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# A Passive RFID Information Grid for Location and Proximity Sensing for the Blind User

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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. The system could be integrated into building code requirements as part of ADA (Americans with Disabilities Act) at a cost of less than $1 per square foot. With an established RFID grid infrastructure blind children and adults will gain the independence and freedom to explore and participate in activities without external assistance. An established RFID grid infrastructure will also enable advances in robotics which will benefit from knowing precise location. In this paper, we present an RFID based information grid system with a reader integrated into the user's shoe, which is connected to the user PDA or cell phone via a Bluetooth. An emphasis is placed on the architecture and design to allow for a truly integrated pervasive environment.*

***Keywords:*** Blind Navigation, Pervasive Information Grid, Proximity Sensing, Wearable Computing.

## 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 reduce the challenges in the classroom, the blind student will miss out on the numerous educational opportunities outside the classroom. The blind student should have the freedom and the ability to attend and find student meetings, meet friends at the Student Union for a cup of coffee, attend a rally on the political topic of the day, go to the gym for a workout or walk to the campus ice cream shop because they have a craving for chocolate.

The following simple statistics and facts put the blind student problem into prospective and set new priorities and challenges to our educational systems.

- The number of blind persons in this country is 1.1 million [1]
- The number of blind school age children is 57,425 [2]
- The number of blind seniors, 65 and over (3.5% of the population 65 and over) is 787,691 [3]
- The projected number of seniors who will be blind by the year 2015 is 1.6 million, and by the year 2030 is 2.4 million [4]
- The number of working age blind who are unemployed is 74% [5]
- The estimated annual costs of blindness to the federal government is $4 billion [6]
- The lifetime cost of support and unpaid taxes for one blind person: is $916,000 [7]

## 1.1 A Brief History of Location Sensing

The history of maps date to Babylonian clay tablets from 2300 B.C. and as man traveled maps became a critical resource in navigation and finding your place in the world [8]. As map making skills increased and man made technical advances there was a driving force for precision and the need to know the precise location of all things on the horizon. MIT developed LORAN during World War II to provide a method for planes to determine location in reference to a rotating RF beacon at a fix tower location. GPS became fully operational in December 8, 1993 and with a relative low cost hand held device a user could determine his location with an accuracy of 150 feet. With differential correction the accuracy increases to 5 meters. On May 1, 2000 the government turned off the introduced error in the GPS signal and increased accuracy to 4 meters [9]. GPS is a tribute to man's ability to answer the question of where am I and how do I get to the place I am going. With the innovation of GPS it has a few short comings that make it impractical as a primary location sensing device. It does not work inside buildings and the accuracy is greatly impacted by tall buildings in cities.

In 1994, the FCC decided that the cellular phones should have the ability to use 911 to identify and bring assistance to your location. The new E911service specifications were finalized in 1998. The FCC established a four-year rollout schedule for Phase II which would locate a caller with-in 50 to 100 meters including inside building, beginning October 1, 2001 and to be completed by December 31, 2005 [10]. Cell phone manufactures are integrating GPS chips into phones and cell phone carriers are working with varying techniques to triangulate position based on signal strength and cell location.

When the FCC set the mandate that cell phones should have the ability to report user location the industry began to think of ways to profit from this knowledge. From targeted marketing of advertisement to location based businesses it would open up the frontier of new opportunities. The FCC in an effort to protect the consumer made the location reporting an opt-in for the user for non-911 services. It may not be possible to provide value add services to the consumer with enough benefit to overcome the need for privacy and reach a critical mass for location based services. This assumes that the cell phone or device must report the location of the user to a central server to benefit from location based services. The first challenge is to develop a technical solution that allows a hand held device to determine location with an accuracy of 2 meters with minimal infrastructure costs, no error and minimal long term maintenance.

The problems in user location detection are complicated by the challenges of resolution, accuracy, privacy, and user orientation. The business motivation or the cost justification of implementing a complex universal location system does not appear to be positive. It is with these observations that a solution is proposed in this paper that addresses a single user group (the blind student population) as a starting point, from which solutions can be adapted to other groups.

## 1.2 Related Work

Numerous papers have been written on location sensing indoor using various forms of triangulation or signal strength pattern matching [11,12]. They each have an infrastructure dependency on RF transmitters that are subject to error based on changes in the space and multi-path reflection problems. In controlled environments results are good but it is difficult to detect error conditions which impact the reliability of the system for the end user.

The Smart floor [13 ] concept attempts to determine user identity using the biometric signature of a person’s footsteps. This approach has the advantage of not forcing the user to wear an electronic device for location detection. The big disadvantage is the dependency on a mechanical or pressure sensitive floor that can accurately detect pressure exerted from a user footstep with enough resolution to determine walking patterns of a single user. This system would need to be trained for each user and deal with variations in weight of the user, injuries and multiple users on the same cell location. The system claims 93% accuracy independent of the type of shoe the user is wearing but does not address the issue of false-positives when a guest enters the smart floor and the ability to determine that this is not a valid user. If location based services are provided based on particular user detection the system would need a way to deal with guest users who have a profile that is a close approximation to a know user. The trial was conducted with a single plate and with controlled instructions to the user to place their foot in the center of the tile. It is not practical to force the user to walk in the center of all tiles in the kitchen. This system is not practical to implement, has privacy issues and is subject to the accuracy of very complicated pattern matching algorithms. The approach does give insight into the use of the floor as a detection device.

The High-Density RFID Tag Space [14] 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 for each tag. The transmission frequency of the active RFID tags is 303.825 MHz which has good read range but the body blocks UHF frequency signals which requires two RFID readers, one on the right and one on the left. With each active tag transmitting its ID, the position of the user is determined by averaging the location of each tag detected. The transmitted ID of each tag is used to lookup the known coordinates of each tag. Determining position by the active RFID grid is only a portion of the research with the main focus on using Finger-Braille to communicate navigation commands to the Deaf-Blind user. The researcher was pleased with the results of determining location using active RFID tags. The issue of dealing with replacing batteries of the Active RFID tags, the per-unit cost or the installation and maintenance of the larger tags is not discussed. These design attributes makes it expensive and not practical to scale this solution beyond a test environment.

Ross and Blasch, in 1996 and 1997 introduced the concept of “Cyber Crumbs: Development of An Outdoor Orientation Infrastructure”, and “Cyber Crumbs: Subject Testing Indoor Orientation Aids” [15]. 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 [16]. 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. The users were required to wear a receiver on either their chest or head with an audio tone indicating that they were inline with the beacon.

RFID and Locust were used indoors to assist with navigation. Information was not provided on the type of RFID tags used in the test but it appears that one of the design goals was to detect the tag from a distance of six feet. At the time the size of the passive RFID readers were very large so a device was constructed to simulate a passive RFID tag that transmitted an RF signal. The antenna was integrated into the cane and using audio tone the user would walk towards the tag based on signal strength and then when in range of less than 10 inches the tag would be read for location information. An attempt to use active RFID tags was not successful because the metal studs in the walls propagated creating phantom signals that made it difficult to detect the location of the tags. It is difficult based on the paper to evaluate the validity of how the RFID tags were used to determine location.

The locust system was installed which consisted of IR transmitters located in the ceiling pointed to the floor. An IR receiver was placed in at the top of the head phone and when a user entered the circle of the beam audio instructions were given along the path.

Twenty visually impaired or blind users tested the system. The RFID system produced no fatal errors in navigation where the locust system produced three fatal errors. No reasons were given as to why the locust system produced fatal errors. Travel time was 30% less using locust versus RFID because the user did not need to find the RFID tag to read its information. The wide read range of the locust system made it easier for the user to navigate.

Drishti [17] uses a combination of DGPS for outdoor navigation and ultrasound positioning devices for indoor navigation. The problems and shortcomings of GPS or DGPS are well documented and when the user is view of a clear sky accurate position can be determined using DGPS. When the user has an obstructed view of the sky when walking around buildings or on a city street in New York City the multi-path routing of the satellite signals introduces an un-measurable error in location. For the blind user having an unknown or undetectable error in location at anytime can make the system difficult to use. Cell phones are beginning to come with integrated GPS which will reduce the size of the GPS hardware. Drishti utilized a large backpack with aerial receiver for correction data to correct for the introduced error in the GPS derived location. It may be possible to create a DGPS-like system by obtaining GPS correction data via the cell phone data network and eliminating the need for large DGPS hardware. The GPS location is still subject to undetectable error from obstructed view of the sky.

The other major shortcoming of GPS is that it does not work inside buildings. Drishti approached this problem by using an alternate measurement technology using ultrasound. The user is required to wear two beacons to receive ultrasonic signals from multiple transmitters mounted in the room. The system delivers accuracy but is also impacted by multi-path problems and blind spots that can introduce unknown errors into the location measurement.

The system also requires a wireless connection to the GIS database to determine the location of objects in the space. With a modern PDA it would be possible to move some portion of the GIS database to the local computing device to minimize the dependence on a wireless connection to the database.

## 2 Requirements and Approach

The blind or visually impaired user relies on familiarity with the environment and/or the aid of a seeing-eye-dog or assistant. The walking cane is the extension to the blind user’s ability to navigate familiar and unfamiliar surroundings. The visually impaired user tends to not rely on the use of a walking cane for navigation. These limitations make it difficult to explore or adapt to new surroundings. The location based system should be able to meet the following criteria.

- The user must be informed of their location in the room within the context of the room.
- The user must be provided feedback as to the current user orientation in the room.
- 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

In an effort to focus on meeting the above requirements, the use of infra-red badges [18] or RF transmitters [19,20] for triangulation have been eliminated as possible solutions. This leaves the smart floor as a potential solution to the problem [21]. It makes sense to design a solution with a set of grid points with locations that are known to the system. In today’s office environment the cost of adding additional networking cables and power to electronic devices is expensive. This focuses our approach further to using the floor as a location based information grid and in a manner that does not require power, wiring, or communication with a central system. The solution must add marginal cost to future floor manufacturing material and provide a relatively low cost upgrade to existing flooring. The solution must maintain the privacy of the user and at the same time deliver information that creates value to the end user. Meeting these design restraints forces a different approach to the problems in location sensing.

The RF-PATH-ID system should be small and non-obvious when worn by the user. We will leverage the computational power and integrated features of the cell phone/PDA. The RFID circuitry will utilize existing OEM boards from manufactures and will connect to the cell phone/PDA using serial or Bluetooth links. The RFID reader circuit board can be integrated into the shoe or walking cane. The antenna for the system is critical both in size and location. The goal is to have the system transparent to the outside observer and pervasive to the user.

The retail industry has made numerous innovations in the passive RF tag technology to solve the problem of inventory management and to act as a theft deterrent. The very same passive RF tag technology is proposed to be used to provide a low cost and flexible solution to the problem of blind navigation in a campus environment.

## 2.1 Indoor Navigation Infrastructure

The low cost nature of passive RFID tags and the characteristics shows promise to meet our design criteria. A single Passive RFID tag represents a single grid point in the system. If an accuracy of one foot is required this would add a material cost of 10 x 12 x $1.00 or $120.0 to a 10 x 12 foot room. Carpet manufactures could integrate the RFID tags as part of the weaving process or the RF ID tags could be integrated into a thin layer material that is applied under the carpet or hard surface flooring. For rooms that have existing carpeting the floor could be easily upgraded by rolling up the carpet applying the RFID flooring material and then reinstalling the existing carpet (Figure 1-a). For tile floors that represent a larger cost to replace it may be possible to insert RFID tags by removing the grout at tile intersection points and then reapplying the grout. Hardwood floors represent a larger installation challenge because of the inability to do an installation without impacting the visible surface.

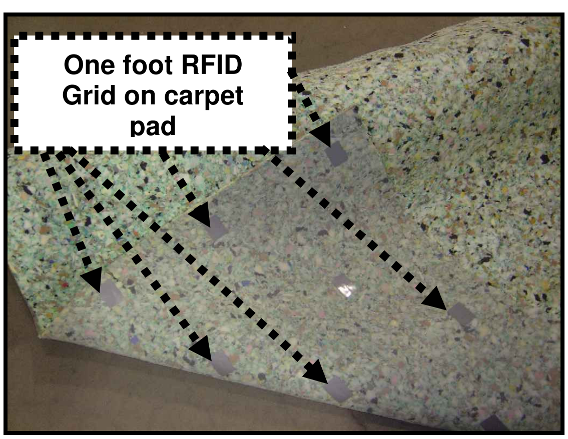


Figure 1 RFID Grid

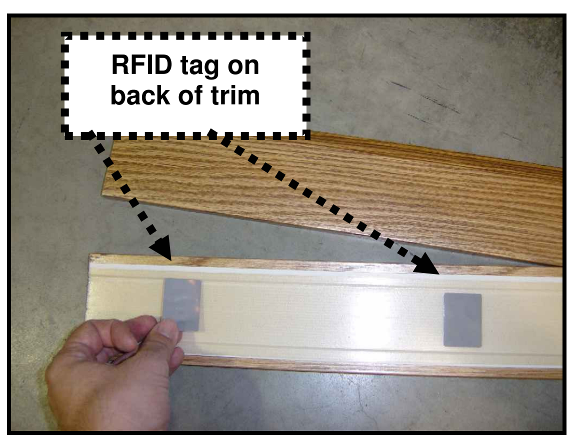


Figure 2 RFID on trim

For areas that provide travel from location-to-location such as sidewalks, hallways, stairs, etc. RFID tags can be located on the edge of the path (Figure 2). This allows for lower implementation costs because a grid is not required to indicate position. The path tends to be narrow and well defined so only a single line of RFID tags along the path are required. The tags would indicate position and describe major locations such as building name, room number, bathroom location, type of door and description of stairs. This would be a modern data extension of Braille and serve as a form of electronic Braille.

## 2.2 Outdoor Navigation Infrastructure

The laundry industry has developed an innovation RFID tag to allow the combination of laundry loads where each clothing item has a RFID tag placed in it. This way the clothing can be separated and sent to the proper customer at the end of each load. The RFID tag is sealed in a small plastic housing about the size of a quarter and is water proof and heat resistance. The use of the laundry tags in the outdoor environment provides a low cost and dependable solution against the harshness associated with outside installations.

The 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 location of RF-PATH-ID tags to established routes. The varying environmental conditions add a level of complexity to installation of tags. When a sidewalk is bordered by grass the RFID laundry tag can be installed on 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 (Figure 3, 4). The user would need to walk over the tag with the RFID reader 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 concrete sidewalk or any road surface (Figure 5). The RFID tag could be inserted into a housing that could be raised and a groove or slot in the shape of a triangle located on the top surface which would indicate the direction of 0 degrees or North (Figure 6). The user could touch the object with a cane or foot feeling for the direction of the slot for user orientation. The user would then be able to determine location and additional information from the RFID tag embedded in the object.

Figure 3 Outdoor RFID stake


Figure 4 RFID Stake at sidewalk


Figure 5 RFID tags at crosswalk


Figure 6 RFID Directional Marker

## 2.3 Room and Path Mapping

Once the grid of passive RFID tags is installed in the flooring a survey is done of the room to determine the precise location of one point in reference to the building or floor. The features of the room are located based on this one fixed point or anchor. With a layout and description of the room each RFID tag is then programmed with position information and feature description of objects in the room. The surveying costs are common to all implementations of systems attempting to implement location sensing. The storage capacity of the RFID tags is limited so a method to describe room attributes as it relates to the location of the RFID tag would be implemented. RFID tags that fall in a traffic pattern that leads 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 server are not required.

The end user would interact with the system by use of an RFID tag reader integrated into a walking cane, an attachment to a shoe or a hand held device. The user can quickly determine his/her location by passing over an RFID tag. To determine orientation the user would extend their foot or cane forward to neighboring cell which would provide relative directional information. This information can then be integrated with a PDA or smart phone via voice input as to the user location, orientation and description of the surroundings. 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 or a potential location in the future. This information can then be used by location based software on the PDA to provide value added services to the blind user.

This system would have immediate impact in the home and offices of individuals who are blind and does not require major infrastructure concerns before the system is practical to the average user. This gives a well defined starting point and a measurable impact to the quality of life of a single individual. With a practical and low cost solution it would be possible for the system to become part of future building codes and part of compliance with ADA rules and regulations. Solving the location awareness problems of the individual who can not see, provides a framework of future services for the general population, and robotic navigation.

## 3 System Design

The goal of this research is to enable blind students to navigate their way on a campus environment and to sense be more aware of their surroundings outdoor, on a building entrance or inside a classroom, a hall, a ballroom, a gym, or a laboratory. To achieve this goal we plan to focus our efforts to innovate and implement a cost effective indoor/outdoor decentralized navigation system for blind students using passive RFID tags.

- Provide an accurate, reliable, and privacy-preserving system that indicates user location and is self-describing of the local space.
- Leveraging advances in passive RFID tags developed for the retail industry will allow for a low cost and reliable system based on a grid design.

We have introduced the concept of using RFID tags as a method to locally store information about the environment where the information is relevant (in-place storage of location-based information). In the following, we discuss the specifics of the RFID tags, the data protocol for storing information and the user interface. We refer to the target system as the RF-PATH-ID system.

### 3.1 RFID Technology Options

RFID covers a range of RF frequencies with specific uses based on the frequency and packaging. Multiple manufactures have developed proprietary and standards based communication protocols. Passive RFID tags do not have a built in power supply; they are powered entirely from the RF field produced by the RFID reader antenna. It is this close coupling which limits read range to 3-6 inches unless the RFID reader is using a very large antenna and strong RF signal. Low Frequency tags because of the packaging requirements for the antenna are being phased out. 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 offer a one-to-one substitute for the barcode with a 12 byte identifier. The UHF tags are favored by Wal-Mart to be integrated into retail products.

| **RANGE CLASSIFICATION** | **LOW FREQUENCY (LF)** | **HIGH FREQUENCY (HF)** | **ULTRA HIGH FREQUENCY (UHF)** |
|---|---|---|---|
| **Frequency Range** | 120-140Khz | 13.56Mhz | 868-956Mhz |
| **Tag Data Size** | 8-32 Bytes | 8-10,000 Bytes | 12 Bytes |
| **Maximum Range** | 10 feet | 10 feet | 40 feet |
| **Typical Range** | 3-6 inches | 3 - 6 inches | 12 feet |
| **Anticollision (Tags that can be read at once)** | around 50 | around 50 | 200-1000 |
| **Tag Cost** | \$3-\$10 | \$0.50-\$5.00 | \$0.75 and up |
| **Tag Form Factor** | Very Sturdy<br>3D (not flat)<br>Variable Size | Sturdy<br>Flat or 3D<br>Variable Size | Sturdy<br>Flat Only<br>Restricted Size |
| **Typical Use** | Animal Tracking<br>ID Badges | Industrial/Scientific/Medical<br>Lead Retrieval Security | Retail Supply Chain<br>Management |

Figure 6 RFID Feature Matrix - Courtesy of Open Tag Systems [22]

The RFID tags selected for this project are manufactured by Texas Instruments and operate at 13.56 MHz in the High Frequency category. The TI tags support storage of 2000 bits or 250 bytes and come in a variety of sizes and form factors with a data retention time > 10 years. The larger the surface area for the tag antenna the better the read range. The cost of the TI ISO-RFID tag in quantity is around \$1 per tag with lower unit costs in the future as volume increase and manufacturing costs are reduced. The TI ISO15693 Transponder can be packaged as part of a label for quick installation or in a PVC or plastic housing for protection.

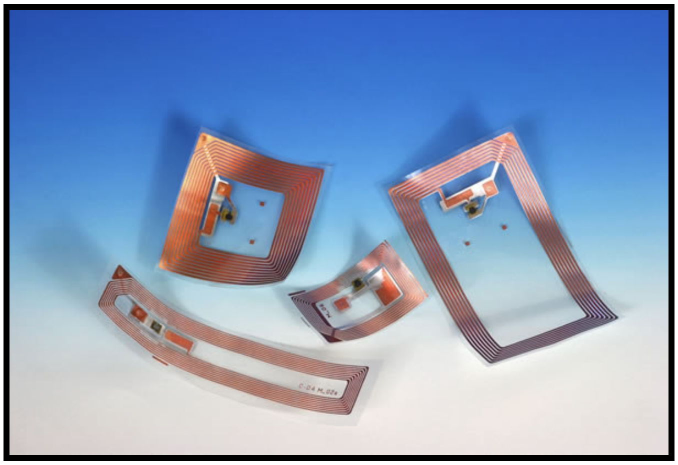

Figure 7 TI ISO15693 HF Transponder Inlay

Figure 8 TI ISO15693 Laundry Tags

## 3.2 Mobile Platform

MIDP 2.0 was selected for the software implementation to maximize the number of cell phone devices that can be used and that support audio voice prompts in the user interface. CLDC 1.1 is required as it supports floating point calculations which are required for calculating distance and direction. In MIDP 2.1, Bluetooth is supported which provides wireless communication to Bluetooth enabled devices. The SPP Bluetooth interface will be used to communicate with embedded devices via the serial port. The embedded device is unaware that serial communication is taking place via wireless.

## 3.3 RFID Reader

The Skyetek M1 and M1-Mini where selected as the RFID readers in this research because of their small size. Both boards come with a built in antenna that is integrated with the circuit board. The specifications state that the read range of the M1 is 75mm with the internal antenna and 150mm with the EA1 external antenna when reading credit card sized RFID tags. The M1-mini has a read range of 70 mm with the internal antenna.

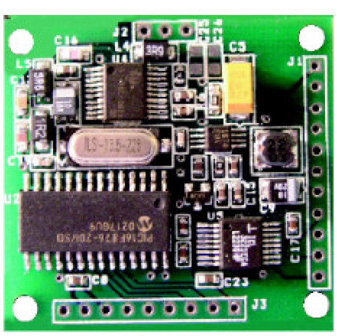

Figure 9 Skyetek M1 RFID Reader
40 mm x 38 mm

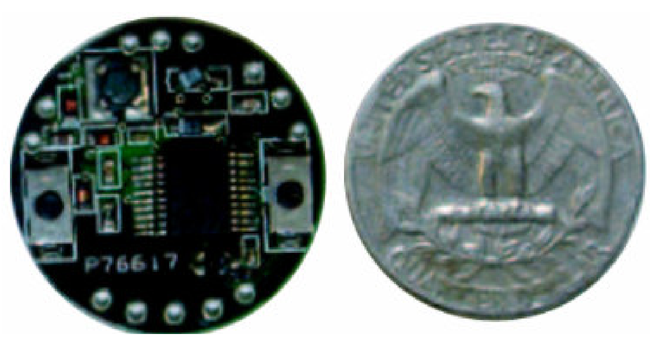

Figure 10 Skyetek M1-mini RFID Reader

Antenna design is a critical element of the system. To maintain accuracy the antenna should be in close proximity to the RFID tag so that absolute positioning is a result. The antenna can be integrated into the end of the cane with minimum gain. It is also desirable to have an antenna that allows maximum tags to be read for information gathering when entering a room. It may be possible to have two antennas integrated in the cane and switching electronically between the two depending on the application.

## 3.4 Data Encoding on RFID Tags

With 2000 bits of information of storage per ID tag allows for a variety of data formats and data elements. At minimum each tag needs its (X, Y) location. Latitude and longitude can be used for long term data services and global positioning. This may create an accuracy and survey problem and potential added expense when laying out tag locations. This problem also exists for a coordinate system that is accurate within a building. Using latitude and longitude still provides for accurate relative or local positioning.

We will investigate information-to-tags distribution schemes whereby detailed information about objects and artifacts in any location can be fully identified despite the storage limitation. We will exploit redundancy in storing key reference artifacts in a room at key locations. This will allow the RF-PATH-ID system to learn quickly about the position of major elements in the room. For instance, the room needs to have its inventory stored at tags concentrated near entrances to the room. The position of objects can be stored as relative to the absolute position of the tag that contains the information. This provides for conservation of storage bits by reducing the length of data that needs to be saved but still maintains resolution.

One design goal we have is for the system to allow for an independent and anonymous use. This eliminates the need for a central server to provide translation or missing information. It is also important to recognize that the future uses and objects to describe are unlimited which makes data formats and codes very important. To achieve such independence and to enable localized processing and interpretation of sensed information, a self-describing data representation is sought. This provides a clear indication that XML could 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, 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 allow for a good compression rate in a hierarchal parent-child format. This format will be referred to as CML for Compact Markup Language.

The following is a basic inventory used to describe common elements found in rooms that would aid for navigation. An exhaustive sampling can be performed to establish a dictionary of objects and then based on object population, an integer or id value can be assigned to it. For objects that are infrequent or not included in the initial inventory the text description of the object can be used without compression.

| OBJECT DICTIONARY | | |
|---|---|---|
| XML_VERSION | DOOR | GARAGE |
| DOC_TYPE_SESSIONMSG | WINDOW | GYM |
| DOC_TYPE_CLIENTMSG | WALL | POOL |
| VERSION | GATE | INFORMATION |
| TAG | FENCE | SINK |
| OBJECT | CHAIR | STOVE |
| TYPE | TABLE | COFFEE_MAKER |
| LOCATION | SOFA | MICROWAVE |
| DELTA | DESK | REFRIGRATOR |
| LATITUDE | BED | THERMOSTAT |
| LONGITUDE | CABINET | LIGHT_SWITCH |
| HEIGHT | BATHROOM | STAIRS |
| OBJECTID | KITCHEN | ELEVATOR |
| PATH | RADIO | COLOR |
| SIDEWALK | COMPUTER | TAXI |
| TV | PHONE | BUS |
| TOILET | VENDING | TRAIN |

Figure 11

This list is fairly descriptive with 51 elements. Allowing for a dictionary of 250 elements and occupying one byte can provide a 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. For data elements that do not contain a dictionary definition then the ASCII representation would be used.

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. This will allow for 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">
       <position type="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 could be reduced to a 3 or 4 bit value. Like the common dictionary to represent common objects needs to be known in advance the Huffman encoding would be based on a global tree structure common for all encodings. To evaluate the potential compression of Huffman encoding a sample XML doc was used that contains 14 objects and there position relative to the 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. From the graph 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 byte 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 standard deviation of .10. The compression ratio does not include the overhead of the CML dictionary or the Huffman encoding/decoding tree as these are common to all tags and stored once in the software application. 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 versus a flat data representation of the objects.

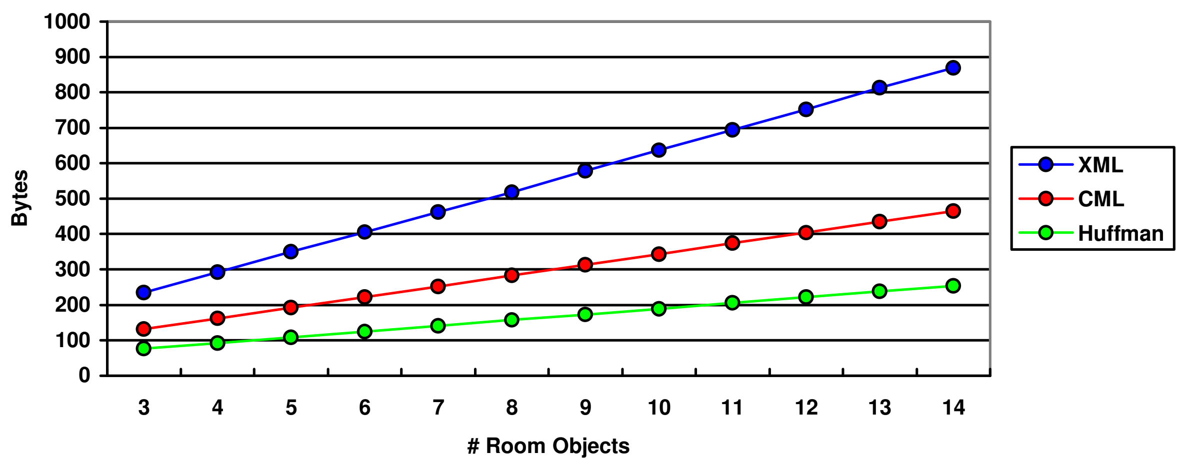


Figure 12 Storage requirement based on number of room objects

## 3.5 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. To determine orientation or angle relative to the axes the user needs to touch two points with a frame of reference of 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 of the two points. The perpendicular to the midpoint would indicate direction and orientation. Based on orientation the system can calculate direction and distance to objects in the room. The spacing and distribution of the tags will play a role in determining the accuracy of the system.

The reading of the RFID grid needs to 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 RFID tags are in a powered off state and must be charged in the presence of an RF field and the tag unique ID returned. The reader then issues a select command with the address of the RFID tag that indicates to all other RFID tags in the RF field that they should not respond to any of the following commands. This design allows for a large number of retail products or merchandise to be in close proximity of each other and one tag at a time can be read once an RF inventory is taken of all available tags currently located in the RF field. The command execution time to select a tag is approximately 140 ms and is required to issue any subsequent read commands.

The 13.56 MHz signal from the 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. Depending on the amount of data to be read the response time will vary. 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 a good read. The following graph shows the read times for four different size tags versus the amount of data to be read. No major difference could be detected between RF tags response time. The increased surface area helps with read range but appears to have no impact on response time. However, the larger the tag the bigger the read range which would make a difference on the read window for the moving reader.

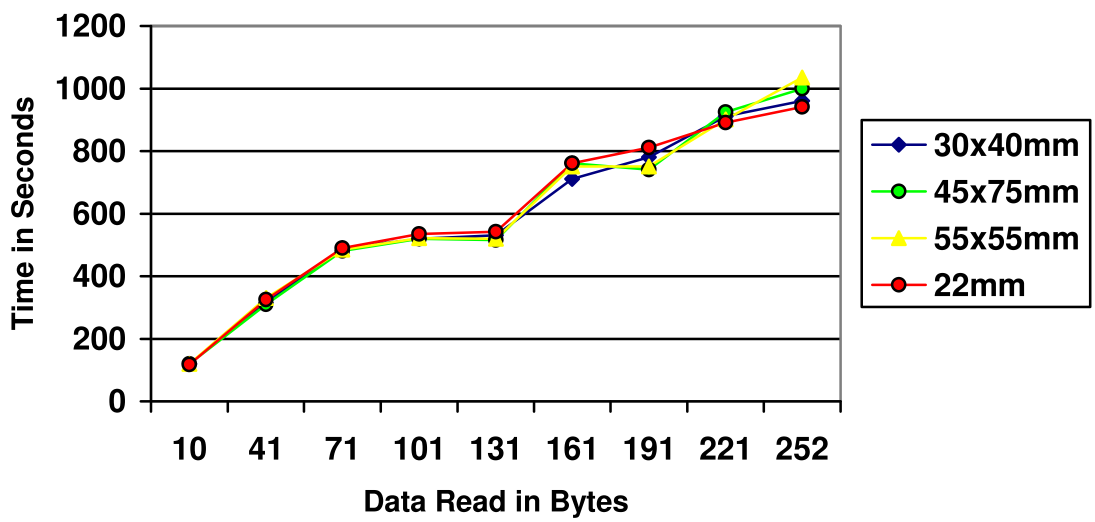


Figure 13 Read latency of various size tags

The Skyetek reader has a limitation that has a large influence on read times. The microprocessor has 80 bytes of available ram. The largest command it can send and receive is 80 bytes minus 16 bytes for command structure leaves 64 bytes of data. To read 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. The initial overhead of setting up the first read and subsequent reads is not linear. To read 252 bytes still takes 900 ms with 140ms setup time to select the tag. By changing to a reader that can support a single read of 255 bytes will improve performance which is important to achieve a full read on a moving reader. The alternative is to have a learning mode in which the RFID reader/software detects a new tag and issues an audio prompt for the user to stop and read the tag. Additional research needs to be done to test how long it takes the user to find the tag. Once the RFID tag is found the maximum read time is under a second. 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. The Tag-it protocol from TI supports the ability to read a tag without selecting it which would save the 140ms required to do a select. With the current implementation it is possible to read a tag fully in under a second with room for improvement by changing readers or tag types.

If each tag required a full-second to read it would not be practical to ask the user to walk in a manner that would allow the reading of a tag every second. The primary design for the RFID tag in the retail industry is to read as many tag identifier 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 read, it is 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.

The following graph 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 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 on reading of tags. The maximum number of tags that can be read is 20, one per 12 inches. Read error is introduced by not walking a straight line because no feedback is given if a tag is being read.

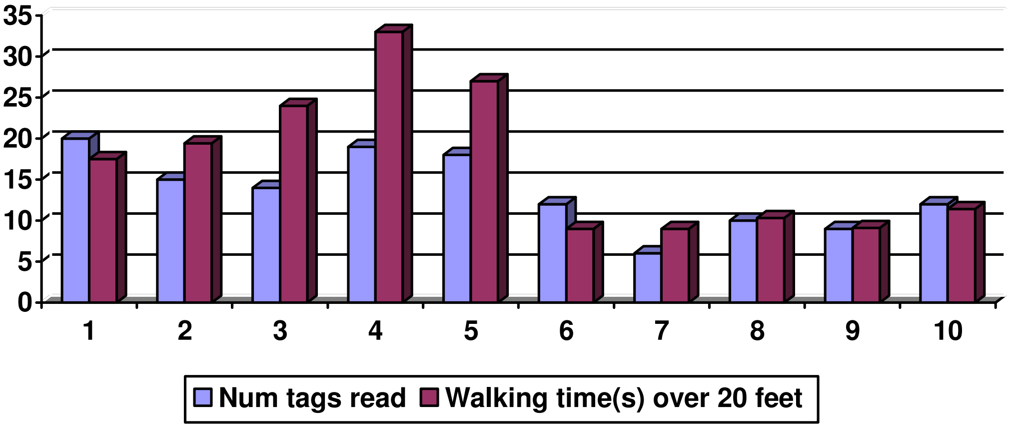


Figure 14 Impact of walking pace on tag reading performance

The average walking speed for a younger walker is 4.95 feet per second [23] so it should take approximately 4 seconds to walk 20 feet. The first group of five walking tests averaged 24 seconds with an average of 17 tags read. The second group of five walking tests averaged 9.6 seconds with an average of 10 tags read. 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. The internal antenna of the Skyetek reader was used for this test. Additional work needs to be done to integrate an antenna along the diameter of the shoe to improve the read range and coverage area. The study needs to be expanded beyond technical validation to include visually impaired and blind users to allow for comparison of overall travel speed in familiar and unfamiliar locations. Results could also be improved by including an RFID reader in each shoe. Integrating the RFID antenna/reader into the walking cane also provides additional reader input with the ability to cover a larger area by moving the cane from left to right while walking.

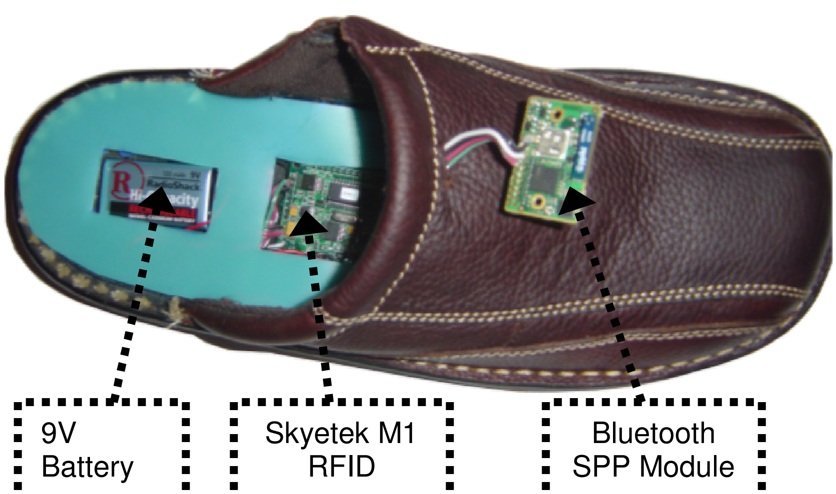


Figure 15 Shoe with integrated RFID reader, battery and Bluetooth module. Inset removed for picture.

The current implementation has the RFID reader integrated into the base of the shoe to minimize the distance of the antenna to the RFID tag. It is also possible to use an external antenna that is installed along the outer edge of the show to maximize read range. The electronics could then be placed in a small enclosure attached to the shoe. This provides for easier maintenance and the ability to use with multiple shoes. It is also possible for a truly pervasive experience to have the electronics manufactured into a custom shoe. The only design requirement to maximize read range is to have the antenna as close as possible to the floor.

## 4 Conclusion and Future Work

We presented requirements, design and implementation of an RFID information grid that can be utilized by blind and visually impaired users via a wearable system consisting of an RFID reader embedded in a shoe (or cane) and a Bluetooth-connected java cell phone. We have shown and established that the concept of setting up an RFID Information Grid in buildings is technically and economically feasible. By leveraging the commodity pricing and innovation in the retail sector the barrier to entry for this technology is low. This allows the adoption of the RFID Grid to be localized at a small business, in a large corporate park, government buildings or on a college campus. This removes the barriers for the blind user to fully integrate into their environment. We hope that by proving the success of this approach on a college campus (University of Florida) as a first step, we may be paving the way for an ADA mandate to *info-grid* all future building constructions.

With an established framework for reliable and accurate location sensing the challenges of communicating to the user an awareness of their surroundings need to be addressed. The blind user is at a disadvantage in using standard user interfaces of cell phones and PDA's. This forces a rethinking of how the blind user interacts with potential pervasiveness of technology. Text-to-Speech and voice recognition can play a significant role in how to solve these problems. Mapping GIS information onto the RFID information Grid in a manner that provides the user the information they need when they need it represents a significant challenge. We are currently working on these issues.

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