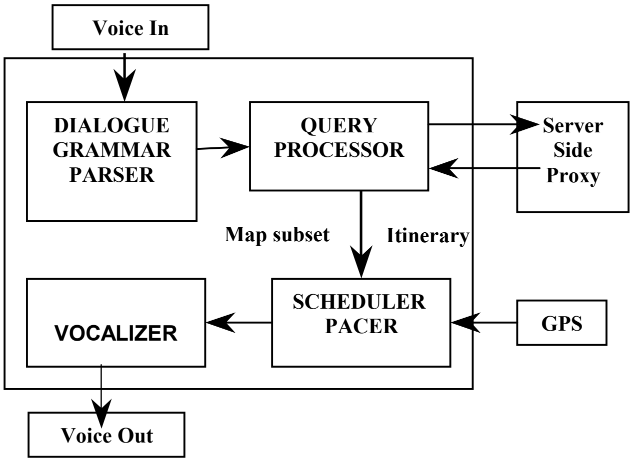


Figure 9. Mobile client components interaction

The mobile client is implemented using Java 1.3, running on Windows 98 wearable with the ViaVoice runtime and the Java COMM API installed. When the client starts up, it creates a synthesizer object, a recognizer object and loads its rule grammar. It then contacts our server, which supplies the client with a dedicated client manager to satisfy requests for information and spatial queries made on the campus database. The client updates its grammar as needed from the database, this is to help it recognize building names, department names, and other areas of interest when spoken by the user. The client then starts up a serial port listener to listen for DGPS coordinates. The client communicates with the client manager over UDP sockets.

The user has the option to be monitored by the server side client manager (one per user). In this case, the user supplies a "monitored" route request to the client manager. The latter will be continuously updated as to the last known location of the user. In cases where contact is lost with the user before reaching destination, the client manger is programmed with the appropriate action such as contacting a campus staff to go to the user's last known location armed with his itinerary to check if he needs assistance.

5. Conclusion and Future Works

We have developed Drishti, *meaning Vision in the ancient Indian language Sanskrit*, a wireless pedestrian navigation system for the visually impaired and disabled. Most systems that have been developed so far lack the kind of dynamic interaction and adaptability to changes that our system provides to the user. We also emphasize contextual awareness that we believe is very important to enhancing the navigational experience, especially for the blind user.

To augment this system we are exploring indoor navigation techniques. Currently our GIS database has building plans registered with the rest of the layers. This facilitates smooth outdoor/indoor navigational handoffs. Further these building plans have extensive information like fire exits, seat arrangement in a classroom, elevator location, stairs with number of steps etc., based on strict building codes. The indoor navigation module is still in testbed phase. We are evaluating various sensors for relative positioning inside the buildings. We would also like to explore the use of sensors to update pedestrian traffic levels to constantly monitor and update our database directly.

GPS is not a foolproof system; we loose track of signals near tall buildings and under tree canopies. At present we compensate such loss with dead reckoning techniques using magnetic compass, user's average travel speed and rules specified in the GIS database. In the future, we plan to incorporate GPS and GLObal NAvigation Satellite System (GLONASS Russian equivalent to GPS) receivers to take advantage of expanded satellite coverage. Studies in urban environment have shown very good position fix density by incorporating GLONASS [19].

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