THE ASOVI SYSTEM: TOWARDS A SOLUTION FOR INDOOR ORIENTATION AND WAYFINDING FOR THE VISUALLY IMPAIRED

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Abstract

Wireless communication technology is currently an expanding resource from which solutions into indoor orientation and wayfinding for the visually impaired can be explored. However, as a technology in its infancy a prevalent system in the field has yet to be established. Further to this, the potential of combining wireless communication technology with a commercially viable interface capable of providing feedback for the end user is as yet unexplored. Research in current wireless and mobile technology combined with acquired knowledge of wayfinding for the visually impaired has culminated in the development of a new system seeking to maximise the potential of technology in the field. Testing with visually impaired participants and subsequent focus group discussion suggests that the ASOVI (Audio Based Spatial Orientation for the Visually Impaired) system is a viable solution to indoor orientation and wayfinding for the visually impaired capable of providing feedback to the end user via a commercially viable platform.

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Dedications and Acknowledgements

This thesis is dedicated in loving memory of my mother PC Lisa Jane Saffery.

I am truly indebted to my supervisors James McDowell and Dr Rupert Ward for all their help and encouragement throughout my research. I am certain that without it this thesis would not have come to fruition. I owe a great deal to my family for their financial and moral support throughout this project and without it this project would not have been completed. I would like to show my gratitude to the Batley Blind Association for help with providing participants for my investigations. Finally I would like to thank Sam Horseman who boosted me morally and provided me with a huge amount of support.

List of abbreviations

3D - Three Dimensional
A-GPS - Assisted GPS
AOA - Angle of arrival
ASCII - American Standard Coding for Information Interchange
ASOVI - Audio Based Spatial Orientation for the Visually Impaired
Cell-ID - Cell phone Identification
DGPS - Differential GPS
DLA - Disability living Allowance
GIS - Geographic Information System
GND - Ground
GPS - Global Positioning System
IR - infrared
IrDA - Infrared Data Association
LOS - line of sight
MoBIC - Mobility of Blind and Elderly People Interacting with Computers
NFC – Near Field Communication
O&M - Orientation and Mobility
PDA - Personal Digital Assistant
PRN - Pseudorandom Noise code
RFID - Radio Frequency Identification
RNIB - Royal National Institute for the Blind
RSS - Received signal strength
RTOF - Return Rime of flight
RTPI - real time passenger information
Rx – Receive
SMP - Smallest M-vertex Polygon
SVM - Support Vector Machines
TDOA- Time difference of arrival
TOA - time of Arrival
USB - Universal Serial Bus
UWB - Ultra-Wideband
Wi-Fi - Wireless Local Area Network
WLAN - Wireless Local Area Network

Chapter 1 - Introduction

This chapter introduces the project by giving a subject background and subsequent focus. It then outlines the thesis objectives and intended methodology proposed to achieve these objectives.

1.1 – Background & Context

Recently technological advancements regarding mobile devices incorporating Global Positioning System (GPS) receivers such as the Apple iPhone 4 (Apple Inc, 2011), has meant that it is now possible to estimate the location of such devices. This information can then be cross-referenced against a geographic information system (GIS) or map such as GoogleMaps, to aid user orientation and wayfinding. It is possible that the advent of this technology may have significant repercussions when utilised for its orientating and wayfinding capabilities to aid the visually impaired.

A significant body of research exists regarding spatial orientation and wayfinding of the visually impaired in outdoor environments and there are several products commercially available to this end. However, there is significantly less research into the spatial orientation & wayfinding of an indoor environment. GPS, the standard technology used for locating a mobile device, requires a line of sight with the satellites surrounding the earth. The use of GPS in an indoor environment is unable to maintain this line of sight and is consequently inaccurate and in some cases will cease to function. Furthermore, indoor environments differ to outdoor environments because they are potentially more complicated to navigate due to their confined spaces. In addition to this, obstacles such as supports, pillars and wall-divides may provide extra hazards for the visually impaired. For instance, an office building with identical floor plans for three different floors provides an easily navigated environment for the visually able traveller but without guidance, may cause confusion and disorientation for the visually impaired traveller due to difficulty in distinguishing between floors on account of their identical floor plan.

For years the visually impaired have had to rely on aids such as canes and guide dogs in conjunction with specialised training that can takes years to master in order to navigate around public places such as shopping centres, airports, bus stations, town centres and train stations. This not only detracts from the independence of the visually impaired but can also deter some from leaving their homes altogether (The Times, 2007). In existing research regarding orientation, mobility, wayfinding and cognitive mapping there is great evidence that orientation within an environment leads to a sense of security and independence and is therefore crucial for the incorporation of the visually impaired within our intricate society (Espinosa & Ochaita, 1998). Thus, to increase independence of the visually impaired and enhance their traversal of buildings in public and private places such as the aforementioned airports, shopping centres and train stations, an effective alternative to GPS must be found. However, this alternative must be accessible and commercially viable. There are products on the market for aiding the navigation of outdoor environments such as Trekker by HumanWare. The company describe the product as, "a hand-held talking GPS" device, although on account of it providing no other functionality and costing £550 per unit it may be considered commercially unviable (HumanWare, 2010).

Currently, the number of registered blind and visually impaired people in the United Kingdom is approximately 370,000 and the estimated number around 2,000,000. The RNIB currently state, "Only one-third of registered blind and partially sighted people of working age are in employment" (RNIB Research, 2011). The government offers Disability Living Allowance (DLA) to those who need care or have walking difficulties due to mental or physical disability. The maximum an individual can receive per week is £125 with the lowest amount being £39.10 (UK Government, 2011). This suggests that for a number of blind and partially sighted individuals dependant on DLA, the disposable income will not be available to purchase single function products such as Humanware's Trekker. In order to increase commercial viability, products such as these must either reduce in cost or incorporate multiple functionality in order to justify such expenditure. One possible solution would be to utilise a mobile phone. A large number of mobile phones currently on the market have multiple uses as personal organisers, handheld games consoles, mp3 players alongside the original functionality of a portable phone. And so, if a mobile phone was developed to offer the additional functionality of orientation and wayfinding in an indoor environment, it may offer a solution to this problem.

Overall, this information suggests that a device that is easily portable for the user, commercially viable on account of its compatibility with an existing multi-functionality and capable of aiding orientation and wayfinding in an indoor environment would have beneficial repercussions for the visually impaired. For example, in buildings such as an airport, it could be used to inform and orientate a user as to which check-in desk to use and how to navigate to it.

1.2 – Research Objectives

With the contextual knowledge outlined above, the following research objective has been outlined. How might it be possible to spatially orientate visually impaired persons within an indoor environment using a combination of mobile phone technology and wireless communication technology?

In order to successfully create an indoor orientation and wayfinding system, research into cognitive mapping must be conducted. This will include investigating the methods by which humans store data using different sensory channels and subsequently use it to traverse both indoor and outdoor environments. This will be followed by further investigation into how the visually impaired create cognitive mapping without the use of vision in order to create an orientation system that can successfully bridge the missing visual channel. Secondly, an investigation into the different technologies available for indoor orientation and positioning will be conducted to evaluate their advantages and disadvantages dependant on technique, accuracy and cost for example. This will culminate in identifying suitable technology with which to develop the system. Finally, research will be conducted into the different mobile technologies in order to identify the most suitable multi-functional device on the market. In doing so, the chosen device may then be developed to incorporate the function of indoor orientation and wayfinding capabilities for the visually impaired providing an alternative solution to standalone devices.

1.3 – Thesis Methodology

To address the objectives outlined, this exploratory investigation must begin by conducting a pinpointed survey into the overlapping areas of wayfinding, mobile technology and indoor positioning technology. Specifically, research into wayfinding will highlight how humans and the visually impaired in particular acquire, store and utilise sensory information in the form of cognitive maps for use in orientation. Having laid a theoretical foundation of wayfinding, orientation and cognitive mapping, an exploration of the opportunities and limitations associated with appropriate wireless communication technologies will be undertaken. This should highlight appropriate technologies for use with an indoor orientation and wayfinding system while taking into account cost, availability, precision and functionality. Following this research, a further exploration of current wayfinding systems on the market will aim to identify current competitor pricing, availability, infrastructure and success. This should provide the knowledge necessary to identify suitable technologies to be used in the design of an indoor orientation and wayfinding solution to aid the visually impaired as outlined in the thesis objectives. Suitable investigations may then be designed and implemented to ascertain the specifications of the proposed technology to be used in order to facilitate the design of a successful system.

Using the information gathered in the previous review and investigation, a peripheral system can then be designed and engineered. Once complete, an investigation with end-user participants will be conducted. This investigation will use a mixture of both qualitative and quantitative methodologies to extract information pertaining to the success of the designed peripheral system. The results of which will then be used to answer the proposed research objective regarding the aid of cognitive mapping processes, orientation and indoor wayfinding of visually impaired individuals.

Chapter 2 – Wayfinding & Cognitive Maps

Current research regarding cognitive mapping defines it as the methods by which humans build up a mental map that provides information regarding the location of objects and their relativity to each other and themselves (Morrongiello, Timney, Humphrey, Anderson, & Skory, 1995). This chapter will introduce and analyse wayfinding and cognitive maps as a primary background contextualisation for the project. It will continue to dissertate different techniques used for orientation and mobility (O&M). These techniques range from using a cane to using audio or haptic feedback that help guide the visually impaired through environments. Having established this, it will be possible to investigate methods to improve cognitive mapping for the visually impaired.

2.1 – Cognitive Maps

A cognitive map can comprise of complex geometric, trigonometric and mathematical data, quite often far more complex than a person could solve using their own knowledge (Golledge, Klatzky, & Loomis, 1996). This information is essential for humans to locomote and is collected using various sensory channels such as vision, audio and touch. It is then processed with a number of mathematical and psychological transformations and turned into a map in the hippocampus of the brain. The hippocampus is the area of the brain that deals with large-scale spatial orientation and navigation (Fortin, et al., 2008).

Cognitive maps are fundamentally a mental representation of the external environment in which an individual is situated. These maps are built up by input from different sensory channels and allow us to navigate the world around us. For instance, a visually able person sat at a desk can see a cup and reach for it, pick it up, take a drink and place it back down with relative ease. This is because their cognitive map will tell them how far away the drink is and the proximity in relation to other objects on a desk etc.

Vision enables humans to calculate distal judgements of objects in relation to themselves and other objects around them. Most of the information essential for creating a cognitive map is thus collected via the visual sensory channel. However, visually impaired people do not have access to information provided by the visual sensory channel. As a result, the visually impaired traveller needs to compensate with information from other sensory channels such as touch or sound (Lahav & Mioduser, 2008). Therefore, limitations of the visual sensory channel can severely compromise development of the system of spatial representation (Morrongiello, Timney, Humphrey, Anderson, & Skory, 1995). Using the earlier example of a visually able indiviual picking up a cup at a desk, if information from their visual sensory channel was prohibited and the cup was moved, they would subsequently have difficulty in locating the cup.

Landmarks are a major contribution in the creation of cognitive mapping and can constitute anything from an elevator in a building to a large statue in the middle of a town square. The use of landmarks is highly prevalent on a daily basis when locomoting. For example, when giving directions to a traveller it may be stated, "turn left at the statue of Harold Wilson, then go straight until you get to the fire station". The statue of Harold Wilson and the fire station are both landmarks that will be used to help create a cognitive map in the traveller's mind. According to urban planner Kevin Lynch, landmarks are the most important cue in any environment (Lynch, 1960). For the visually impaired it is not possible to see landmarks and therefore gain information from them. This prohibits the visually impaired's ability to orientate themselves to the same level of accuracy as a visually able traveller. Landmarks tend to be both static and silent, visable to a traveller before they reach it, upon which they will then start scanning for the next landmark providing orientation within the environment. However, the visually impaired user must walk up to the landmark to identify it and deduce a position within an environment they may know little about. Therefore developing a system to indicate to the visually impaired what and where a landmark may be before they reach it could help greatly in their orientation within an environment.

2.2 – Spatial Coding

According to Millar (1994, p.118), "The term spatial coding is used here for coding in terms of some form of reference. Thus, the location, distance and direction of the position of an object have to be specified (whether or not explicitly) with respect either to oneself, or to external coordinates, or both". There are two different types of reference cue that summate the basics of spatial coding and these are called frames. Frames can be self-referent frames or external frames. Millar expands, "Self-referent frames are centred on the person's body. External frames are based on information from the environment" (Millar, 1994, p.119).

There are two key types of space when it comes to spatial coding: small-scale space and large-scale space. Small-scale space or haptic space is that which a person can manipulate or explore without changing the actual location they are in. In comparison, large-scale space or locomotor space is that in which locomotion is required to navigate or explore (Unger, 2000). This distinction can be made clear by considering that in small-scale space, objects should be within arms reach and therefore found in relation to one's body (self-referent). Whereas in large-scale space we must locomote to explore and in this the body has to translate. This means that finding objects with self-referent frames reduces dependability (Unger, 2000). A major advantage of the visual sensory channel is that during locomotion external frames are updated thus giving distal information to the changing environment around the locomotor. This allows a visually able locomotor to see landmarks and the distance between them resulting in a more detailed cognitive map.

Another major factor in the development of cognitive maps is the length of time that the locomotor has been visually impaired. Those who have had some visual experience will consequently have a heightened spacial ability. For example, according to Unger (2000) the later a subject loses sight, the closer their performance in spatial tasks to that of a sighted subject. This notion is further supported by Dodds, Howarth, & Carter (1982) in a study in which both congenitally and late blind children were asked to walk a short urban route that they had been taught and then point out a small number of locations along the route. They found that the errors increased the further away from the target the children were. All the children were able to walk the route yet they noted that late blind children were more accurate at pointing out the locations. They subsequently surmised that the congenitally blind children coded the route in terms of the changes of heading they made using self-referent coding. This meant that they found it difficult to take this information and use it to create an external representation of the test environment.

2.2.1 Small-Scale Space

According to Millar (1994), people with a small amount of visual experience will mostly use self-referent coding. She found that children without vision do not recieve the same quality of information obtained through other sensory channels as through the visual sonsory channel. Therefore they find other techniques to code the information, leading to using self-referent coding being used more than external coding techniques. This could be exemplified by imagining a person trying to find a static switch that is in the centre of a desk. A sighted person could easily see the switch and press it using external coding as they would be able to see other items on the desk and gain distal information from them. However, if somebody without sight tried to undertake the same task and used the same method of external coding then they would have to use the haptic sensory channel to feel out for other objects to be able to find the switch. In contrast, if they use self-referent coding then they know how far the switch is away from them and in what direction it is. To expand upon this, an example described by Millar (1994) concerns being sat on a train, looking out of the window at an adjacent train. When the other train starts to move, we may wonder which of the trains is moving until we realise that we are still stationary using our kineasthetic senses. This also shows that in certain situations, other sensory channels are more accurate than the visual channel. In this context, the example shows that the mind chooses the most appropriate method of collecting the information for each situation. However, the congenitally blind have never had enough visual experience to have learnt how to use external coding and take note of external cues. As a result, they will select other methods that are the most appropriate for them. This notion is supported by Ungar, Blades, & Spencer (1995b) who investigated blind and partially sighted children's mental rotation capabilities by asking them to examine and recreate a layout of shapes, either from the same location or after a rotation of 90% around the display. The study highlighted that the children who related objects to each other and to the frame itself found it easier to locate the objects when the rotation had been made.

2.2.2 Large-Scale Space

When a visually able person wishes to locomote across a large-scale space such as the lobby of a hotel, avoiding obstacles or judging the distance to the point they wish to locomote to is not problematic. Furthermore, Rieser, Ashmed, Taylor, & Youngquist (1990) also highlight that providing a sighted person has seen the space such as the lobby first, then they can accurately walk to a given point should you remove their sight. One major problem with large-scale space is the influence of traversing objects. A visually able traveller can see these traversing objects using their visual sensory channel and in doing so rapidly update their cognitive maps allowing them to avoid said objects. However, a blind or visually impaired traveller does not have this capacity.

A problem with large-scale space that applies to both sighted and visually impaired persons is that a start point and an end point are not close to each other and so traversing any large urban area has to be done in stages - each with its own goal (Millar, 1994). To illustrate this notion, Figure 2.1 shows a hypothetical map of a city centre with the grey blocks representing tall buildings that line the roads. The traveller must start at point A and finish at point B.

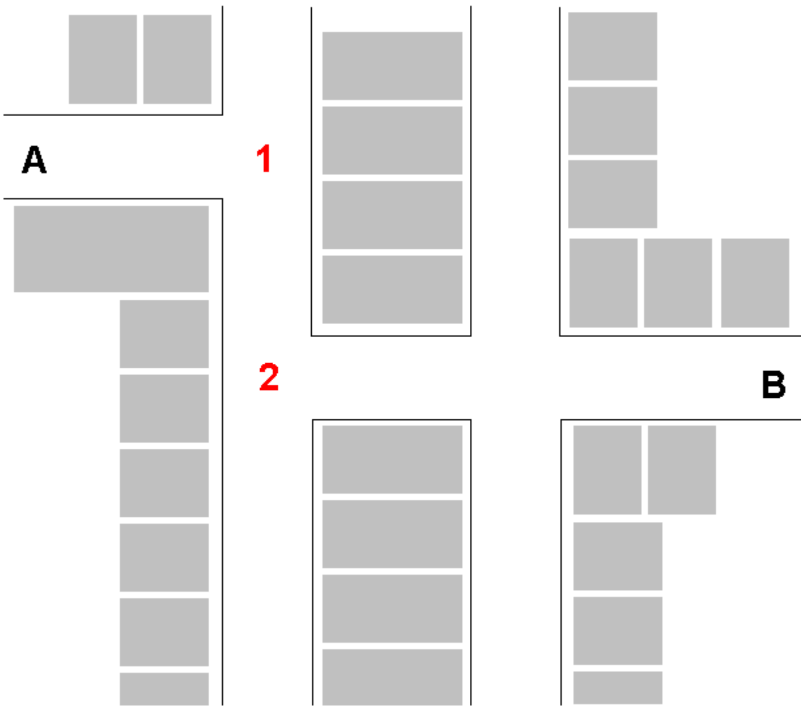

Figure 2.1 - Points in traversing large-scale space.

This process has to be undertaken in three stages because even a visually able traveller cannot see point B from point A. They must instead travel to intermediate point 1, from which point B is still not visible, and so they must next travel to intermediate point 2. Finally from intermediate point 2, they can see the goal of point B (if they have visual information) so the third stage of the journey can be undertaken. Using Figure 2.1 as an example, the information that is received to navigate from point A to B is done so in three sequential stages in comparison to a small-scale space such as a desk, where all the information needed to navigate between points is received in one stage. If the layout of an environment is complicated enough to require many of these stages of data retrieval to get to a goal, then it is very possible for even visually able travellers to become disorientated and lost.

2.3 – Wayfinding

Golledge, Klatzky, & Loomis (1996) argue that, "Wayfinding refers to a person's ability, both cognitive and behavioural, to find his or her way from a specified origin to a specified destination". In order for a person to undertake a wayfinding task they need identifiable landmarks to determine their location, information on the heading in which they are travelling, turning information and a form of dead reckoning called path integration. In current literature, there is almost an integration of the terms, "mobility" and "wayfinding" and the two are often used synonymously. Gollege et al (1996) state, "mobility is often used as a synonym for wayfinding". However, mobility has connotations regarding the restriction of a person's movement due to a physical impairment of some variety whereas wayfinding has connotations of a cognitive skill more than a restriction by impairment (Golledge, Klatzky, & Loomis, 1996).

Many blind and visually impaired persons have had specialist O&M training either using a cane or audio cues from the environment. One of these techniques is linear feature following which consists of locating the end of a pavement or a fence and following this directly. It is also often called shorelining (Golledge, Klatzky, & Loomis, 1996). This technique can be problematic because some routes will have no curb edge, fence or wall to follow resulting in travellers finding themselves disorientated thus forcing them to rely on other techniques of orientation.

Golledge et al (1996) propose that for a blind traveller to improve their wayfinding abilities two main types of information are needed. Firstly, information about the "proximal environment" is required which is then represented in a cognitive map (Golledge, Klatzky, & Loomis, Cognitive Mapping and Wayfinding by Adults Without Vision, 1996). An example of this would be the number of doors passed before getting to the correct office. Secondly, information about the larger environment is also required such as any sudden drops in ground level as occurring in embankments or ditches. As stated earlier, this information is easily collected by a visually able subject whereas a visually impaired user must collect this information via other methods. Golledge et al (1996) then go on to state that audio perception is becoming, "the major substitute for the long distance information processing otherwise provided by vision". Using this research, it can be deduced that audio feedback may be used to provide landmark information and other spatial cues at the same distance as a visually able individual would see them to help visually impaired users orientate themselves.

2.3.1 Path Integration & Dead Reckoning

Dead reckoning is the process in which current position, heading and estimated speeds over a given time are used to calculate a prospective given position. Figure 2.2 shows a diagram of a boat sailing in the sea travelling at 10 knots. The triangle around the boat indicates the direction in which it is travelling and the line then shows its predicted course. The boat is marked on the diagram at the time of 14:30pm. The subsequent times marked on the line indicate its predicted points at 15:00 and 15:30.

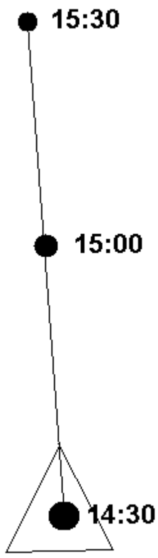

Figure 2.2 - Boats predicted path using dead reckoning.

Although dead reckoning is no longer used in this context, it has in the past been a primary method of marine navigation allowing sailors to navigate across oceans that have no visual landmarks to use for orientation.

The form of dead reckoning used by animals (including humans) is called path integration. Etienne & Jeffery (2004, p180) describe path integration as the "simplest form of navigation (that is used to) ...return to the starting point of a journey without making use of familiar position cues". This occurs using locomotion signals and a single reference point such as a nest in the case of a bird. Path integration can therefore be defined as a number of small increments of movement, noted in reference to the direction and distance from the given starting point used to update a cognitive map. This method uses only one landmark as the starting point used by the animal to remember the distance and direction in which it has travelled.

It can therefore be suggested that landmarks are not essential for spatial orientation although they are beneficial. It is possible that a traveller, knowing the location and direction from which they started, may use kinaesthetic signals to encode how far they have travelled. Although research cited refers to animals navigating a featureless environment, it is possible that visually impaired users can encode each rotation as well as the distal information to build up a cognitive map of the area using these rotation and transformation signals and traverse a complex urban environment. Figure 2.3 uses the same hypothetical city map as figure 2.2 but this time shows the distances the subject has to travel and the rotations they have to undertake.

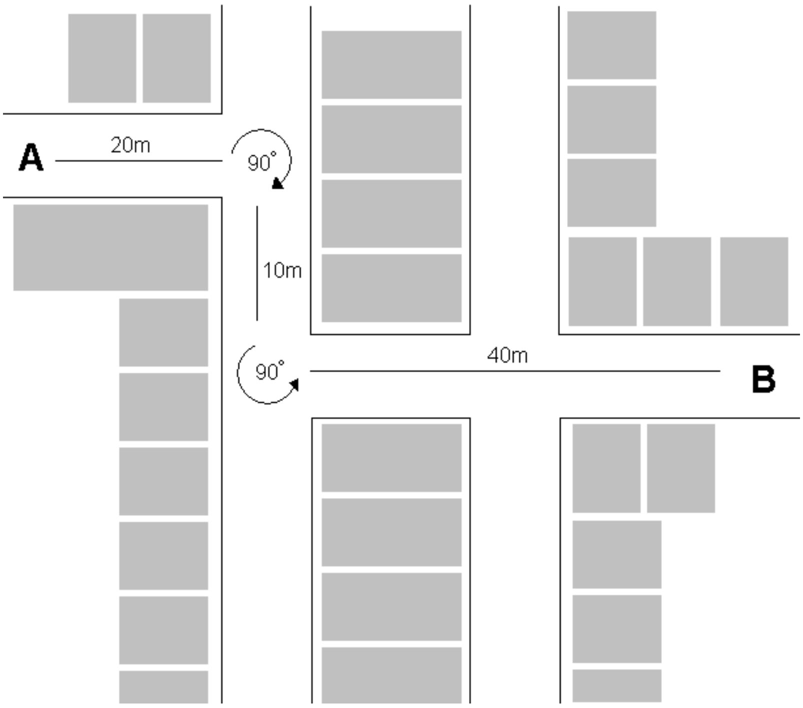

Figure 2.3 - Urban area with distances and angles needed to traverse it.

If a subject was to walk the path from A to B then they would have to encode the route as 20 metres forwards, 90 degree turn to the right, 10 metres forwards, 90 degree turn to the left and finally 40 metres forward to point B. Theoretically, if a visually impaired subject was to walk this path with an aid or using landmarks then they should be able to follow this route a second time more comfortably by using path integration. This also supports research regarding wayfinding in that it too uses a string of spatial tasks or decisions, rather than one continuous operation.

2.3.2 Obstacle Avoidance

One of the most reported problems faced by the visually impaired traveller is the avoidance of obstacles, which is imperative for safe locomotion in an environment. A considerable amount of research exists regarding different aids to help with obstacle avoidance for the visually impaired, for example the Mowat Sensor and the Sonic Guide (Brabyn, 1982, p. 286). The basic operation of these systems is not to spatially orientate but help the traveller avoid everyday environmental obstacles such as lampposts, bollards and benches. While a cane has a maximum reach of about three feet from the body some of these sensors have a range of up to eighteen feet giving the traveller a greater time to react to such obstacles (Golledge, Klatzky, & Loomis, 1996). However due to the fact that these sensors do not spatially orientate, the user still has the potential to become disorientated and consequently lost in any environment. These sensors do not identify individual landmarks and therefore obstacle avoidable is most useful in a close environment. In the larger environment however it gives little help in creating a cognitive map of the environment's layout. For the purposes of a system to aid with spatial orientation, some form of navigation aid is needed. It is possible that this feature could be used in conjunction with an obstacle avoidance feature although care must be taken to not overbear the traveller with information feedback thus causing confusion.

2.3.3 Navigation Aids

Navigation aids, unlike obstacle avoiders, give the user information about the general environment they are either already traversing or are about to traverse. There are a number of aids already on the market that will be reviewed in detail later in this text. These aids use a multitude of methods to provide the user with information about the environment. These methods can include ultrasound, lasers, video cameras and global positioning system (GPS) with the information often fed back to the user using an audio or tactile display.

GPS devices normally link in with a geographic information system (GIS) that triangulates the position of the user and then references it to a map to give the user information about the surrounding environment. The devices then relay verbal commands to the user telling them directions to their destination. These systems rely on the accuracy of the GPS system in use and so will be discussed at a later point in this chapter.

Navigation aids are a highly useful tool for aiding the visually impaired traveller with finding new routes through an environment. O&M training teaches the visually impaired to follow the same paths daily to reach any destination (Jacobson, 1993). However, if a visually impaired traveller was taking the route in the urban environment from Figure 2.3, a burst water pipe causing an obstruction could force traversal of an unknown route resulting in disorientation without the use of a navigation aid. Figure 2.4 exemplifies this circumstance. With a navigation aid however a user could locate a new route from A to B and even navigate the curvature of the route with relative ease.

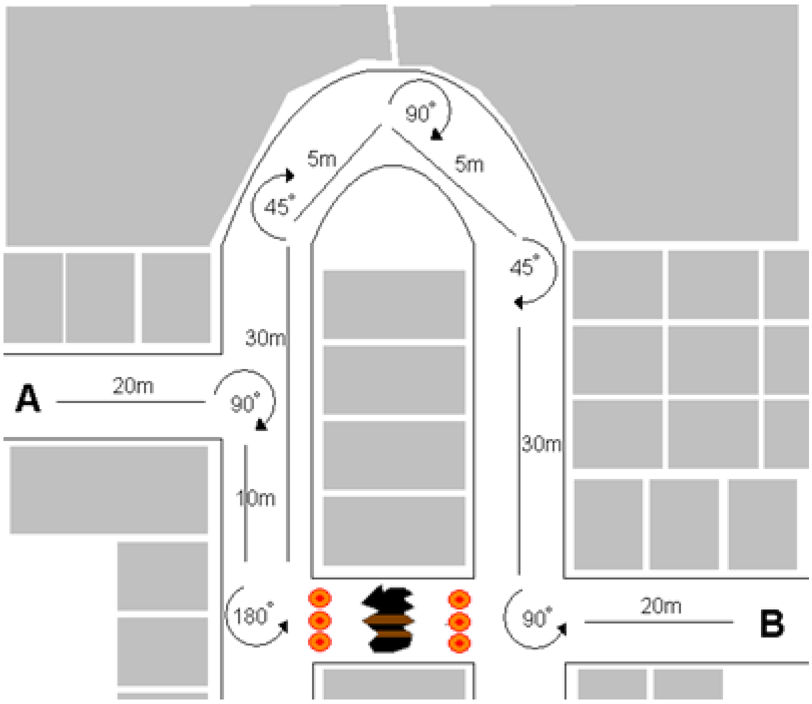

Figure 2.4 - Roadwork's

Note: this is one example of a route that a visually impaired user may take.

In Figure 2.4 the visually impaired traveller reaches the road works repairing the hypothetical burst water pipe and then must rely on a navigation aid to find the most suitable alternative route. It must be noted that if it was possible to link the GIS system up to a modern traffic system such as the GPS systems in use by cars, the road works may have been detected and an alternative route suggested prior.

2.4 – Summary

The literature reviewed in this chapter suggests that the visually impaired can navigate large-scale spaces and work within small-scale spaces efficiently. However, this is made significantly easier with the help of navigational aids and obstacle avoidance techniques. Research has also shown that cognitive mapping abilities are stronger in persons with visual experience although the visually impaired can still create and utilise cognitive maps. Once more, the use of aids can result in the creation of a more comprehensive mapping which in turn, allows for easier and safer traversal of a large-scale space.

Finally, the review outlines the notion that although blind and sighted persons differ in performance when it comes to wayfinding, they have essentially the same abilities to create cognitive maps and utilise them. In utilising other sensory channels such as audio and tactile channels, the visually impaired can gather information to substitute their deficit in vision. However, this supplementary information does not replace fully that gained from the visual sensory channel. It is in this deficit that obstacle and navigational aids can be used to relay additional information to the user. This indicates that a system could be designed to improve the ability of the visually impaired to navigate and wayfinding within an indoor environment. The system would also have the potential to aid in the creation of cognitive maps if it could provide information that would otherwise be ascertained using the visual sensory channel.

Having researched these issues, the next chapter will explore how they may be implicated regarding different wireless communication technologies available and their potential use in the creation of a system to aid orientation and wayfinding for the visually impaired.

Chapter 3 – Indoor Positioning & Orientation

This chapter summarises different types of indoor positioning technologies taking into account costs, availability, setup difficulty, accuracy and usability for the application of spatial orientation for the visually impaired. This chapter also looks at systems for both the visually impaired and able currently available on the market.

Over the past decade there has been a great deal of research into aiding the visually impaired to navigate large-scale spaces and create cognitive maps to help with wayfinding. However the majority of this research is focussed on outdoor navigation in which several studies have looked at the use of GPS for orientation purposes. The initial part of this chapter examines different techniques for indoor positioning. Whilst the systems to be looked are not exclusively intended for use with visually impaired users, nonetheless they will be examined for their potential to be used in this context.

3.1 – Wireless indoor positioning & Orientation

There are three main methods that are used by indoor positioning systems to locate a position of a person or object indoors. These are Triangulation, Scene Analysis and Proximity. Using one of these methods allows for a system to estimate the position of an object or person indoors, however using a combination of one or more of these methods will allow for more accurate results.

3.1.1 Triangulation

Triangulation uses two types of estimation to assess a target's location, lateration and angulation. The process of lateration uses multiple reference points to work out how far objects are in distance from each other and then using this information estimates the position of an object. Angulation, on the other hand, uses two or more reference points and calculates the position of an object by detecting the angles at which the signals interject. There are several algorithms that can be used to calculate these processes using different methods of distal measurement.

One of the methods used for lateration is time of arrival (TOA). This uses the theory that the "distance from the mobile target to the measuring unit is directly proportional to the propagation time" (Liu, Darabi, Banerjee, & Liu, 2007, p. 1068). To calculate an object's position in two dimensions, a minimum of three reference points must be ascertained and used to measure the distance between each and pinpoint the location of the target. Figure 3.1 below shows this.

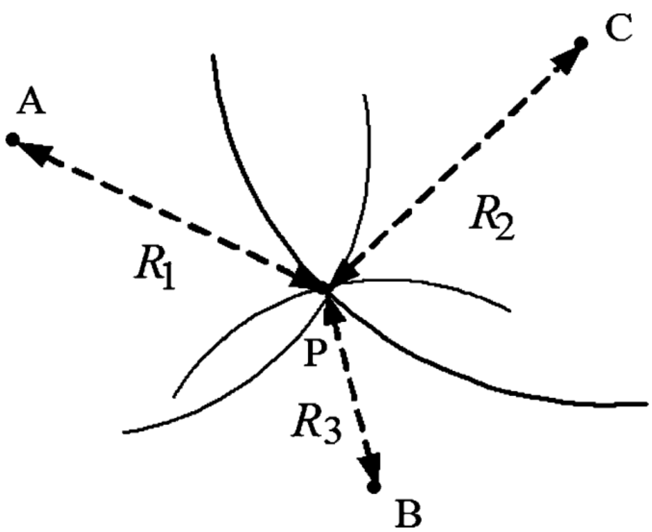

Figure 3.1 - Triangulation with three reference points. (Liu, Darabi, Banerjee, & Liu, 2007)

TOA is calculated by measuring the one-way propagation time and using this data to ascertain the distance between the measuring unit and the target. The process begins by synchronising each of the recievers and transmitters and placing a timestamp on the signal being sent between them in order for the distance travelled by the signal to be calculated. There are several methods for computing TOA, however the basic method uses geometric calculations to derive the exact point of intersection (Liu, Darabi, Banerjee, & Liu, 2007).

Another method for lateration is time difference of arrival (TDOA). This technique measures the difference in time that a signal arrives at from three or more receivers. The technique uses hyperboloids thus is also referred to as hyperbolic positioning. With two receivers an emitter can be traced onto a single hyperboloid, and a third receiver is then introduced to give a second TDOA measurement. From this process, the position of second hyperboloid can be derived. Taking the two hyperboloids and intersecting them will give a curve on which the emitter can be placed. Received signal strenth (RSS) can be used for lateration however several drawbacks exist with this methodology. RSS needs line-of-sight (LOS) to work accurately, without which the signal would take multiple paths (Multipath Effect) thus delaying the signal and causing it to show the wrong position. The multipath effect causes signal delays by reflecting and refracting the signal causing ghosts which in turn cause errors in the distal readings given. This is a common cause of the floating of a GPS position on a mobile device, even when stationary or reading inaccurately a number of metres. Return time of flight (RTOF) is a method that measures the time of flight of the signal as it travels from the transmitter to the receiver and back again. RTOF is very similar to TOA and uses the same type of measuring mechanism (Liu, Darabi, Banerjee, & Liu, 2007).

The main technique of angulation is the angle of arrival (AOA). This technique locates a target by plotting angle lines and then finding the intersection point as shown in Figure 3.2.

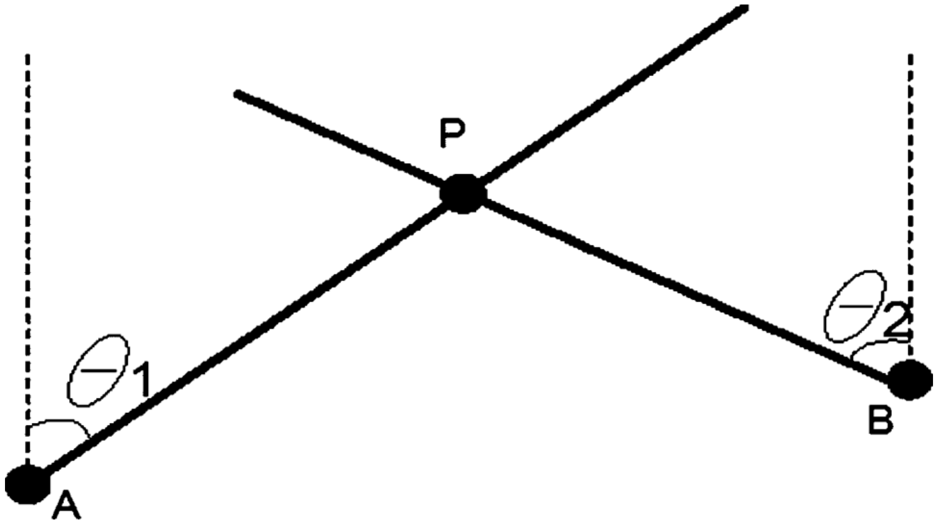

Figure 3.2 - Angle of arrival demonstated (Liu, Darabi, Banerjee, & Liu, 2007).

AOA can be used to calculate a 3D location using three or more measuring units. A major advantage of this method is that the measuring units do not need to be synchronised. One of the disandantages of AOA is that it can, like RSS, be affected by the multipath effect.

3.1.2 Scene Analysis

Scene analysis is an approach that first collects features or fingerprints of the surrounding environment and then estimates the location of an object by matching online measurements with the collected features. Location fingerprinting generally relies on collecting and matching signal characteristics that are location dependant. Fingerprinting has two stages: an offline stage and an online stage. The offline stage involves surveying the environment and its locations in which coordinates and signal strengths are collected and labelled. The online stage involves using a positioning technique to cross-reference the data collected online with that offline to estimate a position. Fingerprinting uses RSS and thus faces the same problems as RSS triangulation regarding signal strength, refraction and reflection. Because of this there are several different algorithms that are presently used. The two main algorithms are the Probabilistic method and the k-nearest-neighbour method (Liu, Darabi, Banerjee, & Liu, 2007).

The probabilistic method cross references the signal characteristics collected in offline mode (S) against the live collected positions (L_i) which there are “n” of. This can then be made into a decision rule equation like this:-

Pick L_i if $P(L_i|S) > P(L_j|S)$ for $i, j = 1,2,3,\ldots,n$ and $j \neq i$.

Simplified $P(L_i|S)$ refers to the probability that the object or person is in the location L_i given the signal characteristics being received “S” (Liu, Darabi, Banerjee, & Liu, 2007).

k-nearest-neighbour method uses the RSS to find the k closest matches from the offline database previously created. Then averaging the k location closest matches (weighted or unweighted) an estimation of the position can be made.

Neural networks with a multilayer perceptron are another available method in which there is one hidden layer with offline readings taken to train the neural network. Online data can then be fed into the network to get a position estimate. Support Vector Machines (SVM) can also be used which is a "technique for data classification and regression" (Liu, Darabi, Banerjee, & Liu, 2007). Finally, there exists smallest m-vertex polygon (SMP) that uses RSS values to find locations with respect to each transmitter independently. M-vertex polygons are created by picking one or more locations from each transmitter and averaging the coordinates of the vertices gives a location estimate (Liu, Darabi, Banerjee, & Liu, 2007).

3.1.3 Proximity

The proximity approach uses a grid of receivers with the exact position of each one placed in the system. A mobile target is considered as nearby when a receiver detects it. When two or more receivers detect the target, it is considered to be near the receiver with the strongest signal strength. This approach is relatively simple to implement and works well with infrared radio (IR) and radio frequency identification (RFID). This method is also used for cell phone identification (Cell-ID) as the phone can be tracked to its nearest cell. However, this is just in the proximity of the cell or the receiver it is near.

3.1.4 Short Range Wireless (Bluetooth + Competitors)

There are several different short-range wireless technologies available however Bluetooth is the most widely recognised and used. Its current competitors include ZigBee, near field communication (NFC) and wireless Universal Serial Bus (USB). These wireless technologies were created focussing on the transfer of information from one computer device to another. Each has a different range of data transfer ranging from 20cm with NFC up to approximately 100m with USB class1 devices. Each of these four different technologies has their own specialised areas. Bluetooth mainly focuses on mobile phone data communication and wireless communication between handsets and their receiver's domestic phones. It first appeared in 1994 and was soon used to transfer data from phone to phone (Hoovers, 2011). ZigBee aims itself more towards very low power, low cost, self-configuring nodes that could be used in conjunction with automatic blinds and lights for example (ZigBee Alliance, 2011). NFC is popular in Japan for detecting a wide range of data on mobile devices from information to advertisements. NFC has a very short range of only a 20cm radius of the transmission point. Wireless USB uses UWB bandwidth and therefore does not classify as short range. UWB will be discussed separately at a later time in the chapter.

The majority of research in positioning is currently on Bluetooth, possibly on account of its cost and availability. There are two methods of calculating a location using Bluetooth signals. The first uses trilateration in which information from several different nodes can be taken into account. Because the signal energy decreases almost proportionally with the distance between the station and the mobile device, an algorithm can be applied and an estimation of the location made (Rodriguez, Pece, & Escudero, 2010). The second method used by Bluetooth to calculate positioning is proximity sensing seen as Bluetooth (Class 2). As it has a range of approximately 10m from the mobile device, it is possible to place a user within a certain distance from a particular node; this however is not as accurate as the trilateration.

There have been several experiments researching whether Bluetooth is a feasible and accurate medium to determine location. A large majority of the experiments use RSS and fingerprinting to obtain a location estimate. RSS is problematic because the signal can encounter several problems as discussed earlier regarding RSS. In a study by Rodriguez, Pece, & Escudero (2010), triangulation was used via RSS obtained from n different access points to estimate the location of the mobile device. Figure 3.3 shows this.

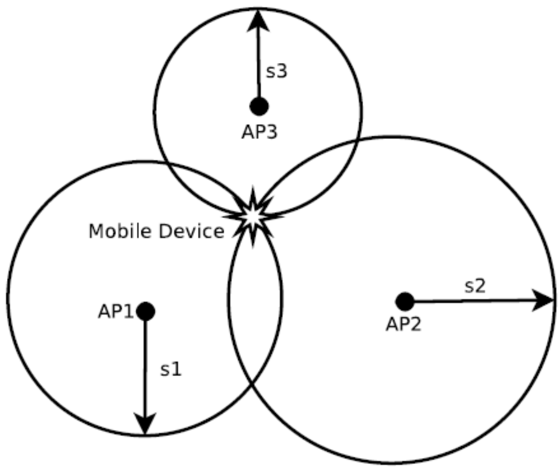

Figure 3.3 - Triangulation using RSS to locate a mobile device (Rodriguez, Pece, & Escudero, 2010).

The heavy calculations required by the investigation were implemented on a server that then sent the information back to the mobile device. This allowed its processing power to be kept to a minimum. The average distance of error with three access points is <= 1 to 2 metres (Rodriguez, Pece, & Escudero, 2010). The study also noted that the the speed of bluetooth can be problematic and the inquiring time very slow at approximately 7-8 seconds. This would cause jittering if Bluetooth were to be used for keeping track of moving objects and would not display a smooth movement progress.

A significant advantage of using bluetooth is that the majority of modern mobile devices and personal digital assistants (PDA) are fitted with a bluetooth transceiver even at the cheaper end of the market, for example the LGA140 from T mobile costing £14.99 (T - Mobile, 2011). Another advantage of bluetooth is that the signal can penetrate through objects such as walls and desks.

3.1.5 Ultrasound

Ultrasound is sound above the audible level for human hearing. This range varies from human to human but in healthy adults its average upper boundary is 20 kHz (20,000 hertz). Figure 3.4 exemplifies the boundaries between sound and ultrasound. The animal kingdom use ultrasound in the form of echolocation to navigate and hunt in the environment. The most famed for using this technique is the bat although it is also utilised by whales and dolphins. Bats have evolved to use echolocation so effectively that they can hunt fast moving prey such as moths without the use of sight.

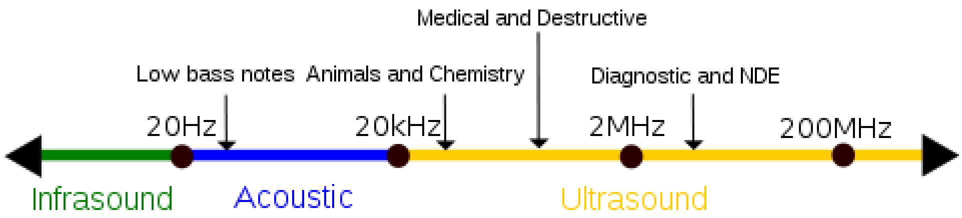

Figure 3.4 - Sound scale identifying Ultrasound (Raferty), 2010)

Echolocation, also known as biosonar, is a process that uses the echo of sound produced as it reverberates off surrounding objects. The returning echos are modified versions of the outgoing pulse and thus the brain of the animal can turn the data into mental images of its surroundings. Distance is calculated from the time it takes for the echo to return to its source based on a speed of 340m per second in open air. For example, a sound taking 4 miliseconds to return to its source means the object is at a range of 68 centimetres (Jones, 2005).

It can be argued that the most famous manmade use of echolocation would have to be the sonar pulse system used by navel vessles and applications. It uses the same principals as echolocation used by the animal kingdom in that a sound is emitted before a reciever waits for the reflected sound. Figure 3.5 shows animals and a submarine each using echolocation and how the wave returns.

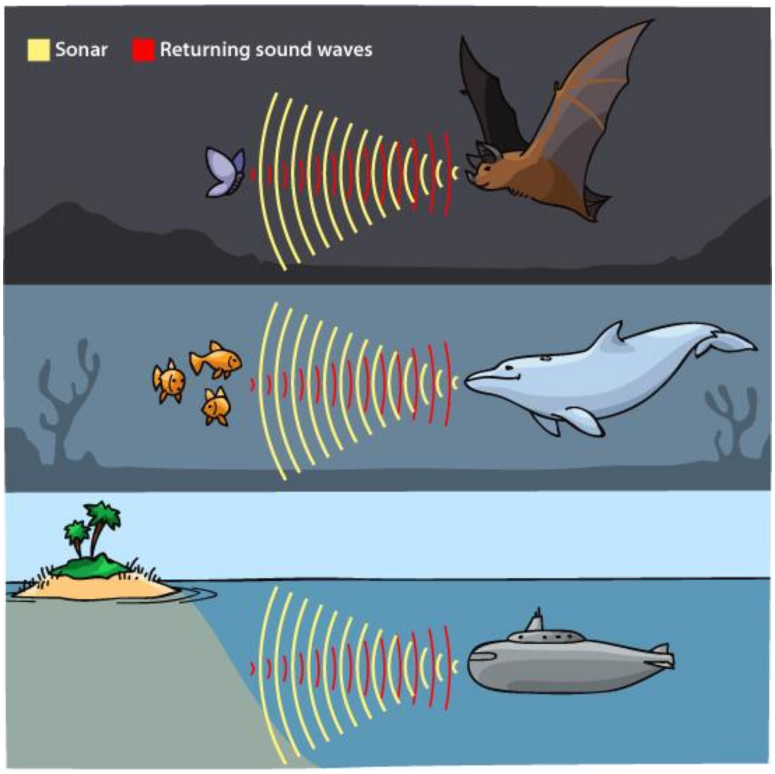

Figure 3.5 - Different examples of Ultrasound (Pitman, 1994).

Although indoor positioning using ultrasound utilises the same fundamental concepts as echolocation in the animal kingdom and the sonar used on a submarine or boat, some differences must be clarified. Ultrasound positioning uses trilateration in which the user wears a transmitter that sends out an ultrasonic wave to be detected by receivers placed around the environment. These signals can then be used to estimate the position of the user. Furthermore, it should be noted that the short wavelength of ultrasound signal does not penetrate walls or doors thus confining the user to one room (Greenemeier, 2008). Figure 3.6 shows a diagram of a transmitter emitting ultrasound waves that travel towards the receivers in a room. Using the speed that sound travels in air, each receiver can work out the distance of the transmitter using methods of trilateration.

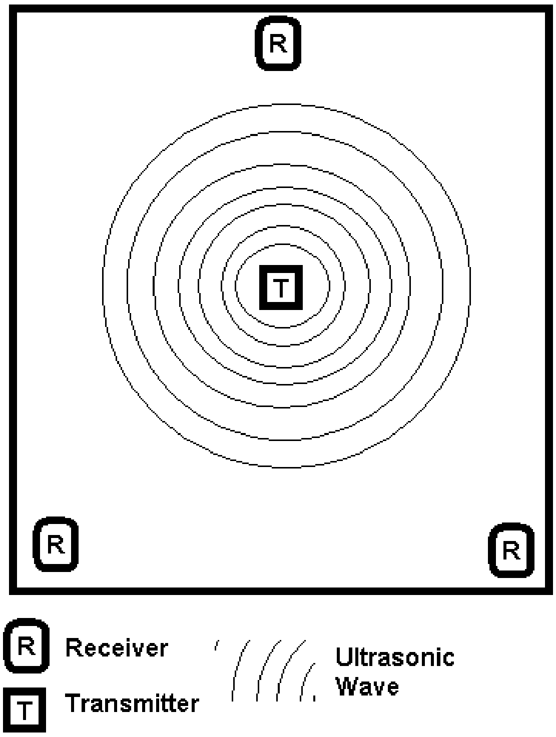

Figure 3.6 - Ultrasound transmitter within an indoor environment.

One of ultrasound's several advantages is its low cost with an ultrasound transceiver costing as little as £12 (Robot Electronics, 2011) or £3.50 per unit for separate receivers and transmitters. Although careful placement of the receivers must be undertaken in order for optimal reception of the ultrasound signal from the transmitter. There also must be some separate system or computer to take the distance readings from the receivers and trilaterate it into an estimate of position.

A primary disadvantage of ultrasound for indoor positioning is the interference caused by environmental changes such as atmospheric temperature or room temperature. These can cause changes in the propagation speeds by up to 3%. Another disadvantage is that echoes emitted from other surfaces must be discounted to avoid inaccuracies in the position estimation (Lorenz, Schmitt, Oppermann, Eisenhauer, & Zimmermann, 2001).

3.1.6 Infrared

Infrared light is electromagnetic radiation with a longer wavelength than visible light. Figure 3.7 shows the position of infrared on the light spectrum.

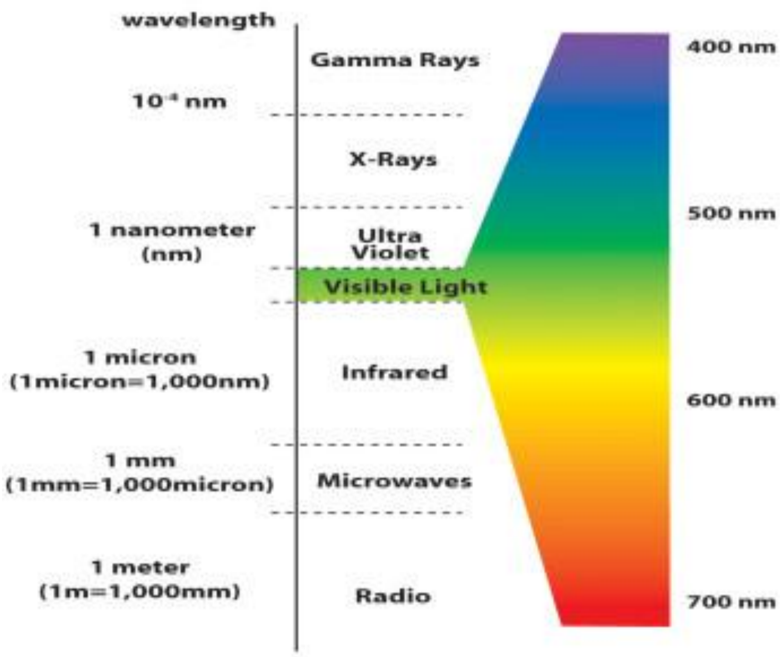

Figure 3.7 – A diagram of light spectrum (The Modern Green, 2008).

Infrared has several uses including night imaging and thermal imaging. More recently, communication between mobile phones, computers and other devices has become possible by using infrared and the Infrared Data Association (IrDA) protocol. Arguably, the most established use of infrared light is with television remote controllers and wireless controllers for games consoles. These devices emit infrared light from light-emitting-diodes (LED's) as a compact beam that has to be aimed in the direction of the receiver. The beam transfers data by modulating on and off rapidly, encoding the data towards the receiver which converts the data into an electrical current to control the device.

Infrared works using line of sight and so, for the purposes of orientation, would require a lack of obstacles or walls to work accurately. This would obviously prove problematic for orientation in most indoor environments. Furthermore, as an infrared beam is fired directionally, the beams would have to correspond to the position of the receivers in each room. This incurs that infrared is not the best-suited technique for triangulation. However, it may be suitable for relaying information such as room names and numbers to a user traversing a corridor.

Infrared transmitters and receivers are of minimal cost with starting prices of £1.00. This would mean that even in a large university building such as Canalside West at the University of Huddersfield it would be a minimal cost to place one at each of the doors to the staff offices and labs allowing users to know what the room is and if it is in use before they enter. This would operate using the aforementioned proximity method. This was used to create the Talking Signs system in America to relay audio information to users who cannot read signs and will be discussed further at a later chapter.

3.1.7 GPS & GPS with Indoor Capabilities

GPS is the most prolific system used for the positioning of people, cars and other objects within the outdoor environment. GPS uses satellites that orbit the earth at an approximate altitude of 20200 kilometres over a time period of 12 hours. Each of the satellites is equipped with an atomic clock for high precision synchronisation. A ground station tracks the satellites ensuring that they are orbiting the earth correctly and transmitting accurate data. Finally, the GPS receivers obtain the signal emitted by the satellites and use this internally to calculate and estimate its position (Chivers, 2006). GPS information is often fed into a GIS and the device position then shown on a map.

For GPS to work at optimal accuracy it must receive signals from a minimum of four satellites orbiting the earth. GPS works with line of sight so a clear path between the satellite and the receiver must exist. Therefore in built-up urban areas the signal can be weakened resulting in unreliable measurements. The multipath effect can also occur if the signal bounces off any nearby buildings. These factors make using GPS indoors difficult because the transmitted signals have to travel through walls (which can comprise of a variety of different materials) and in turn slow the signal down or block them altogether (Chivers, 2006).

Differential GPS (DPGS) uses a set base station that never moves position; it then checks the satellite measurements to determine the error amount from its stationary position. Any mobile GPS receivers in the area that are using DGPS receive this error amount and apply it to their GPS position. This is because any two GPS receivers in one area should be affected by the same atmospheric conditions (Kotsakis, Caignault, Woehler, & Ketselidis, 2001). Figure 3.8 shows DGPS working by the satellites sending signal to the base station and then base station on to the mobile device.

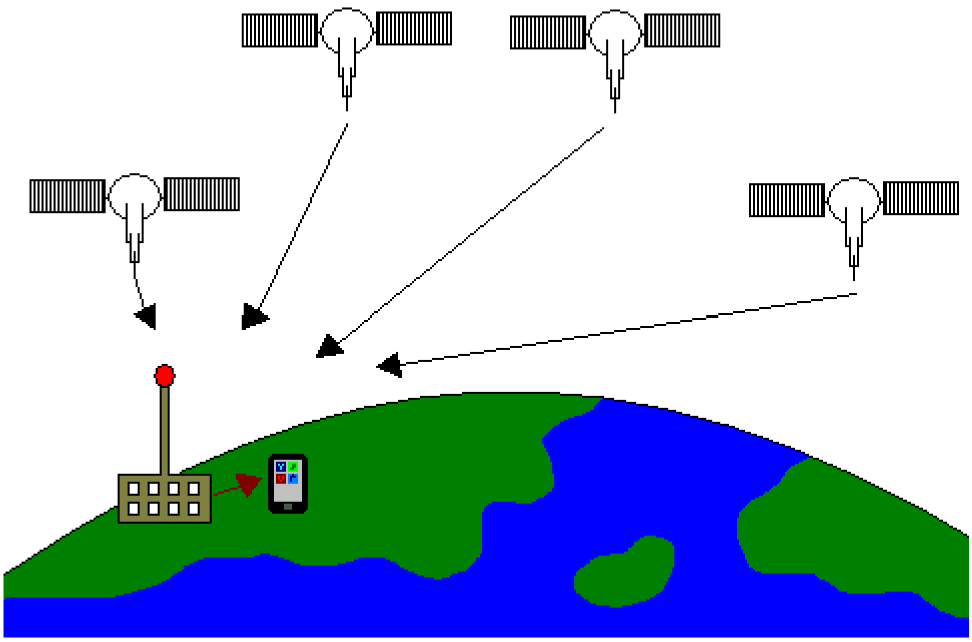

Figure 3.8 - An example of DGPS (Note signals from the satellites go to both the mobile device and the base station).

High Sensitivity GPS are extremely fast GPS receivers that work at high speeds in an open location. The extra power that the receivers use to work at such high speeds can be used to integrate weak signals that are received at indoor locations so that they can be processed into an indoor estimation of position (Wikipedia, 2011). The problem with using high sensitivity GPS is that it is unreliable in an indoor environment become it is too attenuated to work with.

The major advantage of being able to use GPS indoors is that it does not require extra systems - it can work directly from the infrastructure that is already in place. However, the cost of an indoor receiver is quite expensive and requires the extra cost of infrastructure installation. For instance, the u-blox SuperSense high sensitivity GPS receiver costs 85 Euros per unit (U-Blox, 2011) or in GBP, £71.06 per unit (XE Corporation, 2011) (Accurate on 31/01/2012).

Recently GPS has seen a new development called Assisted GPS (A-GPS) which is now commonplace in mobile phone technologies. A-GPS improves the performance of standard GPS by having a different information channel send information to the GPS receiver.

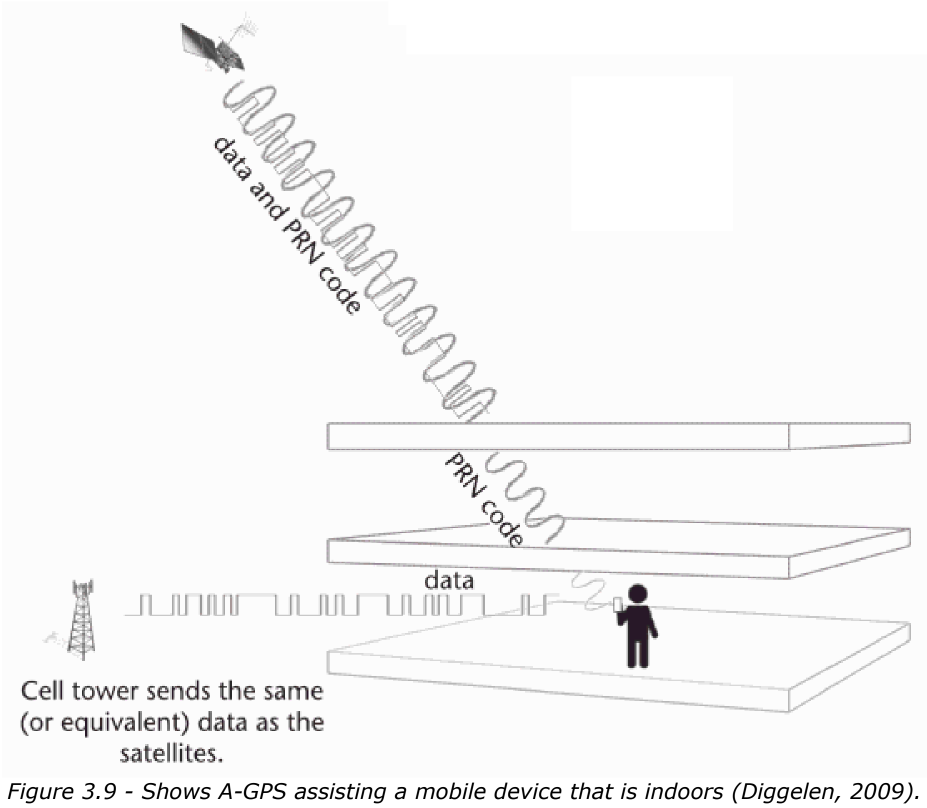

Figure 3.9 - Shows A-GPS assisting a mobile device that is indoors (Diggelen, 2009).

Figure 3.9 depicts a satellite sending data (the square digital wave) and a Pseudorandom Noise code (PRN). As the data hits the walls of the building it is obstructed and cannot pass through. The PRN code however can penetrate but gets weaker as it passes through more and more obstructions. This is where the GPS is 'Assisted' by the cell tower which sends the same data or its equivalent to the mobile device. As the diagram illustrates, the receiver still obtains the information even though it is blocked by several obstacles. Also, it must be noted that even with no obstacles, the signal transmitted from the satellite to the A-GPS receiver will receive the information faster than a standard GPS receiver (Diggelen, 2009). Incidentally, each GPS satellite works on a different frequency to compensate for the Doppler shift effect because most satellites travel at over 3km/s (Diggelen, 2009).

A primary advantage of A-GPS is that it informs the receiver which frequencies to search in order to find the satellite's signal followed by the data from the cell tower instructing the receiver where to look to locate the satellite positions. This not only increases the dwell time (the time the satellite sits over a certain part of the earth) that in turn increases the amount of signal received at each frequency but makes the system much faster overall. This also means that the sensitivity of the A-GPS receiver is increased and can therefore acquire signals at much lower signal strength than standard GPS (Diggelen, 2009).

3.1.8 Radio Frequency Identification (RFID)

RFID is a method of storing data on tags and then retrieving the data with a receiver. It has several modern day applications such as tagging library books and keyless entry for doors for example, an access door in the Canalside West building at the University Of Huddersfield in which only staff and those with disabilities have access. An RFID tag, also referred to as a transponder, has a small amount of data storage that it broadcasts using a built-in antenna. There are two main types of RFID tag: passive and active. An active tag has a power source such as a battery whereas a passive tag runs from power induced from the receiver (Hunt, Puglia, & Puglia, 2007).

There are two methods in which RFID can be used for positioning. The first is the proximity method that relies on low frequency, passive RFID tags transmitting up to approximately a third of a metre (RFID Journal LLC, 2011) meaning that if a user is to pick up tranmission from the tag they must be within its proximity range. Information can then be relayed to the user regarding their position. For example, if each door in a corridor was equipped with an RFID tag that explained to visually impaired users which room they were outside and what it contained, it could aid the creation of cognitive maps thus helping to orientate them within the building. The second method uses active RFID tags within an environment to triangulate the position of the receiver using RSS. Because active tags have a power source and are fundamentally small transceivers, this means that they have a broadcast range of upto tens of metres (Liu, Darabi, Banerjee, & Liu, 2007). The downfall of using RSS with active RFID is that the error margin can be reach upto 2m. Using this method for spatial orientation could be problematic as users could be misguided into objects or become disoriented jeapodising user safety.

3.1.9 Ultra-Wideband (UWB)

UWB is radio signal communication that generates signals with a bandwidth wider than 500MHz. It works by sending incredibly short pulses (less than 1 nanosecond) using very low power (Arslan, Chen, & Benedetto, 2006). The maximum data rate that a digital radio signal can carry is roughly proportionate to its bandwidth providing the signal is above the receiver noise and is unaffected by it (Ingram, 2006). It is for this reason that the first implementations of UWB was in wireless USB because it enables large amounts of data to be sent over very short time periods, which is needed to replace the USB2 data rates of 400MHz. Furthermore, if the data rate of UWB are slowed down additional advantages appear such as increased transmission range and lower transmission power. This means the UWB's original range of 10m or less can be increased greatly making it suitable for covering a large indoor environment. Unlike many other radio frequency signals, UWB does not suffer from the multipath effect. This is because it uses such short pulses to send data so any reflections of the pulses are easily filtered. Also, the signals can pass easily through brick, plaster, clothing and equipment however it does have interference troubles when trying to pass through liquid or metallic materials (Liu, Darabi, Banerjee, & Liu, 2007).

A disadvantage of UWB is that it uses a large proportion of the radio spectrum that may be in use by other services. Satellite television works at frequencies above 10000MHz and so from 1MHz to 10000MHz is divided between other applications such as mobile phones, satellite communications and military applications. Figure 3.10 shows the main European spectrum allocations.

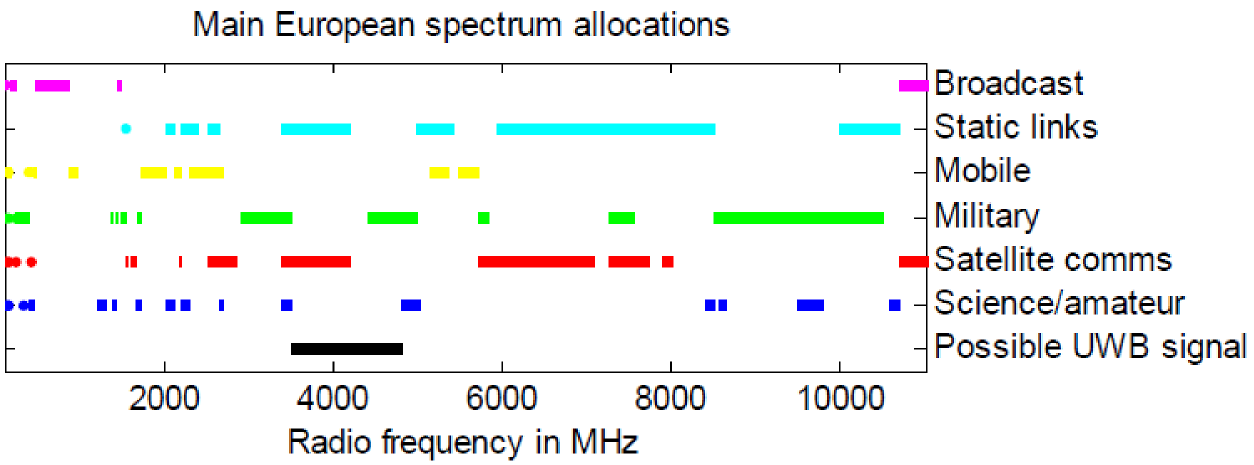

Figure 3.10 - European radio spectrum allocations.

As illustrated in figure 3.10, a large ratio of the spectrum is already allocated to other services and so it is complicated for UWB to share it without implicated interference.

The short-pulse waves used by UWB allow accurate placement by using the TOF and TOA algorithms on the burst transmission from the transmitter to receiver. Also, UWB can utilise the AOA algorithm to enable 3D positioning. Using these algorithms and UWB short-pulses, a high level of precision can be achieved (sub 20cm) (Liu, Darabi, Banerjee, & Liu, 2007). Such accurate indoor location sensing make UWB ideal for use in spatial orientation of the visually impaired - this is because accuracy of 20cm and less is within human reaching distance meaning the possibility of user disorientation is low.

3.1.10 Wireless Local Area Network (WLAN)

WLAN is a radio frequency technology that gained its reputation for wirelessly connecting computers and other wireless devices such as mobile phones, PDA's and laptops to networks and most commonly, the internet. This connection is often advertised as Wireless Fidelity (Wi-Fi) and a large amount of café's, bars and restaurants now use this to allow their patrons to have free access to the internet. WLAN works in both indoor and outdoor environments. An example of this would be the University Of Huddersfield's campus network which mobile phone users can access anywhere on campus.

The accuracy of WLAN positioning systems ranges between 3m to 30m and updates every few seconds. Considering the number of wireless points within the general urban area, the possibility exists for information on the local environment's to be relayed to users including the visually impaired. A major advantage here would be the ability to use existing infrastructure, thus incurring no extra costs to implement. It should be noted that a vital disadvantage would be WLAN's inaccuracy. Furthermore, some areas in a city may have no WLAN access points for hundreds of metres thus a user could be left disorientated (Liu, Darabi, Banerjee, & Liu, 2007).

Another method of positioning using WLAN uses the k-nearest-neighbour technique in which an environment is set up with specifically placed WLAN transceiver points which are then used to estimate the position of the user. This method yields a much more accurate estimation, however it would require the installation of more WLAN points thus adding a greater cost to the project. It also requires to be set up specifically for each environment. There are several methods and packages already on the market to be subsequently discussed that use different techniques however each requires specific adaptation of the environment by adding WLAN points and so falls prey to the problem of having to purchase the infrastructure.

3.2 – Visually Impaired Orientation & Wayfinding Systems

This section aims to review systems previously discussed in their suitability to aid the visually impaired using the techniques mentioned in Section 3.1. These systems are not commercially available to buy but have been part of other research projects and tested to evaluate their use in orientation and wayfinding of visually impaired persons.

3.2.1 LANDMARC

In 2004 collaboration between the Hong Kong University of Science and Technology and Michigan State University developed LANDMARC, an indoor location sensing system using active RFID. LANDMARC uses active RFID tags, much like the landmarks in daily life, to help estimate the location of the user. The LANDMARC project test environment consisted of a network of active RFID tags and some standard passive RFID tags, a wireless network with internet connection, an RFID receiver that can communicate with the wireless network using IEEE 802.11b, a server to implement the calculations and a mobile device used to contact the server via the wireless network. Figure 3.11 illustrates this.

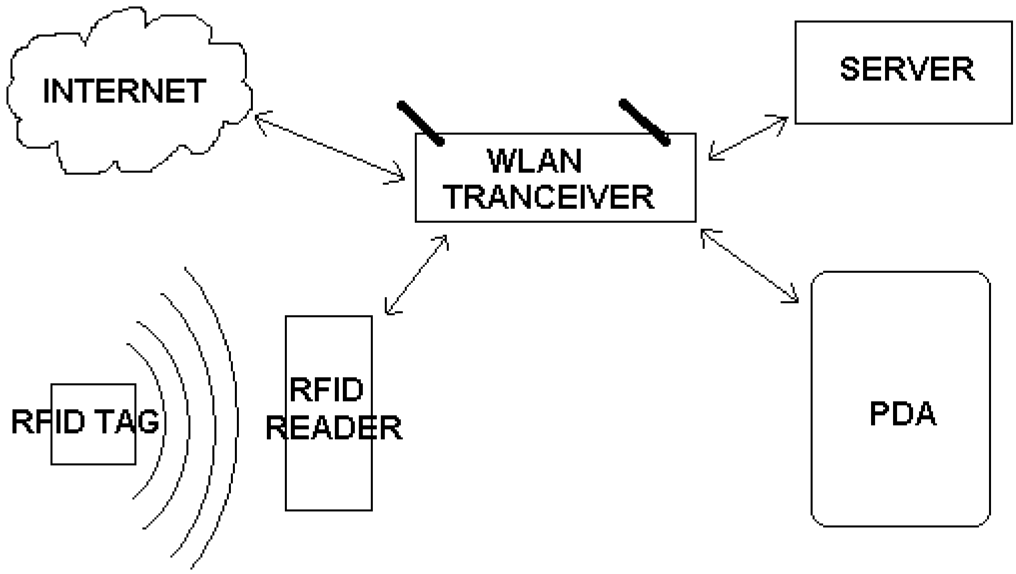

Figure 3.11 - LANDMARC network diagram.

As shown in Figure 3.11, the RFID tags broadcast to the reader that in turn contacts the wireless network sending the data to the server. This is then transmitted to the PDA or other mobile device in use so information can be relayed to the user.

LANDMARC uses k-nearest-neighbours for scene analysis by using RSS strengths of the nearest RFID tags. However, as noted by the group, RFID tags do not allow access to the RSS directly. They instead only report the power (on a scale of 1-8 in this instance) to the reader. Consequentially, they may measure what distance each power level corresponds with but as was found, this may only work correctly in free space. This meant that it is not possible to calculate distance accurately using the power levels and, as concluded by the test group, to accurately use RSS to estimate position would require RFID manufacturers access to granted to the RSS value.

The LANDMARC system showed that RFID is a cheap and viable option for tracking a position within an indoor environment. However, three major limiting factors were highlighted. Firstly, the final conclusion mentioned that the RFID vendors need to allow direct access to the RSS to gain greater accuracy of estimation. Secondly, latency between the tags emitting their ID's needs to be shortened although this is currently unachievable as RFID manufacturers lock the time interval with the average used in the LANDMARC study being 7.5 seconds. Lastly, different tags, even those produced by the same manufacturer using the same batteries, may provide different power levels and different signal strengths. This may result in inaccuracy when trying to calculate the signal strength as no two tags are identical and calculations must assume all tags have the same strengths. The disadvantages of this system outweigh the advantages and as such, the system cannot be used accurately for orientating the visually impaired within an indoor environment.

The research did, however, provide great insight into the pitfalls of RFID for scene analysis(Ni, Liu, Lau, & Patil, 2004).

3.2.2 UCSB Personal Guidance System (UCSB PGS)

Between 1985 and 2008, Jack M Loomis led a team from University of California, Santa Barbara conducted a project concerned with researching and developing a GPS-based navigation system for the aid of the visually impaired. During the extended research period, technology advanced and with it, the project, from using older GPS-based receivers to modern DGPS receivers integrated with a GIS. The system built upon standard GPS with addition of narrated instructions, such as "go forwards" and "turn left" and other points of interest such as landmarks in parks, specific doorways, car parks and other ill-defined areas such as more rural areas. The idea of the UCSB PGS was not only to convey a route to get from point A to point B but also to relay nearby points on interest. This was done, not just by speech but also by giving an impression of auditory virtual reality by spatially orientating sounds to seem as if they are emitted from the position of that particular point of interest.

The study used several different methods to convey information to a user alongside different GPS receivers and other pieces of hardware equipment. The idea of the project was to test each different type of feedback and different types of GPS receiver position such as GPS and DGPS to get the most accurate position. Combined, it aimed to identify the optimal way of orientation using GPS, GIS, auditory and haptic feedback. Figure 3.12 shows a diagram of the system and how it works. Figure 3.13 shows Reginald Golledge with the system on him.

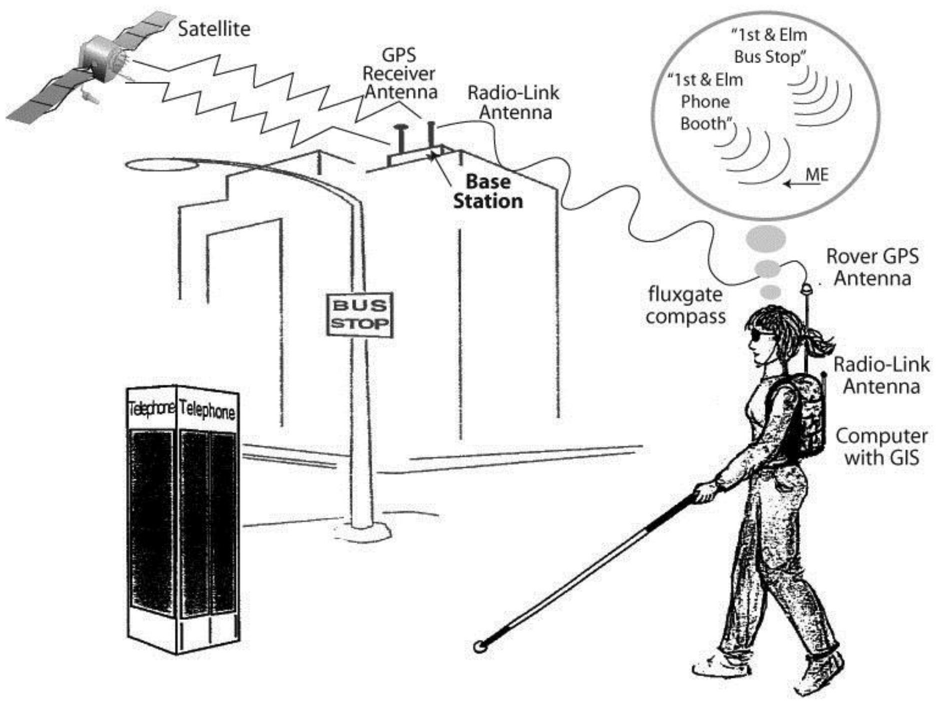

Figure 3.12 – A diagram of UCSB PGS (Golledge, Schematic of the PGS System).

Figure 3.13 - Reginald Golledge demonstrating UCSB PGS(Golledge, Schematic of the PGS System).

One of the downfalls of the UCSB equipment is the size and weight of the equipment. As Figure 3.13 shows, the equipment is very large and for some weaker people may be overly cumbersome when travelling any substantial distance. This could be one of the reasons the system did not reach the commercial market.

3.2.3 MoBIC

The MoBIC project (Mobility of Blind and Elderly People Interacting with Computers) was run by the University of Magdeburg with the aim of helping blind and elderly people in fixing their position and navigating towns. It used GPS in combination with maps and, unlike some other systems, had a pre-journey system where the user can make provisions before they travel with the MoBIC outdoor system taking over in outdoor environments.

The MoBIC team first tested use of the route planning system which involved using a computer with a synthetic speech output. The user then explored electronic maps alongside this allowing the software to find an optimum route. This information was then relayed to the user enabling the creation of a cognitive map of the environment prior to entry. The outdoor system then uses DGPS to give relatively precise information regarding the user's location and an electric compass to give the user bearing. The interaction with this system is done via a small handheld keypad that relays information via artificial speech in the format of clock-type directional commands. An example of this would be, "change direction to 3 o'clock and continue for 100 metres to High Street"(Gill, 1996). A specially designed serial earphone is used allowing the audition of commands without preventing external environment sounds being heard.

MoBIC ran a number of field tests, one of which took place in Berlin with six people attending 25 tutorial sessions before being asked to test two unfamiliar routes of approximately 1200 metres. Both aspects of MoBIC performed to a high standard with feedback from participants positive and testers impressed with the accuracy of the system.

One of the disadvantages to MoBIC was reported in the first part of the system in which users familiarise themselves with an environment before traversal. This made the assumption that the user knows exactly where they are going having an end destination and relies on the system being up to date. If, for example, road works were taking place on the day of travel they would inevitably have some problems navigating the area due to the cognitive map created prior not being wholly accurate.

3.2.4 SpotON

SpotON was a project run by the University of Washington, which aimed to use radio signals, and RSS to obtain distal information to estimate the location of a user in a small-scale indoor environment to guide visually impaired users around indoor environments. The team began by evaluating a piece of RFID equipment currently on the market for the purposes of triangulating position of the user using its RSS. However, after large amounts of experimentation it was found that the accuracy - whilst capable for automating lights in a room upon user entry - is not great enough for the purpose of accurate positioning. Issues were also identified with the time taken to obtain readings from the sensor (in the region of ten to twenty seconds), which was deemed too great for use with moving objects.

The team then developed and engineered a customised piece of hardware aiming to overcome these problems and so track people with greater accuracy and at a faster rate. The customised hardware incurred some extra cost to the project with the hardware cost $120 to manufacture (it was noted, however, that the mass production costs would fall between $30-$40). There were further issues regarding the power needed to run the hardware and as a result, larger batteries were needed in a revised system increasing the weight and size of the product.

One disadvantage of the SpotON system’s functionality was the design feature of processing data using a server before relaying it back to the user. As the project was conducted in the late 1990’s to the early 2000’s, mobile technology was not yet powerful enough to compute the data at a speed necessary to keep track of moving objects. The system’s size was advantageous, however, being small and compact unlike the earlier mentioned UCSB PGS. Figure 3.14 shows an image of the SpotON device in scale against a biro pen.

Figure 3.14 - SpotON compared to a standard biro pen.

The SpotON team concluded that although the system may be accurate to a certain degree, to build a ‘complete’ system other features such as compass, accelerometer and other location devices such as GPS should be used(Hightower, Borriello, & Want, 2000).

3.2.4 Drishti

Drishti is a wireless navigation system that uses several different technologies such as wearable computers, voice recognition systems and voice synthesis systems alongside wireless networking, ultrasound, GIS and GPS. Drishti finds optimised routes through both urban and rural areas taking into account static and dynamic data, such as road works, roadblocks and traffic congestion. The user of the system can command it by using voice input prompting the system to relays its information back via a set of headphones built into the headset as can be seen in Figure 3.15.

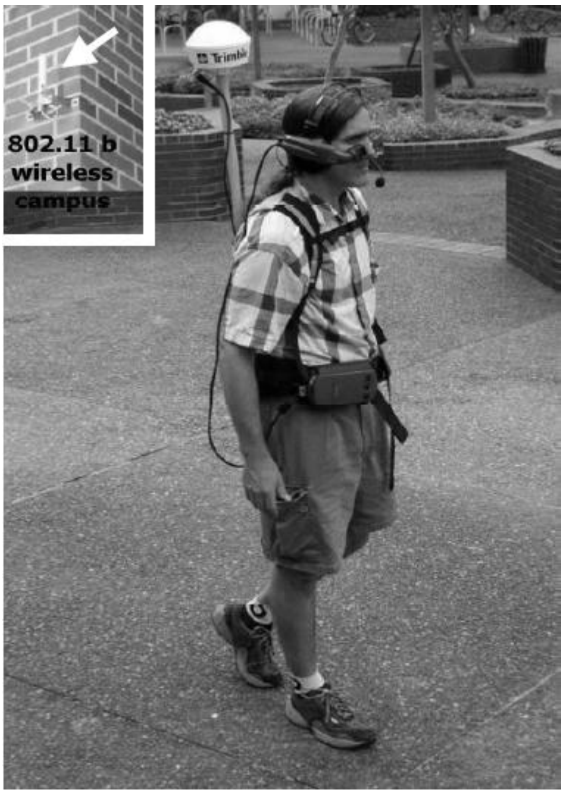

Figure 3.15 - Shows the Drishti wearable system(Helal, Moore, & Ramachandran, 2001).

The system estimates the user’s position using DGPS before voice inputs request route information or information about the environment. When a user enters an indoor environment where GPS no longer functions accurately, the user can command the system to change to ultrasound navigation. Here, two ultrasound sensors control navigation using the time of arrival algorithm.

The accuracy of this indoor system was at its worst 22cm with a mean of 10cm or less out of 22 test cases(Ran, Helal, & Moore, 2003). This confirms that the system can work with reasonable accuracy indoors allowing for general navigation. However, obstacle avoidance may be problematic for the user thus total reliance on the system would not be possible. As mentioned in the prior discussion on ultrasound, it suffers from reflection, which would cause severe inaccuracies in cluttered environments. Another major disadvantage of Drishti is apparent in Figure 3.15, where the equipment is ergonomically cumbersome. Not only does it appear uncomfortable to wear, it could possibly create further feeling of exclusion from visually able society.

3.2.5 Cyber Crumbs

Cyber Crumbs was created in collaboration between Atlanta VA Rehab R&D Centre, Charmed Technology Inc and Georgia Institute of Technology. It is an indoor orientation and wayfinding infrastructure that was designed and created with the visually impaired in mind. Cyber Crumbs works by using infrared to transmit data between the “crumbs” (which are small IR transmitters) and a badge worn around the user’s neck. These crumbs can be compared to a trail of breadcrumbs leading users around buildings. When a user enters a building they must go to an information desk and select their chosen destination/destinations within the building. The information desk then calculates the simplest route to each destination and downloads this route to the user’s badge. These directions are in the form of sequential Cyber Crumb ID numbers and a set of directions that correspond to the landmarks that each crumb is related with(Ross, Lightman, & Henderson, Cyber Crumbs: An Indoor Orientation and Wayfinding Infrastructure, 2005). When traversing the environment the badge receives information from the crumbs. This information is processed and audio information is then relayed via earphones. The crumbs are only placed at strategic points such as office doors, bathroom doors, staircases and hallways junctions thus cutting back on the cost of the infrastructure and only sends relevant information to the user in an attempt to not overburdening them with information.

One advantage of the Cyber Crumbs system is that the crumbs themselves lay dormant in sleep mode to conserve power and thus stop the need for constant battery changes. The crumbs only become active when they sense a badge within up to 12feet. Conversely, a disadvantage of the Cyber Crumbs infrastructure was the high cost of the components needed. Each badge cost $600 to produce and the team were quoted $25 per crumb if they purchased 100 at a time falling further to $5 a crumb if they purchased 100,000. For a facility such as the Canalside West building, University of Huddersfield, careful observations of the schematics revealed it would cost approximately $5000 for crumbs and up to $6000 for the badges if a high volume of visually impaired users were to be catered for summating in a total of $10000 or £6710 (accurate on 20/04/2011)(Ross, Cyber Crumbs for Successfull Aging with Vision Loss, 2004). Another problem was encountered with signal reflections over the distance travelled by signals resulting in system inaccuracy.

3.3 – Commercial Products

During investigations into systems aiming to aid orientation and wayfinding for visually impaired persons, commercial products were found for both indoor and outdoor use. This section briefly examines major products that were uncovered during research.

3.3.1 Loadstone GPS

Loadstone GPS is a free GPS package developed for Symbian-based mobile phones that use the Series60 platform(Kirkpatrick, 2011). Loadstone involves transmitting satellite GPS signals to a Bluetooth GPS device connected to a mobile phone that, using a screen reader, relays information such as points of interest and distance to landmarks to the end user. Loadstone prides itself as a cheap solution, excluding the price of professionally designed maps and expensive pieces of additional hardware. It also allows users to add their own landmarks such as friend's houses, supermarkets, bus stations and train stations. This function will further aid the user to build their own cognitive maps of an environment, increasing familiarity and in turn, confidence and inclusivity into general society.

The major advantage of the Loadstone system is that it is free to use and the user only needs a mobile device compatible with the system. The Loadstone system can be downloaded for free and used as a supplementary system to any existing orientation and wayfinding systems. One disadvantage of the system is that the user must purchase a Bluetooth GPS receiver to be able to triangulate their position to work with the Loadstone system and as such, the system requires financial outlay before it can be functional. Obviously, owning a mobile phone with GPS already installed would negate this disadvantage, as no additional expenditure would be required. Also, by not using a GIS system thus saving costs incurs that accuracy to the user's environment is totally reliant on the addition of personal landmarks. This would be problematic when the user encounters an unknown environment. Therefore, using the Loadstone GPS for exploration is not possible.

3.3.2 Trekker Breeze

Trekker Breeze is a talking GPS unit manufactured by Humanware(Humanware, 2011). Humanware bill the product to be "as simple as your TV remote" and it consists of a controller that can be used in one hand allowing the other to be used with a cane or hold the lead of a guide dog. Trekker orientates the user by giving a verbal description of where they are at the touch of a single button. This information includes that on businesses and public transport buildings such as bus stops and shops. The Trekker handset is lightweight at 7 ounces and has eight hours of functional battery life, which means a user can have full use of the device for an entire day. Similar to Loadstone, Trekker allows users to store landmarks such as their friends' houses or favourite restaurants, allowing them to build a cognitive map of familiar environments. However, unlike Loadstone, Trekker allows full navigation routes in which it can direct the user from a present position to a designated landmark or location. Therefore Trekker can theoretically be used to explore unfamiliar environments.

Unlike other systems, Trekker does not use headphones to relay information instead featuring a speaker built-in to the unit. This feature has both advantages and disadvantages. For instance, the system allows users to hear environmental cues such as moving traffic that earphones may otherwise mask. Likewise, the system may also succumb to ambient noise in the environment, which could mask the information being relayed by the speaker itself. One of Trekker's major disadvantages is the high cost for a piece of equipment with a single functionality. Its cost of 945 Canadian Dollars is equivalent to approximately £600.66 (XE Corporation, 2011) (Accurate on 31/01/2012) which is financially unviable for a visually impaired potential buyer in the UK, should they be unemployed and reliant on DLA.

3.3.3 BrailleNote GPS

BrailleNote GPS is another product from Humanware, which uses two pieces of equipment to aid user's orientation. The system comprises of a custom-built BrailleNote or VoiceNote input/output device that connects to a DGPS receiver. Used in combination, the user can input a destination and then output the needed route from their current position. Similar to Trekker, this system allows the user to store personalised points of interest, but differs in the user interface with the DGPS unit.

A major downfall of this system is not only the size of the BrailleNote or VoiceNote, but also that users must be connected to the DPGS unit via a wire. This could prove ergonomically cumbersome, especially for long distances. Because BrailleNote or VoiceNote can be used for interfacing with other pieces of software such as Windows, it could be considered an advantage that any expenditure for the hardware can be rationalised by using it in several different ways (including orientation and wayfinding). Humanware although manufacturing BrailleNote GPS, market Trekker as their main orientation and wayfinding system.

3.3.4 RNIB React

RNIB React is a talking sign system to help the visually impaired orientate themselves within town centres and is used as a device to improve user confidence and independence. The system is designed so that in addition to orientation, it can deliver additional information such as tourist information and real time passenger information (RTPI). RNIB React uses radio frequency technology to contact speaker units placed in strategic locations to a fob in the possession of the user. When a speaker unit picks up a broadcasted signal from the user's fob, a recorded message is emitted at a suitable volume for the surrounding ambient noise conditions. The opening message gives information to orientate the user to their current location followed by further, more detailed information including RTPI. The system has been installed in a number of locations throughout the UK including Newcastle City Centre, Newcastle Metro station, Birmingham City Centre and First Scotland Rail Stations(RNIB Business Development Team, 2008). A primary motivation of RNIB React's is to enable social inclusion of the visually impaired. The system is designed to facilitate independent travel around urban areas and public transport. This ensures that councils and other authorities fulfil part of their obligations as outlined by the Disabilities Discrimination Act.

A large advantage of the RNIB react system is that the transmission fob carried by the user universal across UK locations and as a result a user can travel from Newcastle to Birmingham and the fob will work in both locations. Another major advantage of this system is that it may be use to foreign visitors to the UK. This is because the messages have the potential to be user specific for instance; Russian tourists could use a specific fob that prompted Russian messages. One disadvantage of the system would be that it uses speakers for message playback which need a 120/240v ac 5A-fused power supply. Consequentially, the system is significant in size and so its location requires sufficient space and a readily available power supply(RNIB Business Development Team, 2008). This also requires the RNIB to employ people to install the units correctly and safely resulting in greater expenditure. Figure 3.16 shows the size of the speaker unit fitted to an electronic bus stop.

Figure 3.16 - RNIB React Speaker (RNIB Business Development Team / SFX Technologies, 2007).

The cost of the RNIB React system is illustrated in the table below and can be considered expensive in comparison with other available systems on the market(RNIB Business Development Team, 2008). As is shown, the system can cost up to several hundred thousand GBP to equip a large facility such as a university campus.

Component	Price (ex. VAT and delivery)
RNIB React 3 speaker unit	£2000.00 Plus VAT
RNIB React RTI speaker unit	£3000.00 Plus VAT
RNIB React Trigger Fob	£25.00 Plus VAT
RNIB React Fixing Bracket	£27.00 Plus VAT
RNIB React Message recording + Implementation up to 50 messages	£750.00 Plus VAT
RNIB React Message recording + Implementation up to 51 - 100 messages	£1500.00 Plus VAT

3.3.5 Talking Signs

Talking Signs is a system that reads signs and points of interest out aloud to users by utilising infrared technology. The project was initiated as collaborative research between Smith-Kettlewell Eye Research Institute and the Rehabilitation Engineering Research Centre in San Francisco, California. The system works using permanently installed transmitters that send infrared signals to a handheld receiver, which then decodes the signal and outputs it as an audio voice message to the user. The transmitters are placed at landmark locations such as information desks, stairs, cash machines and pedestrian crossings. There, by continuously looping, they send the message to the receivers aiding user orientation. Figure 3.17 shows a diagram of Talking Signs implemented in a town centre in which information at a pedestrian crossing can be sent to the user replacing the "cuckoo and chirp" noises more commonly used as a method of indicating when it is safe to cross a road(Noyce & Barlow, 2003, p. 26). This means that information can be sent directly to the user rather than it being emitted by a speaker and being masked by ambient environmental noise. One of the major advantages of the system is its high versatility and ability to work in both indoor and outdoor environments providing the transmitter has access to a 12VDC current. However, as seen in Figure 3.18, an urban environment may result in obstructions to the infrared signal which relies on line of sight communication.

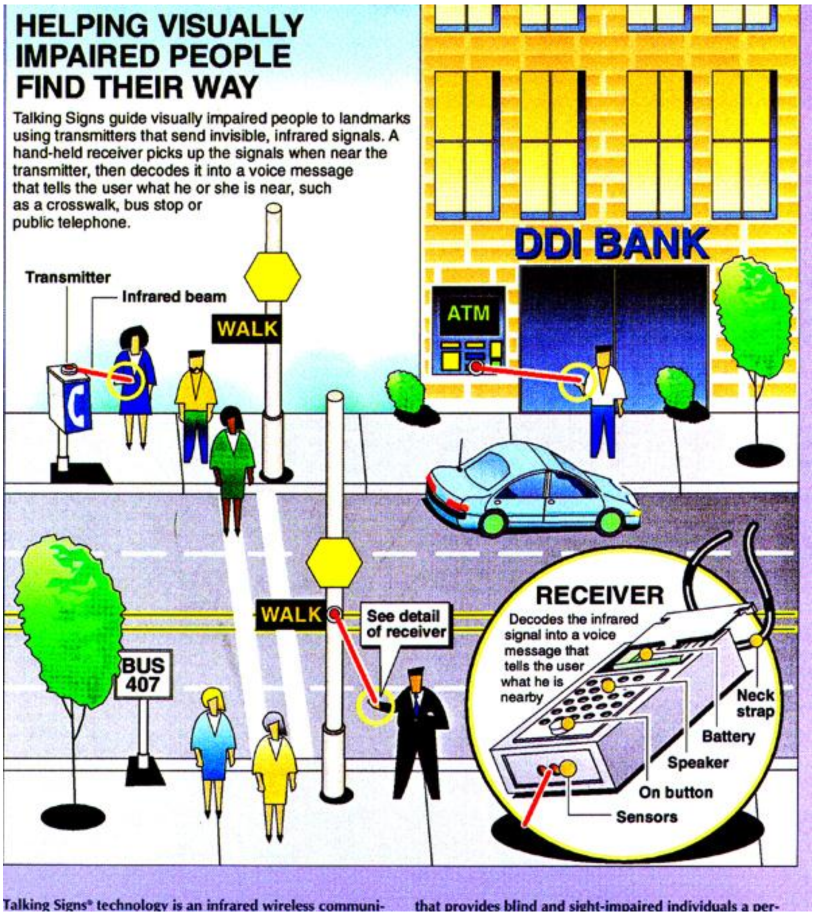

Figure 3.17 - A town centre scene demonstrating how Talking Signs works(TalkingSigns).

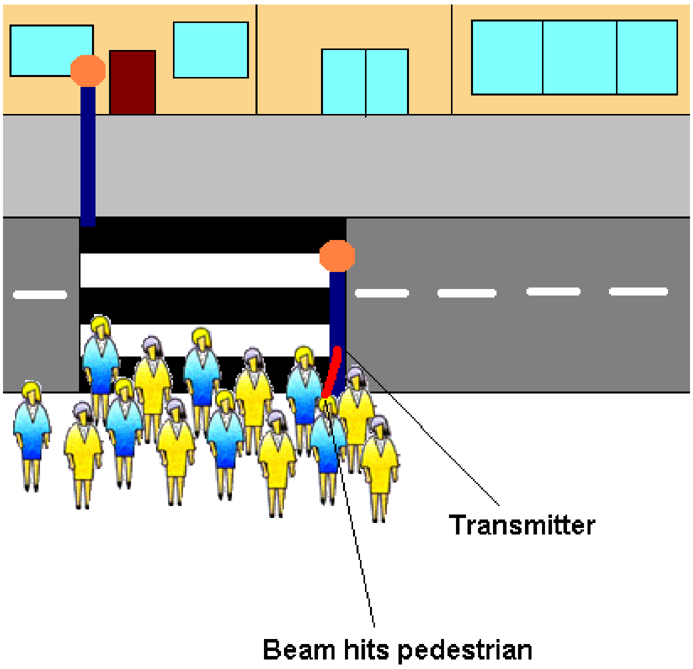

Figure 3.18 – Shows a transmission beam hitting pedestrian thus rendering the system non functional. (Pedestrians from (TalkingSigns)).

3.3 – Summary

The literature reviewed in this chapter gives insight into the functionality of positioning technologies highlighting both benefits and drawbacks of each. As such, the literature suggests that although some boast a much greater accuracy than others (such as ultrasound technologies), at times the cost of the infrastructure may be too great for widespread installation and deems some technologies unsuitable for spatial orientation of the visually impaired in an indoor environment. Other drawbacks revealed include the need for line of sight between transmitters and receivers, showing that indoor environment with walls, desks, pillars and office equipment or irregularly shaped rooms may not be conducive for technologies such as ultrasound. Additional issues of consideration were highlighted during the review of existing projects and commercial technologies such as the UCSB PGS which, although highly acclaimed and advanced, is also ergonomically cumbersome. With one of the universal motivations for creating assistive technology being the improvement of integration and inclusivity of the visually impaired into the general public, wearing such a piece of equipment can prove counterproductive to this aim.

Taking each of these factors into account, a suitable technology to use in conjunction with existing mobile technology must be selected. The most accurate technologies are suggested to be Ultrasound and UWB, however the drawbacks outlined during the review deem them unsuitable for the purposes of solo spatial orientation of the visually impaired using mobile technology. Other technologies such as infrared also use line of sight as exemplified by Talking Signs, but using line of sight in an indoor environment can cause problems due to furniture, walls, pillars and other obstacles. This means that infrared alone is not a viable option for spatially orientating the visually impaired in an indoor environment using mobile technology.

Two technologies that have a relatively cheap infrastructure are GPS and RFID, with standard GPS being available on most modern mobile devices. However, as explained earlier, GPS has a problem with indoor use due to its line of sight nature. Although it is possible for signals to penetrate some materials and thus, if used under certain circumstances, it may be possible to use standard GPS for the orientation of the visually impaired within an indoor environment using the mobile devices built-in GPS. Secondly, the cost of the RFID infrastructure is relatively low and can be installed within an indoor environment with relative ease. Using a modern mobile device to process the signals within the environment and give feedback to the user is possibly a viable option for spatially orientating the visually impaired within an indoor environment. Furthermore, using a mobile device as the transceiver means the device is discrete and manageable in contrast to the more cumbersome designs previously discussed. This would be conducive to the aim of improving user integration with the general population. If the mobile device has other functions such as GPS, then it is possible for a user to use it to guide them into an indoor environment before an alternative system takes over orientation. To summarise, it is clear that some technologies lend themselves more successfully to the task given based on issues of cost, system design and finally the discreteness of the device. The two that have stood out as potential systems are RFID and GPS.

Chapter 4 – Mobile Technology

The recent appearance of Smartphones on the UK market with the capability for allowing applications to run from the mobile device, built-in GPS and features such as the screen reader for the iPhone (for use with the visually impaired) has presented several options for the development of an indoor positioning system. This chapter reviews a variety of current mobile phones that may be suitable to use with a specialised system for helping orientate the visually impaired within an indoor environment. Phones will be analyzed for ease of use for the visually impaired, cost and additional services.

4.1 – Samsung Galaxy S II

The Samsung Galaxy S II is a touch screen phone that has no accessibility features for the visually impaired making it extremely difficult for them to use. The phone is free for those who sign to a minimum contract of 24 months at £41 per month (Vodafone, 2011) or can be purchased outright for £499.99(Three, 2011). The device can run a multitude of different applications, however it has been noted that due to the number of different Android operating system based phones available on the market, some have trouble supporting a great deal of applications(Popular Mechanics, 2011). This could inhibit a user successfully obtaining valuable applications that can offer positioning support to the visually impaired. The device does however have GPS and comes with a built-in GIS for orientation.

4.2 – HTC Sensation

The HTC Sensation is a touch screen phone which, like the Samsung Galaxy S II, has no accessibility features for the visually impaired. Due to its complex nature, it has no standard layout which would prove difficult for visually impaired users. The phone is free if a contract is taken out for a minimum of £34 per month for 24 months (Vodafone, 2011). It can also be purchased without a contract for £449.99 (Three, 2011). Again, and with the same drawbacks as the Samsung Galaxy S II, the HTC Sensation uses the Android operating system. An advantage of the HTC Sensation is that it comes with built-in GPS and GIS allowing a user to orientate themselves within an outdoor environment.

4.3 – BlackBerry Torch

The BlackBerry Torch has both a touch screen for selecting applications and keypad for typing text which would allow visually impaired users to more easily use services such as email and the internet as long as they are familiar with a QWERTY keyboard. An application for the BlackBerry has recently been released that reads aloud the screen contents which would allow visually impaired users to navigate the phone’s features with greater ease while using services such as the built-in camera or the navigation software. This piece of software is supplied by HumanWare at a single expenditure of £280 and is called Oratio (HumanWare, 2011). The phone is free if a contract is undertaken for a minimum of 24 months at £31 a month (Vodafone, 2011). It can also be bought outright for £414.99(Three, 2011). Including the added cost of Oratio the phone can be considered expensive for the visually impaired. It does however have built-in GPS and GIS allowing the user to orientate themselves within an outdoor environment and this feature used in conjunction with Oratio could be used to enhance independence of the visually impaired in traversing outdoor environments. Not all of the BlackBerry applications will be compatible with Oratio thus limiting it usability reducing the Smartphone in functionality.

4.4 – Apple iPhone 4

The Apple iPhone is arguably the most established Smartphone on the market. It is a touch screen device but does have a built-in advanced screen reader allowing visually impaired users to use a wide range of applications and features. The screen reader narrates the text alongside additional information such as the battery life, time and position of the icons on the screen. The screen reader, called VoiceOver by Apple, allows a user to tap the icon to select an icon and hear its name before tapping again to launch the program selected (Esquirol, 2011). The problem with locating icons and the keyboard for creating emails and text messages has since been negated by Bruno Fosi's design of silicone casing embossed with the keyboard layout and icon positioning. Using their haptic sensory channel, the visually impaired may now locate applications and the keyboard (Fosi, 2008). Figure 4.1 illustrates Fosi's design retaining all screen functionality of sliding and touching.

Figure 4.1 - Bruno Fosi's silicone case for the iPhone that allows users to feel the screens layout.

Various iPhone applications aimed towards visually impaired users currently exist and it may be because of this that the iPhone was recently reviewed as, "the most revolutionary thing to happen to the blind for at least the last ten years" (VanHemert, 2010). This statement occurred after a reviewer reading of blind iPhone user Austin Seraphin, and his utilisation of an application using the iPhone camera to identify colours enabling him to see the sky and his pumpkin plants for the first time. Seraphin goes on to say that, “I love my iPhone. It changed my universe as soon as it entered it.”(Seraphin, 2010). The application, called ColorID, takes a photograph of a scene and analyses it before reading out the colours on screen citing them in a range of descriptions from “orange” to “atomic orange”. Figure 4.2 illustrates ColorID running a photograph analysis.

Figure 4.2 - ColourID identifying colours from a photograph taken with the iPhone (Esquirol, 2011).

Another iPhone application for the visually impaired is the money reader, LookTel. Whilst this application only currently works with US dollars, similar applications are currently being developed to work with different currencies on a global scale. LookTel works by scanning money with the iPhone’s camera, analysing the picture before announcing to value of the money to the user. Figure 4.3 shows LookTel identifying some American dollar bills.

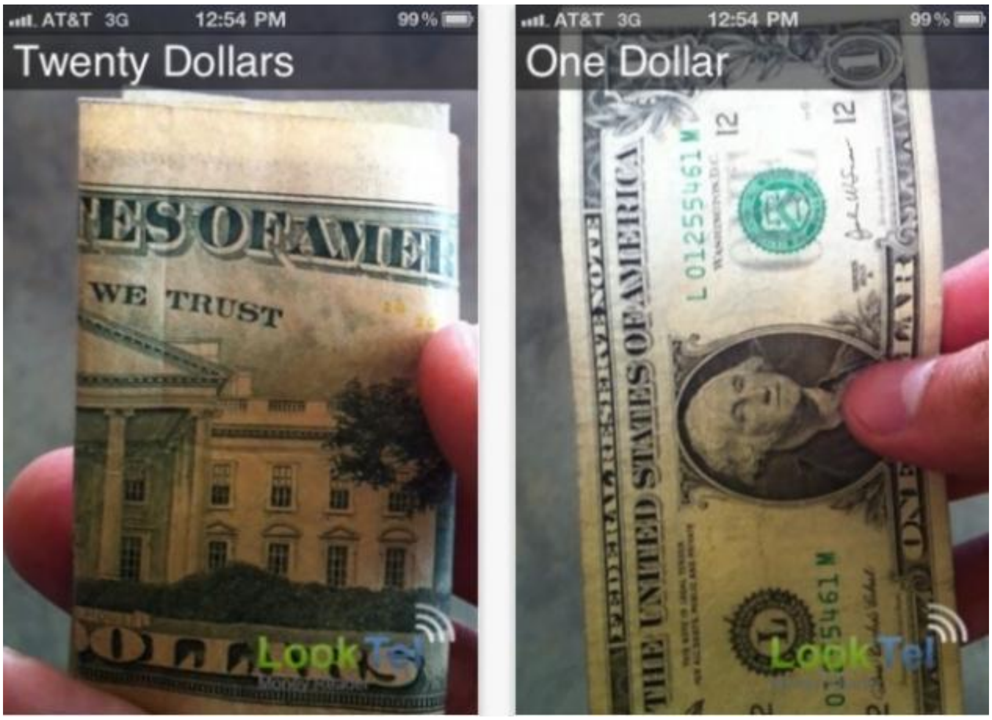

Figure 4.3 - LookTel identifying American dollar bills (Esquirol, 2011).

There are hundreds more applications for the iPhone that help the visually impaired. Audiobooks is an application allowing users to listen to over 2,200,000 audio books for free (Apple, 2011) while the oMoby application uses the iPhone's camera to identify everyday shopping items(Apple, 2011). There are also applications aimed at the general public that in conjunction with screen reader prove useful to the visually impaired. These include ToiletFinder UK which locates the nearest public toilet. When considering the multi-functionality of a standard 16 gigabyte iPhone 4, its contracted tariff of 24 months at £40 a month (Vodafone, 2011) or cost of £499.99 without a contract (Three, 2011) may be justifiable for a visually impaired individual on DLA. An additional benefit of the iPhone 4 is its A-GPS functionality providing a higher accuracy than standard GPS. It also comes packaged as standard with Google Maps to use as a GIS with the option of several other GIS packages available at varying costs.

4.5 – Summary

Comparatively, most modern Smartphones are similarly priced and all can be obtained for free by signing a contract with a phone company. Therefore, as most members of the public already own a mobile phone, adapting a Smartphone as a wayfinding and navigation device would further expand its multi-functionality. This information supports the notion that a Smartphone could be used in conjunction with wireless communication technology to provide a solution to a commercially viable system for the indoor navigation of the visually impaired.

Whilst all Smartphones are powerful, some are completely inaccessible to the visually impaired and so even if these phones have applications aimed towards visually impaired users, these are redundant if the user cannot navigate the phone's menus due to lack of screen readers and assistive technology. As can be seen in Table 4.4 below, the Samsung Galaxy S II and HTC Sensation do not come equipped with screen readers nor can one be purchased and consequently are not suitable options.

The BlackBerry Torch is a phone with GPS capabilities and a screen reader. However the cost of the screen reader is not favourable in comparison with the Apple iPhone which has the capacity for a free screen reader with an arguably better functionality (Schroeder, 2010). Therefore, the iPhone is clearly the market leader for use with the visually impaired on account of its free screen reading functionality, multiple assistive applications currently in development and silicone overlays by the aforementioned Bruno Fosi. This is illustrated in Table 4.4. The iPhone is a multiple function device that can act as a mobile phone, navigation aid, internet browser, item identifier and a monetary identifier. It also supports additional applications that give visually impaired users the ability to see colours around them and have them described in detail. This explains why people such as Paul Schroeder, vice president of programs and policy at the American Foundation for the Blind, praises the iPhone and the assistance and advancements it is pioneering for the visually impaired(Schroeder, 2010).

Phone	Purchase Price	Contract Price (phone free)	Screen Reader	Overlay	Other Applications	GPS
Samsung Galaxy S II	£499.99	£41 pm	NO	NO	YES	YES
HTC Sensation	£449.99	£34 pm	NO	NO	YES	YES
Blackberry Torch	£414.99	£31 pm	YES (£280)	NO	YES	YES
Apple iPhone 4	£499.99	£40 pm	YES	YES	YES	YES (AGPS)

Table 4.4 Summary of Smartphone functionality

Chapter 5 – Evaluation of Technology

The information outlined in earlier chapters of this thesis suggests that obtaining accurate positional information within an indoor environment is a difficult task. The following chapter documents testing undertaken to investigate the selected mobile device, the Apple iPhone 4's ability to help spatially orientate the visually impaired within an indoor environment using its AGPS. Based on the results of this investigation, which highlighted the unsuitability of the iPhone 4's AGPS, further testing was then undertaken to explore if RFID technology could provide a suitable alternative (because of the advantages outlined in Chapter 3). Here, the chosen RFID receiver's read range was investigated to ensure that it was capable of being used in conjunction with a peripheral system.

5.1 – iPhone Indoor GPS Performance

The first investigation was aimed to test the accuracy of the iPhone's Assisted GPS chip by locating a singular position inside various public environments such as a bus station or a public library. The public environments that were tested differ structurally regarding the materials they are constructed from and it was therefore important to test the iPhone's A-GPS chip's ability to receive data using a Pseudo Random Noise (PRN) code in a variety of conditions. The Apple iPhone is advertised to have A-GPS that, as explained in Chapter 3, uses a ground station and a PRN code to transmit the same information as the satellite through numerous obstacles. If the standard analogue satellite signal cannot penetrate the structural materials of the building or its potential obstructions, then the PRN code has a greater chance of penetration due to its robust digital nature. Initial anecdotal reports of the iPhone and its A-GPS system ascertained from personal use suggest that this system does not perform adequately in indoor environments and suffers greatly from signal attenuation, often reverting to the use of its Wi-Fi positioning system. I foresee the results of this investigation aligning with the aforementioned reports rendering the iPhone's A-GPS unsuitable for indoor orientation of the visually impaired.

This investigation was initiated by finding suitable locations within public indoor environments throughout a town centre. The locations (as seen below in table 5.1) were chosen on recommendation by the Batley Blind Association due to their common usage by the public and the visually impaired. A high accuracy GPS receiver was used to record the exact latitude and longitude of a specific point in each location with that position then marked on the ground using a dot stamp. This point was then referenced against the exact latitude and longitude as recorded by a custom-built iPhone application implemented in the same location. Following this process, the latitudinal and longitudinal position of both sets of data were recorded into a geographic information system in order to measure the difference in metres between the two points. This data provided the discrepancy of the iPhone's A-GPS in comparison to the high accuracy GPS reciever within the indoor environments.

One problem that may have compromised the data originated from the iPhone’s Wi-Fi location function. This occured when the nearest Wi-Fi point was used to calculate the position of the phone because an A-GPS signal was not available. To negate this problem, Wi-Fi communication was prohibited during all the investigations forcing the phone obtain its location using other methods.

In order for the iPhone’s A-GPS to be considered accurate enough for use in an indoor environment, the discrepancy between the device and its high accuracy counterpart must be suitably low. If the discrepancy between the device and its counterpart is too great, guiding users in possible confined spaces could become problematic. It should be noted that the iPhone’s GPS data is accurate to the fourth decimal and as such, the data of the high accuracy GPS device has been rounded accordingly. The results of the aforementioned investigation examining the accuracy of the iPhone’s A-GPS chip can be seen below in table 5.1.

Location Name	Actual Location	iPhone Location	Discrepancy
University Building	53.6410, -1.7786	53.6374, -1.7944	1116.57m
Students Union	53.6430, -1.7784	53.6412, -1.7733	389.64m
Restaurant	53.6449, -1.7794	53.6452, -1.7794	22.48m
Shopping Mall	53.6461, -1.7812	53.6458, -1.7812	40.54m
Bank	53.6465, -1.7827	53.6461, -1.7729	648.12m
Café	53.6457, -1.7829	53.6457, -1.7829	7.78m
Shop	53.6448, -1.7827	53.6461, -1.7729	660.86m
Bus Station	53.6455, -1.7863	53.6374, -1.7944	1043.38m
Train Station	53.6486, -1.7847	53.6461, -1.7729	828.75m

Table 5.1 Results of location with both high accuracy GPS and iPhone GPS

As can be seen from the table of results, there was a variable amount of discrepancy between the GPS locations of the iPhone and the high accuracy GPS device. A discrepancy range between 14.7m and 1,108.79m shows clearly that the iPhone 4 cannot be relied upon for accurate indoor spatial orientation. Furthermore, even if the discrepancy was not over such a wide range, the smallest discrepancy of 7.78m would not be suitable in the context of orientation in an indoor environment. In conclusion, this data rules out the use of the iPhone’s built-in A-GPS to orientate the blind within an indoor environment.

The iPhone was chosen as a multi-function device based on its commercial viability. Although, there are some GPS receivers on the market that boast indoor functionality on account of their ability to track extremely weak signals alongside using additional algorithms that help reduce the multipath effect and potential signal reflections. One such example would be the aforementioned uBlox SuperSense (uBlox, 2011). However, due to the high cost of the uBlox chip, the net cost of a working product may prove beyond the realms of commercial viability especially considering the average income of an individual on disability benefits. In conclusion, on account of the fact that the Broadcom BCM4750 (Chipworks, 2011) (iPhone’s standard GPS chipset) does not have the required accuracy to safely orientate the visually impaired within an indoor environment, an alternative solution must now be identified.

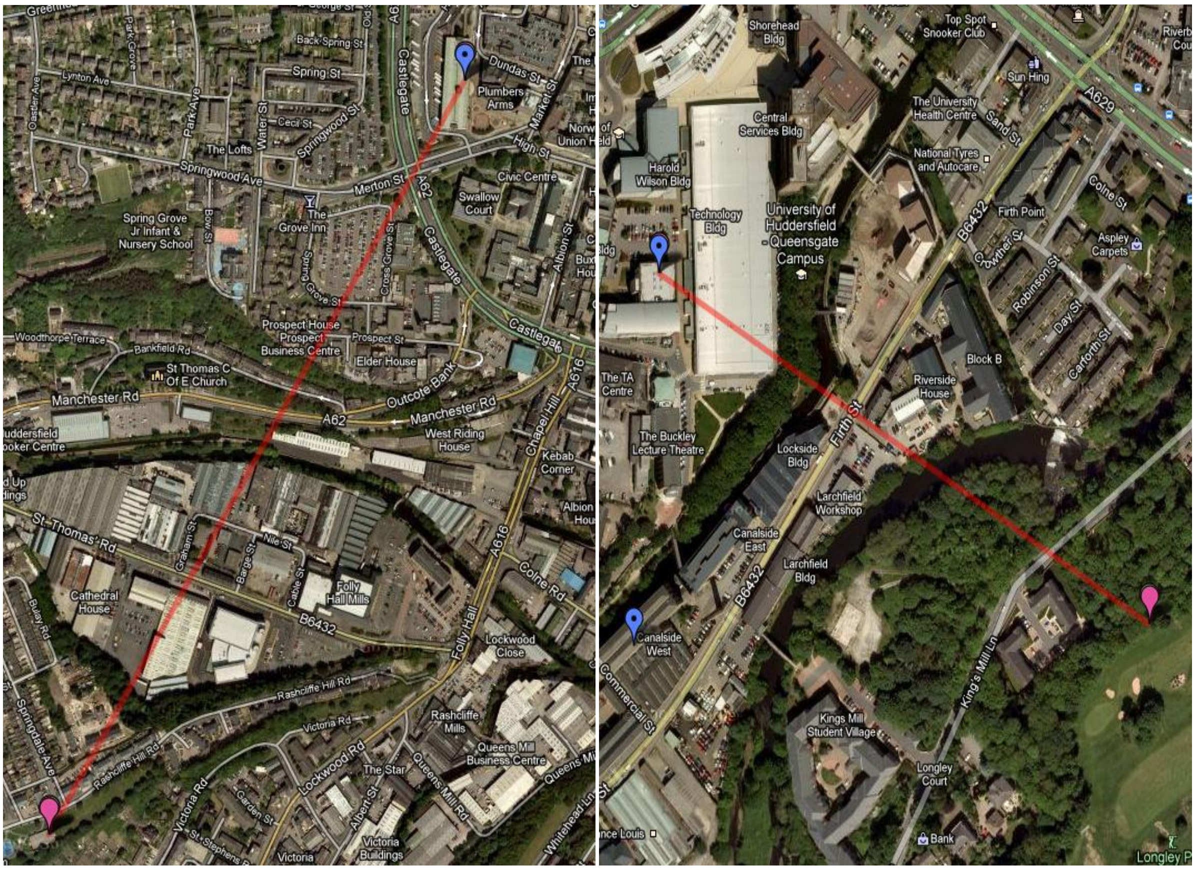

Figure 5.2/5.3 – Showing the use of GoogleMaps to work out straight line distance between points (Google, 2011).

Figure 5.4 – Showing the use BROADCOM BCM4750 Chipset in the iPhone4 (Chipworks, 2011).

5.2 – RFID Receiver Read Range

There are several frequencies of RFID, however to keep costs to a minimum, low frequency passive RFID tags running at 125khz were selected. An RFID reader must also be selected so that its data can be sent to the Apple iPhone for interpretation. The RFID reader chosen was the ID-12 Innovation chip that is retailed by SparkFun Electronics (SparkFun Electronics, 2011). The aim of this investigation was to evaluate the distance from which the chosen receiver can read RFID tags. The reader specification states that the device has a read range of 10cm (SparkFun Electronics, 2011). Therefore this investigation aimed to test that the specified read range upholds when the device is implemented in a peripheral system. It is to be noted that various methods of RFID card placement within the peripheral system were considered and that attachment to the tip of a blind cane with tags hidden under flooring was deemed the most efficient. Furthermore, the investigation acted as an initial testing of the overall functionality of the device.

To effectively evaluate the read range, it was measured at a number of different angles and through a multitude of materials such as carpet, laminate flooring and wood flooring alongside a control condition using no material obstacle. This aimed to imitate the real life scenario of a visually impaired user scanning with a cane. In the context of the investigation, this was the receiver system being used from a variety of different angles and through various materials. Figure 5.6 demonstrates the specific angle positioning of the RFID card in relation to the receiver. A controlled testing environment was designed using a 30cm rule secured to a wooden base with the device reader secured at the 0cm mark (see Figure 5.5). An RFID card was then attached to a purpose built slide, allowing for accurate intervallic movements of 1mm. In order to obtain the average range, the cards were moved at 1mm intervals towards the ID-12 chip from 15cm onwards, through the selected test materials. The ID-12 was then linked up via the peripheral system to the iPhone, which was programmed to play an alert tone when the chip had been detected. Once the chip had been detected, the distance was recorded and the process repeated.

One problem that may have occurred during the investigation was that the acquired batch of manufactured cards could have been defective, therefore affecting the read range of the peripheral system. To ensure that the results for the investigation were not biased according to a single batch of RFID chips, five separate cards from five separate batches were used alternately to ensure accurate data was collected. It should be noted that when placing the material obstacles in front of the RFID reader, the material's reverse side was placed flush to the chip before recalibrating the measuring system to account for the added thickness of each different material that was measured.

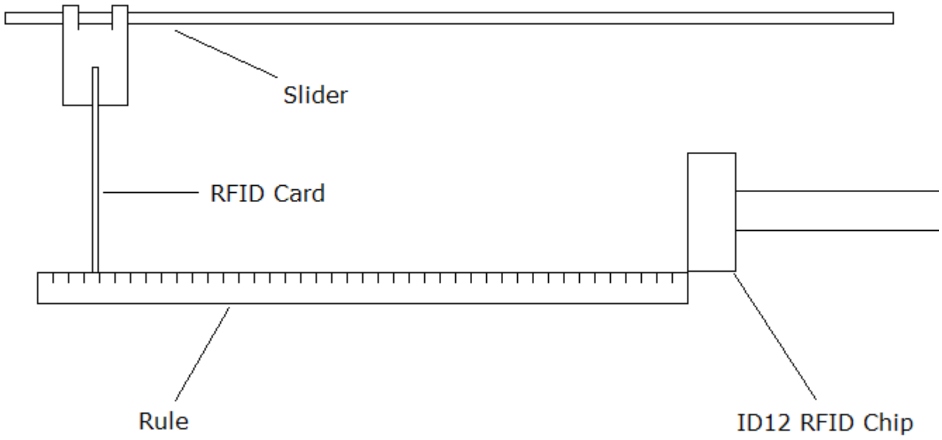

Figure 5.5 – Diagram of experiment configuration.

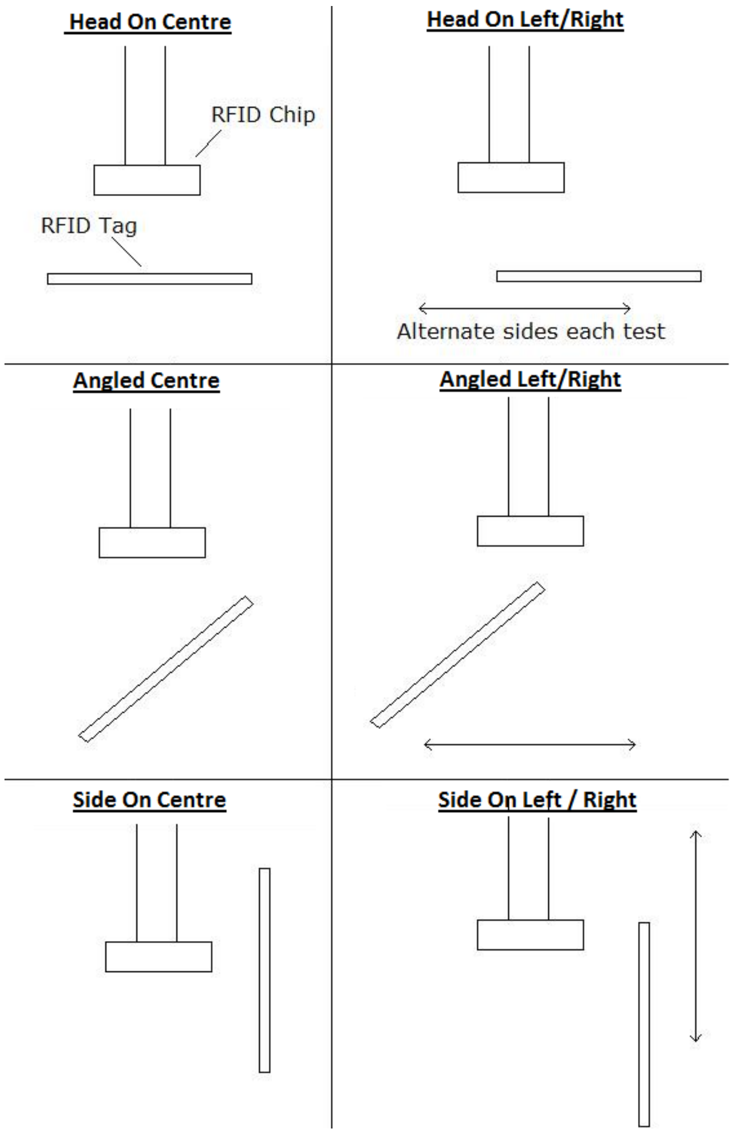

Figure 5.6 – Diagram of experiment angles and positions.

Singular intervals of 1mm were deemed suitable in the investigation as they provided sufficient accuracy to give useful end data but without being so diminutive a unit that it would not have an active effect on the system. To gain an accurate average, the readings were taken 25 times at each angle through each material respectively. Once the experiment had been conducted, the data was analysed and a mean value for each angle within each material calculated. The data recorded was not anticipated to have a large enough deviation from each another to warrant using mode or median averages and therefore calculating a mean average was deemed sufficient to show the differences between angles and materials. A desirable outcome would show that the average read range at different angles and through different materials is as close to 10cm as possible, with the ideal outcome being that all eventualities have a maximum read range of exactly 10cm. However, if the investigated read range does not align with the 10cm specified by Sparkfun, it is anticipated that the system will still be viable. This is because, even with a small read range, the cane would still function successfully as the electromagnetic field produced will still contact the RFID card allowing it to transmit its data sufficiently.

After the investigation was conducted (data in Appendix B), the following graph was generated using the mean averages of the data collected ascertaining the read ranges of the RFID cards through a number of materials at given angles. The red line indicates the read range as specified by the manufacturer of the ID-12 RFID reader.

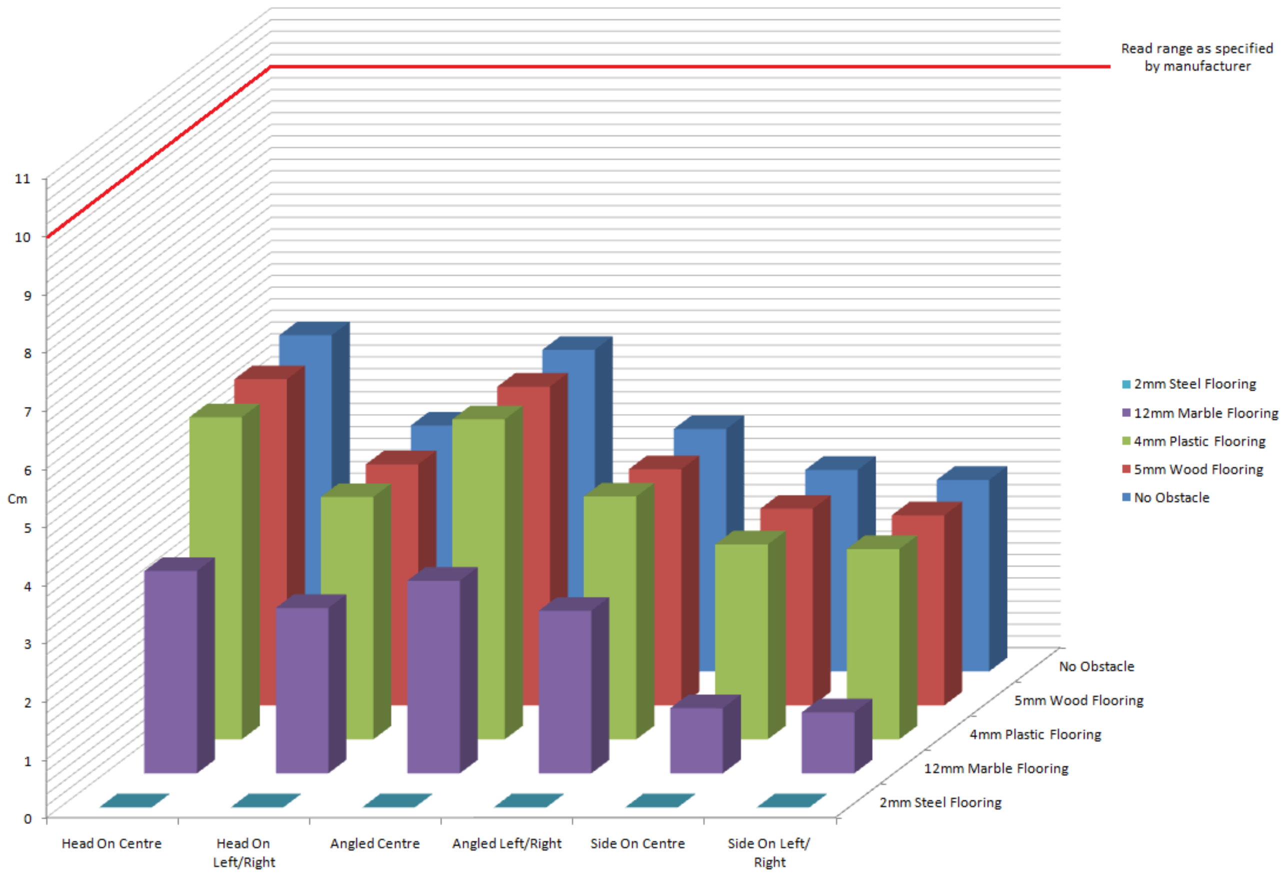

Figure 5.7 – A graph to show read ranges of RFID chips through various materials at a number of specified angles.

The initial test was conducted using no material obstacle. The graph shows that the specification of 10cm read range given on the website of the chip manufacturer was not accurate in this case, with a minimum deviation of 3.8cm. As discussed prior, it is still possible for the peripheral system to be successful with read ranges smaller than 10cm. With no obstacle, the lowest read range recorded was 3.2cm, which is still adequate enough for a user using the RFID device to read the tags placed on the floor. A standard card read would most likely be "Angled Centre" or "Angled Centre Left/Right" in which case the mean range tested at 5.5cm or 4.2cm respectively, which is more than adequate for the purpose of the peripheral system.

Testing on both 4mm reinforced plastic flooring and 5mm wood flooring yielded very similar results, which also correlated to the initial results gained without material obstruction as discussed prior. Both materials cause little to no disturbance of signals by the RFID reader. This suggests that both material types should work effectively with the RFID reader.

As can be seen from the graph at Figure 5.7, the marble flooring caused a decrease in the read range. This is because the material affects the penetration depth of the electromagnetic field given off by the RFID reader. Despite the reduction in read range, marble flooring is still adequate for use with the peripheral system. However, these results highlight the fact that some materials can cause the penetration depth of the electromagnetic field to diminish. As a result, penetration depth is a concern when placing the peripheral system in environments with metallic robust flooring. It is possible that this type of flooring material may detrimentally alter the penetration depth of the electromagnetic field thus rendering the peripheral system inefficient. To investigate these concerns further, metallic steel flooring (as used in industrial sites) was tested to ascertain if penetration depth of the electromagnetic field would be affected.

As Figure 5.7 shows, the metal flooring did not allow the electromagnetic field of the RFID reader to penetrate. This proved to be the case in all eventualities of angle placement of the cards. It should be noted that the primary use of steel flooring is for high traffic areas where durability is key, for example industrial warehouses. Although it must be stated that it is possible that a visually impaired person may want access to such an environment, a primary aim of the system is to be installed in commonly used indoor environments.

Figure 5.7 clearly shows a trend in the read ranges at the different angles through the range of materials tested. This excludes 2mm steel flooring as an exception to the trend due to it being non penetrable by the RFID receiver. Head on centre and angled centre show the highest read ranges throughout all materials with head on left/right and angled left/right consistently showing similar values but with a decrease of 2cm compared to the centre readings. This can be equated to the electromagnetic field not contacting the copper coil inside the card as efficiently when the card is held at an extremity, figure 5.8 demonstrates this.

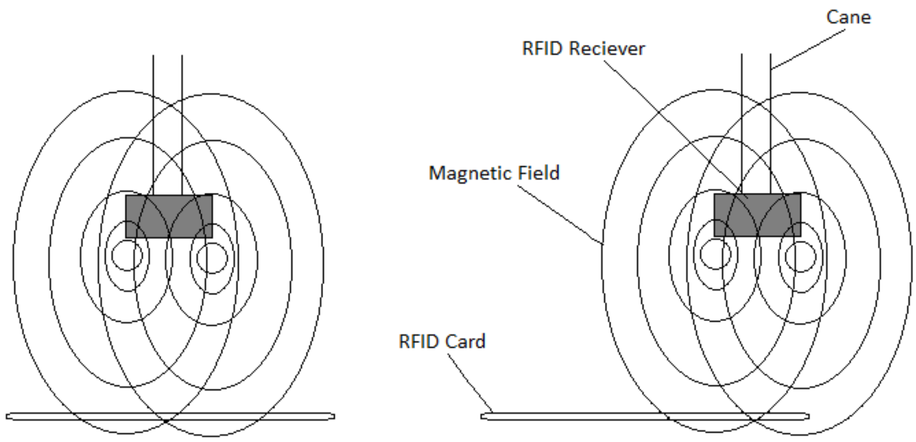

Figure 5.8 Magnetic field induction on RFID cards at different angles.

This investigation highlights that it is possible for the system architecture to function correctly in a multitude of different environments and angles. Although when embedded behind certain materials the read range of the system is adversely affected, it still functions to a level that would allow the system to operate correctly. It also highlighted that certain flooring materials such as metal will cause the system to cease functioning. However, it was concluded that as the target installation environments would not commonly be constructed from such materials, the system should be able to be successfully installed. From this, the project can progress onto the next stage in which this information will be used to design and engineer a commercially viable and accessible system to aid the visually impaired with indoor navigation and wayfinding.

Chapter 6 – Design of a Peripheral Device

Using information derived from the previous chapters, a design for a peripheral device to be attached to a mobile phone for the use with spatial orientation and the creation of cognitive maps for the visually impaired will be outlined. Used in conjunction with the mobile device, the peripheral system should be able to identify landmark positions within the indoor environment, identify obstacles such as pillars and stairs and inform the user of each room they pass as "Computer Laboratory" or "Gary Jones's Office – Head of Computer Games Programming". The device should also be able to identify supplementary items or objects such as artwork, emergency posters, fire extinguishers and windows. The system will be referred to from this point onwards as the ASOVI system (Audio based Spatial Orientation for the Visually Impaired).

6.1 – Technology Used

Chapter 3 outlined and analysed different wireless communication technologies and current systems on the market utilising these technologies. It was deduced that RFID is conducive for use with a mobile device. Strategically placed RFID tags should be able to identify landmarks, rooms, obstacles and any other points of interest such as works of art, water fountains etc. It also has a relatively cheap infrastructure allowing buildings to be appropriately labelled for a small financial outlay.

Chapter 4 outlined and analysed available Smartphones currently on the market. The Apple iPhone 4 is the most easily accessed by the visually impaired and boasts a wide range of applications with the potential to prove most valuable to visually impaired users. As such, a combination of the Apple iPhone 4 and RFID will be used to create the ASOVI system attempting to spatially orientate the visually impaired within an indoor environment.

6.2 – Design of the Electronics

As outlined in the earlier chapter, the 125 KHz ID12 RFID receiver was selected (SparkFun Electronics, 2011). The chip's features are outlined on the company's website as:

- 5V supply
- 125 kHz read frequency
- EM4001 64-bit RFID tag compatible
- 9600bps TTL and RS232 output
- Magnetic stripe emulation output

(SparkFun Electronics, 2011)

The chip is to be soldered to a breakout board in order to then solder it successfully into a working circuit. Breakout boards are used in electronics to allow wires to be hooked to the chip or device that then send the signal onto other chips or devices (CNC Router Source, 2011).

The battery power of an iPhone is not sufficient to sustain the 5V supply of the peripheral system and so an additional power source must be considered. Several battery packs are available that are capable of generating the specified 5V however the need for the device to be small and lightweight must be considered in order to maximise the comfort and discretion of the end user. As such, an AA battery pack that uses a 5V DC to DC step-up to take the 3V outputted by the two AA batteries and step it up to 5V was selected.(SparkFun Electronics, 2011).

Once the system was engineered to have the ability to read data, it must then be capable of transmitting this data to the iPhone. The built-in serial port of the iPhone allows communication between peripheral devices and the phone. The serial communication uses 3.3V which conflicts with the RFID chip’s output at 5V and so connecting the two would cause damage to the iPhone. A level converter to step down the voltage level from 5V to 3.3V is therefore required to prevent this circumstance (SparkFun Electronics, 2011).

Once the level converter has been connected, a means of sending the data to the iPhone must be implemented. This is achieved by reconfiguring a standard USB iPhone or iPod data cable. The head of the cable must be stripped to reveal a 30 pin connector, with 4 pins attached to the 4 cables in the USB wire. Figure 6.1 shows a diagram of the 30 pin connector.

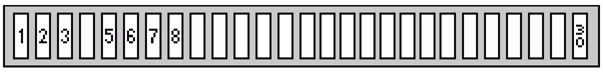

Figure 6.1 – A diagram of an iPhone cable 30 pin connector (Pinouts.RU, 2010).

Using the configuration specification found at Pinouts.RU, the 4 cables are removed from their current positions and reconfigured into the following positions.

- Pin 1 for ground cable (GND)
- Pin 13 for the serial data receive cable (Rx)
- Pin 18 for the 3.3V power cable (+)
- The fourth pin is removed as it is redundant.

The USB head on the opposite end of the cable is then removed in order to place the wires through the appropriate holes on the level converter. This will allow data sent through the converter at 5V into the cable, which operates at 3.3V.

The ASOVI system was then soldered with the addition of two wires (from pin 7 to pin 1 and from pin 11 to pin 2) to the RFID breakout board. This is to allow the data to be outputted in ASCII (American Standard Coding for Information Interchange). Finally, a switch was added to allow the power to be turned on or off to conserve battery life. Figure 6.2 shows a diagram of the system.

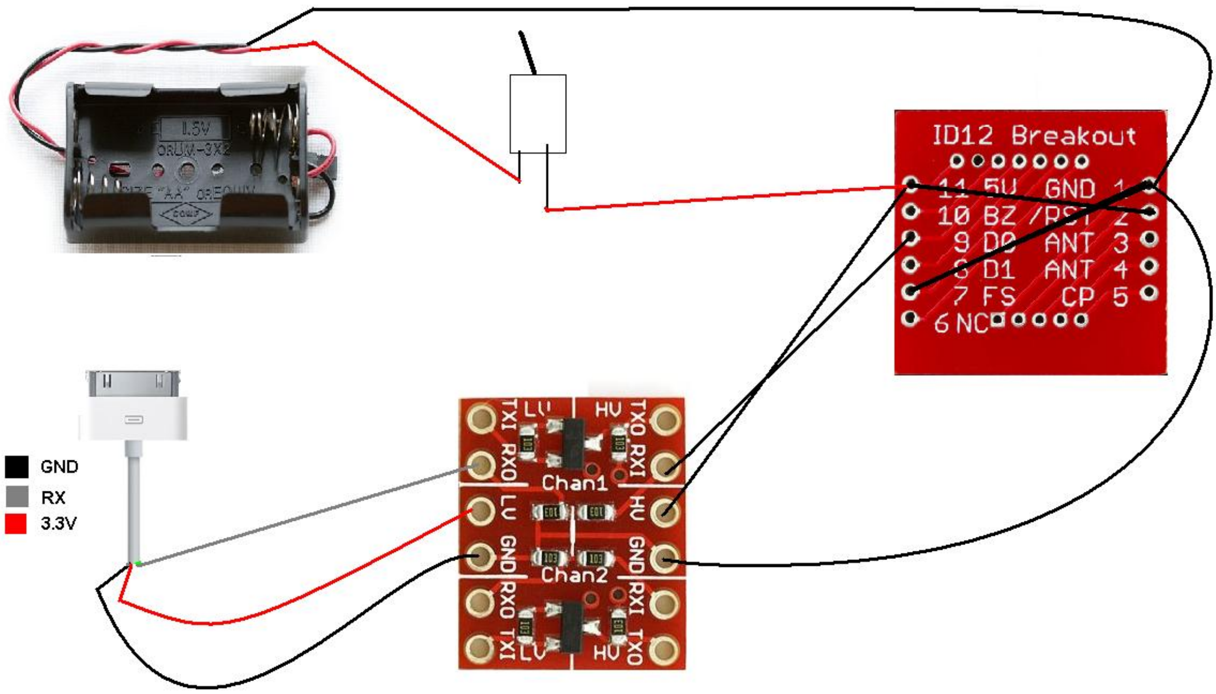

Figure 6.2 - A diagram of the circuit used for the peripheral device.

Figure 6.2 illustrates that the battery pack provides power to the ID-12 RFID breakout, soldered into the RFID receiver chip. This in turn powers the chip which transmits its data to the level converter as well as passing current and ground cables through to it. The converter then steps the power from 5V to 3.3V and sends the data through the Rx (receive) channel up into the iPhone along with the 3.3V power and ground.

6.3 – Design of the Application

Data is then to be transmitted into the serial port of the iPhone from the RFID reader. This process requires the bespoke coding of an application to open the serial port and listen for any data being received. However, the iPhone software development kit uses Objective C, which lacks the specific functionality needed to access the serial port. As an alternative, a framework called OpenFrameworks is used. OpenFrameworks allows the coding language C++ to be used and its functions accessed easily. Using this, an application is then created to allow a serial port to be opened and listen for incoming data which is then dealt with as necessary. The code for the program can be found in Appendix A.

The 125 kHz tags in use each have a 20 digit unique identification number that is broadcast to the reader. The screen of the iPhone outputs this identification number so that it can be noted. Once this process is complete, it is hard coded into the application. The phone can then output a specific response if a specific identification number or a set of running identification numbers is scanned. For example, a loud warning sound could emit to advice the user of any imminent obstacles followed by speaking the name of the imminent obstacle whilst the phone vibrates to warn the user.

6.4 – Physical Design

Low frequency RFID has a limited broadcast range and so a method must be created to ensure that the signals broadcast by the strategically placed tags are successfully received by the reader. This method must allow the user to traverse indoor areas and easily detect signals from tags placed at obstacles, doors and other points of interest without the need to move the reader excessively.

The proposed solution was to modify a standard guide cane used by the visually impaired to scan areas for imminent obstacles such as steps and curbs. The modification would allow the RFID reader to be situated on the end of the cane in order to detect tags placed on or under the floor (depending on the building itself). This will allow the RFID tags to be detected by the cane, which will then send the data to the user's iPhone. Figure 6.3 shows a design for the modified cane. It should be noted that the wiring shown in Figure 6.3 is not accurate and purely symbolises a completed electrical circuit. The diagram illustrates the position of the RFID reader on the bottom of the cane, the position of the battery pack and a holster in which to place the iPhone. This holster allows the user to use the cane without having to carry the iPhone separately. It also allows the vibrations of the phone to transfer through to the cane giving haptic feedback to the user.

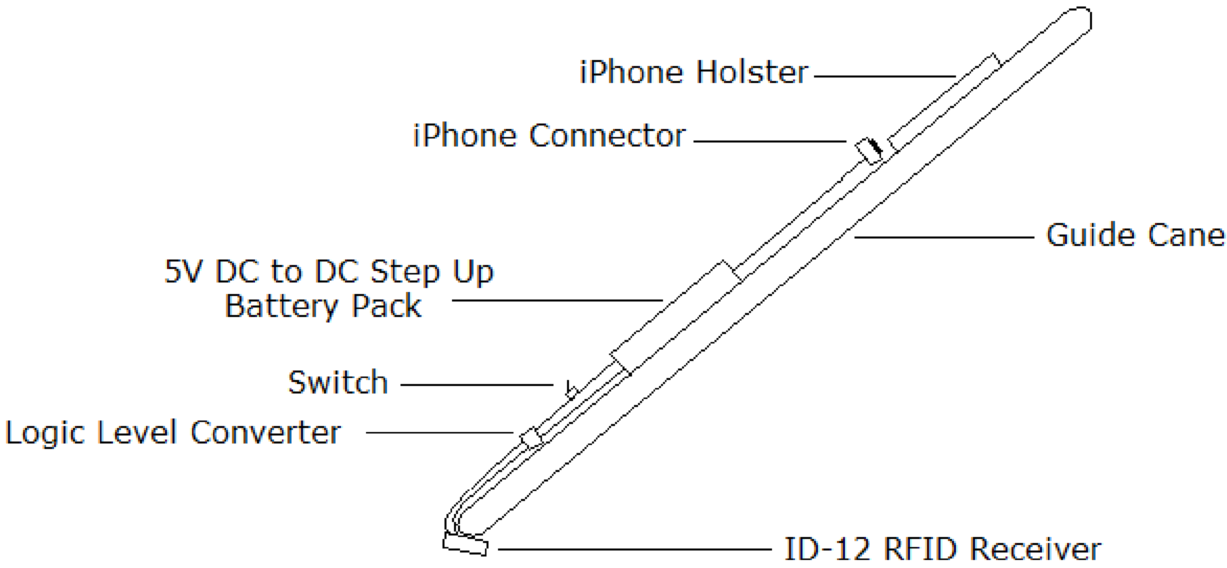

Figure 6.3 - The design of the modified RFID device.

Figure 6.4 shows how the cane would react when a user is in danger of colliding with an obstructive obstacle, such as stairs or a plant pot. In the diagram, the receiver induces the tag to send it the unique identification number. This in turn is transmitted to the iPhone which then processes the data prompting an immediate response. As a result, the iPhone will vibrate and emit a loud auditory warning alerting the user to an imminent obstacle. Both haptic and audio information has been implemented aiming to bridge the sensory gap due to the visual impairment of the user. Figure 6.5 shows tags in an arc formation that will be situated at points of interest such as doors, artworks and fire extinguishers. Because the tags are not directional, the arc formation is used to enable a user to detect the direction of their traversal and which side of a corridor a door may be situated, for instance. This is due to the fact that as the user scans with the cane, the tags will only be activated if the cane is on the correct side to receive data from the point of interest. The design also incorporates a large enough projection of the arc from the point of interest to allow the user to easily scan it without excessive searching.

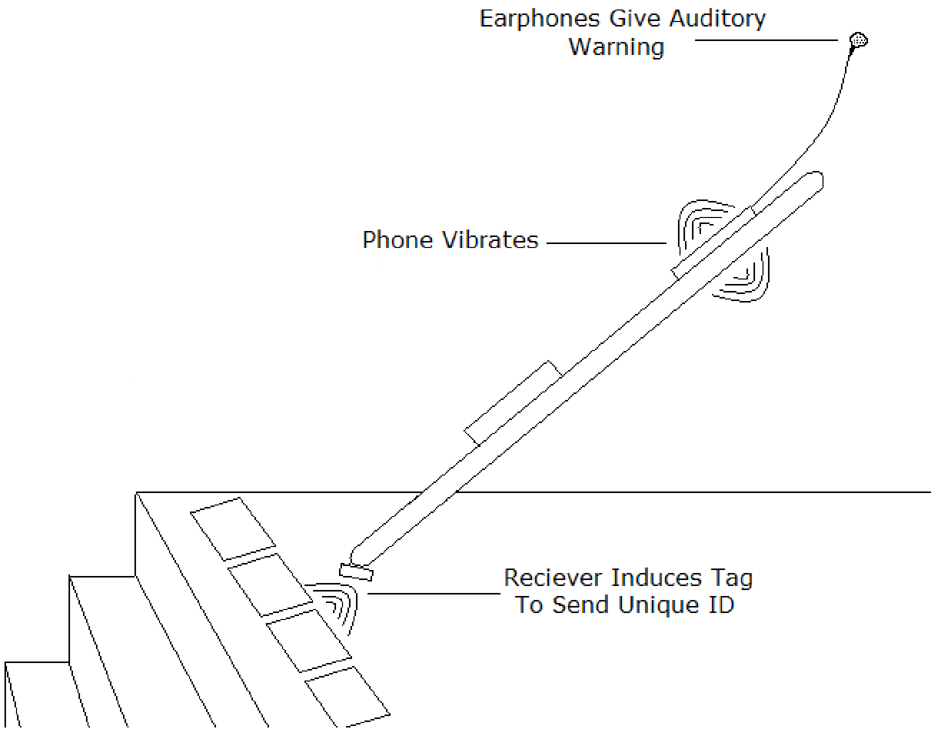

Figure 6.4 - RFID device heading towards an obstacle.

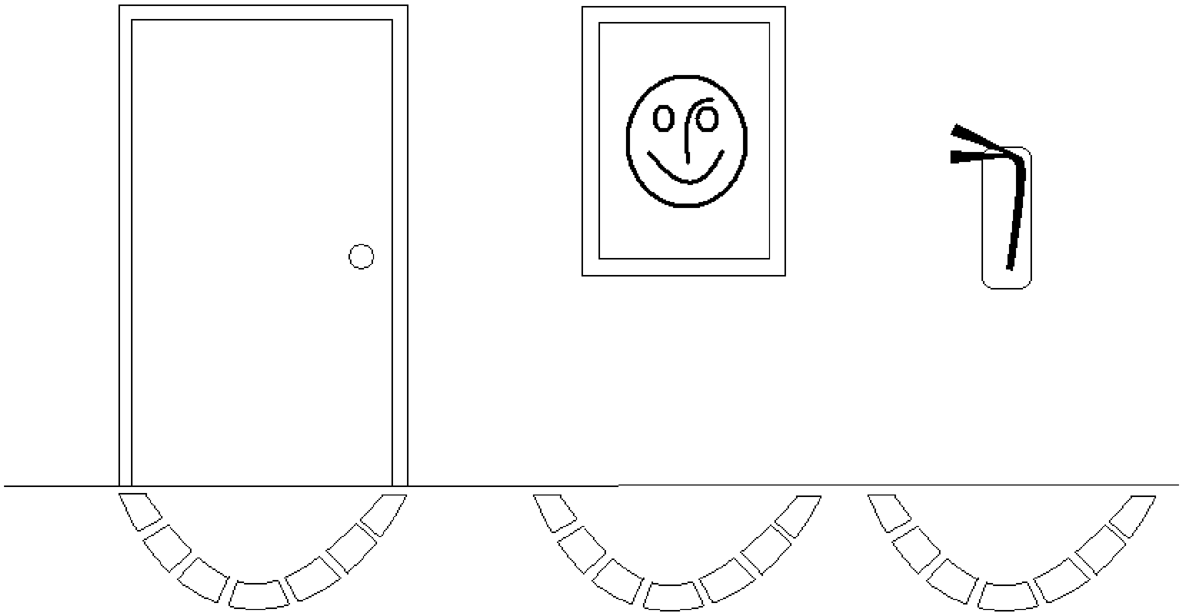

Figure 6.5 - Arcs of tags showing points of interest.

Chapter 7 – Evaluation

The following chapter evaluates the ASOVI system (as outlined in chapter 6) and its ability to aid the visually impaired in the navigation of indoor environments, aid in the creation of cognitive maps and finally, its general reception with the target market. It outlines the investigation conducted with an end-user group of participants before analysing the observational data recorded and the subsequent feedback gained during qualitative focus group discussions. This will be followed by outlining and analysing the investigation designed to test the ability of the ASOVI system to aid in the creation of cognitive mapping in the visually impaired. Both investigations will provide information to aid the future development and refinement of the ASOVI system.

7.1 – ASOVI's Ability to Aid in the Navigation of Indoor Environments and its Reception with the Target Audience

The goal of this investigation was to test the ASOVI system's ability to help a user navigate an indoor environment and locate specific landmarks or points of interest. Furthermore, the experiment aimed to highlight any successful points or problems with the ASOVI system by means of observation of the investigation and focus group discussion.

Based on the research summarised in Chapters 2 and 3, the ASOVI system should successfully be able to aid users in their navigation of indoor environments. The end goal is to use a combination of auditory and haptic means to provide visually impaired users similar information gained by sighted individuals using their visual channel. Secondly, the ASOVI system combines the use of a standard blind cane with RFID capabilities. This function allows for the user to utilise the standard functionality of a cane for general obstacle avoidance, such as another individual moving along the same path, alongside the aforementioned information acquisition. It should be noted that the ASOVI system uses the same functionality, such as haptic and audio feedback, as other successful commercial systems. However, by using techniques that are already successful but applying them in a different context and combination with a refined systemic methodology, more successful results should be evident.

The investigation was initiated by taking the schematic of the designated test environment in order to locate and mark potential obstacles and points of interest. The selected target environment for the test area was the fourth floor of the Canalside West building on the University of Huddersfield Campus. This particular area was selected on account of the high level of points of interest in one environment allowing for optimal test data to be collected. Once the testing environment had been designed, measurements were taken and the number of RFID cards to mark the area calculated. The cards were then scanned and their unique identification numbers placed into the iPhone

program so that each card would react upon scanning. A voice output was then created to give information, instruction or alert upon the scanning of any card in a particular card ark.
Figure 7.1 shows the schematic of the floor and the proposed arcs and lines of cards. Table 7.2 describes the different obstacles and points of interest that were marked on the schematic paired with their respective instructions or alerts.

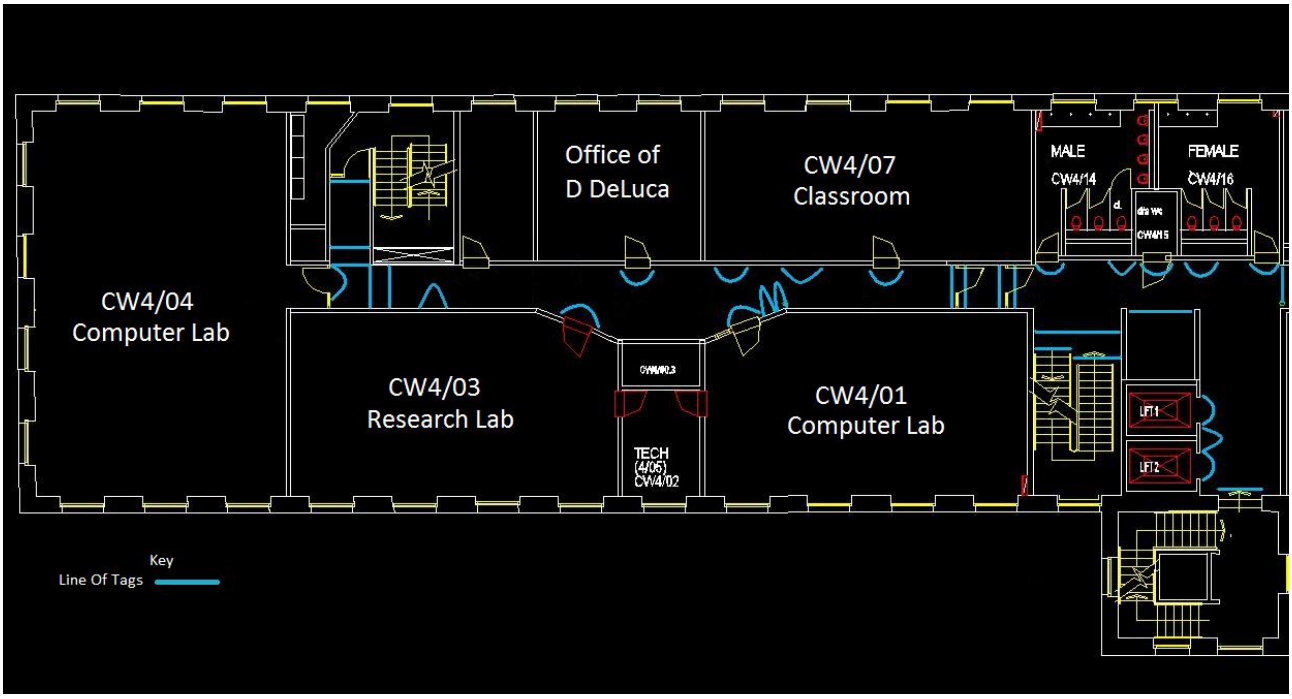

Figure 7.1 Schematic of floor four Canalside West with mapped card arc locations.

Following preparation of the environment which involved placing the tags in their designated locations, a trial investigation was implemented to ensure that each of the card arcs functioned correctly, sending both haptic and audio feedback to the user ensuring optimal data collection and user safety. Once the integrity of the system had been confirmed, the participants were taken into the environment and situated in the room CW4/07. A number of test arcs were also installed in room CW4/07 to allow the participants to become accustomed to the ASOVI system in a controlled environment. This allowed for the participants to become familiar with the vibrations sent down the cane and also the style in which the audio instructions and observations are relayed to them. Once the participants were comfortably accustomed with the ASOVI system, they were then instructed to begin the investigation.

Obstacle / Point of Interest	Instruction Given
Fire Escape Door	Fire door to stairwell
Trigger For Corridor Turn Left	NO INSTRUCTION GIVEN FOR PROGRAMMING USE ONLY
Corridor Turn Left	Corridor left turn imminent CW4/04 on the right
CW4/04 Computer Labs	CW4/04 A and B Computer Labs
Corridor Turn Right	Corridor right turn imminent CW4/04 straight ahead
Trigger For Corridor Turn Right	NO INSTRUCTION GIVEN FOR PROGRAMMING USE ONLY
Fire Extinguisher Point	Fire extingusher point CO2 small, water large.
CW4/03 Research Lab	CW4/03 Research Lab Restricted Access
CW4/06 Office of D DeLuca	CW4/06 Office of D DeLuca
Artwork Dots	Point of Interest - Modern Artwork - Coloured Dots
Artwork Chipboard	Point of Interest - Artwork - Picture of a chipboard
CW4/01 Computer Lab	CW4/01 Computer Lab
Emergency Phone	Emergency phone on wall, pick up and it will dial security automatically
First Aid Kit	First aid kit on wall
CW4/07 Classroom	CW4/07 Classroom
Entrance Door Keep Left	Entrance Door Keep Left
Entrance Door Keep Right	Entrance Door Keep Right
Entrance Door Keep Left	Entrance Door Keep Left
Entrance Door Keep Right	Entrance Door Keep Right
Male Toilets	Male Toilets
Water Fountain	Water fountian on wall, push handle operated
Disabled Toilet	Disabled access toilet, trigger key needed
Fire Extinguisher Point	Fire extingusher point CO2 small, water large.
Female Toilet	Female Toilet
End Of Test Area	Warning end of test area, please do not enter.
Lift Door	Lift entrance
Lift Controls	Lift controls, you are on floor four. Top button to go up, bottom to go down
Lift Door	Lift entrance
End Of Test Area	Warning end of test area, please do not enter.
Seating Area	Entrance to seating area
Stairs Approaching	Warning stairs approaching, down on the left and up on the right
Downward Stairs Imminent	Downward Stairs Imminent
Upward Stairs Imminent	Upward Stairs Imminent

Table 7.2 Obstacles / points of interest and the instruction given by them.

The investigation began by asking a participant to find a room, piece of artwork or any other obstacle or landmark. This aimed to imitate real life in which people would normally have a point of departure and destination to a journey. During this process, observations were recorded on the participant's progress noting how confidently they use the system, any hesitations or problems that occur and finally how successfully and efficiently they traverse to their target. This process occurs three times, each with a different target destination before the participant was once again seated in CW4/07. The entire investigation was then repeated with all participants before a focus group discussion was initiated to gain the participant's personal feedback on the ASOVI system. A focus group discussion was chosen to allow qualitative data to be collected by allowing participants to share and build upon each other's opinions.

One of the problems anticipated during the investigation is due to the RFID cards being unable to be placed under the flooring of the environment. In a real life situation, this would be desirable but as this would incur construction work to achieve in the test environment, this is not feasible. Therefore, it should be noted that the environment does not completely represent a finished installation of the ASOVI system. However, as shown in Figure 5.5, the system works adequately through the non-metallic materials tested. The intended environment uses stone and carpet flooring indicating that the RFID receiver should have sufficient penetration depth if the infrastructure were fully installed. Another anticipated problem was that participants may prefer the use of their own personal cane. This is because canes for the visually impaired come with a variety of tips from large balls to straight nibs. Each user will have their own preference of tip and each cane is also size specific to the user's height. This means the custom-built cane that was modified as part of the ASOVI system is rendered useless. To negate this problem, a separate system was assembled that could be easily affixed to each individual's specific cane.

Once the investigation was complete, the observations were analysed and cross-referenced. Analysis comprises of identifying any trends, similarities or patterns as observed during each participant's completion of the task. For example, if more than one participant find some of the audio information overbearing and that this caused them consequent difficulty or disorientation, it may be concluded that this problem would be encountered en mass prompting further analysis, implications and possible solutions to be noted. The focus group feedback was also analysed in a similar manner to the observation data, identifying trends, similarities and patterns before looking for possible solutions and implications of given feedback.

Upon completion of the investigation, the following conjectures were drawn from the noted observations (Observations in Appendix C). During the investigation it became apparent upon observation that each of the participant's RFID receiver was snagging on the floor of the environment. As a consequent of this, the participants often mistook this snagging for an obstacle causing false positives to occur in the cognitive mapping process. This suggests that the cane needs to be physically modified so that the RFID receiver is situated inside the tip of the cane allowing the ball on the end to rotate and maintain constant contact with the floor. This should be noted when modifying the design for the cane in future development.

Cross-referencing observations made for each participant confirmed that, on occasion, the participants dislodged RFID cards from their position on the floor with their cane. It is clear that this was due to the position of the RFID cards on top of the flooring material. As the intended design would place the infrastructure under flooring material, this should not cause a problem in a real life situation.

Another similarity observed in all participants was that as they spent longer using the ASOVI system, their confidence increased in traversing the environment. This could be attributed to initial nervousness regarding an unknown situation with an unknown device that they are reliant on for safe orientation and wayfinding. Upon full accustomisation of the user with the system, suitable trust is established as the user gains confidence. It could be argued that this would be the case for any method of navigation new to the user, such as a guide dog or long cane.

It was commonly observed among the different participants that they occasionally failed to scan card arcs on account of the methodology of their cane usage in the environment. The card arc design for the placement of the RFID cards was intended to be a solution for directional problems. For instance, a user hitting a straight line of cards would want to know which side of a corridor a door was on, and for this to occur, information such as "door on left" would have to be conveyed. This information would be problematic if a user encounters the line of cards from the opposite direction due to the aforementioned door 'on the left' now being on the user's right. As a result, a false cognitive map would be created. However, as a result of the potential for card arcs to be missed in some cases, a straight line system must be implemented. The solution to the previous problem posed by a straight line design would be the use of triggers in the programming of the system. This would mean that when a user encounters a line of tags, the system would log the scanned line and then upon encountering the next line of tags it will be able to determine which direction the user has arrived from and give the correct information – in this instance, either "Door on left" or "Door on right". This suggests that using lines of tags across the corridor or protruding from any landmark would be more effective for orientation and the method should be adopted during further development of the ASOVI system.

Another common observation is that card arcs were missed because some participants scanned the environment at great speed. This suggests that when the receiver is moved at pace, it does not have enough time for its electromagnetic field to pass sufficient power to induct the card to then pass its data to the receiver. This shows that although the read ranges of the RFID receiver seemed to be acceptable, as shown in the earlier investigation, this range may drop when the system is moving in situ. A possible solution for this would be to use a RFID receiver with a larger read range meaning that the larger electromagnetic field will be in contact with the RFID card for longer thus allowing it have the power to send its data to the receiver, even when the system is used at speed.

Finally, a correlation was noted in observing that participants were successful in locating targets during the task. This suggests that the system can successfully aid in the traversal of environments by alerting users to landmarks and features that are not normally apparent. Although, there were variations in the time it took each participant to correctly identify target locations. This implies that some of the slower timings were not caused by problems with the ASOVI system but by participatory discrepancies and accessibility of selected locations. It is also possible that these timing differences would be apparent in sighted individuals when trying to find different locations within an indoor environment, with the more perceptive individuals noticing some of the more obscure and less accessible locations faster than others.

Following completion of the task, the focus group discussed feedback on the system. It should be noted that although the focus group was question initiated, the general discussion did not follow a structured path and subsequently, responses have been divided into categories and analysed accordingly.

7.1.1 Information feedback from the device

The response from the participants with regard to the audio and haptic feedback suggested that some improvements could be made to the design of the ASOVI system. During the discussion it became apparent that the participants thought the ability to increase the volume of audio feedback would be essential in busy, loud environments. However, there were concurrent concerns about the system's audio distorting or completely masking the ambient noise in the environment that is often used as a source of orientation. As a proposed solution to this, wireless headphones that allow cleanly audible sound to be heard while simultaneously allowing the audition of ambient noise could be implemented in future development.

Another issue was discussed when one member of the group observed that "sometimes the phone was still playing the last instruction when I found a new object". This suggests that audio overlap occurred due to the close proximity of the card arcs. The participants then proposed a solution stating that they felt the speed of the audio could have been increased, allowing for multiple arcs in close proximity to be scanned without this audio overlap. This modification would have to be executed with particular care as to avoid the audio becoming unintelligible. And so, as a proposed solution to this problem, the information conveyed at each landmark or point of interest could be reduced in length by conveying only vital information in a concise manner.

During the focus group's discussion of haptic feedback, one participant stated that if they "know when an audio message was coming" they were prepared to focus on the audio feedback. They went on to explain that if an auditory warning was transmitted, it was much more clear what obstacle was approaching rather than the "guesswork involved with vibrating products". This feedback has large implications for the ASOVI system on account that if its vibrations are redundant, the mobile device can be detached from the cane and be stored elsewhere. This detachment of the mobile device reduces the weight of the cane, making it closer to that of a standard cane. This would relieve users from manipulating extra weight repeatedly during traversal. Also, this detachment would reduce the risk of theft involved with the public display of an expensive piece of technology.

7.1.2 Alternate delivery methods and mobile devices

During the discussion, feedback on the delivery method of a cane and the mobile device was requested. One participant identified themselves as a qualified cane instructor and then went on to say that "for the majority of people that mobilise, the cane is their first choice". This suggests that the cane is possibly the best method of delivery for the ASOVI system. However, it should be mentioned that another participant was primarily a guide dog user and although capable of using a cane, they primary preference for orientation and wayfinding was with the use of a guide dog. It was mentioned by this particular participant that although the system could help identify and give information that their dog could not, they would not return to using a cane as it is unable to offer "the companionship of a dog". This lead to the suggestion of a clip-on ASOVI device, which could be attached to a dog's harness or the shoe of a user. Taking into account the earlier proposal of detaching the mobile device from the cane, the ASOVI system has the potential for multiple application methods increasing its accessibility to the target audience.

Following the discussion on delivery methods, the use of the Apple iPhone was considered. A unanimous agreement between the participants was reached that if a user already has an iPhone then it would be "perfect", however many of the target users may already own one of the other smartphones available on the market and may therefore be reluctant to purchase another with the sole purpose of use with the ASOVI system. It was then suggested that making the ASOVI system compatible with multiple platforms such as "Android" would make it more appealing to the target user base.

7.1.3 ASOVI Marketability

When the participants were asked about the comparison between the ASOVI system and other market competitors, the common consensus stated that ASOVI was superior and had a significant amount of potential. One participant commented that "…other systems alert you to approaching things but they don't tell you what it is" whilst another commented that the ASOVI system "makes you feel a lot more comfortable" than the market competitors. This suggests that the ASOVI system compares well to the other technology available on the market and that it could possibly prove more successful than these products.

Furthermore, the participants were asked if they would trust the system to orientate them and aid in the traversal of an environment. Although each participant articulated this differently, they were all in agreement that a large-scale investigation must be performed where full building traversal and larger test group was available. One participant commented that, "You have always got to know where you are, however it has the makings of a brilliant prompt to assist in getting from A to B". Another commented that, "going out of one building and next door" would allow them to become more trusting of the system as it would help highlight any potential weaknesses. It may therefore be deduced that further investigation should be conducted over a larger test area.

The participants were questioned whether they would purchase and use the system if it became commercially available. One participant responded that they would, "definitely use the system" with another agreeing that it would, "definitely improve mobility around a building". This concludes that the system was well received by the participants and suggests that the system would be commercially viable given the correct testing and marketing in order to enable it to compete with current technologies available on the market.

7.1.4 Requested additional features

In conclusion to the focus group, participants were invited to suggest additional ideas and improvements to the ASOVI system. In response, they voiced that the system conveyed too much information. For example, one participant said, "you had a fire extinguisher down there, if there's a fire the last thing I want to do is fight it. I'm running anywhere I can". Another participant passed comment on the artwork on the wall saying, "The artwork's all good, but if I'm in a hurry I don't want to take note of the artwork anymore than you would if you were in a hurry" further stating that, "…if I was waiting about then maybe I would, so having a way of changing between levels of information would be good". In response to this observation, the newly released iPhone 4S and its voice recognition functionality was highlighted and when discussed further, the participants unanimously suggested that they would prefer a method of asking the ASOVI system to direct users to landmarks within buildings. One participant stated, "If you could ask it to take you to the front entrance or whatever it would be amazing". This suggests that the ASOVI system should utilise the iPhone 4S "Siri" voice recognition software to allow a checkpoint system that can guide a user, step-by-step, to their intended goal. This voice recognition software would also allow users to select the level of detail conveyed by the system to allow superfluous features such as artwork and points of interest to be optional. Another advantage of this feature would be that, in the case of an emergency, the user would only receive information guiding them to the most efficient escape route.

To summarise, the investigation has highlighted that the ASOVI system can successfully aid the navigation of the visually impaired through an indoor environment. It has also shown that the participants from the target user group received the system well and that if developed further, they would purchase and use the system to aid navigation through indoor environments.

7.2 – ASOVI's Ability to Aid in the Creation of Cognitive Maps

The goal of this investigation was to test the ASOVI system's ability to help a user create a cognitive map of an environment. Currently, there exists no standardised methodology to investigate if a successful cognitive map has been created within a participant's mind. While various approaches have been taken to do so for example (Lotfi & Sanchez, 2009) get participants to recreate the area using building blocks, nothing has been standardized. Consequently, a methodology must be designed to investigate successful cognitive mapping.

Previous investigation has suggested that the ASOVI system can successfully aid the visually impaired with wayfinding and orientation. Once information about an environment has been successfully conveyed using the ASOVI system, as highlighted in the earlier investigation, it should be retained in the mind as a cognitive map. The amount of accuracy and detail of the cognitive map should be positively correlated to the area explored and time spent in the environment. However, due to the number of willing participants it was unable to take separate test groups of participants and allow them different amounts of time in the environment to test this theory. It should also be noted that some fluctuation of results between participants can be expected on account that even the sighted population's ability to create cognitive maps varies from person to person.

The investigation began by taking each participant into a separate office to ensure that the other participants did not overhear the questions or answers given which may have resulted in them inadvertently adding additional data to their cognitive map. The participants were asked to describe a route to a specific location in the test vicinity using data ascertained by the ASOVI system in the previous investigation. The participant's answers provided data that will then be cross-referenced to determine whether the system succeeded in aiding the creation of cognitive maps.

One foreseeable problem with this method of investigation is that it does not allow the testing of distal reading within the cognitive mapping process. However, as the ASOVI system does not give distal data in audio or haptic format, it still relies on the user's human dead reckoning system as they are traversing the environment. This means testing of distal reading within the cognitive mapping process is extraneous to the ASOVI system's ability to aid it.

Once collected, the data was cross-referenced between participants and analysed quantitatively in graphical format for the number of correct locations identified. Two graphs were plotted; the first shows each participant's correct and incorrect answers against each other in an attempt to quantify the accuracy of the cognitive maps created and the second shows the question's success rate against the other questions in order to highlight any particular area that the participant group struggled or excelled at in the test environment.

After the investigation was conducted (Questions in Appendix D), the following graphs were generated using the amount of correctly answered questions.

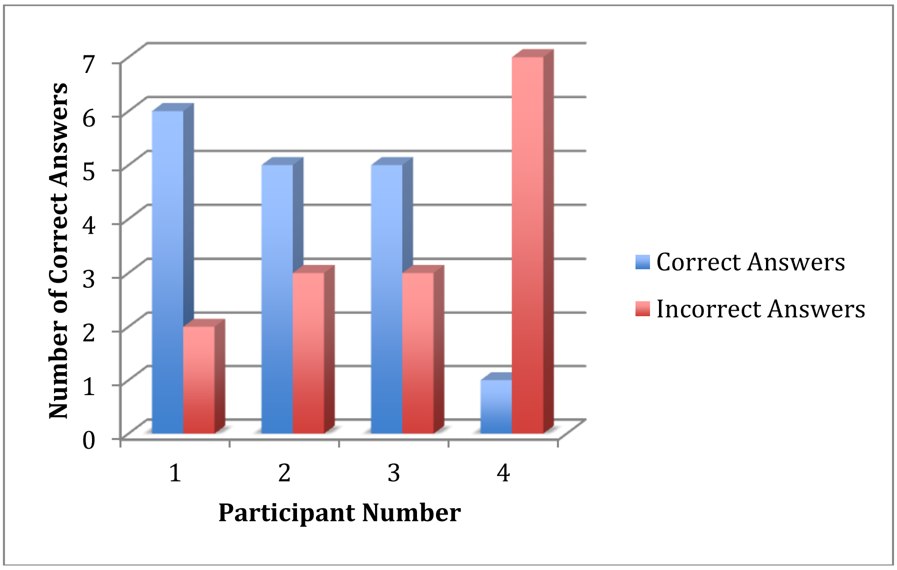

Figure 7.3 A graph to show the number of correct and incorrect answers by each participant.

The graph in figure 7.3 shows that, apart from participant 4, each of the participants answered more questions correctly than incorrectly. This suggests that the ASOVI system does aid in the creation of cognitive maps. Participant 4 only answered one question correctly and it is likely that this is due to the individual traversing the environment rapidly resulting in the system being unable to read any card arcs. Subsequently, the ASOVI system was then unable to convey the information back to participant 4, as discussed in the previous investigation. The first three participants have a very similar quantity of correct and incorrect answers. This implies that the fourth participant is an anomaly and their lack of cognitive mapping of the test environment is due to the speed of their movement and cane technique.

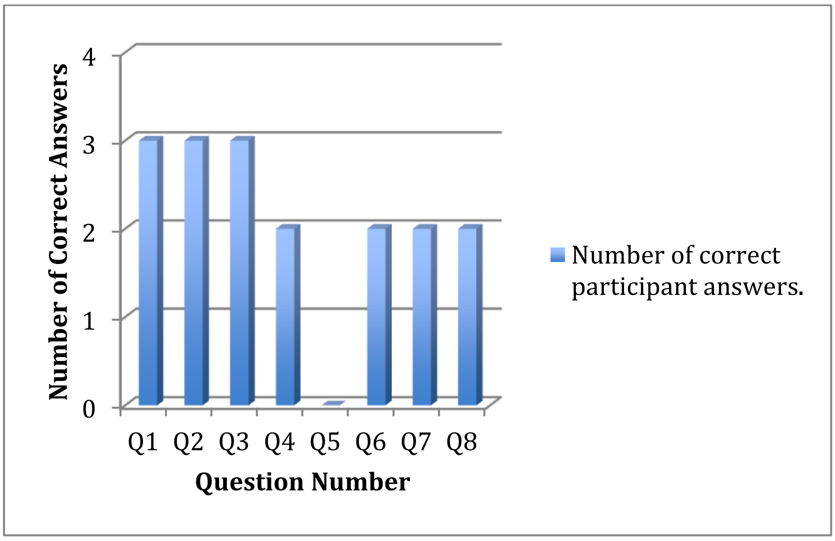

Figure 7.4 A graph to show the number of correct answers on each question.

The graph in figure 7.4 shows that the average number of correct answers per question is two. This equates to half of the participant group being able to correctly answer the questions, taking into account the fact that one participant did not receive full environment information. Furthermore, this can then be roughly equated to state that two thirds of the participants successfully used the ASOVI system to aid in the creation of cognitive maps.

Question 5 is a clear anomaly due to its large deviation from the rest of the results. Question 5 asked for the route, "From Lifts to the Security Phone". The security phone card arc was nestled in between CW4/01 and the first-aid box. This may indicate that the participants did not scan the card arc when traversing the area or that there was too much information placed in such a small area. This issue could be solved by changing the card arc system to straight lines, providing a longer time between the points of interest, as proposed in the previous investigation. It may also be the case that the questions that were answered incorrectly by participants would have yielded correct answers had the participants used the system in a particular environment for an extended period of time and on multiple occasions as would be likely in the real life implementation of the system as previously discussed.

Overall, the data gathered from the questions posed to the participants suggests that the ASOVI system (although dependant on some minor amendments as discussed) can help with the creation of cognitive maps.

Chapter 8 – Conclusion and Further Research

This chapter will conclude the thesis by summarising and evaluating the research that culminated in the development and testing of the ASOVI system. It will then continue to outline further research and development as a result of these findings.

8.1 – Summary of Findings

It was established in section 1.1 that there are currently no commercially viable and accessible systems available to aid the orientation and wayfinding of indoor environments for the visually impaired. It was consequently proposed that a possible solution would be to develop a system that would combine multi-functional devices such as mobile phones with wireless communication technology as this would negate the problems presented by the indoor use of GPS alongside issues of cost and accessibility.

Research conducted in Chapter 2 regarding wayfinding and cognitive mapping concluded that although the visually impaired are successful in creating cognitive maps using other available sensory channels, this does not equate the cognitive mapping capabilities of a visually able individual. As such, the visually impaired are capable of navigating an indoor environment although this capability is improved with the use of navigational aids. Further research also suggested that these cognitive mapping abilities improved in a positive correlation with the length of time spent in any one environment.

Chapter 3 continued to review wireless communication technology and its use for orientation and wayfinding. It was ascertained that at present, many systems are not wholly successful on account of cost efficiency and ergonomic design. Furthermore, many are not suitable for indoor orientation of wayfinding for the visually impaired. Having analysed the available wireless technology, it was concluded that GPS and RFID infrastructures presented two possible avenues of investigation on account of their accuracy, cost and compatibility with mobile phones.

Research in Chapter 4 was used to identify which mobile phone would prove the most conducive platform to design the ASOVI system for. The Apple iPhone 4 was highlighted as having high levels of multi-functionality, free screen reading and an overlay already in existence to aid its use with the visually impaired. Having identified the iPhone as the most suitable multi-function device, testing was designed to establish if the AGPS functionality of the iPhone would be sufficiently accurate for indoor orientation and wayfinding for the visually impaired. Testing was conclusive that the iPhone AGPS was not suitable for this purpose which lead to the use of RFID technology in the subsequent design of the ASOVI system. Before the ASOVI system could be designed, testing was undertaken to assess the functionality and application of the RFID reader in order to ensure the system would function when implemented in a real life situation. The read range of RFID system was investigated with the receiver placed behind a variety of materials (to simulate the potential flooring materials that may occur in the real life implementation of the system). The results of this investigation showed that the system's read range, although below that of the manufacturer's specification, would be suitable for the ASOVI system and its infrastructure.

Using the research from the previous chapters, the ASOVI system was then designed and engineered. The ASOVI system was created using RFID to allow users to locate points of interest and landmarks. This would aid in the orientation and wayfinding of the user while further facilitating the creation of cognitive maps. An RFID receiver was placed on the end of cane, enabling it to receive and transmit data from points of interest into an iPhone. A custom-programmed piece of software then dealt with this data, translating it into auditory and haptic feedback. The cane was chosen to work with RFID cards placed under flooring in arcs in front of points of interest.

The investigation that followed was created to test the ability of the ASOVI system to aid in navigation and orientation within indoor environments and its reception with the target audience. Participants were asked to locate landmarks or points of interest within a test environment using the ASOVI system. It was concluded that the ASOVI system was successful in aiding the visually impaired participants to wayfind and navigate in the test environment. However, it was highlighted that the ASOVI system had problems with reading some of the RFID cards placed in the environment due to the speed at which the participants traversed the test area. It was established that a greater read range is needed to compensate for this factor and as such, a different RFID receiver may be needed. In addition, it was found that the configuration of the card arc system caused reading problems and that as a result, straight lines of cards protruding from objects or points of interest would be more efficient. A focus group following the task produced significantly positive feedback, concluding that the system has commercial value.

The final investigation was designed to ascertain whether the ASOVI system has a positive effect on the ability of a visually impaired user to create cognitive maps of their environment. Having gained experience of the test environment with the ASOVI system in the previous investigation, participants were then asked to describe routes from one of point of interest to another. Overall, this investigation showed that the ASOVI system was successful in aiding visually impaired users to create cognitive maps of the indoor environment. Having evaluated anomalies in the investigation data, it was concluded that with further development, real life installation of the ASOVI system would mean that users may be exposed to indoor environments on multiple occasions and for potentially extended periods of time resulting in more uniform positive results.

8.2 – Future Research

Investigations undertaken as part of this thesis highlighted several areas of further development to be implemented in order to make the ASOVI system suitable for the UK market.

Although the ASOVI system tested successfully in its ability to aid indoor navigation and wayfinding, the investigation discussed in section 6.3 indicated that the read range of the RFID receiver was not suitable and an alternative with a greater read range should be obtained. This would incur further research into the RFID market or possible inquiry into the bespoke manufacture of a model specifically engineered to the needs of the ASOVI system. Furthermore, observations noted during this investigation marked the positioning of the RFID receiver on the tip of the cane as preventing its use as a method of obstacle avoidance. As a result, it may be possible to modify the design of the cane and reposition the RFID receiver within its tip and so avoiding the possibility of the receiver snagging on flooring materials. Regarding RFID receiver positioning, it was also suggested during the focus group session that the receivers could be developed to fit onto shoes or guide dog collars, for example. This would widen its target market to include visually impaired persons who do not rely on a cane as their primary method of obstacle avoidance.

Testing revealed that infrastructure design using arcs of RFID cards placed around a landmark or point of interest was somewhat flawed. This was particularly highlighted when observing the different styles of orientation utilised by some of the visually impaired participants. One possible solution to this issue may be to use straight lines of RFID cards perpendicular to the landmarks or points of interest. This would prevent users from inadvertently missing points of interest and landmarks. Another advantage of using straight lines of RFID cards would be that they would allow for the implementation of a checkpoint system which could guide a user on a route from A to B. This feature was a suggestion made by participants following the investigation. In conjunction with a checkpoint system enable by using straight lines of RFID cards, the recently released iPhone 4S' voice recognition function, 'Siri' could be utilised. This would allow the user to ask the ASOVI system to guide them from A to B, using spoken commands in tandem with the aforementioned lines of RFID cards as checkpoints.

Participants reported that the headphones would benefit from louder and more clearly intelligible audio whilst still allowing the ambient noise from the environment to infiltrate for safety reasons. This indicates further research should be undertaken into methods of improving the headphones to this end. It was also suggested that the ASOVI system could be developed to work on different mobile smart phones to accommodate those users that already owned different models. This development would be conducive to one of the prime objectives of the system: as a solution to the commercial in-viability of other currently available wayfinding systems on the market.

8.2 – Conclusion

In viewing the project as a whole, the ASOVI system was successful in its aims of providing indoor orientation and wayfinding for the visually impaired using an accessible, commercially viable platform. This was achieved by combining the Apple iPhone 4, which is commercially viable on account of its multi-functionality and is also accessible to the visually impaired with the use of RFID technologies, which proved conducive with an indoor environment at a commercially viable cost. The ASOVI system tested positively with a group of end-user participants, successfully aiding in navigation and wayfinding within an indoor environment alongside supplementing the creation of cognitive maps. Investigation processes undertaken throughout the project have also highlighted several exciting areas of future research necessary to develop the ASOVI system for release in the commercial market.

Appendices

Appendix A

```
#include "testApp.h"
#include <stdio.h>
#include <string.h>
#include <unistd.h>
#include <fcntl.h>
#include <errno.h>
#include <termios.h>
#include <stdlib.h>
#include <OpenAL/al.h>
#include <OpenAL/alc.h>
#include <AudioToolbox/AudioToolbox.h>




static struct termios gOriginalTTYAttrs;

//--------------------------------------------------------------
void testApp::setup(){



	ofBackground(0, 0, 0);
	ofSetBackgroundAuto(true);



	glEnableClientState( GL_VERTEX_ARRAY );  // this should be in OF 
somewhere.
	glPointSize(60);
	glEnable(GL_POINT_SMOOTH);



	// initialize the accelerometer
	ofxAccelerometer.setup();



	// touch events will be sent to myTouchListener
	ofxMultiTouch.addListener(this);
```

```
	getSerial = openSerialOther();


	font.loadFont(ofToDataPath("verdana.ttf"),8, false, true);
	nTimesRead = 0;
	nBytesRead = 0;
	readTime = 0;
	memset(bytesReadString, 0, 4);


	numBytes = 15;
	lastBuffer = new unsigned char[numBytes]; // this buffer gets filled
	memset(lastBuffer, 0, numBytes);


	totalData ="";




}

//--------------------------------------------------------------
bool testApp::openSerialOther() {
	otherSerialFD = -1;
   struct termios  options;
   printf("Initializing Serial Port... ");
   otherSerialFD = open("/dev/tty.iap", O_RDWR | O_NOCTTY |
O_NONBLOCK);
   if (otherSerialFD != -1) {
		if (fcntl(otherSerialFD, F_SETFL, 0) != -1) {
			if (tcgetattr(otherSerialFD, &gOriginalTTYAttrs) != -1) {
				options = gOriginalTTYAttrs;
				cfsetspeed(&options,B9600);


				if (tcsetattr(otherSerialFD, TCSANOW, &options) == -
1)
```

```
                    {
                            printf("Error setting tty attributes %s -
%s(%d).\n",
                                    "/dev/tty.iap", strerror(errno), errno);
                            return false;
                    }


                    printf("[DONE]\n");
                    return true;
                } else {
                    printf("[FAIL]\n");
                    printf("Error getting tty attributes %s - %s(%d).n",
"/dev/tty.iap", strerror(errno), errno);
                    if (otherSerialFD != -1) {
                            close(otherSerialFD);
                    }
                    return false;
                }
            } else {
                printf("[FAIL]\n");
                printf("Error clearing O_NONBLOCK %s - %s(%d).n",
"/dev/tty.iap", strerror(errno), errno);
                if (otherSerialFD != -1) {
                    close(otherSerialFD);
                }
                return false;
            }
        } else {
            printf("[FAIL]\n");
            printf("Error setting TIOCEXCL on %s - %s(%d).n", "/dev/tty.iap",
strerror(errno), errno);
            if (otherSerialFD != -1) {
                close(otherSerialFD);
            }
            return false;
        }


        return false;
}



//------------------------------------------------------------
```

```
void testApp::otherSerial() {


	unsigned char tmpByte[15];
	char tmpByte2[10];
	memset(tmpByte, 0, 15);
	memset(tmpByte2, 0, 10);



	if (read(otherSerialFD, tmpByte, 15) == -1) {
		printf("Read Error.rn");
	}



	printf("RFID Number: \n");
	sprintf(tmpByte2,
"%01x%01x%01x%01x%01x%01x%01x%01x%01x%01x\n", tmpByte[1],
tmpByte[2], tmpByte[3],
			tmpByte[4],
tmpByte[5],tmpByte[6],tmpByte[7],tmpByte[8],tmpByte[9],tmpByte[10]);


	memcpy(lastBuffer,tmpByte2, 10);


	string tstr;
	tstr = (const char*)tmpByte2;
	totalData += tstr + "\n";




	NSArray *paths =
NSSearchPathForDirectoriesInDomains(NSDocumentDirectory,
NSUserDomainMask, YES);
	NSString *documentsDirectoryPath = [paths objectAtIndex:0];
```

```
	NSString *filePath = [documentsDirectoryPath
stringByAppendingPathComponent:@"myfile.txt"];



	NSString* result = [NSString stringWithUTF8String:totalData.c_str()];
	NSData* settingsData;
	settingsData = [result dataUsingEncoding: NSASCIIStringEncoding];


	if ([settingsData writeToFile:filePath atomically:YES])
		NSLog(@"writeok");






	//---if statements for checking cards
	if(whoBeIt != 1)
	{
		if(strncmp(tmpByte2,"34433030323045413045",20) == 0 ||
			strncmp(tmpByte2,"34433030323045414639",20) == 0 ||
			strncmp(tmpByte2,"34433030323041414537",20) == 0 ||
			strncmp(tmpByte2,"34433030323130344134",20) == 0 ||
			strncmp(tmpByte2,"34433030323043364135",20) == 0 ||
			strncmp(tmpByte2,"34433030323044383136",20) == 0 ||
			strncmp(tmpByte2,"34433030323044363442",20) == 0 ||
			strncmp(tmpByte2,"34433030323041464442",20) == 0 ||
			strncmp(tmpByte2,"34433030323043433834",20) == 0 ||
			strncmp(tmpByte2,"34433030323130333743",20) == 0 ||
			strncmp(tmpByte2,"34433030323130333841",20) == 0 ||
			strncmp(tmpByte2,"34433030323046323130",20) == 0 ||
			strncmp(tmpByte2,"34433030323045354431",20) == 0 ||
		   strncmp(tmpByte2,"34433030323042464335",20) == 0 ||//109
		   strncmp(tmpByte2,"34433030323045423744",20) == 0) //110
		{
			whoBeIt = 1;
			synth.stop();
			synth.loadSound("sounds/fireDoorToStairwell.caf");
			synth.play();
```

```
				AudioServicesPlaySystemSound(kSystemSoundID_Vibrate);

			}
	}





	if(whoBeIt != 2)
	{
		if(strncmp(tmpByte2,"34433030323045434345",20) == 0 ||
		  strncmp(tmpByte2,"34433030323130304533",20) == 0 ||
		  strncmp(tmpByte2,"34433030323042454642",20) == 0 ||
		  strncmp(tmpByte2,"34433030323044364634",20) == 0 ||
		  strncmp(tmpByte2,"34433030323043343139",20) == 0 ||
		  strncmp(tmpByte2,"34433030323045414634",20) == 0 ||
		  strncmp(tmpByte2,"34433030323046324331",20) == 0 ||
		  strncmp(tmpByte2,"34433030323044374630",20) == 0 ||
		  strncmp(tmpByte2,"34433030323046394438",20) == 0 ||
		  strncmp(tmpByte2,"34433030323046423541",20) == 0 ||
		  strncmp(tmpByte2,"34433030323043363041",20) == 0 ||
		  strncmp(tmpByte2,"34433030323045383138",20) == 0 ||
		  strncmp(tmpByte2,"34433030323042424538",20) == 0 ||
		  strncmp(tmpByte2,"34433030323130354639",20) == 0 || //111
		  strncmp(tmpByte2,"34433030323042433435",20) == 0) //112
		{
			whoBeIt = 2;
			synth.stop();
			synth.loadSound("sounds/404.caf");
			synth.play();
			AudioServicesPlaySystemSound(kSystemSoundID_Vibrate);

		}
	}



	if(whoBeIt != 3)
	{
		if(strncmp(tmpByte2,"34433030323046353332",20) == 0 ||
					strncmp(tmpByte2,"34433030323043393737",20)
== 0 ||
					strncmp(tmpByte2,"34433030323045414135",20)
== 0 ||
					strncmp(tmpByte2,"34433030323130433839",20)
== 0 ||
```

```
                    strncmp(tmpByte2,"34433030323045374345",20)
== 0 ||
                    strncmp(tmpByte2,"34433030323041353045",20)
== 0 ||
                    strncmp(tmpByte2,"34433030323043373341",20)
== 0 ||
                    strncmp(tmpByte2,"34433030323045363733",20)
== 0 ||
                    strncmp(tmpByte2,"34433030323046443445",20)
== 0 ||
                    strncmp(tmpByte2,"34433030323043324546",20)
== 0 ||
                    strncmp(tmpByte2,"34433030323046354541",20)
== 0 ||
                    strncmp(tmpByte2,"34433030323130324142",20)
== 0 ||
                    strncmp(tmpByte2,"34433030323043303545",20)
== 0 ||
    strncmp(tmpByte2,"34433030323046383638",20) == 0 || //113

    strncmp(tmpByte2,"34433030323044454539",20) == 0)//114
        {
            whoBeIt = 3;
            synth.stop();
            synth.loadSound("sounds/fireExtingiusherPoint.caf");
            synth.play();
            AudioServicesPlaySystemSound(kSystemSoundID_Vibrate);

        }
    }




    if(whoBeIt != 4)
    {
        if(strncmp(tmpByte2,"34433030323045393146",20) == 0 ||
                    strncmp(tmpByte2,"34433030323044464137",20)
== 0 ||
                    strncmp(tmpByte2,"34433030323044303845",20)
== 0 ||
                    strncmp(tmpByte2,"34433030323041353936",20)
== 0 ||
                    strncmp(tmpByte2,"34433030323045423630",20)
== 0 ||
```

```
                    strncmp(tmpByte2,"34433030323046383438",20)
== 0 ||
                    strncmp(tmpByte2,"34433030323042304234",20)
== 0 ||
                    strncmp(tmpByte2,"34433030323045383236",20)
== 0 ||
                    strncmp(tmpByte2,"34433030323045374341",20)
== 0 ||
                    strncmp(tmpByte2,"34433030323046373243",20)
== 0 ||
                    strncmp(tmpByte2,"34433030323043413132",20)
== 0 ||
                    strncmp(tmpByte2,"34433030323043423331",20)
== 0 ||
                    strncmp(tmpByte2,"34433030323044324137",20)
== 0 ||
                    strncmp(tmpByte2,"34433030323041384630",20)
== 0 || //115
                    strncmp(tmpByte2,"34433030323045393337",20)
== 0) //116
          {
               whoBeIt = 4;
               synth.stop();
               synth.loadSound("sounds/406Damien.caf");
               synth.play();
               AudioServicesPlaySystemSound(kSystemSoundID_Vibrate);

          }
     }



     if(whoBeIt != 5)
     {
          if(strncmp(tmpByte2,"34433030323130453231",20) == 0 ||
                    strncmp(tmpByte2,"34433030323044304133",20)
== 0 ||
                    strncmp(tmpByte2,"34433030323042344432",20)
== 0 ||
                    strncmp(tmpByte2,"34433030324345313343",20)
== 0 ||
                    strncmp(tmpByte2,"34433030323044304342",20)
== 0 ||
                    strncmp(tmpByte2,"34433030323130454332",20)
== 0 ||
```

```
                        strncmp(tmpByte2,"34433030323043373345",20)
== 0 ||
                        strncmp(tmpByte2,"34433030323045333430",20)
== 0 ||
                        strncmp(tmpByte2,"34433030323044373236",20)
== 0 ||
                        strncmp(tmpByte2,"34433030323043353544",20)
== 0 ||
                        strncmp(tmpByte2,"34433030323046413631",20)
== 0 ||
                        strncmp(tmpByte2,"34433030323046383345",20)
== 0 ||
                        strncmp(tmpByte2,"34433030323043423439",20)
== 0 ||
                        strncmp(tmpByte2,"34433030323042433531",20)
== 0 || //117
                        strncmp(tmpByte2,"34433030323045423845",20)
== 0)//118
            {
                whoBeIt = 5;
                synth.stop();
                synth.loadSound("sounds/403ResearchLab.caf");
                synth.play();
                AudioServicesPlaySystemSound(kSystemSoundID_Vibrate);

            }
        }



        if(whoBeIt != 6)
        {
            if(strncmp(tmpByte2,"34433030323044334430",20) == 0 ||
                        strncmp(tmpByte2,"34433030323044373437",20)
== 0 ||
                        strncmp(tmpByte2,"34433030323041393330",20)
== 0 ||
                        strncmp(tmpByte2,"34433030323044354445",20)
== 0 ||
                        strncmp(tmpByte2,"34433030323041364536",20)
== 0 ||
                        strncmp(tmpByte2,"34433030323130364438",20)
== 0 ||
                        strncmp(tmpByte2,"34433030323043304638",20)
== 0 ||
```

```
                            strncmp(tmpByte2,"34433030323044373339",20)
== 0 ||
                            strncmp(tmpByte2,"34433030323131303642",20)
== 0 ||
                            strncmp(tmpByte2,"34433030323044453832",20)
== 0 ||
                            strncmp(tmpByte2,"34433030323044394234",20)
== 0 ||
                            strncmp(tmpByte2,"34433030323130344137",20)
== 0 ||
                            strncmp(tmpByte2,"34433030323041363346",20)
== 0 ||
                            strncmp(tmpByte2,"34433030323045464635",20)
== 0 || //119
                            strncmp(tmpByte2,"34433030323130433730",20)
== 0)//120
             {
                    whoBeIt = 6;
                    synth.stop();
                    synth.loadSound("sounds/ArtworkDots.caf");
                    synth.play();
                    AudioServicesPlaySystemSound(kSystemSoundID_Vibrate);

             }
      }




      if(whoBeIt != 7)
      {
             if(strncmp(tmpByte2,"34433030323130313037",20) == 0 ||
                            strncmp(tmpByte2,"34433030323042314535",20)
== 0 ||
                            strncmp(tmpByte2,"34433030323042303539",20)
== 0 ||
                            strncmp(tmpByte2,"34433030323045364443",20)
== 0 ||
                            strncmp(tmpByte2,"34433030323041363330",20)
== 0 ||
                            strncmp(tmpByte2,"34433030323043433639",20)
== 0 ||
                            strncmp(tmpByte2,"34433030323042343141",20)
== 0 ||
```

```
                    strncmp(tmpByte2,"34433030323046354334",20)
== 0 ||
                    strncmp(tmpByte2,"34353030463843313136",20)
== 0 ||
                    strncmp(tmpByte2,"34433030323044393531",20)
== 0 ||
                    strncmp(tmpByte2,"34433030323046384536",20)
== 0 ||
                    strncmp(tmpByte2,"34433030323130364545",20)
== 0 ||
                    strncmp(tmpByte2,"34433030323041354644",20)
== 0 ||
                    strncmp(tmpByte2,"34433030323045304644",20)
== 0 ||
                    strncmp(tmpByte2,"34433030323043383045",20)
== 0 )
          {
               whoBeIt = 7;
               synth.stop();
               synth.loadSound("sounds/ArtworkChipboard.caf");
               synth.play();
               AudioServicesPlaySystemSound(kSystemSoundID_Vibrate);

          }
     }




     if(whoBeIt != 8)
     {
          if(strncmp(tmpByte2,"34433030323045364330",20) == 0 ||
                    strncmp(tmpByte2,"34433030323042443236",20)
== 0 ||
                    strncmp(tmpByte2,"34433030323042313632",20)
== 0 ||
                    strncmp(tmpByte2,"34433030323130453739",20)
== 0 ||
                    strncmp(tmpByte2,"34433030323130443038",20)
== 0 ||
                    strncmp(tmpByte2,"34433030323046454436",20)
== 0 ||
                    strncmp(tmpByte2,"34433030323044343935",20)
== 0 ||
```

```
                    strncmp(tmpByte2,"34433030323046414339",20)
== 0 ||
                    strncmp(tmpByte2,"34433030323043383432",20)
== 0 ||
                    strncmp(tmpByte2,"34433030323044304238",20)
== 0 ||
                    strncmp(tmpByte2,"34433030323043324234",20)
== 0 ||
                    strncmp(tmpByte2,"34433030323046363243",20)
== 0 ||
                    strncmp(tmpByte2,"34433030323046363338",20)
== 0 ||
                    strncmp(tmpByte2,"34433030323045443346",20)
== 0 ||
                    strncmp(tmpByte2,"34433030323042453941",20)
== 0 )
        {
            whoBeIt = 8;
            synth.stop();
            synth.loadSound("sounds/401CombLab.caf");
            synth.play();
            AudioServicesPlaySystemSound(kSystemSoundID_Vibrate);

        }
    }


    if(whoBeIt != 9)
    {
        if(strncmp(tmpByte2,"34433030323130423537",20) == 0 ||
         strncmp(tmpByte2,"34433030323042333832",20) == 0 ||
         strncmp(tmpByte2,"34433030323045343236",20) == 0 ||
         strncmp(tmpByte2,"34433030323043324432",20) == 0 ||
         strncmp(tmpByte2,"34433030323044433644",20) == 0 ||
         strncmp(tmpByte2,"34433030323044384345",20) == 0 ||
         strncmp(tmpByte2,"34433030323130433239",20) == 0 ||
         strncmp(tmpByte2,"34433030323130314342",20) == 0 ||
         strncmp(tmpByte2,"34433030323130384642",20) == 0 ||
         strncmp(tmpByte2,"34433030323043363438",20) == 0 ||
         strncmp(tmpByte2,"34433030323046343037",20) == 0 ||
         strncmp(tmpByte2,"34433030323044323241",20) == 0 ||
         strncmp(tmpByte2,"34433030323130434331",20) == 0 ||
         strncmp(tmpByte2,"34433030323044323235",20) == 0 ||
         strncmp(tmpByte2,"34443030374135454435",20) == 0 )
        {
            whoBeIt = 9;
            synth.stop();
```

```
                synth.loadSound("sounds/EmergencyPhone.caf");
                synth.play();
                AudioServicesPlaySystemSound(kSystemSoundID_Vibrate);

            }
    }



    if(whoBeIt != 10)
    {
            if(strncmp(tmpByte2,"34433030323130423037",20) == 0 ||
             strncmp(tmpByte2,"34433030323130314132",20) == 0 ||
             strncmp(tmpByte2,"34433030323044304134",20) == 0 ||
             strncmp(tmpByte2,"34433030323043463236",20) == 0 ||
             strncmp(tmpByte2,"34433030323045303339",20) == 0
||//(140)
             strncmp(tmpByte2,"34433030323044323833",20) == 0 ||
             strncmp(tmpByte2,"34433030323044324439",20) == 0 ||
             strncmp(tmpByte2,"34433030323044423836",20) == 0 ||
             strncmp(tmpByte2,"34433030323043424343",20) == 0 ||
             strncmp(tmpByte2,"34433030323045383436",20) == 0 ||
             strncmp(tmpByte2,"34433030323041423539",20) == 0 ||
             strncmp(tmpByte2,"34433030323043373446",20) == 0 ||
             strncmp(tmpByte2,"34433030323042363936",20) == 0 ||
             strncmp(tmpByte2,"34433030323043303531",20) == 0 ||
             strncmp(tmpByte2,"34433030323044353543",20) == 0)
            {
                whoBeIt = 10;
                synth.stop();
                synth.loadSound("sounds/FirstAidKit.caf");
                synth.play();
                AudioServicesPlaySystemSound(kSystemSoundID_Vibrate);

            }
    }



    if(whoBeIt != 11)
    {
            if(strncmp(tmpByte2,"34433030323041423438",20) == 0 || //151
             strncmp(tmpByte2,"34433030323043313736",20) == 0 ||
             strncmp(tmpByte2,"34433030323046304641",20) == 0 ||
             strncmp(tmpByte2,"34433030323043394336",20) == 0 ||
             strncmp(tmpByte2,"34433030323043463433",20) == 0 ||
             strncmp(tmpByte2,"34433030323041423343",20) == 0 ||
             strncmp(tmpByte2,"34433030323046304239",20) == 0 ||
```

```
            strncmp(tmpByte2,"34433030323130323635",20) == 0 ||
            strncmp(tmpByte2,"34433030323043343630",20) == 0 ||
            strncmp(tmpByte2,"34433030323041463131",20) == 0 ||
            strncmp(tmpByte2,"34433030323043383744",20) == 0 ||
            strncmp(tmpByte2,"34433030323043433643",20) == 0 ||
            strncmp(tmpByte2,"34433030323046373739",20) == 0 ||
            strncmp(tmpByte2,"34433030323045353635",20) == 0 ||
            strncmp(tmpByte2,"34433030323130423034",20) == 0 ) //165
           {
                whoBeIt = 11;
                synth.stop();
                synth.loadSound("sounds/407ClassRoom.caf");
                synth.play();
                AudioServicesPlaySystemSound(kSystemSoundID_Vibrate);

           }
       }




       if(Loader != 1)
       {if(strncmp(tmpByte2,"34433030323043424641",20) == 0 ||
        strncmp(tmpByte2,"34433030323043333243",20) == 0 ||
        strncmp(tmpByte2,"34433030323046423637",20) == 0 ||
        strncmp(tmpByte2,"34433030323130423939",20) == 0 ||
        strncmp(tmpByte2,"34433030323043413532",20) == 0 ||//(170)
        strncmp(tmpByte2,"34353030423842323845",20) == 0 ||
        strncmp(tmpByte2,"34433030323044313241",20) == 0 ||
        strncmp(tmpByte2,"34433030323044424631",20) == 0 ||
        strncmp(tmpByte2,"34433030323043344532",20) == 0 ||
        strncmp(tmpByte2,"34433030323041394134",20) == 0 ||
        strncmp(tmpByte2,"34353030424534384531",20) == 0 ||
        strncmp(tmpByte2,"34433030323045413443",20) == 0 ||
        strncmp(tmpByte2,"34433030323041433046",20) == 0 ||
        strncmp(tmpByte2,"34433030323130303742",20) == 0 )
           {
                Loader = 1;
           }
       }



       if(whoBeIt != 12 && Loader == 1)
       {
           if(strncmp(tmpByte2,"34433030323045353533",20) == 0
||//(180)
```

```
        strncmp(tmpByte2,"34433030323045374634",20) == 0 ||
        strncmp(tmpByte2,"34433030323130304434",20) == 0 ||
        strncmp(tmpByte2,"34433030323130333537",20) == 0 ||
        strncmp(tmpByte2,"34433030323046373230",20) == 0 ||
        strncmp(tmpByte2,"34433030323042323742",20) == 0 ||
        strncmp(tmpByte2,"34433030323043394442",20) == 0 ||
        strncmp(tmpByte2,"34433030323130433444",20) == 0 ||
        strncmp(tmpByte2,"34433030323046394430",20) == 0 ||
        strncmp(tmpByte2,"34433030323130454442",20) == 0 ||
        strncmp(tmpByte2,"34433030323042394133",20) == 0
||//(190)
        strncmp(tmpByte2,"34433030323042354238",20) == 0 ||
        strncmp(tmpByte2,"34433030323042343130",20) == 0 ||
        strncmp(tmpByte2,"34433030323046313136",20) == 0 )
       {
           whoBeIt = 12;
           Loader = 0;
           synth.stop();
           synth.loadSound("sounds/CorridorLeftTurn.caf");
           synth.play();
           AudioServicesPlaySystemSound(kSystemSoundID_Vibrate);

       }
   }



   if(Loader != 2)
   {
   if(strncmp(tmpByte2,"34433030323045323030",20) == 0 ||
    strncmp(tmpByte2,"34433030323044434439",20) == 0 ||
    strncmp(tmpByte2,"34433030323130364431",20) == 0 ||
    strncmp(tmpByte2,"34433030323046434142",20) == 0 ||
    strncmp(tmpByte2,"34433030323043303045",20) == 0 ||
    strncmp(tmpByte2,"34433030323045454435",20) == 0 ||
    strncmp(tmpByte2,"34433030323043414138",20) == 0 ||//(200)
    strncmp(tmpByte2,"34433030323131314443",20) == 0 ||
    strncmp(tmpByte2,"34433030323046313842",20) == 0 ||
    strncmp(tmpByte2,"34433030323046454530",20) == 0 ||
    strncmp(tmpByte2,"34433030323043374434",20) == 0 ||
    strncmp(tmpByte2,"34433030323130323945",20) == 0 ||
    strncmp(tmpByte2,"34433030323045463033",20) == 0 ||
    strncmp(tmpByte2,"34433030323046383245",20) == 0 )
   {
       Loader = 2;
   }
   }
```

```
	if(whoBeIt != 13 && Loader == 2)
	{
		if(strncmp(tmpByte2,"34433030323043323241",20) == 0 ||
		  strncmp(tmpByte2,"34433030323041374136",20) == 0 ||
		  strncmp(tmpByte2,"34433030323130424230",20) == 0
||//(210)
		  strncmp(tmpByte2,"34433030323043424338",20) == 0 ||
		  strncmp(tmpByte2,"34433030323046463638",20) == 0 ||
		  strncmp(tmpByte2,"34433030323044374342",20) == 0 ||
		  strncmp(tmpByte2,"34433030323043324235",20) == 0 ||
		  strncmp(tmpByte2,"34433030323046363132",20) == 0 ||
		  strncmp(tmpByte2,"34433030323045414638",20) == 0 ||
		  strncmp(tmpByte2,"34433030323046463646",20) == 0 ||
		  strncmp(tmpByte2,"34433030323130393630",20) == 0 ||
		  strncmp(tmpByte2,"34433030323130343131",20) == 0 ||
		  strncmp(tmpByte2,"34433030323041463239",20) == 0
||//(220)
		  strncmp(tmpByte2,"34433030323130443734",20) == 0 )
		{
			whoBeIt = 13;
			Loader = 0;
			synth.stop();
			synth.loadSound("sounds/CorridorLeftRight.caf");
			synth.play();
			AudioServicesPlaySystemSound(kSystemSoundID_Vibrate);

		}
	}



	if(whoBeIt != 14)
	{
		if(strncmp(tmpByte2,"34433030323130353341",20) == 0 ||//222
		  strncmp(tmpByte2,"34433030323046304335",20) == 0 ||
		  strncmp(tmpByte2,"34433030323045373842",20) == 0 ||
		  strncmp(tmpByte2,"34433030323041434133",20) == 0 ||
		  strncmp(tmpByte2,"34433030323043393036",20) == 0 ||
		  strncmp(tmpByte2,"34433030323042363332",20) == 0 ||
		  strncmp(tmpByte2,"34433030323130434539",20) == 0 ||
		  strncmp(tmpByte2,"34433030323044443234",20) == 0 ||
		  strncmp(tmpByte2,"34433030323044353235",20) == 0
||//(230)
		  strncmp(tmpByte2,"34433030323043314530",20) == 0 ||
		  strncmp(tmpByte2,"34433030323130363833",20) == 0 ||
		  strncmp(tmpByte2,"34433030323046433444",20) == 0 ||
```

```
          strncmp(tmpByte2,"34433030323045344332",20) == 0 ||
          strncmp(tmpByte2,"34433030323043464546",20) == 0 ||
          strncmp(tmpByte2,"34433030323045374346",20) == 0)//236
        {
            whoBeIt = 14;
            synth.stop();
            synth.loadSound("sounds/maleToilet.caf");
            synth.play();
            AudioServicesPlaySystemSound(kSystemSoundID_Vibrate);

        }
    }



    if(whoBeIt != 15)
    {
        if(strncmp(tmpByte2,"34433030323043413730",20) == 0 ||//237
          strncmp(tmpByte2,"34433030323042433032",20) == 0 ||
          strncmp(tmpByte2,"34433030323045394342",20) == 0 ||
          strncmp(tmpByte2,"34433030323046454235",20) == 0
||//(240)
          strncmp(tmpByte2,"34433030323041453846",20) == 0 ||
          strncmp(tmpByte2,"34433030323044434430",20) == 0 ||
          strncmp(tmpByte2,"34433030323045413537",20) == 0 ||
          strncmp(tmpByte2,"34433030323045414434",20) == 0 ||
          strncmp(tmpByte2,"34433030323044364641",20) == 0 ||
          strncmp(tmpByte2,"34433030323043464343",20) == 0 ||
          strncmp(tmpByte2,"34433030323042343438",20) == 0 ||
          strncmp(tmpByte2,"34433030323131303541",20) == 0 ||
          strncmp(tmpByte2,"34433030323042344233",20) == 0 ||
          strncmp(tmpByte2,"34433030323041383835",20) == 0
||//(250)
          strncmp(tmpByte2,"34433030323042434638",20) == 0)//251
        {
            whoBeIt = 15;
            synth.stop();
            synth.loadSound("sounds/waterFountain.caf");
            synth.play();
            AudioServicesPlaySystemSound(kSystemSoundID_Vibrate);

        }
    }



    if(whoBeIt != 16)
    {
```

```
        if( strncmp(tmpByte2,"34433030323043363146",20) == 0 ||//252
          strncmp(tmpByte2,"34433030323041374343",20) == 0 ||
          strncmp(tmpByte2,"34433030323045463334",20) == 0 ||
          strncmp(tmpByte2,"34433030323042373143",20) == 0 ||
          strncmp(tmpByte2,"34353030424535373242",20) == 0 ||//256
          strncmp(tmpByte2,"34433030323046383543",20) == 0 ||
          strncmp(tmpByte2,"34433030323130383541",20) == 0 ||
          strncmp(tmpByte2,"34433030323045463642",20) == 0 ||
          strncmp(tmpByte2,"34433030323130343942",20) == 0
||//(260)
          strncmp(tmpByte2,"34433030323131304432",20) == 0 ||
          strncmp(tmpByte2,"34433030323041373936",20) == 0 ||
          strncmp(tmpByte2,"34433030323046464346",20) == 0 ||
          strncmp(tmpByte2,"34433030323045304342",20) == 0 ||
          strncmp(tmpByte2,"34433030323046453943",20) == 0 ||//265
          strncmp(tmpByte2,"34433030323042414242",20) == 0 ||
          strncmp(tmpByte2,"34433030323043373731",20) == 0 ||
          strncmp(tmpByte2,"34433030323046393042",20) == 0 ||
          strncmp(tmpByte2,"34433030323042463132",20) == 0 ||
          strncmp(tmpByte2,"34433030323130303843",20) == 0
||//(270)
          strncmp(tmpByte2,"34433030323041363734",20) == 0 ||
          strncmp(tmpByte2,"34433030323046413031",20) == 0 ||
          strncmp(tmpByte2,"34433030323130314436",20) == 0)//273
        {
            whoBeIt = 16;
            synth.stop();
            synth.loadSound("sounds/DisabledToilet.caf");
            synth.play();
            AudioServicesPlaySystemSound(kSystemSoundID_Vibrate);

        }
    }



    if(whoBeIt != 17)
    {
        if(strncmp(tmpByte2,"34433030323044444335",20) == 0 ||//274
          strncmp(tmpByte2,"34433030323041374235",20) == 0 ||
          strncmp(tmpByte2,"34433030323046353541",20) == 0 ||
          strncmp(tmpByte2,"34433030323130463242",20) == 0 ||
          strncmp(tmpByte2,"34433030323042374241",20) == 0 ||
          strncmp(tmpByte2,"34433030323130413135",20) == 0 ||
          strncmp(tmpByte2,"34433030323046443042",20) == 0
||//(280)
          strncmp(tmpByte2,"34433030323045463543",20) == 0 ||
          strncmp(tmpByte2,"34433030323041454432",20) == 0 ||
```

```
            strncmp(tmpByte2,"34433030323046353734",20) == 0 ||
            strncmp(tmpByte2,"34433030323042433442",20) == 0 ||
            strncmp(tmpByte2,"34433030323042364337",20) == 0 ||//285
            strncmp(tmpByte2,"34433030323043443942",20) == 0 ||
            strncmp(tmpByte2,"34433030323042424137",20) == 0 ||
            strncmp(tmpByte2,"34433030323042364539",20) == 0)//288
        {
            whoBeIt = 17;
            synth.stop();
            synth.loadSound("sounds/femaleToilet.caf");
            synth.play();
            AudioServicesPlaySystemSound(kSystemSoundID_Vibrate);

        }
    }




    if(whoBeIt != 18)
    {
        if(strncmp(tmpByte2,"34433030323042343546",20) == 0 ||//289

            strncmp(tmpByte2,"34433030323042373237",20) == 0
||//(290)
            strncmp(tmpByte2,"34433030323044354242",20) == 0 ||
            strncmp(tmpByte2,"34433030323130323546",20) == 0 ||
            strncmp(tmpByte2,"34433030323044364531",20) == 0 ||
            strncmp(tmpByte2,"34433030323042463042",20) == 0 ||
            strncmp(tmpByte2,"34433030323043323131",20) == 0 ||//295
            strncmp(tmpByte2,"34433030323130394643",20) == 0 ||
            strncmp(tmpByte2,"34433030323046344445",20) == 0 ||
            strncmp(tmpByte2,"34433030323041433433",20) == 0 ||
            strncmp(tmpByte2,"34433030323041353230",20) == 0 ||
            strncmp(tmpByte2,"34433030323041354338",20) == 0
||//(300)
            strncmp(tmpByte2,"34433030323130453338",20) == 0 ||
            strncmp(tmpByte2,"34433030323045314330",20) == 0 ||
            strncmp(tmpByte2,"34433030323046443243",20) == 0)//303
        {
            whoBeIt = 18;
            synth.stop();
            synth.loadSound("sounds/fireExtingiusherPoint.caf");
            synth.play();
            AudioServicesPlaySystemSound(kSystemSoundID_Vibrate);

        }
```

```
	}



	if(whoBeIt != 19)
	{
		if(strncmp(tmpByte2,"34433030323044423834",20) == 0 ||//304
		  strncmp(tmpByte2,"34433030323041393134",20) == 0 ||
		  strncmp(tmpByte2,"34433030323045443444",20) == 0 ||
		  strncmp(tmpByte2,"34433030323046454444",20) == 0 ||
		  strncmp(tmpByte2,"34433030323045413830",20) == 0 ||
		  strncmp(tmpByte2,"34433030323045463941",20) == 0 ||
		  strncmp(tmpByte2,"34433030323130364231",20) == 0 ||
//(310)
		  strncmp(tmpByte2,"34433030323045363445",20) == 0 ||
		  strncmp(tmpByte2,"34433030323042364445",20) == 0 ||
		  strncmp(tmpByte2,"34433030323043304436",20) == 0 ||
		  strncmp(tmpByte2,"34433030323045434346",20) == 0 ||
		  strncmp(tmpByte2,"34433030323045394536",20) == 0 ||//315
		  strncmp(tmpByte2,"34433030323044343746",20) == 0 ||
		  strncmp(tmpByte2,"34433030323046373241",20) == 0 ||
		  strncmp(tmpByte2,"34433030323044423641",20) == 0 ||
		  strncmp(tmpByte2,"34433030323046333735",20) == 0)//319
		{
			whoBeIt = 19;
			synth.stop();
			synth.loadSound("sounds/EndOfTestArea.caf");
			synth.play();
			AudioServicesPlaySystemSound(kSystemSoundID_Vibrate);

		}
	}



	if(whoBeIt != 20)
	{
		if(strncmp(tmpByte2,"34433030323046353639",20) == 0
||//(320)
		  strncmp(tmpByte2,"34433030323046453934",20) == 0 ||
		  strncmp(tmpByte2,"34433030323045394646",20) == 0 ||
		  strncmp(tmpByte2,"34433030323043304130",20) == 0 ||
		  strncmp(tmpByte2,"34433030323041384230",20) == 0 ||
		  strncmp(tmpByte2,"34433030323042364444",20) == 0 ||//325
		  strncmp(tmpByte2,"34433030323044434344",20) == 0 ||
		  strncmp(tmpByte2,"34433030323043433330",20) == 0 ||
		  strncmp(tmpByte2,"34433030323042394139",20) == 0 ||
		  strncmp(tmpByte2,"34433030323130353631",20) == 0 ||
```

```
            strncmp(tmpByte2,"34433030323044374230",20) == 0
||//(330)
            strncmp(tmpByte2,"34433030323041453535",20) == 0 ||
            strncmp(tmpByte2,"34433030323042463537",20) == 0 ||
            strncmp(tmpByte2,"34433030323046414531",20) == 0 ||
            strncmp(tmpByte2,"34433030323046314346",20) == 0 ||
            strncmp(tmpByte2,"34433030323042444632",20) == 0)//335
           {
                whoBeIt = 20;
                synth.stop();
                synth.loadSound("sounds/seatingArea.caf");
                synth.play();
                AudioServicesPlaySystemSound(kSystemSoundID_Vibrate);

           }
    }



    if(whoBeIt != 21)
    {
           if(strncmp(tmpByte2,"34433030323041453637",20) == 0 ||//336
            strncmp(tmpByte2,"34433030323042323334",20) == 0 ||
            strncmp(tmpByte2,"34433030323046363235",20) == 0 ||
            strncmp(tmpByte2,"34433030323041433445",20) == 0 ||
            strncmp(tmpByte2,"34433030323130393142",20) == 0
||//(340)
            strncmp(tmpByte2,"34433030323046373436",20) == 0 ||
            strncmp(tmpByte2,"34433030323046393944",20) == 0 ||
            strncmp(tmpByte2,"34433030323043464536",20) == 0 ||
            strncmp(tmpByte2,"34353030424532464132",20) == 0 ||
            strncmp(tmpByte2,"34353030423845463435",20) == 0 ||//345
            strncmp(tmpByte2,"34353030424532364433",20) == 0 ||
            strncmp(tmpByte2,"34353030424534373141",20) == 0 ||
            strncmp(tmpByte2,"34433030323045464333",20) == 0 ||
            strncmp(tmpByte2,"34433030323041414430",20) == 0 ||
            strncmp(tmpByte2,"34433030323046334642",20) == 0
||//(350)
            strncmp(tmpByte2,"34433030323045394131",20) == 0 ||
            strncmp(tmpByte2,"34433030323046364536",20) == 0 ||
            strncmp(tmpByte2,"34433030323043354336",20) == 0 ||
            strncmp(tmpByte2,"34433030323131303236",20) == 0 ||
            strncmp(tmpByte2,"34433030323046303432",20) == 0 ||//355
            strncmp(tmpByte2,"34433030323044464234",20) == 0 ||
            strncmp(tmpByte2,"34433030323043453441",20) == 0 ||
            strncmp(tmpByte2,"34433030323042384444",20) == 0 ||
            strncmp(tmpByte2,"34433030323131314534",20) == 0 ||
```

```
            strncmp(tmpByte2,"34433030323043454536",20) == 0
||//(360)
            strncmp(tmpByte2,"34433030323044343436",20) == 0 ||
            strncmp(tmpByte2,"34433030323041463838",20) == 0 ||
            strncmp(tmpByte2,"34433030323046383437",20) == 0 ||
            strncmp(tmpByte2,"34433030323042433432",20) == 0 ||//364
            strncmp(tmpByte2,"34433030323045303041",20) == 0)//365
        {
            whoBeIt = 21;
            synth.stop();
            synth.loadSound("sounds/stairsApproaching.caf");
            synth.play();
            AudioServicesPlaySystemSound(kSystemSoundID_Vibrate);

        }
    }




    if(whoBeIt != 22)
    {
        if(strncmp(tmpByte2,"34433030323043393933",20) == 0 ||//366
            strncmp(tmpByte2,"34433030323041353339",20) == 0 ||
            strncmp(tmpByte2,"34433030323130413544",20) == 0 ||
            strncmp(tmpByte2,"34433030323044303133",20) == 0 ||
            strncmp(tmpByte2,"34433030323045353830",20) == 0
||//(370)
            strncmp(tmpByte2,"34433030323046414436",20) == 0 ||
            strncmp(tmpByte2,"34433030323042344142",20) == 0 ||
            strncmp(tmpByte2,"34433030323046454443",20) == 0 ||
            strncmp(tmpByte2,"34433030323042313633",20) == 0 ||
            strncmp(tmpByte2,"34433030323046343935",20) == 0 ||//375
            strncmp(tmpByte2,"34433030323130433338",20) == 0 ||
            strncmp(tmpByte2,"34433030323130374344",20) == 0 ||
            strncmp(tmpByte2,"34433030323043354241",20) == 0 ||
            strncmp(tmpByte2,"34433030323046354333",20) == 0 ||
            strncmp(tmpByte2,"34433030323044353136",20) == 0
||//(380)
            strncmp(tmpByte2,"34433030323130313545",20) == 0)//381



        {
            whoBeIt = 22;
            synth.stop();
            synth.loadSound("sounds/downStairs.caf");
```

```
                synth.play();
                AudioServicesPlaySystemSound(kSystemSoundID_Vibrate);

            }
    }



    if(whoBeIt != 23)
    {
            if( strncmp(tmpByte2,"34433030323043413438",20) == 0 ||//382
             strncmp(tmpByte2,"34433030323042303236",20) == 0 ||
             strncmp(tmpByte2,"34433030323042313730",20) == 0 ||
             strncmp(tmpByte2,"34433030323130313736",20) == 0 ||//385
             strncmp(tmpByte2,"34433030323044344546",20) == 0 ||
             strncmp(tmpByte2,"34433030323046443033",20) == 0 ||
             strncmp(tmpByte2,"34433030323046384332",20) == 0 ||
             strncmp(tmpByte2,"34433030323041354344",20) == 0 ||
             strncmp(tmpByte2,"34433030323131313246",20) == 0
||//(390)
             strncmp(tmpByte2,"34433030323043374632",20) == 0 ||
             strncmp(tmpByte2,"34433030323043443343",20) == 0 ||
             strncmp(tmpByte2,"34433030323130463645",20) == 0 ||
             strncmp(tmpByte2,"34433030323045333830",20) == 0 ||
             strncmp(tmpByte2,"34433030323041463246",20) == 0 ||//395
             strncmp(tmpByte2,"34433030323041393137",20) == 0 ||
             strncmp(tmpByte2,"34433030323045373239",20) == 0)//397v



            {
                whoBeIt = 23;
                synth.stop();
                synth.loadSound("sounds/upStairs.caf");
                synth.play();
                AudioServicesPlaySystemSound(kSystemSoundID_Vibrate);

            }
    }



    if(whoBeIt != 24)
    {
            if( strncmp(tmpByte2,"34433030323042394539",20) == 0 ||//398
             strncmp(tmpByte2,"34433030323130344436",20) == 0 ||
             strncmp(tmpByte2,"34433030323043344138",20) == 0 ||
//(400)
```

```
            strncmp(tmpByte2,"34433030323043453834",20) == 0 ||
            strncmp(tmpByte2,"34433030323046313631",20) == 0 ||
            strncmp(tmpByte2,"34433030323046303242",20) == 0 ||
            strncmp(tmpByte2,"34433030323043343333",20) == 0 ||
            strncmp(tmpByte2,"34433030323041453732",20) == 0 ||//405
            strncmp(tmpByte2,"34433030323043453930",20) == 0 ||
            strncmp(tmpByte2,"34433030323046384632",20) == 0 ||
            strncmp(tmpByte2,"34433030323130414143",20) == 0 ||
            strncmp(tmpByte2,"34433030323045443135",20) == 0 ||
            strncmp(tmpByte2,"34433030323044453334",20) == 0
||//(410)
            strncmp(tmpByte2,"34433030323041344445",20) == 0 ||
            strncmp(tmpByte2,"34433030323044464339",20) == 0 ||
            strncmp(tmpByte2,"34433030323042434237",20) == 0 ||
            strncmp(tmpByte2,"34433030323044434138",20) == 0 ||
            strncmp(tmpByte2,"34433030323130333842",20) == 0 ||//415
            strncmp(tmpByte2,"34433030323042443731",20) == 0 ||
            strncmp(tmpByte2,"34433030323045413843",20) == 0 ||
            strncmp(tmpByte2,"34433030323130413237",20) == 0)//418


           {
                whoBeIt = 24;
                synth.stop();
                synth.loadSound("sounds/EndOfTestArea.caf");
                synth.play();
                AudioServicesPlaySystemSound(kSystemSoundID_Vibrate);

           }
     }



     if(whoBeIt != 25)
     {
           if( strncmp(tmpByte2,"34433030323042423039",20) == 0 ||//419
            strncmp(tmpByte2,"34433030323044413743",20) == 0
||//(420)
            strncmp(tmpByte2,"34433030323043353330",20) == 0 ||
            strncmp(tmpByte2,"34433030323045393441",20) == 0 ||
            strncmp(tmpByte2,"34433030323045383031",20) == 0 ||
            strncmp(tmpByte2,"34433030323046363838",20) == 0 ||
            strncmp(tmpByte2,"34433030323044333842",20) == 0 ||//425
            strncmp(tmpByte2,"34433030323041443945",20) == 0 ||
            strncmp(tmpByte2,"34433030323043414332",20) == 0 ||
            strncmp(tmpByte2,"34433030323044443046",20) == 0 ||
            strncmp(tmpByte2,"34433030323043463045",20) == 0 ||
```

```
          strncmp(tmpByte2,"34353030423845333337",20) == 0
||//(430)
          strncmp(tmpByte2,"34433030323041373539",20) == 0 ||
          strncmp(tmpByte2,"34433030323044433133",20) == 0 ||
          strncmp(tmpByte2,"34433030323046333139",20) == 0)//433




        {
            whoBeIt = 25;
            synth.stop();
            synth.loadSound("sounds/liftControls.caf");
            synth.play();
            AudioServicesPlaySystemSound(kSystemSoundID_Vibrate);

        }
    }



    if(whoBeIt != 26)
    {
        if( strncmp(tmpByte2,"34433030323130423232",20) == 0 ||//434
          strncmp(tmpByte2,"34433030323043394430",20) == 0 ||//435
          strncmp(tmpByte2,"34433030323044334433",20) == 0 ||
          strncmp(tmpByte2,"34433030323043394331",20) == 0 ||
          strncmp(tmpByte2,"34433030323046424131",20) == 0 ||
          strncmp(tmpByte2,"34433030323044313935",20) == 0 ||
          strncmp(tmpByte2,"34433030323042393931",20) == 0
||//(440)
          strncmp(tmpByte2,"34433030323045373136",20) == 0 ||
          strncmp(tmpByte2,"34433030323045443230",20) == 0 ||
          strncmp(tmpByte2,"34433030323046354636",20) == 0 ||
          strncmp(tmpByte2,"34433030323042374243",20) == 0 ||
          strncmp(tmpByte2,"34433030323045344232",20) == 0 ||//445
          strncmp(tmpByte2,"34433030323043463535",20) == 0 ||
          strncmp(tmpByte2,"34433030323044453532",20) == 0 ||
          strncmp(tmpByte2,"34433030323130333143",20) == 0 ||
          strncmp(tmpByte2,"34433030323042324335",20) == 0 ||
          strncmp(tmpByte2,"34423030373646453946",20) == 0)//(450)




        {
            whoBeIt = 26;
```

```
                synth.stop();
                synth.loadSound("sounds/liftEntrance.caf");
                synth.play();
                AudioServicesPlaySystemSound(kSystemSoundID_Vibrate);

            }
        }



        if(whoBeIt != 27)
        {
            if(strncmp(tmpByte2,"34433030323045323239",20) == 0 ||//451
              strncmp(tmpByte2,"34433030323041373943",20) == 0 ||
              strncmp(tmpByte2,"34433030323044383236",20) == 0 ||
              strncmp(tmpByte2,"34433030323130463333",20) == 0 ||
              strncmp(tmpByte2,"34433030323042384641",20) == 0 ||//455
              strncmp(tmpByte2,"34433030323130343631",20) == 0 ||
              strncmp(tmpByte2,"34433030323130393233",20) == 0 ||
              strncmp(tmpByte2,"34433030323044443645",20) == 0 ||
              strncmp(tmpByte2,"34433030323131304246",20) == 0 ||
              strncmp(tmpByte2,"34433030323043313446",20) == 0
||//(460)
              strncmp(tmpByte2,"34433030323130344643",20) == 0 ||
              strncmp(tmpByte2,"34433030323042454343",20) == 0 ||
              strncmp(tmpByte2,"34433030323044443733",20) == 0 ||
              strncmp(tmpByte2,"34433030323045313731",20) == 0 ||
              strncmp(tmpByte2,"34433030323046443339",20) == 0)//465




            {
                whoBeIt = 27;
                synth.stop();
                synth.loadSound("sounds/EntranceDoorRight.caf");
                synth.play();
                AudioServicesPlaySystemSound(kSystemSoundID_Vibrate);

            }
        }



        if(whoBeIt != 28)
        {
            if( strncmp(tmpByte2,"34433030323042353633",20) == 0 ||//466
```

```
            strncmp(tmpByte2,"34433030323046373337",20) == 0 ||
            strncmp(tmpByte2,"34433030323042453931",20) == 0 ||
            strncmp(tmpByte2,"34433030323130333538",20) == 0 ||
            strncmp(tmpByte2,"34433030323045434631",20) == 0
||//(470)
            strncmp(tmpByte2,"34353030423843383138",20) == 0 ||
            strncmp(tmpByte2,"34433030323046454241",20) == 0 ||
            strncmp(tmpByte2,"34433030323131314139",20) == 0 ||
            strncmp(tmpByte2,"34433030323046463243",20) == 0 ||
            strncmp(tmpByte2,"34433030323046323645",20) == 0 ||//475
            strncmp(tmpByte2,"34433030323046384132",20) == 0 ||
            strncmp(tmpByte2,"34433030323043383337",20) == 0 ||
            strncmp(tmpByte2,"34433030323130343941",20) == 0 ||
            strncmp(tmpByte2,"34433030323041443936",20) == 0 ||
            strncmp(tmpByte2,"34433030323045453738",20) == 0)//(480)




        {
            whoBeIt = 28;
            synth.stop();
            synth.loadSound("sounds/EntranceDoorLeft.caf");
            synth.play();
            AudioServicesPlaySystemSound(kSystemSoundID_Vibrate);

        }
    }



    if(whoBeIt != 29)
    {
        if(strncmp(tmpByte2,"34433030323045354633",20) == 0 || //481
            strncmp(tmpByte2,"34433030323131303044",20) == 0 ||
            strncmp(tmpByte2,"34433030323043383438",20) == 0 ||
            strncmp(tmpByte2,"34433030323045414238",20) == 0 ||
            strncmp(tmpByte2,"34433030323044453044",20) == 0 ||//485
            strncmp(tmpByte2,"34433030323044303934",20) == 0 ||
            strncmp(tmpByte2,"34433030323042414544",20) == 0 ||
            strncmp(tmpByte2,"34433030323045424544",20) == 0 ||
            strncmp(tmpByte2,"34433030323046353634",20) == 0 ||
            strncmp(tmpByte2,"34433030323044343545",20) == 0
||//(490)
            strncmp(tmpByte2,"34433030323042433937",20) == 0 ||
            strncmp(tmpByte2,"34433030323045363436",20) == 0 ||
            strncmp(tmpByte2,"34433030323045423130",20) == 0 ||
```

```
		strncmp(tmpByte2,"34433030323042373735",20) == 0 ||
		strncmp(tmpByte2,"34433030323046323735",20) == 0 ||//495
		strncmp(tmpByte2,"34433030323046433741",20) == 0 ||
		strncmp(tmpByte2,"34433030323045343833",20) == 0)//497




		{
			whoBeIt = 29;
			synth.stop();
			synth.loadSound("sounds/liftEntrance.caf");
			synth.play();
			AudioServicesPlaySystemSound(kSystemSoundID_Vibrate);

		}
	}



}






//--------------------------------------------------------------
void testApp::update(){





	if (getSerial){
		otherSerial();
	}



}

//--------------------------------------------------------------
void testApp::draw(){
	// Serial
```

```
        font.drawString("Cerberus 0.1" , 120, 20);
        font.drawString("Scanned Tag:\n" , 20, 70);
        font.drawString(totalData, 80, 90);
        ofSetColor(0xFFFFFF);
        tag1.draw(40,85);








}

void testApp::exit() {
        serial.close();
        printf("exit()\n");
}

//--------------------------------------------------------------
void testApp::mouseMoved(int x, int y ){
        // this will never get called



}

//--------------------------------------------------------------
void testApp::mouseDragged(int x, int y, int button){
}

//--------------------------------------------------------------
void testApp::mousePressed(int x, int y, int button){
        ofEnableSmoothing();
}

//--------------------------------------------------------------
void testApp::mouseReleased(){
        //      printf("mouseReleased\n");
        printf("frameRate: %.3f, frameNum: %i\n", ofGetFrameRate(),
ofGetFrameNum());
}

//--------------------------------------------------------------
void testApp::mouseReleased(int x, int y, int button){
```

```
}

//--------------------------------------------------------------
void testApp::touchDown(float x, float y, int touchId,
ofxMultiTouchCustomData *data){
	printf("touch %i down at (%i,%i)\n", touchId, x,y);
}
//--------------------------------------------------------------
void testApp::touchMoved(float x, float y, int touchId,
ofxMultiTouchCustomData *data){
	printf("touch %i moved at (%i,%i)\n", touchId, x,y);
}
//--------------------------------------------------------------
void testApp::touchUp(float x, float y, int touchId, ofxMultiTouchCustomData
*data){
	printf("touch %i up at (%i,%i)\n", touchId, x,y);
}
//--------------------------------------------------------------
void testApp::touchDoubleTap(float x, float y, int touchId,
ofxMultiTouchCustomData *data){
	printf("touch %i double tap at (%i,%i)\n", touchId, x,y);
}
```

Appendix B

Tables of investigation data pertaining to the "RFID Device Read Range Experiment".

No Obstacle																											**Mean**
Head On Centre	5.8	5.7	5.6	6.0	5.7	5.9	5.5	5.8	5.6	5.6	5.9	5.8	5.6	5.7	5.9	5.8	6.0	6.1	5.7	5.6	6.0	6.2	5.6	5.6	5.8		5.8
Head On Left/Right	4.2	4.1	4.3	4.1	4.2	4.2	4.2	4.1	4.3	4.2	4.4	4.2	4.3	4.2	4.2	4.2	4.3	4.2	4.3	4.1	4.4	4.2	4.2	4.4	4.2		4.2
Angled Centre	5.6	5.6	5.5	5.6	5.4	5.7	5.5	5.5	5.5	5.6	5.5	5.5	5.4	5.5	5.5	5.5	5.7	5.5	5.6	5.5	5.5	5.6	5.5	5.4	5.5		5.5
Angled Left/Right	4.2	4.1	4.1	4.0	4.1	4.1	4.2	4.2	4.1	4.2	4.2	4.3	4.2	4.2	4.2	4.1	4.2	4.3	4.2	4.2	4.1	4.1	4.2	4.2	4.2		4.2
Side On Centre	3.5	3.4	3.5	3.5	3.4	3.5	3.5	3.4	3.4	3.5	3.4	3.4	3.4	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.4	3.4	3.5		3.5
Side On Left/ Right	3.2	3.3	3.3	3.3	3.4	3.2	3.2	3.2	3.3	3.4	3.3	3.2	3.3	3.3	3.3	3.3	3.2	3.2	3.3	3.4	3.3	3.4	3.3	3.3	3.4		3.3
5mm Wood Flooring																											**Mean**
Head On Centre	5.6	5.7	5.7	5.7	5.6	5.6	5.8	5.6	5.6	5.5	5.6	5.7	5.7	5.6	5.6	5.5	5.6	5.6	5.6	5.5	5.5	5.7	5.5	5.6	5.5		5.6
Head On Left/Right	4.1	4.1	4.2	4.2	4.1	4.1	4.3	4.1	4.1	4.2	4.1	4.1	4.2	4.2	4.2	4.1	4.1	4.1	4.2	4.2	4.1	4.1	4.2	4.1	4.1		4.1
Angled Centre	5.5	5.5	5.5	5.4	5.5	5.6	5.5	5.5	5.4	5.6	5.5	5.5	5.4	5.5	5.5	5.4	5.5	5.4	5.4	5.5	5.6	5.5	5.4	5.5	5.4		5.5
Angled Left/Right	4.0	4.0	4.1	4.0	4.1	4.1	4.0	4.2	4.2	4.1	4.1	4.0	4.0	4.0	4.1	4.1	4.0	4.1	4.0	4.2	4.0	4.1	4.0	4.0	4.0		4.1
Side On Centre	3.4	3.4	3.5	3.4	3.3	3.3	3.4	3.4	3.4	3.3	3.3	3.4	3.3	3.5	3.5	3.4	3.4	3.4	3.3	3.3	3.4	3.4	3.4	3.4	3.3		3.4
Side On Left/ Right	3.3	3.2	3.3	3.3	3.2	3.2	3.3	3.3	3.4	3.3	3.3	3.3	3.2	3.3	3.3	3.2	3.2	3.3	3.3	3.3	3.2	3.3	3.2	3.2	3.3		3.3
4mm Plastic Flooring																											**Mean**
Head On Centre	5.6	5.5	5.6	5.6	5.6	5.6	5.6	5.5	5.6	5.6	5.6	5.5	5.5	5.6	5.4	5.5	5.5	5.6	5.5	5.4	5.5	5.5	5.5	5.6	5.5		5.5
Head On Left/Right	4.1	4.2	4.1	4.2	4.2	4.2	4.1	4.1	4.2	4.2	4.0	4.1	4.1	4.2	4.2	4.2	4.1	4.2	4.3	4.2	4.2	4.2	4.2	4.2	4.2		4.2
Angled Centre	5.5	5.5	5.4	5.4	5.4	5.5	5.5	5.6	5.6	5.5	5.6	5.5	5.5	5.6	5.5	5.4	5.5	5.6	5.4	5.5	5.6	5.4	5.6	5.5	5.5		5.5
Angled Left/Right	4.2	4.1	4.2	4.2	4.1	4.1	4.2	4.3	4.2	4.2	4.1	4.2	4.1	4.2	4.2	4.2	4.1	4.2	4.2	4.1	4.1	4.3	4.2	4.3	4.1		4.2
Side On Centre	3.3	3.4	3.4	3.4	3.4	3.5	3.4	3.3	3.3	3.4	3.3	3.3	3.3	3.4	3.3	3.5	3.4	3.3	3.3	3.3	3.3	3.3	3.3	3.4	3.3		3.4
Side On Left/ Right	3.2	3.3	3.3	3.3	3.3	3.2	3.3	3.3	3.2	3.3	3.3	3.1	3.3	3.3	3.3	3.3	3.4	3.2	3.3	3.2	3.3	3.3	3.3	3.3	3.2		3.3
12mm Marble Flooring																											**Mean**
Head On Centre	3.4	3.5	3.5	3.6	3.5	3.5	3.5	3.4	3.6	3.4	3.4	3.5	3.4	3.4	3.5	3.4	3.5	3.6	3.5	3.5	3.5	3.4	3.4	3.5	3.6		3.5
Head On Left/Right	2.9	2.8	2.8	2.9	3.0	2.8	2.9	2.8	2.8	2.8	2.9	2.8	2.8	2.9	2.8	2.8	2.8	3.0	2.8	2.8	2.9	2.8	2.8	2.8	2.9		2.8
Angled Centre	3.3	3.3	3.4	3.3	3.3	3.3	3.5	3.4	3.4	3.3	3.3	3.3	3.2	3.3	3.3	3.3	3.2	3.4	3.5	3.3	3.3	3.2	3.2	3.2	3.3		3.3
Angled Left/Right	2.8	2.9	2.9	2.8	2.8	2.7	2.8	2.8	2.8	2.9	2.7	2.7	2.8	2.8	2.8	2.7	2.8	2.8	2.8	2.7	2.9	2.8	2.8	2.8	2.8		2.8
Side On Centre	1.2	1.1	1.0	1.1	1.1	1.1	1.1	1.2	1.1	1.1	1.2	1.1	1.2	1.1	1.0	1.1	1.2	1.1	1.1	1.1	1.2	1.1	1.2	1.1	1.1		1.1
Side On Left/ Right	1.0	1.1	1.0	1.1	1.2	1.0	1.0	1.0	1.0	1.0	1.1	1.1	1.0	1.0	1.1	1.0	1.2	1.0	1.0	1.1	1.1	1.0	1.0	1.1	1.0		1.0

2mm Steel Flooring																											**Mean**
Head On Centre	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0.0
Head On Left/Right	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0.0
Angled Centre	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0.0
Angled Left/Right	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0.0
Side On Centre	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0.0
Side On Left/ Right	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0.0

Appendix C

Participant 1: -

Some card arcs are not being scanned due to the speed at which the user is scanning with the cane.

Some information is lasting too long and causing the participant to stop and wait while the information has finished being conveyed.

Participant seems confident while using the system and traversing at a good speed.

Participant finds the target location without difficulty.

Participant missing some card arcs due to using opposite wall for walking in a straight line.

The above-mentioned walking technique causes participant to miss the target location on first traversal causing them to double back.

Participant gaining in confidence with the ASOVI system.

Participant struggling with RFID receiver attached to the ball on the end of the cane due to the fact the ball needs to rotate and is causing problems with the wires and movement.

Participant hitting multiple arcs causing them to slow down.

Participant has slight eyesight (enough to make out showed objects) and due to the cards being placed on top of the flooring as the modification of the environment is not possible this is causing distraction.

Participant 2: -

Participant has trouble with the RFID receiver being attached to the bottom of the cane. Receiver keeps snagging on the floor and when the end of the cane rolls as designed the wires wrap around the cane and on one occasion this causes a short circuit and the cane to cease functioning.

Participant cautious at first when using the ASOVI system however gaining confidence as time passes.

As the cards are placed on top of the environment the cane snags some of the cards and moves them from their intended arc position.

Participant find target location however due to the afore mentioned problems this takes some time.

Participant missing some card arcs due to following the wall as a mode of orientation during traversal of the environment.

Some card arcs not being scanned efficiently due to the speed and method of scanning with the cane.

Some information is lasting too long and causing the participant to stop and wait while the information has finished being conveyed.

Participant 3: -

Participant has trouble with reading the cards due to speed of movement of the cane.

Participant has trouble scanning some cards due to speed of the scan.

Participant misses some card arcs due to following the wall for orientation. (Participant verbally mentions that they are a qualified cane teacher and that using a wall is commonplace)
Participant successfully finds target location without any difficulty.
The receiver snags on the floor repeatedly (participant verbally communicates that it is snagging and thus hinders the scan).
Participant reacting positively to feedback and taking note of warnings (end of test area / stairs approaching).
As the cards are placed on top of the environment the cane snags some of the cards and moves them from their intended arc position.

Participant 4: -

Travelling at very high speed with a huge amount of confidence.
Due to speed of travel a large amount of card arcs being missed.
The receiver snags on the floor repeatedly.
As the cards are placed on top of the environment the cane snags some of the cards and moves them from their intended arc position.
The participant is having trouble locating the specified area due to lack of information, as traversal speed is that of a slow jog not a walk.

Appendix D

Q1. From CW4/01 to CW4/04.
Q2. From CW4/01 to Office Of Damien De Luca.
Q3. From Office Of Damien De Luca to Modern Artwork – Dots.
Q4. From CW4/07 to Male Toilets.
Q5. From Lifts to Security Phone.
Q6. From Water Fountain to Seating Area.
Q7. From First Aid Box to Corridor Left Turn.
Q8. From Disabled Toilet to CW4/01.

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