RFID Information Grid for Blind Navigation and Wayfinding

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Abstract

We describe a navigation and location determination system for the blind using an RFID tag grid. Each RFID tag is programmed upon installation with spatial coordinates and information describing the surroundings. This allows for a self-describing, localized information system with no dependency on a centralized database or wireless infrastructure for communications. We describe the system and report on its characteristic performance, limitations, and lessons learned.

1. Introduction

Blind students are at a tremendous disadvantage when they arrive on a college campus, where they must somehow face the challenges of being an incoming freshman who can not find their classrooms, meet with academic advisors, or find the line to stand in during the professor's office hours to ask a question about homework. It is a daunting task that places an immeasurable burden on the hopes and dreams of a future productive member of our society. Even in an ideal academic setting in which a university has unlimited resources to minimize classroom challenges, the blind student will miss out on numerous educational and experiential opportunities outside the classroom. The following facts put the blind student dilemma into perspective and the challenges for our educational systems in the United States.

- Number of working age blind who are unemployed: 74% [1]
- Estimated annual cost of blindness to the US government: $4 billion [2]
- Lifetime cost of support and unpaid taxes for one blind person: $916,000 [3]

The problems in user location detection for the blind students are complicated by the challenges of resolution, accuracy, privacy, user orientation and reliability. This paper presents a solution to the problem of wayfinding for the blind. Our solution addresses the following challenging requirements:

- The user must be informed of their location in the room within the context of the room, or outdoors within familiar contexts such as intersections, bus stations, and buildings.
- The system should be able to report the location, distance and direction of items in the room such as office equipment, furniture, doors and even other users.
- It must be a reliable system that minimizes the impact of installation and maintenance to the building owner
- It must provide absolute location with no possibility of error from outside influences
- The system should not be obvious to an external observer
- The proposed solution should meet or exceed the standards proposed in the Principles of Universal Design [4].

2. Requirements and Design

An information grid based on passive, low-cost, High Frequency RFID tags is installed under the flooring and used to convey precise location and detailed attributes about the surrounding areas. In the university environment, RFID tags can be installed along outdoor pathways, in building hallways and in rooms. By storing all information in the RFID tags about the surrounding space, dependencies on a remote spatial databases is not required or the need for wireless infrastructure to support a connection to the database. The base RFID information grid can provide the foundation of precise indoor/outdoor location for the blind user, aid in automated navigation for electronic wheelchair users, and supports service robotics that can use the RFID tags to determine exact location.

The central computational system for the blind user should be based on commodity electronics such as advanced cell phones or a PDA that support Bluetooth and Java programming for application development.

The user sensor network is designed to run on Bluetooth using the Serial Port Profile (SPP) for wireless communication to wearable peripherals. To accommodate the blind and the visually impaired, an RFID reader from Skyetek is integrated into a walking cane and a shoe. The unit cost of each Bluetooth RFID combination reader is $170.

2.1. Indoor Navigation Infrastructure

A single passive RFID tag represents a single grid point in the system. Carpet manufactures could integrate the RFID tags as part of the weaving process or the RFID tags could be integrated into a thin layer of material that is applied under the carpet or hard surface flooring. Rooms that have existing carpeting could be easily upgraded by rolling up the carpet, applying the RFID flooring material and then reinstalling the existing carpet.

For pathways that provide travel from location-to-location such as sidewalks, hallways, stairs, etc. RFID tags can be located on the edge of the path. This allows for lower implementation costs because a grid is not required to indicate position. The path tends to be narrow and well defined that only a single line of RFID tags are required. The tags would indicate position and describe major locations such as building names, room numbers, bathroom locations, type of door and description of stairs.

2.2. Outdoor Navigation Infrastructure

To provide protection from the environment an RFID tag designed for the laundry industry can be used. The RFID tag is sealed in a small plastic enclosure with a diameter of 22 mm and is waterproof and heat resistance.

Outdoor campus navigation is primarily concerned with route information from origin to destination. This limits the amount of information that needs to be stored or conveyed to the end user and the density of RFID tags to established routes. When a sidewalk is bordered by grass the RFID tag can be installed along the edge of the sidewalk aligned with the sidewalk joint or crack serving as an indicator to the end user that a tag is located on the corresponding edge. The user would need to move the RFID reader over the edge to determine location and additional route possibilities.

The outdoor RFID tag could also be used in metropolitan areas to indicate location, surrounding street names and addresses by mounting to the sidewalk or any road surface.

2.3. Room and Path Mapping

Once the grid or path of passive RFID tags is installed, a space survey is done to determine the precise coordinate of one reference RFID tag in the space. The features of the room are located based on this fixed anchor. With a layout and description of the room, each RFID tag is then programmed with position information and descriptions of objects in the room. The storage capacity of the RFID tags is limited so a uniform method to describe room attributes as they relate to the location of the RFID tag is required. RFID tags located in a traffic pattern leading to a door would provide information related to the door location, type of handle and opening direction. Storage of information in the RFID tags based on their location allows for a flexible system with absolute positioning, and at the same time, protects the privacy and location of the user because external links to a central database server are not required.

If detailed information about the room is available in a central system the smart phone can send a location query for a room based on current location. This information can then be used by location based software on the smart phone to provide value added services to the blind user.

2.4. RFID Technology Options

RFID covers a range of RF frequencies with specific uses based on the frequency and packaging. Passive RFID tags do not have a built in power source; they are powered entirely from the RF field produced by the RFID reader antenna. It is this close coupling which limits read range to 75-150 mm unless the RFID reader is using a very large antenna and strong RF signal. The High Frequency tags offer the advantage of storing up to 10K bits of data and are paper thin. The UHF tags have improved read range which is important in supply chain management and offers a substitute for the barcode with a 12 byte read-only identifier. The RFID tags selected for this project are manufactured by Texas Instruments and operate at 13.56 MHz in the High Frequency category with storage of 2000 bits and data retention time exceeding 10 years.

2.5. Mobile Software Platform

The Java 2 Micro Edition (J2ME) Mobile Information Device Profile version 2.1 (MIDP 2.1) was selected as the platform for software implementation to maximize the number of PDAs and cell phones that can be used and Bluetooth support for communication to peripherals. The SPP Bluetooth interface enables communication between the embedded devices via the serial port of the embedded device.

The Skyetek M1 and M1-Mini where selected as the RFID readers in this research because of their small size and integrated antenna. The specifications state that the read range of the M1 is 75mm with the internal antenna and 150mm with the EA1 external antenna. The M1-mini has a read range of 70 mm.

2.6. Data Encoding on RFID Tags

A variety of data formats and data elements can be achieved with 2000 bits of information storage per ID tag. At a minimum, each tag will store its world coordinates. Latitude and longitude can be used for long term data services and global positioning. The inventory of the room would be stored at tags concentrated near entrances to the room to enable discovery when the user enters the room. The position of objects in the room can be stored relative to the absolute position of the tag reducing the amount of data required to describe the location of the object.

To enable RFID-based localized processing and interpretation of sensed information of *any* object, a self-describing data representation is sought. XML could obviously be a strong candidate format. While XML will allow for maximum data flexibility, this will be achieved at the expense of very verbose and overly descriptive coding. With a limited storage of 250 bytes per tag, an XML format would not allow for maximum data storage.

A hybrid XML data format that uses dictionary tags to represent the data grammar of the system would provide a good compression rate in a hierarchal parent-child format. This format will be referred to as CML for Compact Markup Language. Allowing for a dictionary of 250 elements and occupying one byte can provide good compression and still allow for the verboseness and hierarchical structure of XML. If the dictionary exceeds 250 elements then the primary dictionary can be reduced to 0-127 and a two byte allocation could be used for dictionary values greater than 128 at the expense of an extra byte for dictionary values greater than 128. Data elements that do not contain a dictionary definition can use an ASCII representation.

The following XML represents a typical data set stored on an RFID tag and the non-white space length is 251 bytes. The CML format compresses down to a length of 117 bytes enabling approximately six room objects to be stored per tag with maximum flexibility in the type of data that can be stored.

```
<tag>
  <location>
    <latitude>1234.5678</latitude>
    <longitude>5678.1234</longitude>
  </location>
  <object type="chair">
    <positiontype="delta">10 10</position>
  </object>
  <object type="table">
    <position type="delta">10 -10</position>
  </object>
 </tag>
```

Further compression can be achieved by using Huffman encoding for variable length encoding based on the frequency of each data dictionary value. The XML tags used for open, close and attribute would have a very high frequency and would be reduced to a 2 bit value. The numeric characters 0-9 would also have a high frequency and would be reduced to a 3 or 4 bit value. Like the common dictionary in CML used to represent common objects the dictionary needs to be known in advance for Huffman encoding.

This dictionary would be based on a global tree structure common for all encodings reducing the need to store the Huffman dictionary on the tag. To evaluate the potential compression of Huffman encoding a sample XML doc was used that contains 14 objects and their position relative to the RFID tag. This XML doc was used to generate a Huffman encoding tree based on the frequency of the CML data bytes. This common histogram tree is then used to compress a series of CML data descriptions with the addition of one room object per iteration. A 14 object XML representation is 869 bytes and the CML size is 465 bytes and the Huffman encoded version of the CML file is 254 bytes. By using Huffman encoding it is possible to store on a single 250 bytes tag the latitude and longitude of the tag and the relative location of 14 objects in the room. The compression from XML to CML results in a compression ratio average of 1.83 with a standard deviation of .025. The compression from XML to Huffman encoding results in a compression ratio average of 3.31 with a .10 standard deviation. By using CML and Huffman encoding to represent an XML data structure it is feasible to store verbose flexible descriptions and locations of spatial objects.

3. Proximity Sensing

Knowing the location of objects in a room via absolute coordinates is an important design requirement. It is important to determine user orientation so navigation to the object can occur. In order to determine orientation or angle relative to the walking axes, the user needs to touch two points with a frame of reference to the user body. If the user sweeps left to right touching two points, the coordinates of the two tags can be used to determine the midpoint. The perpendicular to the midpoint would indicate direction and orientation.

The reading of the RFID grid should have minimal impact on how the user walks through the space. This creates a requirement that the tags must be read as quickly as possible, when the reader, which is attached to the shoe or walking cane, is moving. The command execution time for tag selection is approximately 140 ms and is required to issue any subsequent read commands.

It would not be practical to ask the user to walk in a manner that would allow the reading of only one tag every second. The primary design for the RFID tag in the retail industry is to read as many tag identifiers as possible in the shortest amount of time. The statement that 50 tags per second can be read at once refers to reading of the unique 8 byte identifier found on every tag. Once the 8 byte identifier or tag address is known, it is then used to issue commands directly to that tag. This fast read time and unique identifier can be used to determine location along a known path.

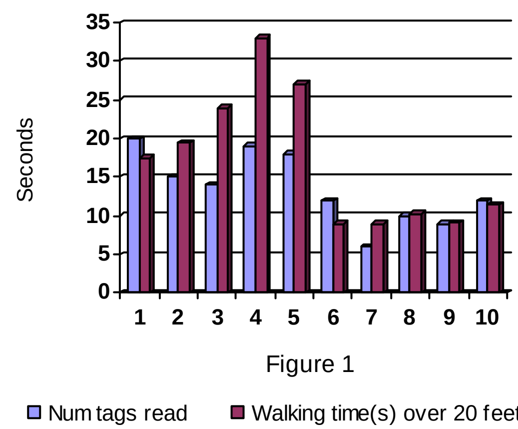

Figure 1

The graph in Figure 1 indicates the number of tag addresses read along a 20 foot carpet path with a 55mm x 55mm tag placed every 12 inches. The tags were placed on the bottom side of the carpet and no visual or audio indicators were provided when walking along the path. Before the first step is taken the RFID reader shoe is aligned with the first tag. This is used to indicate the start time while the last tag at the end of the path is read to indicate the stop time. Two walking paces were tested to determine the impact of a normal walking speed and a fast pace in reading of tags. The maximum number of tags that can be read along the path is 20, one per 12 inches. Read error is introduced by not walking a straight line because feedback is not given if a tag has been read.

The first group of five walking tests averaged 24 seconds with an average of 17 tags detected. The second group of five walking tests averaged 9.6 seconds with an average of 10 tags detected. The second walking group was at a quick pace so the difference of a 4 second time and 9.6

second time could be related to the standing start and stop time over a short distance. The initial results of reading a tag every two feet at a quick walking pace without any form of feedback is promising. Additional work needs to be done to integrate an antenna along the diameter of the shoe to improve the read range and coverage area. Results could also be improved by including an RFID reader in each shoe and the walking cane.

The 13.56 MHz signal from the RFID reader has the commands to that tag, modulated in the RF. The tag must then retransmit the response to the command on the same signal. If the command to read 10 bytes of data is issued, the tag must access its memory, retrieve the data and modulate it back to the reader. The response time will vary depending on the amount of data to be read. This has a direct impact on the amount of time it takes for the reader, which is moving, to have the tag in its RF field of view and get an accurate read.

The Skyetek reader has a limitation that influences read times. The microprocessor used on the reader has 80 bytes of available ram; the largest command it can send and receive is 80 bytes minus 16 bytes for command structure, which leaves 64 bytes of data. Therefore, reading 71 bytes of data requires two reads one for 64 bytes and one for 7 bytes. The overhead of issuing multiple reads does not appear to cause a major time penalty as we go from 10 to 252 bytes. To read 71 bytes takes 500 ms and to read 252 bytes takes 900 ms with the 140ms setup time to select the tag. After the RFID tag is found, the maximum read time is under one second and once this data is read from the tag, it can be stored as part of the application so that a full read in the near-future is not required using the address of the tag as a reference index.

4. Related Work

The High-Density RFID Tag Space [5] uses active RFID Tags on a grid density of 1.2 meters. Active RFID tags have a battery power source which allows for a stronger transmission signal but at a higher unit cost and long term maintenance.

Ross and Blasch, in 1996 and 1997 introduced the concept of Cyber Crumbs [6]. The Cyber Crumb concept centered around using a beacon at key locations along a path that could provide the user feedback on changing direction along a path. Comparisons are made of systems using GPS/Digital Compass, outdoor IR beacons, passive and active RFID systems and the Locust IR system developed at MIT Media Lab [7]. The GPS based system proved difficult because of the overall location readings varied by 25 meters and the negative impact of large metal objects on the accuracy of the Digital Compass. IR Beacons with a transmit range of 85 feet were tested to assist with blind users walking in the direction of the IR Beacon.

Drishti [8][9] uses a combination of DGPS for outdoor navigation and ultrasound positioning devices for indoor navigation for the blind. It targeted campus environments and aimed at providing precision navigation on “walkable” areas outdoors, and on supporting on-demand querying of proximity information.

5. Conclusion

The concept of setting up an RFID Information Grid in buildings is technically and economically feasible. The barrier to entry for this technology is low as a result of leveraging the commodity pricing and innovation in the retail sector. This permits the adoption of the RFID Grid to be localized in small businesses, large corporate parks, government buildings or college campuses. Our grid approach is based on mature technology and is economically feasible that we believe it could become an ADA mandate for all future building construction with demonstrated success on a college campus and other public/private venues.

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7. References

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