A Context-aware Navigational Autonomy Aid for the Blind

(NAAB)

A thesis submitted for the degree of

Doctor of Philosophy

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Abstract

Reaching a specific destination in unfamiliar environments is a real challenge for people with a vision disability, even if they use a white cane or guide dog. The focus of this thesis is to develop an integrated Navigational Autonomy Aid for the Blind (NAAB) system. The main target of NAAB is to produce a system that helps blind and visually impaired (BVI) people to navigate independently, particularly in unfamiliar indoor environments. The services that NAAB produce for BVI people include assistance to identify their current position precisely, guidance to their desired destinations and assistance with avoiding people who are likely to intersect their paths.

In the navigational literature, several applications have been developed to assist BVI people. Most are designed to work in outdoor environments. The major limitation of most navigation applications designed to assist BVI people in indoor environments is that each provides one specific service, such as positioning, navigation or obstacle avoidance. However, these applications rarely all incorporate these services, nor work effectively in indoor environments. Further, there are no commercially available integrated navigation systems to assist BVI people to navigate independently and reach their destination precisely in buildings they are visiting for the first time. This highlights the need to further address the research challenges.

Considering this problem, the main focus of this research is to investigate and develop an integrated navigation system that should be suitable to assist BVI people inside buildings and provide four services for them: positioning, navigation, avoidance of humans in their path (for blind users) and assistance with safe road crossing.

NAAB has three components: active radio frequency identification (RFID), quick-response (QR)-code and a 3D camera (Kinect). The integrated term refers to multiple technologies and multiple services providing for BVI people. The first is positioning, which aims to assist BVI people to indicate their current location precisely. Positioning in NAAB systems could be done by RFID alone, with 2-m accuracy, but once the QR-code was integrated into the system directionality concerns with RFID were resolved.
and accuracy was increased as well. The developed RFID positioning algorithm is not based on received signal strength (RSS) but on a novel technique of positioning that has been developed as a combination of RSS with attenuation control level by the RFID reader, which is carried by the user.

The second service produced for BVI people by NAAB is navigation, which aims to assist BVI people to reach their desired destination. Navigation includes positioning based on a developed positioning algorithm, determining the most preferable path for the user from their current location to the destination through the shortest path in most cases, and detection of deviation of the user from the suggested path to recalculate the path to the destination from the wrong location, as far as is possible. The efficiency of the proposed navigation system (NAAB) was tested on eight blind participants and their perspectives regarding the system were taken into account to improve the usability of the system.

Kinect is a device developed by Microsoft to use in interactive games. It was chosen because it has a 3D camera that is normally used for human pose detection for games. However, such a depth camera can also be used to predict movement of objects in front of the user to alert them about any objects that may intersect their path.

By use of Kinect, NAAB can detect moving people in the path of the user and predict the movement of each person to warn the user about any potential intersection with these people. Therefore, Kinect was integrated to NAAB as the third service.

This thesis presents an additional service for BVI people, to assist them to cross the street independently. The presented approach provides the user with significant information such as detection of a pedestrian crossing signal from any point of view, when the pedestrian crossing signal light is green, the detection of dynamic and fixed obstacles, predictions of the movement of fellow pedestrians and information on objects that may intersect the user’s path. The approach here is based on capturing multiple frames using a depth camera attached to a user’s headgear and the efficiency of using a speeded-up robust features (SURF) algorithm for object recognition to assist blind people is discussed.
Declaration of Originality

I certify that except where due acknowledgement has been made, the work is that of the author alone; the work has not been submitted previously, in whole or in part, to qualify for any other academic award; the content of the thesis is the result of work which has been carried out since the official commencement date of the approved research programme; and, any editorial work, paid or unpaid, carried out by a third party is acknowledged.

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• I acknowledge the perfect proofreading job done by Elite Editing.

• I ask my parents to forgive me for neglecting their rights by spending too long away of them. So I ask my father Mr Ahmed and my mother Mrs Azzah to accept this thesis as a gift.
Credits

Portions of the material in this thesis have previously appeared in the following publications:

**Journal Papers**


**Fully Peer-reviewed Conference Papers**


The thesis was written in the WinEdt 7.0 editor and typeset using the LATEX 2ε document preparation system.

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<tbody>
<tr>
<td>API</td>
<td>Application Programming Interface</td>
</tr>
<tr>
<td>AttnL</td>
<td>Attenuation Level</td>
</tr>
<tr>
<td>BS</td>
<td>Base Station</td>
</tr>
<tr>
<td>BVI</td>
<td>Blind and Visually Impaired</td>
</tr>
<tr>
<td>CV</td>
<td>Computer Vision</td>
</tr>
<tr>
<td>DFR</td>
<td>Direct Front Range</td>
</tr>
<tr>
<td>DR</td>
<td>Dead Reckoning</td>
</tr>
<tr>
<td>ETA</td>
<td>Electronic Travel Aid</td>
</tr>
<tr>
<td>GIS</td>
<td>Geographic Information System</td>
</tr>
<tr>
<td>GPS</td>
<td>Global Positioning System</td>
</tr>
<tr>
<td>HS</td>
<td>Haptic Sight</td>
</tr>
<tr>
<td>IR</td>
<td>Infrared</td>
</tr>
<tr>
<td>LR</td>
<td>Left Range</td>
</tr>
<tr>
<td>MA</td>
<td>Mobile Agent</td>
</tr>
<tr>
<td>NAAB</td>
<td>Navigational Autonomy Aid for the Blind</td>
</tr>
<tr>
<td>Abbreviation</td>
<td>Term</td>
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<td>--------------</td>
<td>-------------------------------------------</td>
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<tr>
<td>POI</td>
<td>points of interest</td>
</tr>
<tr>
<td>QR-code</td>
<td>quick-response code</td>
</tr>
<tr>
<td>RFID</td>
<td>radio frequency identification</td>
</tr>
<tr>
<td>RR</td>
<td>right range</td>
</tr>
<tr>
<td>RSS</td>
<td>received signal strength</td>
</tr>
<tr>
<td>RSSI</td>
<td>received signal strength indicator</td>
</tr>
<tr>
<td>SIFT</td>
<td>scale-invariant feature transformation</td>
</tr>
<tr>
<td>SLAM</td>
<td>simultaneous localisation and mapping</td>
</tr>
<tr>
<td>SSI</td>
<td>signal strength indicator</td>
</tr>
<tr>
<td>SURF</td>
<td>speeded-up robust features</td>
</tr>
<tr>
<td>VA</td>
<td>Vision Australia</td>
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<tr>
<td>VAOMS</td>
<td>Vision Australia’s orientation and mobility specialists</td>
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<tr>
<td>WHO</td>
<td>World Health Organization</td>
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Chapter 1: Introduction

There are many navigational technologies that could be used to aid blind and visually impaired (BVI) people, but each of them has limitations. An example is the Global Positioning System (GPS), which fails to support BVI people in two aspects: it is not sufficiently accurate and does not work everywhere, as confirmed by Al-Shaery et al. (2013). For instance, it does not work inside buildings (indoor environment) and works poorly in some areas such as in cities between skyscrapers. Therefore, the first aim of this thesis is to build a system that works efficiently in indoor environments and provides the user with very accurate position information using an integrated navigational system incorporating radio frequency identification (RFID) and quick-response (QR) code. Navigation requires avoiding fixed objects and moving objects whose path intersects a user’s path. A necessary aspect for practical use that still requires research is a method that allows BVI people to navigate a crowded scene. Therefore, the second part of this thesis aims to assist BVI people by providing them with path planning to help them to arrive at their destination safely. Path planning involves estimating a user’s path and comparing this with objects in front of them, and then notifying them if there are fixed objects or moving objects whose path intersects theirs.

The proposed navigation system also includes features for error detection based on a novel algorithm that is able to detect the wrong path from the first metre. Once the system recognises this, it has the ability to recalculate the path and provide the user with voice instructions to assist them to reach their destination. Another service the system provides in outdoor environments is assistance for BVI users to cross the street safely. Also, it takes into account that path planning, object classification and location identification are all synchronised, so that the user sees the complete picture.

In Australia, an organisation called Vision Australia (VA, see http://www.visionaustralia.org) aims to assist BVI people. With respect to orientation and mobility matters, it can help BVI people by providing various services to them. For instance, VA’s orientation and mobility specialists (VAOMS) are highly trained and
skilled to ensure they can assist BVI people to learn how to move around as safely as possible by increasing their confidence in themselves, which may be affected as a consequence of blindness. VAOMS assess both the individual’s needs and the environments in which they travel to identify and reduce any potential risks. Also, VAOMS train BVI people to cross roads safely by teaching them the general rules for pedestrians and the safe kinds of road that they should use, such as those with traffic light controlled crossings and audio–tactile traffic light crossings. VAOMS train BVI people to locate steps, gutters and uneven surfaces, and use public transport and taxis.

To own a guide dog is expensive: it costs AU$35,000 to breed, raise and train each dog, and this is funded solely by the generosity of the community (VA 2014a). VA has made substantial contributions to assist BVI people to travel safely, but their services are lacking in navigational systems to assist BVI people to reach their destination, particularly in unfamiliar indoor environments. As VAOMS still use traditional training techniques to train BVI people to be able to navigate independently in unfamiliar indoor environments, this thesis aims to contribute to resolving this concern by producing a navigation system that does not require pre-training about the new environment (buildings in most cases).

1.1 Motivation for the Study

Losing one’s vision through accident or illness is a traumatic experience with potential social and emotional effects (Macular Degeneration Support 2011). One of the most significant rehabilitation steps for people who have recently become blind, or have low vision, is for such people to regain their ability to navigate and react to their immediate environment as before and therefore to feel that they are still in control. For blind people and those with low vision, determining their current location is a significant challenge.

The World Health Organization (WHO 2011) estimates that more than 180 million people around the world suffer from a reduction of full vision, with 40 to 45 million of these being blind. Based on estimates by VA in 2013, 357,000 people in Australia are blind or have low vision and this number is projected to increase to 564,000 by 2030.

Both training BVI people to become familiar with an environment to navigate inside it
independently and owning a guide dog are difficult and expensive solutions. Therefore, many contributions have been made over a long period to assist blind people with respect to navigation, but there has been much less work on integrating these modalities, and currently each works in isolation from the others.

1.2 The Blind or Visually Impaired

According to VA (2014b) a person could be considered blind if they cannot see at 6 m what a person with normal vision can see at 60 m, or if their field of vision is less than 20°. A person is considered to have low vision when they have permanent loss that cannot be corrected with glasses and that affects their daily activities. These people will be referred to collectively as BVI people. Those who are completely blind have needs that do not exactly match those with low vision, but for the purposes of navigation through this thesis, these will be treated identically unless specifically mentioned otherwise.

1.3 Positioning and Navigation

The aim of this thesis is to investigate the potential of using an integrated system of active RFID, QR-code and a 3D camera (Kinect) to produce a navigation system that achieves two main goals: (1) assisting BVI people to indicate their position precisely—a service called 'positioning' in this thesis; and (2) guiding BVI people to their destination using the most preferable path by providing them with voice instructions.

1.4 Scope of the Thesis

Guiding blind users to their desired destination precisely using an integrated system is the subject of ongoing research. This thesis focuses on designing a navigational system that integrates active RFID, QR-code and Kinect. The work used the attenuation features of active RFID, then integrated the results with QR-code to achieve higher accuracy, then used Kinect to avoid any objects that may intersect the path of users so that they will reach their destination safely. Accuracy of positioning using the proposed attenuation control radio signal is around 2 m by that technique alone, and the precision
of positioning is increased by integrating that algorithm with QR-code. The purpose of this research is to aid blind users to reach particular destinations in unfamiliar environments.

### 1.5 Research Questions

The overall objective of this thesis is the integration of several services to aid blind users with navigation. The questions below address each service and their combination:

1. Under what circumstances could RFID ranging be used to identify user location?
2. In terms of usability and practicality, is RFID technology sufficient to establish a navigation system for blind people, or is it necessary to integrate it with another technology such as QR-code?
3. Given a path for users to follow, when they miss the path, how is the proposed navigation system able to recognise that? Further, how can the accuracy of positioning of RFID technology be employed to provide safe paths for blind users, where each potential danger could be marked on a map by RFID tags? Also, how could the proposed system assist blind users to cross streets safely in outdoor environments?
4. In a crowded scene, as there are many fixed and moving objects, how could Kinect be used to estimate the real intersection points with the user and some of these objects? How can path planning be employed for this?

### 1.6 Research Contributions

The aims and objectives of this research are to address the above research questions, and its contributions are summarised by the following points:

- It has discussed using active RFID for positioning purposes. The outcome of that research was a new positioning technique based on a combination of controlling attenuation levels (AtnL) and signal strength indicator (SSI) to determine the current position precisely.

- To increase the efficiency of the positioning service from a practical perspective, QR-code was integrated into the positioning system.
Based on new positioning algorithms, a navigation system was developed that guides users to their destinations through the most suitable path taking into account their preferences.

An error-detection feature was added to the system. Once users miss their suggested path, the system can detect this and as far as is possible, recalculate an alternative path to assist them to reach their destination.

As users are walking to their destination, the system can assist them to avoid moving people that may intersect their path.

In outdoor environments, the system provides an additional service for blind people, which is to assist them to cross the street safely.

Obtaining either outdoor or inside-building maps is beyond scope of this thesis. Path planning inside buildings is achieved using a map provided by the building infrastructure; for example, WiFi. For outside environments a map is obtained as a street map from Google or open street map, for example.

Figure 1.1: The proposed navigational system
1.6.1 Navigational Autonomy Aid for the Blind

The proposed system is summarised in Figure 1.1., where the cubes represent the hardware components—active RFID, QR-code and Kinect—and the rounded rectangles represent the main service algorithms of the system. Once a blind user enters the building, they are provided with an XML file representing a map of the building, the information and directions in these files been entered manually. The XML file been created manually and the waypoints been selected where the user need to take an action such as turn left, turn right or the points of interest. The waypoints were created manually. It is expected that this process be automated, but this was beyond the scope of this thesis. That file includes floor plans and all points of interest (POI) data for the corresponding building. During this research, downloading the file was done manually by the author on the users’ devices, but future development work should aim to do this automatically. Users are assumed to have already downloaded the proposed navigation application on their portable device, which might be their smartphone or notebook computer, for example. When the download of the database file is complete, the navigation application asks the user this question phonetically: ‘Where would you like to go?’, which confirms that the application is ready for use. The user’s role is determining their destination, then using the voice recognition application: the system will convert that request to text to recognise that destination from the database file in the navigation application, to begin the guiding process. The navigation process follows three steps: (1) the system indicates the initial position of the user using the new RFID algorithm, which is based on a technique of attenuation control using the nearest RFID tag to indicate the current position of the user as a start point in this case; (2) the user is asked to scan the surrounding area using a camera to detect QR-code using a built-in QR-code reader application. This is an optional step because the system works successfully without it, but it is recommended as it enhances the accuracy of provided instructions: the accuracy of the RFID algorithm is around 2 m, so the chance of error almost disappears using the integrated system of QR-code with RFID; (3) the navigation application determines the most preferable route for the user then starts providing voice instructions. Route calculation is based on Dijkstra’s (1959) algorithm, which indicates the shortest path between two points (the current position and the destination). In cases where the destination is located on another floor, the system generates the question: ‘Your destination is located at the upper/lower level: would you like to avoid stairs?’ If
the user responds positively, the system guides them to lifts if they are available. The system has been designed to work interactively with the user: for instance, if the desired destination is a toilet and there are two toilets, one on the same level and another on an upper level but the upper one is closer than the one on the same level, the navigation application will give the user the opportunity to choose between these two POI.

Moreover, the proposed system provides two further services to BVI users: (1) it tracks them during movements when they are using the system, to re-guide them to their desired destination if they lose the suggested path; and (2) an obstacle-avoidance feature is available in the system based on Kinect, which can easily detect humans in front of the user, while the developed algorithm estimates the paths of these people to warn the blind user if any person may intersect their path. With more research, the system should be able to avoid a range of objects other than humans.

1.7 Thesis Outline

The thesis consists of nine chapters:

- Chapter 2 classifies and analyses previous navigation systems designed to assist BVI people.
- Chapter 3 describes issues relevant to the proposed navigation system, such as variation in sensitivity of devices and the effect of orientation of the RFID reader.
- Chapter 4 presents the new positioning algorithm using active RFID, an algorithm based on integration of RSS and attenuation control.
- Chapter 5 describes a solution to the limitations identified in previous chapters and how QR-code can resolve them, and discusses the benefit of integration of these two techniques, as summarised in the upper part of Figure 1.2.
- Chapter 6 presents the integrated navigation system using RFID and QR. Further, tracking and error-detection algorithms are described in this chapter. These contributions are summarised in the lower part of Figure 1.2.
- Chapter 7 presents user tests of the proposed system and the impression of users
regarding that system.

- Chapter 8 includes two additional services for the blind: assisting them to cross the street safely and to detect and avoid moving objects that may intersect their path.

- Chapter 9 concludes the thesis and presents suggestions for further research on this topic.

![Diagram of positioning and navigation system](image)

**Figure 1.2: The sequence of steps involved in the positioning and navigation system**
Chapter 2: Literature Review

2.1 The Problem of Navigation for the Blind

With respect to navigational assistance for BVI people there are several aspects of contributions that have been developed. Some researchers have addressed concerns relating to describing current surrounding environments to BVI people, which are commonly based on computer vision (CV) algorithms (see the last column of Table 2.1). Other groups of researchers have aimed to detect objects in the area surrounding BVI people and provide them with some information about these objects (Bhatlawande et al. 2012). Also, there is a group of researchers (see the fifth column in Table 2.1) that has produced object-detection algorithms, not to describe them to BVI people but to assist them to avoid these objects. Such algorithms are termed ‘obstacle-avoidance’ or ‘anti-collision’ systems. Their purpose is to give BVI people the ability to move independently and travel from place to place safely. Some researchers have concentrated on positioning and navigation concerns, producing various systems designed to assist BVI people to indicate their positions, and guide them to their destination (see the third column in Table 2.1).

This thesis aims to produce a package of navigational systems called NAAB, the main benefits of which are to assist BVI people to determine their position accurately; to provide them with instructions that guide them to reach their desired destination via their preferred path; and to assist them to avoid humans that may intersect their path. NAAB includes an error-detection feature designed to recognise when the user misses their path and to re-guide them via a more suitable alternative path where possible according to their current location, to ensure they reach their destination.
Table 2.1: Related work on navigation systems to assist blind people

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2.2 Motivation for Research

GPS is the most famous navigation system and was designed to use in outdoor environments. Some researchers have adapted GPS for use by BVI people. As the GPS transmitter must be visible to at least four satellites, it works poorly or not at all in indoor environments. Even in outdoor environments, the accuracy of GPS is not particularly helpful for BVI usage, being at best 10 m in most cases. Therefore, other navigational systems for BVI have been developed in the last decade. These systems depend on technologies such as RFID, CV algorithms, ultrasound and infrared (IR) systems. Each has been designed for a specific purpose, in isolation from the others. For instance, most ultrasonic systems produced to assist BVI people are for obstacle-avoidance purposes, so they are not able to determine the position of the user or provide any navigational instructions to guide them to their destination. On the other hand, systems that guide BVI users to their destination have several limitations; for example, they do not support anti-collision features, or they provide imprecise path planning instructions.

2.3 Navigational Systems to Assist the Blind

The previous systems designed to assist BVI people in terms of navigation can be classified based on the kind of navigational service provided.

2.3.1 Previous Work

Two forms of navigation have been proposed to assist the blind: path planning systems, and systems for obstacle avoidance.

Path Planning Systems

The first group of researchers aimed to produce path planning instructions to BVI people that guide them to their desired destination, either via the shortest path or based on other methods to select a more applicable path for the user (see Table. 2.1). Nicolau et al. (2009) identified the elements and rules that the navigational instructions should
include to produce an appropriate navigation interface for BVI people. Another study (May et al. 2003) summarised the information requirements in pedestrian navigation into five categories: distance, junction, road type, street name/number and landmarks. Shoval et al. (1998) produced an electronic travel aid (ETA) device called Navbelt, which assists BVI people in selecting their preferred travel path. The level of assistance can be automatically adjusted according to the surrounding environment and the user’s needs. Wu et al. (2007) produced a path planning algorithm using A* and Dijkstra’s (1959) algorithm to facilitate navigation by BVI people via the shortest path. Sanchez et al. (2007) designed navigation software based on GPS to assist BVI people to travel in outdoor environments. Kostopoulos et al. (2007) produced a navigational assistance system for BVI people based on map image analysis, and the instructions were produced as Haptic Audio for users. Patel and Vij (2008) presented a technique and results using spatial knowledge, and explained how cognitive maps could be useful for BVI people. Mooi et al. (2010) designed a framework that indicates the most efficient RFID tag placement for indoor navigation systems for BVI people. Shamsi et al. (2011) indicate position and provide navigation information to BVI users based on a wireless mesh network. Au et al. (2013) introduced a tracking and navigation system based on RSS in wireless local area network. Amemiya and Sugiyama (2010) distributed IR sensors placed at the corners of the walls inside buildings for positioning purposes, because they found that GPS did not provide accurate positioning information.

Many applications have been developed to assist BVI people to navigate in outdoor environments based on GPS (Garaj et al. 2007; Heuten et al. 2008; Holland et al. 2002; Ivanov 2011; Koiner et al. 2012; Sanchez & de la Torre 2010), and by pointing to GPS locations (Magnusson et al. 2012), but these were not designed for BVI people. Joseph et al. (2013) produced a navigation system based on camera and landmark sensing and simultaneous localisation and mapping (SLAM) to guide BVI people to their destinations inside buildings. Prudhvi and Bagani (2013) produced an assistance navigation system for BVI people based on GPS for positioning and sonar (sound navigation and ranging) for obstacle avoidance. Oliveira (2013) used two video cameras to analysis surrounding environments of BVI people to navigate without interference. Kassim et al. (2013) designed a navigation system for BVI people based on passive RFID with a reading range up to 3.7 cm. Asad and Ikram (2012) used a vanishing point technique to navigate for BVI people. Marston et al. (2006) came up with a usability test
for a navigation system based on GPS for BVI people, by performing two experiments using eight participants. Ross and Lightman (2005) produced a navigation system based on ‘Cyber Crumb’, which can read braille signs at 16 feet. Paisios et al. (2011) proposed a mobile navigation system based on WiFi and accelerometer sensors to assist BVI people to remember paths they had previously walked on. Hong and Murray (2013) detail a GIS (geographic information system)-based method for finding an optimal path in complex environments. Fallah (2010) produced a navigation system for BVI people using a mobile phone containing an accelerometer and magnetometer, which localises users based on 3D model and dead reckoning (DR).

Tracking BVI users and helping them navigate to their destination based on IR is an active way-finding system presented by Jain et al. (2013). Song and Yang (2010) proposed Haptic Sight (HS) as a new interface providing immediate spatial information to BVI people to assist them to navigate independently. Ghiani et al. (2008) distributed inside museums at known locations RFID tags that detected objects within around 5 m, and electronic compasses used for sensing user direction in absolute orientation degrees. A localisation and navigation system called NAVTAR has been proposed by Fallah et al. (2012) to assist BVI people in indoor environments. Ross and Blasch (2000) developed and evaluated three orientation interfaces—a stereophonic sonic guide, speech output and shoulder-tapping system—and concluded that a combined tapping—speech interface is more useful for BVI users. Arning et al. (2012) investigated users’ experiences and acceptance of two kinds of navigation devices—screen and projector—with the aim of modelling navigation device acceptance. Polacek et al. (2012) validated audio-based navigation instructions used to guide BVI people to their destination and identified usability issues of the ‘Wizard of Oz’ tool. Hussain et al. (2012) suggested that hybrid sounds in auditory feedback for navigation by BVI people are more effective than non-speech instructions and are pleasant compared to speech-only feedback. They came up with the concept of hybrid auditory feedback in mobility assistance applications for BVI people, which may result in improved mobility experience.

**Avoidance of Obstacle Systems**

A group of researchers has focused on obstacle-avoidance concerns, proposing various systems with the ability to warn users about any collisions in their path. Anti-collision
systems for BVI people could be classified into two sub-groups: systems that simply assist BVI users to avoid obstacles by informing them about obstacles, without any further navigational information; and systems that provide additional services for BVI people—navigational instructions to assist them to reach their destination based on a pre-defined route, with no regard to obstacle avoidance.

In the first category, most researchers (e.g. Bhatlawande et al. 2012; Borenstein & Ulrich 1997; Calder & David 2010; Sethu Selvi et al. 2008; Shim & Yoon 2002; Shoval et al. 1994) use ultrasonic technology for obstacle-avoidance purposes. Shoval et al. (1994) proposed a Navbelt system consisting of a belt, computer and ultrasonic sensor, which can guide the blind traveller around obstacles or provide an acoustic image of the surroundings. An improved version of Navbelt is presented in Borenstein and Ulrich (1997). Shim and Yoon (2002) proposed a robotic cane called ‘Roji’, which consists of a long handle with a button-operated interface and a sensor head unit attached at the distal end of the handle. Sethu Selvi et al. (2008) developed a cost-effective device that warns BVI users of obstacles in front of them based on the principle that blind people always walk in a straight path, hence the required surveillance path is just 25° to either side. The device consists of an ultrasonic transmitter and receiver pair strapped to each knee of the user to avoid obstacles in their path. Calder and David (2010) produced a tactile interface to warn BVI users about obstacles in their path based on ultrasound technology. Bhatlawande et al. (2012) used a network of ultrasonic sensors that can detect obstacles up to 500 cm from the BVI user and can calculate distance to these obstacles and provide users with speech information about the detected obstacle and its distance. Mpitziopoulos et al. (2008) produced the PROTECT system, which employs autonomous software objects referred to as ‘mobile agents’ (MAs), which are able to locate and inform the BVI user of potential risks via wireless sensor network technology. PROTECT comprises three tiers, where the first tier is a base station (BS), the second is mobile sinks and the third is stationary sensor nodes. An alarm is issued by a sensor node and the BS then launches a number of MAs supplied with near-optimal itineraries that visit the nodes in the alarm’s surrounding area and notify the BVI user of potential hazards in their surrounding area.

Research in the second category aimed to guide BVI people to their destination, not just avoid obstacles (e.g. Shoval et al. 1998; Ulrich & Borenstein 2001). A guidance feature
using navigational instructions has been added to the Navbelt system to assist BVI users to reach their destination. Prudhvi and Bagani (2013) used GPS for positioning and sonar technology for obstacle-avoidance purposes. Oliveira (2013) proposed a system that consists of a mobile device with two video cameras, a belt providing force feedback cells 360° around the waist, and a power supply for the belt. Based on a CV algorithm such as pattern recognition, Hwang et al. (2012) proposed a navigation system for BVI people that can predict paths to them and detect any obstacles in their path. Garaj et al. (2007) combined video images with GPS and compass directions to navigate for BVI users and protect them from any collision in their paths.

2.4 Indoor Navigation Systems to Assist the Blind

In recent years, many GPS applications have been developed to assist BVI people to navigate in outdoor environments (see Column 7, Table 2.1). As most of these applications are based on GPS, which works poorly or not at all inside buildings, researchers have targeted other technologies that work effectively in indoor environments (see Table 2.2).

2.4.1 Previous Work

This section discusses previous navigation systems (see Table 2.2) that have been developed to assist BVI people in indoor environments.

Some researchers (e.g. Fallah 2010; Fallah et al. 2012; Wu et al. 2007) have used the technique of DR for navigation purposes in indoor environments to assist BVI people. In path planning algorithms proposed by Wu et al. (2007) the relationship between different objects in indoor environments is represented based on a new data structure called a ‘caucus tree’, which generates an ‘intelligent map’ to be used in path planning calculations. The paths produced are called ‘virtual hand rails’ and are based on DR. Fallah (2010) proposed a navigation device called AudioNav based on a system that localises the user using a 3D model of the building and a DR approach requiring an accelerometer and magnetometer. AudioNav provides information and directions using augmented reality. Subsequently, the author of AudioNav produced an improved
navigation system called Navatar, presented in Fallah et al. (2012).

Based on RFID technology, Ghiani et al. (2008) proposed a localisation system to improve BVI visitor experiences in museums by providing them with information about artworks or scientific specimens in their current location. Mooi et al. (2010) presented a framework that aims to determine the most efficient placement of RFID tags in indoor navigation systems for BVI use.

**Table 2.2: Previous navigation systems to assist blind and visually impaired people in indoor environments**

<table>
<thead>
<tr>
<th>Research</th>
<th>Technology employed</th>
<th>Purpose of research</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wu et al. 2007</td>
<td>dead reckoning</td>
<td>path planning</td>
</tr>
<tr>
<td>Patel &amp; Vij 2008</td>
<td>cognitive maps</td>
<td>navigation after training in virtual environment</td>
</tr>
<tr>
<td>Mooi et al. 2010</td>
<td>RFID</td>
<td>RFID tag-placement framework</td>
</tr>
<tr>
<td>Au et al. 2013</td>
<td>RSS</td>
<td>positioning and navigation</td>
</tr>
<tr>
<td>Joseph et al. 2013</td>
<td>landmark extraction</td>
<td>positioning and navigation</td>
</tr>
<tr>
<td>Ross &amp; Lightman 2005</td>
<td>Cyber Crumb and brailleNavigation</td>
<td></td>
</tr>
<tr>
<td>Fallah 2010</td>
<td>dead reckoning</td>
<td>positioning and navigation</td>
</tr>
<tr>
<td>Jain et al. 2013</td>
<td>infrared</td>
<td>navigation and obstacle avoidance</td>
</tr>
<tr>
<td>Song &amp; Yang 2010</td>
<td>haptic interface</td>
<td>improving the way of delivering instructions to BVI</td>
</tr>
<tr>
<td>Ghiani et al. 2008</td>
<td>RFID</td>
<td>positioning and orientation</td>
</tr>
<tr>
<td>Fallah et al. 2012</td>
<td>dead reckoning</td>
<td>positioning and navigation</td>
</tr>
<tr>
<td>Amemiya &amp; Sugiyama 2010</td>
<td>infrared and motion</td>
<td>Navigation</td>
</tr>
<tr>
<td>Arning et al. 2012</td>
<td>sensor</td>
<td>analysing BVI perspectives regarding two navigation devices</td>
</tr>
<tr>
<td>Hussain et al. 2012</td>
<td></td>
<td>improving the way of delivering instructions to BVI users</td>
</tr>
</tbody>
</table>

The advantages and disadvantages of the technologies used is further discussed in section 3.1
Some researchers have used IR technology for navigation to assist BVI people in indoor environments (e.g. Amemiya & Sugiyama 2010; Jain et al. 2013). Hussain et al. (2012) proposed a new form of sound called ‘hybrid audio’ to improve deliverance of navigational instructions to BVI people by dividing the instruction phrase into two parts: speech and non-speech, or changeable and constant parts. For instance, the phrase ‘room number 324’ can be divided into two parts, where ‘room number’ is non-speech or constant, and ‘324’ represents the dynamic, or speech part of the instruction. Arning et al. (2012) investigated users’ experience and acceptance of two kinds of indoor navigation devices (screen v. projector) for modelling navigation device acceptance. The results revealed variation in navigation device acceptance: ~50% screen acceptance and 61% projector acceptance. Song and Yang (2010) proposed a new interface of navigation system for BVI people called HS. This device can provide information for around 15 steps ahead of the user. It uses double-acting cylinders and direction control valves, which are operated by electrical signals created from information received through ultrasonic or IR sensors wirelessly. The aim of HS is to provide information that represents the outline of the building layout. This kind of information assists users to know where they are and how to move inside the building, but it requires preknowledge of the environment.

Ross and Lightman (2005) developed an indoor path planning system to assist BVI people based on the ‘Cyber Crumb’ concept. The proposed system uses digital chips distributed along building walkways—like a trail of crumbs to follow. These chips are used to store information used for navigation purposes. A wireless network of crumbs provides access from any point in the building to a central server that provides orientation and way-finding information. Joseph et al. (2013) proposed a navigation approach based on a semantic map of the building generated from floor plan maps. The current position of the user is indicated based on a visual cue. To confirm the visual cue the system extracts the encrypted location cue—which could be any landmark sample—and then guides the user to their desired destination by the shortest route.

Patel and Vij (2008) proposed a spatial cognitive map technique based on training BVI users about computer-simulated (virtual) environments belonging to buildings that they live in, so they can understand the surrounding environment and navigate in that
environment safely. Using RSS and compressive sensing techniques, Au et al. (2013) proposed a positioning, navigation and tracking system to assist BVI people.

2.5 Findings

Developing navigation systems to assist BVI people is an ongoing field of research. There is a strong relationship between the technology and the systems produced, where researchers try to engage new technology to design navigation systems to aid BVI people. For instance, once RFID appeared, researchers used that technology widely in the navigation systems they produced. The same situation occurred with ultrasonic technology, GPS and Kinect devices (produced for gaming in 2010), which are being used to assist BVI people to navigate independently.

Accuracy is a significant issue in navigation systems, and is one important feature that distinguishes navigation systems from each other. As mentioned above, many navigation systems designed to assist BVI people are based on GPS technology, for which accuracy is very low in indoor environments. In another example, Fallah et al. (2012) produced a navigation system to assist BVI people based on DR, but suggested that the accuracy of their system requires improvement. The accuracy of positioning of NAAB is around 2 m by RFID itself, which is increased by integrating the RFID system with QR-code. The tolerance value of distance estimation between the user and QR-code was determined experimentally to be ±2 cm (p 70).

An integrated system still requires substantial research. As an outcome of surveys of available navigation systems developed to aid BVI people, it is apparent that each system aims to produce a specific service. However, the current study seeks to combine several of these strategies in order to improve performance by applying each technology to address the weak spots of the other, thus ending up with a better system overall.
2.6 Challenges and Contributions

What will happen to BVI people when they visit an unfamiliar area such as a clinic for the first time? Even if they have their guide dogs with them, they are more likely to fail to reach their destination unless they ask for assistance from sighted people in those areas. Signs designed to assist BVI people are helpful for people who are familiar with that environment, but have more limited use for BVI people visiting that environment for the first time, particularly in terms of them reaching a specific destination.

2.7 The Proposed System Components

The proposed system consists of the following five elements:

1. Printed QR-code, which stores location information embedded inside circles to be detected easily from longer distances (see Figure 3.7).
2. An optical sensor, which can be built in to a smartphone, tablet or whatever mobile portable device the system needs to detect and decode QR-code.
3. RFID tags (seen as ‘B’ in Figure 3.1). These tags have been distributed at known
positions inside the building and can be classified based on their purpose, as either identification or indicator tags. Identification tags are used to identify offices, rooms, toilets and so on. Indicators tags are distributed in the corners, and are used for error-detection purposes. For each trip, there should be one source indicator tag and one destination indicator tag. The strength of the signal that belongs to the source indicator tag should be decreasing during all periods of the trip, because the RFID reader carried by the user is moving away from that tag. In contrast, the strength of the signal belonging to the destination indicator tag should be increasing synchronously.

4. An RFID reader—a wide-ranging omnidirectional device (shown as ‘A’ in Figure 3.1), which is a mobile reader designed to be carried by the user.

5. A positioning and navigation application (or ‘app’) responsible for processing tasks and providing information to the user.

2.7.1 The System Services

This thesis aims to describe an accurate integrated navigational system to assist BVI people to navigate to their destination independently and safely in indoor environments. The proposed system provides the following services to BVI people:

1. A positioning service that can indicate the current position of the user accurately. Further, it uses radio frequency technology to explore the surrounding area. This technique increases the reliability of the system from the perspective of the user. For instance, when the user needs a toilet, they can ask the system to check the availability of toilets in relation to their current position. Based on and RFID signal attenuation technique the system can answer the query of the user and estimate the distance to that destination. That information is provided to the user synchronously: if the range of the RFID reader carried by the user contains any RFID tag belonging to a toilet, it would be detected and the user informed about the distance to that tag. Therefore, the positioning service aims to indicate the current position of the user at the starting point of the route, and for tracking purposes until the user reaches their destination (see the upper part of Figure 1.2). All location information has been encoded in RFID tags and QR-codes, which are imbedded inside circles (see Figure 3.7) to be detected from longer distances. To achieve that goal the system would run through the sequence steps,
beginning with detecting circles using a circle-detection algorithm. Then the user is provided with the calculated distance between themselves and circles. Finally, the user comes closer to that circle to decode QR-code, to indicate their current position. The system then compares that position information with the RFID system. For instance, when the QR-code indicates that the user is in front of a particular office, the RFID reader should be in the range of the RFID tag belonging to that office. For more details about positioning refer to Chapters 4 and 5.

2. The navigation service’s role is guiding users to their destination. After the system indicates the current position of the user, it will ask them to specify a destination via voice recognition. Then the system will ask the user to determine their most preferable path—for instance, if the selected destination is located at another level, the system would ask the user ‘Do you prefer to use the lift or stairs?’ The system then calculates the shortest route between the current position and the desired destination, based on Dijkstra’s (1959) algorithm through the most preferable path. Then the system provides users with path voice instructions. Finally, the system tracks the suggested path to detect any errors that may occur. When the user mistakenly misses the path, the system has the ability to recognise this and provides them with an alternative path (see the bottom part of Figure 1.2). Refer to Chapter 6 for more details about navigation services.

3. The QR-code has been integrated into the RFID positioning system. Although radio frequency code has been selected because it works omnidirectionally (which makes the system work effectively), in order to resolve orientation concerns, QR-code has been integrated.

4. The positioning accuracy of the system has been increased by integrating QR-code, although the system has achieved a 2-m range of positioning based on the proposed RFID positioning algorithm alone. Figure 2.1 includes the components of the developed system and the relationship between the provided services.

5. A voice recognition feature has been added to the system to allow users to determine their destination by voice, and then have the system guide them to that destination via their most preferred path. For instance, when the desired destination is a photocopy room and there is one photocopy room on the level where the user currently is and another on an upper level, but the distance to the
second one is shorter than that to the first, the system would give the user the opportunity to choose one of them. Then, if the user selects the upper one the system will ask: ‘Do you want to avoid stairs?’ If they answer in the affirmative, the system will direct them via the lift, which represents a more suitable route.

6. The proposed system includes an anti-collision feature and a human-detection algorithm has been added to the system using Kinect. Obstacle identification is beyond the scope of the current research, but because humans are the more likely obstacle in crowded environments, this feature been added to the proposed system to investigate how it could be integrated. Therefore, the system can detect any human in front of the user and predicts the path of that person to warn the user when any person may intersect their path.

7. An error-detection algorithm has been developed. If the user misses the suggested path, the system can recognise this and inform the user about their error. The system would then try to determine the current position of the user to recalculate an alternative path to the same destination using the tracking algorithm. Although other systems may recalculate a path if the user misses the turn, they do not inform them. This can lead to user confusion and distrust. It is better to inform the user than not.

2.8 Summary

This chapter has summarised a survey of previous positioning and navigation systems developed to assist BVI people. The studies were characterised based on the parameter relating to the kind of navigational service they provide to BVI people. Based on navigation system, all research was classified into two groups: path planning and avoidance of obstacles. Finally, the survey concentrated on indoor navigation systems. The analysis of previous navigation research suggests the need for research and development of an integrated navigation system that works on multiple platforms effectively and does not require expensive infrastructure. Therefore, the aim of this research is to produce an integrated navigation system to assist BVI people to navigate independently and safely in indoor environments, based on RFID and QR-code.
Chapter 3: Overall Issues with RFID, QR-code and Kinect Relevant to Navigation

3.1 Technologies Used in Navigational Systems for Blind and Visually Impaired People

In Section 2.3.1 previous research was classified based on the kind of services they proposed to assist BVI people. This section discusses the technologies used in navigation systems that have been developed to assist BVI people to navigate independently in indoor or outdoor environments. Each technology has deficiencies and strengths. For instance, GPS is based on communication with satellites, so it could work anywhere on the earth, but at the same time it works poorly or not at all in indoor environments such as inside buildings. It also does not work well in built-up areas with tall buildings, such as central business districts. Table 3.1 summarises the advantages and disadvantages of these technologies.

In the following points the technologies used are presented in more detail.

*Global Positioning System*

GPS is a navigation satellite system. It indicates the position of the GPS transmitter when it is visible for at least four satellites. The concept is based on known positions of satellites and the required time for messages to arrive at the GPS receiver from at least four satellites to calculate the distances to these satellites. By knowing the locations of satellites, the distances to them and the propagation velocity, the position of the GPS receiver can be estimated. GPS has been used by many researchers in the field of navigation to assist BVI people (e.g. Bagani 2013; Ivanov 2011; Garaj et al. 2007; Heuten et al. 2008; Koiner et al. 2012; Marston et al. 2006; Prudhvi & Holland et al. 2002; Sanchez et al. 2007; Sanchez & de la Torre 2010). Sanchez et al. (2007) developed sound-based software embedded in a pocket personal computer (PC) to assist BVI people by providing them information based on GPS satellites to orient and navigate around
Table 3.1: The technologies used in navigational systems for blind and visually impaired people

<table>
<thead>
<tr>
<th>Technology</th>
<th>Advantage</th>
<th>Disadvantage</th>
</tr>
</thead>
<tbody>
<tr>
<td>GPS</td>
<td>works anywhere outdoors</td>
<td>unavailable indoors</td>
</tr>
<tr>
<td>Active RFID</td>
<td>long range, applicable for use indoors and could be used as one mobile reader and multiple fixed tags</td>
<td>multiple fixed readers for triangulation and one mobile tag and requires battery</td>
</tr>
<tr>
<td>Passive RFID</td>
<td>certain in indoor settings and does not require batteries</td>
<td>short range</td>
</tr>
<tr>
<td>Ultrasonic</td>
<td>little interaction with environment</td>
<td>line of sight</td>
</tr>
<tr>
<td>IR</td>
<td>works well at night</td>
<td>line of sight and may not work well in sunlight</td>
</tr>
<tr>
<td>Computer vision</td>
<td>object ID possible, recognises colours</td>
<td>line of sight</td>
</tr>
<tr>
<td>NAAB</td>
<td>omnidirectional, long range, certain in indoor, one mobile reader and multiple fixed tags</td>
<td>line of sight to decode QR-code</td>
</tr>
</tbody>
</table>

POIs in the city. Koiner et al. (2012) presented a navigation application in a cell phone that includes such aspects as GPS and a compass to help BVI people to travel from starting points to their destinations. Prudhvi and Bagani (2013) proposed services to BVI people such as providing them with audible information and haptic feedback, helping them to localise where they are. They also proposed a service consisting of an emergency button that triggers an SMS that includes the GPS coordinates of the user, to a remote phone number asking for help. Marston et al. (2006) evaluated two kinds of interfaces of guidance system based on GPS with the help of eight BVI participants. Holland et al. (2002) produced a prototype of spatial audio navigation interface for GPS. Sanchez and de la Torre (2010) examined the utility of an audio-based GPS application for navigation in outdoor environments for BVI people, and found that the application was successful: the mean performance of the group regarding the execution of the routes was 11 points out of the total of 17 points. Ivanov (2011) proposed an algorithm for BVI people navigation along a GPS track, arguing that the algorithm treats the problem of
lack of accuracy of GPS maps: ‘To reduce random errors in the GPS data an algorithm for filtering of GPS positions is used. It combines the following techniques: knowledge-based GPS data pre-processing, a fuzzy estimation of noise level in GPS data and an adaptive Kalman filtering’. Heuten et al. (2008) produced a tactile vibrator belt that guides BVI users to their destination based on GPS. Garaj et al. (2007) combined video images with GPS and compasses to navigate for BVI people with the added feature of obstacle avoidance.

Radio Frequency Identification

The introduction of RFID technology was as an electronic alternative identification technology to traditional barcodes. Its critical advantages include high range of detection, that it does not require line of sight between reader and tag, that its tags have the feature of write–read of information, and can store larger amounts of data than a barcode. According to Puffenbarger et al. (2007), RFID tags fall into three categories: active, passive and semi-passive. Active RFID covers a very wide area but requires a power supply source, which are batteries in most cases. Passive tags are powered by external radio signal, which is the magnetic field from the reader. Semi-passive RFID can function either way. RFID technology been used for various purposes, such as tracking assets, surveillance and positioning. Researchers that have used RFID to assist BVI people include Ghiani et al. (2008), Kassim et al. (2013) and Mooi et al. (2010). Ghiani et al. (2008) proposed a solution for flexible orientation and location awareness as a museum guide for BVI people, based on RFID with a 5-m detection range and an electronic compass to determine the orientation of the user. Kassim et al. (2013) designed a navigation system for BVI people based on passive RFID, which requires very short distances to communicate between reader and tag: it can detect RFID tags up to 3.7 cm away in the best case. Mooi et al. (2010) proposed a framework that guides the placement of RFID tags in indoor environments to facilitate an efficient navigation system for BVI people.

Ultrasonic Technology

Most research in this area has been designed to assist BVI people to avoid obstacles, as mentioned in Section 2.3.1. Relevant research is shown in Table 2.1, and includes

**Infrared Technology**

Amemiya and Sugiyama (2010) developed a haptic direction indicator that produces directional information through kinesthetic cues based on a pseudo-attraction force technique to present a persistent pulling or pushing sensation in mobile devices with sufficient angular resolution for force presentation on a 2D plane. To apply the system using the pseudo-attraction force technique, the user holds the force display and carries a notebook computer with a custom-built circuit. The notebook computer is wirelessly connected to a remote computer that receives information from the IR sensors distributed in the corners of corridors inside the building. Jain et al. (2013) proposed an IR-based active way-finding system for the visually impaired: the system downloads the floor plan of the building, locates and tracks the user inside the building, finds the shortest path and by voice instruction guides the user step by step to reach their destinations.

**Computer Vision**

Computer vision techniques are widely used in systems produced to assist BVI people (e.g. Asad & Ikram 2012; Hwang et al. 2012; Joseph et al. 2013; Kostopoulos et al. 2007; Oliveira 2013; Pradeep et al. 2010; Rahhal et al. 1996). The path prediction system was proposed by Hwang et al. (2012) and implemented for smartphones to detect obstacles and provide path planning instructions on visual interface. The visual interface is a useful method for elderly people with cognitive impairments but is not helpful for blind people, who require another kind of interface, such as audio or tactile. Asad and Ikram (2012) proposed a guidance navigation system for BVI people but the scope of their system is limited to a straight path because it is based on a vanishing point technique. The straight paths have parallel edges that seem to converge to a single point called the vanishing point. The system detects edges on which vanishing points are calculated, and then notifies the user about their deviation from a straight path. Oliveira (2013) proposed a path feedback system based on a mobile device that takes fixed-rate
dual images of the surrounding environment and reconstructs a 3D model to extract features such as footpath corners, walls and obstacles, and then determines which of the force feedback actuators on a 360° belt worn on the waist of the user, to produce a path feedback. As proposed by Joseph et al. (2013), landmarks such as room numbers and doors could be used as parameters to infer way points to each room, and a semantic plan generated from the posted floor plan maps of the buildings could be used to assist with navigation by BVI people.

SLAM is a technique designed for use in navigation in robotic systems, and is used by some researchers in the navigational field to assist blind people: for example, Pradeep et al. (2010) presented a navigation system to help BVI people avoid obstacles in their paths based on an integrated system of stereovision odometry and feature-based metric-topological SLAM. As stated by Pradeep et al. (2010); ‘[SLAM] incorporates noisy sensor data and motion model to reliably compute camera trajectory and scene information and can be used to maintain reliable estimates of pose’. Kostopoulos et al. (2007) proposed a framework of map image analysis that provides BVI people with useful navigation information. The analysis focuses on the extraction of street names, road network structure and POIs. Rahhal et al. (1996) proposed a local guidance system (LGS) that uses image-processing techniques to extract the most important features in the path of the blind, such as straight lines, circles, double lines, bright spots, dark spots, tree-like patterns, stair patterns and corner-like patterns. These features are used to detect objects for anti-collision purposes, to assist the blind to walk safely.

*Dead Reckoning*

Dead reckoning is a method to calculate the current position based on a known previous position and estimated speed of object for a period of time. Researchers that have used this method in the field of assistance navigation systems for BVI people include Fallah (2010), Fallah et al. (2012) and Wu et al. (2007). The latter proposed a path planning system using the A* and Dijkstra (1959) algorithms to calculate the shortest path ‘to operate on an Intelligent Map, that is based on a new data structure termed cactus tree which is predicated on the relationships between the different objects that represent an indoor environment’. That path planning algorithm is based on the DR technique. Fallah (2010) used a mobile device that includes an internal or external accelerometer and
magnetometer to localise the user using a 3D model of the building produced using the DR approach. Fallah et al. (2012) presented a navigation system for BVI people called Navatar, which combines DR with sensor-based localisation by incorporating a role for the user as an ‘intelligent sensor’ to confirm the presence of a landmark.

3.2 Overall Issues with Technologies Used in the Proposed System

After the survey of the available technologies, the RFCode shown in Figure 3.1 was selected because it has significant features as described in the following section. The main limitation of RFCode, which is its lack of directionality, was later explored, and this concern was resolved by integrating QR-code into the system. To produce a complete package of the navigation prototype, Kinect was added to the system to assist BVI users to avoid people that may intersect their paths.

3.2.1 Issues Regarding Active RFID

RFCode M220 has been chosen because it has the following features:

- An omnidirectional RFCode reader transmits signal for 360° and the M175 active rugged tag receives and responds to the initial signal from the reader from any angle.
- The RFCode M220 reader has a long range, up to 70 m. This device has one disadvantage, which is that it requires its own battery for either reader or tag; although for long ranges such as 70 m, fewer tags are needed.
- The RFCode M220 reader has been designed to be a portable device. Further, it works synchronously when the user is moving because it has been designed to hang on their belt.
- The algorithm of the proposed navigation system is based on an attenuation feature, whose significance is its ability to control the range of the reader by increasing and decreasing the AtnL of the reader to achieve the desired precise results.

This section discusses some potential problems regarding orientation and sensitivity
effects of tags and reader, and whether these problems are significant.

*Orientation and Sensitivity Variations*

Although the technology used in this system is ideally omnidirectional and with all tags identical, in practice we need to confirm these assumptions. The next three subsections discuss this in more detail.

![Figure 3.1: A, RFCODE M220 mobile reader; B, M175 active rugged tag](image)

*Reader Orientation Effect*

The RFID reader used here is claimed to have an omnidirectional range, but the results in Figure 3.2 indicate that signals are not equal in all directions. To test this, signal strength was used as an indicator on three levels—40, 50 and 55 dB—and the distances were registered for each level from different angles. The reader was placed on the floor as shown in Figure 3.3 and the tag was then moved from ‘infinity’ inwards until it was discovered by the reader and given the predetermined received signal strength indicator (RSSI) value (40, 50 and 55 dB), at which point the distance was recorded between the reader and the tag. It was found that when the direction of the reader’s antenna was rotated 180° as shown in the left part of Figure 3.3, the RSSI increased and was higher than when the antenna was pointing at the tag, as shown in the right part of Figure 3.3 and by the results presented in Figure 3.2. However, these are within the quantisation boundaries imposed by the AtnLs, and so the reader orientation differences are insignificant compared to other environmental effects. The RFCODE reader has a
significant feature, which is that control of its range is based on the level of attenuation, where it has eight pre-programmed levels with 5-dB separation. It was found that any effect mentioned in Najera et al. (2011) will tend to reduce user uncertainty, such as when the ‘body’ approaches the desired tags and its RSS increases. It was reasonably assumed that the user is always travelling forward. In deployment, the reverse (body) direction will typically be shielded.

Figure 3.2: The directional sensitivity of the reader used was sufficiently omnidirectional to allow the system to operate as described as shown for three signal strength levels based on the average of three tags
Figure 3.3: The degree of orientation of the RFID reader in relation to the active tag: 180° on the left and 0° on the right

Tag Orientation Effect

The orientation of the tag was found not to play a significant role, as shown in Figure 3.4. To test this, the experiment was repeated for the same tag under the same circumstances but with different orientations, providing consistent results as shown in the same figure.

Figure 3.4: The directional sensitivity of the tags used was sufficiently omnidirectional to allow the system to operate as described. The experiment was repeated with the same tags, giving consistent results as shown in the first and second round
**Differences in Sensitivity of Tags**

Active RFID systems can support wide signal ranges. Typically, each tag has its own power source such as a battery, which may affect tag sensitivity. Upon analysis, sensitivity was found to differ from tag to tag, but in general, differences in sensitivity of tags are insignificant. As an example, the ranges of three randomly selected tags for three AtnLs were measured, and the results showed that tags A and B were very similar, but tag C was a little stronger (see Figure 3.5).

Another experiment was conducted on the same tags, with a fixed distance between tag and reader. RSSI readings were taken three times for all AtnLs, with results indicating that tag C was always stronger than tags A and B, as shown in Figure 3.6. In actual deployment, a calibration stage will be required to ensure tag sensitivity is relatively uniform, so that signal strength can be used as a distance estimator.

![Figure 3.5: The distance at which each tag was initially discovered by the reader, for one of three attenuation levels. This is representative of differences in sensitivity for different tags](image)
Figure 3.6: Sample readings were quite consistent between samples. Differences were due to tag sensitivity variation. Tags that were too different (as in tag C here) were not used for the rest of the study.

3.2.2 Issues Regarding QR-codes

The most significant practical feature of QR-code is that it responds quickly. Further, the ability to store sufficient amounts of positioning data is a core feature of QR-code. QR-code software is easily available, widely distributed and open source. It also works quite well in the field (Denso 2011; Furht 2011; Wave 2010).

QR-Code Properties

QR-code has been placed inside a circle as shown in Figure 3.7, to be readable from a greater distance. A circle is easily detected from further distances. Once a circle is detected, the system estimates the distance between the user and that circle and provides the user with that information. The user can then come closer to the circle to scan the impeded QR-code and obtain accurate positioning information, as shown in Figure 3.8. A circle not viewed normally to its plane will appear as an ellipse at some orientation. A circle decoder can easily be generalised to an ellipse detector, and its orientation can be estimated, allowing the device to tell the user to move more in front of the code if the circle is detected but the QR-code cannot be read (see the last point of Section 3.2.2 for details on limitations of QR-code-reading orientation).
Figure 3.7: The QR-code, which includes positioning information

![QR-Code Image]

Figure 3.8: The sequence of positioning steps using QR-code

QR-Code Size

The dimensions of the QR-code are $18.5 \times 18.5$ cm, which was printed on A4 white paper. That size of QR-code been chosen based on the range of the used camera. Visibility between waypoint to the next. Using standard 50mm camera specifications.

QR-code Location

All QR-codes were distributed at the same height—1.8 m on the left-hand side of doors.

Successful Reading Field of View of QR-Code

Circles could be detected easily from up to 3 m away. The maximum QR-code decoding distance was 1.5 m when the camera was exactly in front of the QR-code in the ‘f’ position in Figure 3.9. When the camera is moved to the left or right side, the detection distance decreases, establishing an inverse relationship between successful detection distance and angle of view. The maximum angle at which the QR-code could be decoded was $43.9^\circ$, represented by angles AR and AL in Figure 3.9, where point A represents the position of the QR-code. These angles were calculated based on Equations 3.1, 3.2 or 3.3, because $eb$ represents the opposite side of angle AR, and $Ae$
represents the adjacent side of the same angle. This is based on Pythagoras’ theorem (Equation 3.4) as well as the empirical study; the hypotenuse represented by $Ab$ is 111 cm. Outside of this range, the system would fail to decode the QR-code:

\[
\tan \angle AR = \frac{eb}{eA}
\]
\[
\sin \angle AR = \frac{eb}{Ab}
\]
\[
\cos \angle AR = \frac{Ae}{Ab}
\]
\[
Ab^2 = eb^2 + Ae^2
\]

![Figure 3.9: The field of view of the QR-code in which it is successfully decoded by the system](image)

### 3.2.3 Issues Regarding Kinect

Kinect is a device developed by Microsoft and normally used for human pose detection for games. It was chosen for this study because it has a 3D camera. However, such a depth camera can also be used to predict movement of objects in front of the user to alert them about any objects that may intersect their path.
Kinect can read up to 4 m, but as shown in Figure 3.10, its field of view is divided into three parts. The first part is direct front range (DFR), with a width of 80 cm in the range +40 to −40 on the x-axis. An object within this range has a high chance of intersection with the user unless it is drifting away from the user’s path, which is denoted by the values of Z. The system ignores any object in the left range (LR) and right range (RR) until it enters DFR. Therefore, the system alerts the user only about objects that approaching the user within DFR based on the value of z and x axis, (see Table 3.2).

Table 3.2: Classification matrix that classifies objects in front of Kinect

<table>
<thead>
<tr>
<th>Estimation of motion of object</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>DFR</td>
</tr>
<tr>
<td>Coming</td>
<td>warning</td>
</tr>
<tr>
<td>Leaving</td>
<td>ignoring</td>
</tr>
</tbody>
</table>
3.3 Summary

As the aim of this study was to produce a usable integrated navigation system for BVI people, it focused on usability matters. Therefore, the devices in the proposed NAAB system were selected carefully in term of usability by BVI people. For instance, with the active RFID the user does not need to point to anything, which is an improvement on most visual systems. Further, it reached a reasonable level of accuracy, although tags can be expensive because they require batteries. To increase the accuracy of the system and solve lack of directionality in the RFID system, QR-codes were subsequently integrated into the system. QR-codes are cheap to produce and are a good compromise that is able to resolve significant limitations of RFID once they are integrated. The efficiency of the system was increased as a result of that integration. The Kinect addresses a different problem, that of avoidance of moving obstacles.

This chapter has discussed some potential problems relating to properties of used devices. For instance, the effect of orientation of the RFID reader and tag, and variation in sensitivity of RFID tags. Further, QR-code properties were discussed, such as the size and location of the QR-code, and its reading distance and field of view. The field of view of Kinect was also presented in this chapter.
Chapter 4: A Positioning System Using Active RFID

As discussed in Chapter 3, active RFID technology is a good candidate for positioning purposes to assist BVI people. With this in mind, this chapter presents a new positioning algorithm based on a combination of attenuation control and RSS using active RFID technology.

4.1 Introduction

For blind people and those with low vision, determining their current location is a significant challenge. Various researchers have discussed navigation issues using RFID technology in order to assist visually impaired people. This work falls into three categories. The first uses passive RFID technology for positioning in indoor environments. An advantage of this approach is that it does not require a power supply because it depends on the power of the probe signal itself. Further, passive RFID is relatively inexpensive. The second approach uses active RFID technology in both indoor and outdoor environments, but few of the proposed systems use active RFID technology by itself, rather in combination with other technologies such as GPS. The third category uses active RFID exclusively, based on distributing transmitters (readers) in the ceiling for triangulation purposes and the RSSI technique to estimate the position of a tag carried by the user. All of these approaches have some disadvantages:

- The passive RFID approach requires a very short distance for communication between the reader and the tag.

- The combined RFID system is disabled or may provide inaccurate positioning information when GPS is unavailable, such as between skyscrapers or inside buildings.

- Existing systems using active RFID alone are more costly because they are based on distributing readers rather than distributing tags.

In the current research, the aim is to develop a positioning system that is able to inform users of their current position in indoor environments, and provide them with useful
information to guide them to their destination using active RFID technology. The novelty of the system is the use of RFID for locating the position of the user using antenna gain controls to selectively receive RFID tag responses at different signal strengths. So instead of measuring the signal strength of the RFID signal directly, the signal strength is implied using a set of impedance settings covering a number of ranges. The process is automatic and quantises the RFID distances. This approach will more easily tolerate small environmental differences. The direct measurement of signal strength is still used, but only for closer proximity measurement where the uncertainty is reduced. This new technique automatically combines these two methods at various ranges to produce a range estimate for each RFID tag.

A successful detection rate of 93.5% has been achieved, as well as a false positive rate of 1%, and the system could estimate the position of the reader in outdoor settings with less than 2-m uncertainty in all cases. The proposed system works efficiently in circumstances when GPS fails to work (especially indoors) and provides useful information to blind people, with higher accuracy than GPS. In deployment, the system will appear as shown in Figure 4.1: when a user enters a building they would receive a floor plan and a list of tags via WiFi, indicating tag positions and labels. The system would then use these to allow positioning indoors. For instance, when users would like to check whether a floor level has an elevator or not, the system will inform them from the downloaded file and estimate the distance to the elevator, indicating the user’s position from the destination of interest. In contrast, a passive RFID system cannot provide this kind of service via a similar technique (exploring the surrounding area). Further, in the outdoor environment, the system is able to indicate the position of the user on a pedestrian path and inform them of surrounding objects of interest. It is not intended to replace the cane, only to provide an independent positioning system at metre resolutions.
4.2 Background and Related Work

Many localisation technologies have been developed, such as those by Najera et al. (2011), Ni et al. (2004), and Papapostolou and Chaouchi (2011). Some of these works can be extended into positioning using RFID technology (Tesoriero et al. 2008) and designed to assist people with visual impairments. These works can be classified into three groups, as follows.

4.2.1 Passive RFID Tag Systems

The work of Fukasawa and Magatani (2012), and Seto and Magatani (2009) was based on using colour sensors and a passive RFID system, which required a distance of less than 50 cm to communicate between the tag and the cane. Ganz et al. (2010; 2011) used a passive RFID system that required a distance of 23 cm, and the system of Liu et al. (2007) required less than 10 cm, to transfer data from the tag to the reader. Also, Di Giampaolo (2010) produced an indoor navigation system based on passive RFID technology that indicated the location of users based on a grid of passive tags located on the ceiling at known positions. da Silva Cascalheira et al. (2012) succeeded in indicating the middle of a door by computing the power of the receiving signal, then comparing
signals to choose the largest one, which represents the middle of the door. To achieve this goal, it was necessary to deploy an antenna on the doors and a pair of antennas with the receiver. It also needed an RF-DC converter radio frequency to direct a current and microcontroller unit (MCU) to compare the signal strength of each antenna, which was useful in assisting blind people to enter or exit rooms through its doors but it did not guide them to those doors.

Faria et al. (2010) and Shiizu et al. (2007) each combined electronic white canes with RFID technology to improve guidance systems for people with visual impairments. The most advantageous feature of passive RFID is that it does not require an external power source because it depends on a magnetic field through absorbing the energy radiated by the reader to transfer data from the tag to the reader. However, this kind of communication requires a short detection range, which is a disadvantage because the system will perform best when the user is inside its range (which is very narrow in almost all passive systems); therefore it requires another technology or method to guide blind people to the points of that system. Kiers et al. (2011) and Szeto and Sharma (2007) both stated that they will develop a wider range with new passive tags, which may contribute to solving some of these limitations.

4.2.2 Hybrid RFID Systems

Researchers such as Kaiser and Lawo (2012), Schmitz et al. (2011) and Yelamarthi et al. (2010) produced useful systems for blind people, but they are dependent on navigation systems that integrate GPS with RFID, therefore will fail to navigate the user when GPS signals are absent. Kaiser and Lawo (2012) suggest an indoor and outdoor navigation system, in which indoor navigation is achieved by use of an integrated system SLAM approach designed for mobile robots and an inertial measurement unit that usually contains accelerometers, a gyroscope and magnetometers. In contrast, the outdoor system is based on a combination of GPS and pedestrian dead reckoning. Kaiser and Lawo (2012) outlined that ‘data processing will be accomplished by wearable computing devices’ and that the system will be ‘totally independent of any network or networked computer’. Although this system shows promise with further development, it will still have limitations when GPS is not available.
4.2.3 Active RFID Systems

A system based on active RFID developed by Oktem et al. (2008) uses the more costly strategy of distributing transmitters (readers) in the ceiling for triangulation purposes then applies the RSSI technique to estimate the position of a tag carried by the user. Chumkamon et al. (2008) tried to use the ultra-high frequency RFID system within a proximity range up to 10-15 m using general packet radio service networks for a navigation device for blind people but they found that there were delay problems in their system. Mooi et al. (2010) produced an efficient RFID tag-placement framework for an indoor navigation system for blind people, but it did not solve any of the problems of dependency, short range or cost and it merely produced a guideline for tag placement in indoor environments.

4.3 Overview of the Proposed System

The system consists of a smartphone, notebook or laptop with custom software installed, a mobile RFID reader and an earpiece to the smartphone. The RFID reader is connected to the smartphone by Bluetooth and communicates via WiFi (or Bluetooth) to obtain maps of tag locations. The user communicates by voice using standard smartphone interfaces, and is informed via audio of tag locations or directions (see Figure 4.1 for a concept diagram of the system when deployed). It uses RFCode M175 rugged tags, operating at a frequency of 433 MHz, as shown in Figure 3.1(B). These active RFID tags have a wide transmission range of more than 70 m. Each tag should be located at a known location, such as an office door, entrance of a department or at a known position on the side of a path. Also, the tags should be installed high up to minimise the likelihood of humans intercepting the signal as reported by Najera et al. (2011). With respect to water attenuation, a tag accidentally covered by a nurse’s hand, even with a high-performance tag (such as the AlienALN-9554M) and reader, would reduce the reading distance from 5–8 m, to less than 1 m with unreliable reading accuracy. The user hangs the mobile reader in his or her belt, as shown in Figure 4.1. The reader used in the proposed system is the RFCodeM220 Mobile Reader, weighing 162 g with the belt clip, as shown in Figure 3.1(A).
The system offers a customised terminal-based interface to communicate to and from the tag reader via two kinds of communication interfaces—Bluetooth Serial 1.1 and wired USB 2.0—so users can install the mobile version application processing interface on their smartphones. The reader has eight factory-programmed attenuation ranges with 5-dB separation. The system will determine the user’s position based on the AtnL itself or based on a combination of AtnLs and RSSI, as described in section Overview of indoor positioning system and section Overview of outdoor positioning system.

4.3.1 Components of the System

As shown in Figure 4.1, the device is easy to carry. The system contains hardware and software. The hardware consists of the reader, multiple tags and a smartphone, tablet or laptop containing an application programming interface (API) of the system. The software consists of the RFID reader programme and the API, which contains the closest tag algorithm and the user position algorithm. Figure 4.2 summarises the layer model of communication between system components. The system is nearly omnidirectional and has a wide range of around 70 m with high sensitivity. The system has been designed for both indoor and outdoor environments, so it can be used to assist
blind users to reach their destination, such as a particular apartment, lift, specific classroom, or particular shop. Tags should be fixed at known locations and a mobile reader will indicate the user’s current location. The mobile software has been designed to be easy to use by the blind: for example, the user can give a voice command by saying ‘my position’, or ‘my global’, or by pressing the buttons (for low-vision people) as shown in Figure 4.3. Additionally, the user selects either an indoor or outdoor platform; the system will change the AtnL accordingly and the reader scans for tags using all ranges. Figure 4.4 illustrates the system’s steps from beginning to end, and Figure 4.5 shows an excerpt of an XML file that includes the positioning database. An indoor platform and tag that are detected in a narrow range would have a higher priority over other tags on a wider range. Hence, based on this concept, the range itself could be sufficient to indicate the closest tag, unless more than one tag is detected within the same range. When there are two or more tags discovered in the same range, the system uses a combination of range and signal strength. This algorithm is summarised in Figure 4.6. Also, an outdoor platform tag that is detected in a close range has a higher priority over other tags in a wider range. Therefore, the closer tags should be assigned higher weights, based on Equation 4.1, as shown in Figure 4.8.

![Image](image.png)

**Figure 4.3:** The interface of positioning system (PC-laptop development version)
4.3.2 Overview of the Indoor Positioning System

Before the user enters a building, they should choose an indoor platform so that the system will use an available connection offered by the particular building, such as WiFi, to retrieve the tag information for that building. This information is retrieved for the whole building as an XML database.

```xml
<?xml version="1.0" encoding="UTF-8" ?>
<RFTrack version="1.0">
<assets>
    <asset name="Exit 11" desc="exit">
        <tag id="00068652" taggroupid="NAAB" />
        <location x="20.30" y="5" floor="11"/>
    </asset>
    <asset name="post graduate" desc="my office">
        <tag id="00068653" taggroupid="NAAB" />
        <location x="9" y="8" floor="1" floor="11"/>
    </asset>
    <asset name="Scada Lab" desc="Scada Lab">
        <tag id="00068654" taggroupid="NAAB" />
        <location x="15.80" y="12.80" floor="11" />
    </asset>
    <asset name="Staff Room" desc="Ron's Office">
        <tag id="00068655" taggroupid="NAAB" />
        <location x="10.90" y="12.80" floor="11" />
    </asset>
    ...
</assets>
</RFTrack>
```

Figure 4.5: An excerpt of an XML file showing typical tag data

An excerpt of this file is shown in Figure 4.5. Such a connection is only needed to download the map files. Only RFID technology, not WiFi, is used for positioning in this research. After downloading the map file from any network connection (usually WiFi or broadband), the RFID reader starts to scan to locate the tags surrounding the user, and provides information on them. The wide-range feature is very useful in these circumstances. For instance, when the blind user requires a toilet, the system will determine if there is one in the surrounding area by comparing the detected tags with the
tags in the database belonging to that building. If there is a toilet, the system will estimate its distance and distinguish the door of the men’s toilet from that of the ladies’ toilet. Therefore, the system plays two roles: first, it explores POI; and second, it detects the destination accurately through using the algorithm, as shown in Figure 4.6.

Assuming that each door has been identified by one tag with a unique identification number, and that in front of the user there are two doors, A and B, the user’s destination being door A rather than door B, the RFID reader will scan using an AtnL from one to eight. The tag that is closer to the user will have a higher RSS and can be detected at a higher AtnL, and different attenuation settings can be used to separate signals with lower strength from this one. Thus, the attenuation setting alone may be sufficient to isolate the desired tag as the closest tag to a user. This will occur if A and B are not detected on the same AtnL. However, if A and B are very close to each other, they are more likely to be detected on the same AtnL, in which case the system will use RSSI as another indicator to determine which is closer to the user.

Note that the absolute RSSI is not used for distance measurements. Rather, the relative RSSI between different tags is used, thus avoiding some common errors that might affect the absolute measure. The RFID reader used is omnidirectional. Transmitting signals for all directions is an advantage because it makes the system work effectively, but at the same time is a disadvantage because the orientation of the user is not known, so directional instructions would be very difficult if not impossible. Therefore, QR-code (described in detail in Chapter 5) has been integrated into the system. When a QR-code tag is detected, the system provides accurate directional instructions such as ‘turn left’ or ‘turn right’ based on the position of the tag and the calculated path to the desired destination of the user. The results in the usability test chapter (Chapter 7 confirm that a combination of these two techniques leads to a higher degree of satisfaction for the blind user.
Figure 4.6: Flowchart of algorithm to indicate the closest tags

4.3.3 Overview of the Outdoor Positioning System

Positioning of the RFID reader is based on the combination technique (attenuation control and RSS) and consists of two main steps: (1) the system indicates the weight value for each tag based on the range in which that tag has been detected; (2) the system estimates the position of the RFID reader using the mass centroid method based on a pre-indicated weight factor for each tag.
**Indication of Weight Factor**

Outside buildings, the system works as a supplement to GPS because it provides more accurate positioning information to the user. The system has been designed to indicate the position of the user at trajectories of 4-m widths. Based on the algorithm shown in Figure 4.8, the system scans using decrement AtnLs until it detects at least three different tags. It starts with the highest level of attenuation (1) to detect the closest tags first and give them a higher priority (more weight) over distant tags, based on the following equation:

\[ W_i = \text{RSSI} \times ((\max AtnL) + 1) - (AtnL_{current}) \] (4.1)

where \( \text{RSSI} \) represents the average of the received signal strength indicator, \( \max(AtnL) \) represents the maximum level of attenuation (equal to 8 in this system) and \( AtnL_{current} \) represents the current AtnL at which the tag was detected. Using this equation, the closest tags would be assigned a higher weight, and *vice versa*: for instance, when \( AtnL_{current} \) equals 1, as at the start of the algorithm, \( \text{RSSI} \) in this case will be multiplied by eight because the maximum level of the attenuation of this system is 8, plus 1 equals 9, minus 1 equals 8. The opposite will happen if \( AtnL_{current} \) equals 7, in which case \( \text{RSSI} \) will be multiplied by 2 because 8 plus 1 equals 9, minus 7 equals 2; consequently, the weight of the tags detected on that level will be lower. Table 4.1 summarises how this equation works.

<table>
<thead>
<tr>
<th>AtnL</th>
<th>((\text{mean(SSI)})\times X)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>X=8</td>
</tr>
<tr>
<td>2</td>
<td>X=7</td>
</tr>
<tr>
<td>3</td>
<td>X=6</td>
</tr>
<tr>
<td>4</td>
<td>X=5</td>
</tr>
<tr>
<td>5</td>
<td>X=4</td>
</tr>
<tr>
<td>6</td>
<td>X=3</td>
</tr>
<tr>
<td>7</td>
<td>X=2</td>
</tr>
<tr>
<td>8</td>
<td>X=1</td>
</tr>
</tbody>
</table>

**Calculation of the Position of the RFID Reader**

After assigning weights to surrounding detected tags, the position of the RFID reader is estimated based on the mass centroid method, which calculates \(x\)- and \(y\)-coordinates as
shown in Algorithm 1 below; a snapshot of the C# code belonging to the RFID reader positioning task is shown in Figure 4.7, followed by a flowchart summarising all of the steps of the system.

**Algorithm 1** The mass centroid method algorithm

```csharp
1: for range = 1 to range = 8 do
2:   stop the reader
3:   Clear the detected tags list tagList.Clear
4:   adjust the range of the reader belong to the current range
5:   Run the reader
6:   for i = 1 to n do
7:     {where n is the number of detected tags in that range}
8:     sumWeightedSignal = sumWeightedSignal + W_i * detectedTags
9:     tagFromConfig ← getTagData
10:    weightedSignalWithRealX ← W_i * tagFromConfig.XLocation
11:    weightedSignalWithRealY ← W_i * tagFromConfig.YLocation
12:    sumWeightedSignalWithRealX = sumWeightedSignalWithRealX + weightedSignalWithRealX
13:    sumWeightedSignalWithRealY = sumWeightedSignalWithRealY + weightedSignalWithRealY
14:   end for
15: end for
16: X ← sumWeightedSignalWithRealX/sumWeightedSignal
17: Y ← sumWeightedSignalWithRealY/sumWeightedSignal
```

```
}

// Get Factor
int weightFactor;
tagIdWithFactor.TryGetValue(tagId, out weightFactor);

double weightedsignal = avgSignal * (double)weightFactor;
sumweightedsignal += weightedSignal;

RPTag tagFromConfig = tagConfiguration.GetTag(tagId);

double weightedSignalWithRealX = weightedSignal * tagFromConfig.XLocation;
double weightedSignalWithRealY = weightedSignal * tagFromConfig.YLocation;

sumWeightedSignalWithRealX += weightedSignalWithRealX;
sumWeightedSignalWithRealY += weightedSignalWithRealY;

reader.SendRFReaderCommand("M,0");

//Calculate X, Y

double X = sumWeightedSignalWithRealX / sumWeightedSignal;
double Y = sumWeightedSignalWithRealY / sumWeightedSignal;

exactlocation.x = (float)Math.Round((double)X, 2));
break;
```

**Figure 4.7:** A snapshot of a specific part of code used in the centroid method
4.4 Experiments and Results

The main goal of the experimental work in this thesis was to confirm that the combination approach to quantised distance measurement using active RFID tags and a map of their locations achieves reasonable results. This section describes the results relating to indoor positioning using both algorithms, followed by outdoor positioning. Detection reliability using the quantised approach and the use of RSSI as a distance measure are then examined.
4.4.1 Indoor Localisation Technique Implementation

All tags have been distributed at known positions, so each tag represents one particular location. The role of the system is to indicate the closest tag to the user when the RFID reader is carried by the user. As an initial calibration step, Figure 4.9 presents the experimental implementation. Dots A, B, C, D and E represent the location of fixed tags, and numbers 1–15 represent the real locations of the readers. When tags are equidistant, the system was 100% successful in indicating the closest tag for each location. For example, tag A is the closest tag to location 1 and it was detected in this position on AtnL 1, as shown in Table 4.2. Also, the same tag was detected alone on AtnL 2 at position 2. For all 15 samples, the system indicates the closest tag by giving a tag that is detected on a narrow range higher priority over other tags on wider ranges.

The following information should be known at any time: the user’s position within the map (from the local tags); the user’s direction of travel (from proximity to other tags prior to the target); the direction of the user based on the QR-code (QR-code was later integrated into the system to resolve the orientation problem, and will be discussed in detail in the next Chapter); and the location of tags from the map. From all of these, it is possible to describe a vector direction given the measured distance, relative to current user orientation. Given that the user’s orientation is known, the relative orientation of the tag is also known from its position and the user’s calculated position. The system can thus be used to guide the user to a tagged object, or to establish the user’s position and orientation within a field of tags.

![Figure 4.9: Calibration set, with equal distances between tags](image)

53
Table 4.2: The results using power attenuation to indicate the closest tag

<table>
<thead>
<tr>
<th>Reading position</th>
<th>Closest tag</th>
<th>Attenuation level</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>A</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>A</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>B</td>
<td>2</td>
</tr>
<tr>
<td>4</td>
<td>B</td>
<td>1</td>
</tr>
<tr>
<td>5</td>
<td>B</td>
<td>2</td>
</tr>
<tr>
<td>6</td>
<td>C</td>
<td>2</td>
</tr>
<tr>
<td>7</td>
<td>C</td>
<td>1</td>
</tr>
<tr>
<td>8</td>
<td>C</td>
<td>2</td>
</tr>
<tr>
<td>9</td>
<td>C</td>
<td>3</td>
</tr>
<tr>
<td>10</td>
<td>D</td>
<td>2</td>
</tr>
<tr>
<td>11</td>
<td>D</td>
<td>1</td>
</tr>
<tr>
<td>12</td>
<td>D</td>
<td>2</td>
</tr>
<tr>
<td>13</td>
<td>E</td>
<td>2</td>
</tr>
<tr>
<td>14</td>
<td>E</td>
<td>1</td>
</tr>
<tr>
<td>15</td>
<td>E</td>
<td>1</td>
</tr>
</tbody>
</table>

4.4.2 Evaluation of the Indoor System (Case Study 1)

To evaluate the efficiency of the system, a practical experiment was conducted—the system’s role being to describe the current position of users by indicating the closest door to them. Tags were placed on laboratory doors, represented by A, B, C, D and E in Figure 4.10. Readings were then taken from various locations (1–11) along the corridor, as shown in the same figure. The system aims to inform the user of a destination of interest in the surrounding area. Further, as shown in this case study, the system identified the laboratory based on the user’s location. Table 4.3 illustrates how the system indicated the tag closest to a user. For instance, at position 1, the reader could not discover any tag on AtnLs 1 and 2, but on AtnL 3, tag A and tag B were detected. Hence, it was necessary to use a combination technique to indicate which one of them to select. At position 2, the reader was very close to tag A, so A was detected alone on AtnL 1, so the AtnL technique was sufficient to indicate the closest tag. As shown in
Table 4.3, there was a partial error at position 3: the system reported that the user was in the middle of A and B—which is true, but it was biased 45 cm to tag A. In contrast, the system had very high accuracy at position 9: the reader was closer to tag E than to tag D by only 5 cm and the system was able to detect this.

![Figure 4.10: Case Study 1: indication of laboratory doors in a straight corridor](image)

Table 4.3: The results using a combination of attenuation level and signal strength indicator to indicate the closest tag to the user

<table>
<thead>
<tr>
<th>Reading position</th>
<th>Closest tag</th>
<th>Positioning technique</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>AtnL Level</td>
<td>AtnL Only</td>
</tr>
<tr>
<td>1</td>
<td>A</td>
<td>3</td>
</tr>
<tr>
<td>2</td>
<td>A</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>A,B</td>
<td>2</td>
</tr>
<tr>
<td>4</td>
<td>B</td>
<td>1</td>
</tr>
<tr>
<td>5</td>
<td>C</td>
<td>1</td>
</tr>
<tr>
<td>6</td>
<td>D</td>
<td>4</td>
</tr>
<tr>
<td>7</td>
<td>D</td>
<td>2</td>
</tr>
<tr>
<td>8</td>
<td>D</td>
<td>1</td>
</tr>
<tr>
<td>9</td>
<td>E</td>
<td>2</td>
</tr>
<tr>
<td>10</td>
<td>E</td>
<td>2</td>
</tr>
<tr>
<td>11</td>
<td>E</td>
<td>1</td>
</tr>
</tbody>
</table>
4.4.3 Evaluation of the Indoor System (Case Study 2)

To evaluate the reliability of the system in a real environment, further experiments were conducted in more complex area, as shown in Figure 4.11 where the black squares represent tags and the numbers in the corridors represent the positions of reading locations. The system succeeded in all cases in determining the positions of the user by describing the surrounding tags as shown in Table 4.4, where the first column contains sample numbers representing sample positions in Figure 4.11. The second column should indicate the tags first identified and the power level where they were first found. Clearly, at the 70-m range all tags are detectable in Figure 4.11. However, as per the flowchart in Figure 7.6, the system scans only until the first level at which tags are found: at that level the tags found are indicated in column three. The next column in Table 4.4 shows ground truthing of the measured results. The ‘true positive’ column represents accurate identification of tags as well as accurate distance of the tags from the sample location in terms of AtnL. For instance, for sample 29 the user was close to tag 29 and tag 30, so it should detect both tags and this is what occurred: therefore, true positive equals 2 for that sample. The ‘false negative’ column represents the number of missing tags that were not identified at the level at which other tags were detected. For instance, for sample 22 the system was supposed to detect two tags, but it detected only one of them; so true positive equals 1 and false negative equals 1 as well. The ‘false positive’ column represents the number of tags that were identified correctly but at the wrong distance. For example, for sample 4, the system should detect only tag office 407: that tag was detected correctly but a further unexpected tag was also detected—tag for lab 37—so true positive equals 1 and false positive is 1 also.
Figure 4.11: Case Study 2: indication of user position in a crowded indoor environment

Table 4.4: The results for Case Study 2: evaluation of detection reliability in a more complex circumstance

<table>
<thead>
<tr>
<th>Sample No</th>
<th>The correct closest tags</th>
<th>The estimated closest tags</th>
<th>True</th>
<th>False</th>
<th>False</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Office 004</td>
<td>Office 004</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>Office 004 and Lab 37</td>
<td>Office 004 and Lab 037 and Office 007</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>Office 001 and Lab 037 and Office 067</td>
<td>Office 004 and Lab 037 and Office 007</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>4</td>
<td>Office 007</td>
<td>Office 007</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>5</td>
<td>Office 007 and Office 013</td>
<td>Office 007</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>6</td>
<td>Office 007 and Office 013</td>
<td>Office 007 and Office 013</td>
<td>2</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>7</td>
<td>Office 013</td>
<td>Office 013</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>8</td>
<td>Office 004 and Lab 036</td>
<td>Office 004 and Lab 036 and Office 013</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>9</td>
<td>Office 004 and Office 016 and Lab 036</td>
<td>Office 004 and Office 016 and Lab 036 and Office 013</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>10</td>
<td>Office 016 and entrance</td>
<td>Office 016 and entrance</td>
<td>2</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>11</td>
<td>entrance</td>
<td>entrance</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>12</td>
<td>entrance and Office 017</td>
<td>entrance and Office 017 and Office 037 and Office 004</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>13</td>
<td>Office 017</td>
<td>Office 017</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>14</td>
<td>Office 017 and Office 018 and Office 019</td>
<td>Office 017 and Office 018 and Office 019</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>15</td>
<td>Office 018 and Office 019</td>
<td>Office 018 and Office 018 and Office 020</td>
<td>2</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>16</td>
<td>Office 020</td>
<td>Office 018 and Office 018 and Office 020</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>17</td>
<td>Office 020 and Office 021 and Office 022</td>
<td>Office 020 and Office 020</td>
<td>2</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>18</td>
<td>Office 021 and Office 022</td>
<td>Office 021 and Office 022</td>
<td>2</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>19</td>
<td>Office 022 and Office 023 and Exit 318</td>
<td>Office 022 and Office 023 and Exit 318</td>
<td>3</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>20</td>
<td>Exit 318</td>
<td>Exit 318</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>21</td>
<td>Office 023 and Exit 318</td>
<td>Office 023 and Exit 318</td>
<td>2</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>22</td>
<td>Office 023 and Office 025</td>
<td>Office 023</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>23</td>
<td>Office 023 and Office 025</td>
<td>Office 023</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>24</td>
<td>Office 025</td>
<td>Office 025</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>25</td>
<td>Office 025 and Office 026</td>
<td>Office 025 and Office 026 and Office 027</td>
<td>2</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>26</td>
<td>Office 026</td>
<td>Office 027</td>
<td>2</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>27</td>
<td>Office 027 and Office 028</td>
<td>Office 027 and Office 027 and Office 028</td>
<td>2</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>28</td>
<td>Office 028 and Office 029</td>
<td>Office 028 and Office 028</td>
<td>3</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>29</td>
<td>Office 029</td>
<td>Office 029</td>
<td>2</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>30</td>
<td>Office 030</td>
<td>Office 031</td>
<td>2</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>31</td>
<td>Office 031 and Office 032</td>
<td>Office 031 and Office 032</td>
<td>2</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>32</td>
<td>Office 032</td>
<td>Office 032</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>33</td>
<td>Office 033</td>
<td>Office 033</td>
<td>2</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>34</td>
<td>Office 034</td>
<td>Office 034</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>35</td>
<td>Office 034 and Entrance</td>
<td>Office 034 and Entrance and Office 017</td>
<td>2</td>
<td>0</td>
<td>1</td>
</tr>
</tbody>
</table>

Total number of tags: 63 4 16
Figure 4.12: PC-based development window of the second algorithm in an indoor environment

4.4.4 Evaluation of the System in an Indoor Environment Using the Second Algorithm

The second algorithm was applied in an indoor environment for evaluation purposes, as shown in Figure 4.12. The numbers in the corridors represent pre-calibrated positions taken during debugging. The measurements are taken at these positions, and Table 4.5 shows the differences between measured and real positions. For example, the circle represents the estimated position of sample 7. In an indoor environment, the user could depend on the first algorithm instead of the second algorithm because the first algorithm provides useful information synchronously to the user by describing the surrounding tags based on the current position of the user. This may be of more immediate relevance than the user’s actual position.
Table 4.5: Positional accuracy of the second algorithm

<table>
<thead>
<tr>
<th>Position</th>
<th>Real X</th>
<th>Real Y</th>
<th>Est X</th>
<th>Est Y</th>
<th>Error(m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.6</td>
<td>6.60</td>
<td>3.66</td>
<td>7.14</td>
<td>2.12</td>
</tr>
<tr>
<td>2</td>
<td>4</td>
<td>6.60</td>
<td>4.40</td>
<td>7.07</td>
<td>0.61</td>
</tr>
<tr>
<td>3</td>
<td>6.5</td>
<td>6.60</td>
<td>6.20</td>
<td>6.48</td>
<td>0.32</td>
</tr>
<tr>
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<td>9</td>
<td>6.60</td>
<td>9.49</td>
<td>5.98</td>
<td>0.79</td>
</tr>
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<td>11</td>
<td>6.60</td>
<td>11.63</td>
<td>6.58</td>
<td>0.63</td>
</tr>
<tr>
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<td>13</td>
<td>6.60</td>
<td>12.32</td>
<td>6.60</td>
<td>0.68</td>
</tr>
<tr>
<td>7</td>
<td>15</td>
<td>6.80</td>
<td>14.71</td>
<td>6.63</td>
<td>0.33</td>
</tr>
<tr>
<td>8</td>
<td>18</td>
<td>7</td>
<td>16.51</td>
<td>6.28</td>
<td>1.65</td>
</tr>
<tr>
<td>9</td>
<td>20</td>
<td>7.20</td>
<td>18.20</td>
<td>7.14</td>
<td>1.80</td>
</tr>
<tr>
<td>10</td>
<td>18</td>
<td>9</td>
<td>17.93</td>
<td>7.28</td>
<td>1.72</td>
</tr>
</tbody>
</table>

4.4.5 Outdoor Localisation Technique Implementation

As described in the Overview of outdoor positioning system section, higher attenuation leads to a narrower range. Therefore, the system does not deal equally with all reference tags, but assigns a weight to each of them, based on a combination of RSSI from that tag and the used AtnL, as shown in Equation 4.1. For instance, the average of RSSI for the tag that is detected on AtnL 1 will be multiplied by 8 and so on, as described in Table 4.1.

4.4.6 Evaluation of the System in an Outdoor Environment

To test the success of the system in an outdoor environment, tags were placed on the sides of a pedestrian path in Edward Park in a zigzag formation on each side of the path, 4-m apart, as shown in Figure 4.13. A–F represents reference tags; the red solid line represents the real path and the blue dashed line represents the estimated path. The readings were taken at positions 1–7. Table 4.6 presents the reference tags used for each position and the AtnL, and Table 4.7 presents the real coordinates and estimated coordinates for the path points. The positions were estimated using the mass centroid method, based on the weights given to each tag, calculated by a combination of RSSI and AtnL. As shown in Table 4.7, errors occurred at around 1 m or less.
Although a larger interval between tags can be used, given the maximum range of 70 m, the uncertainty also increases due to the range setting available. Clearly, there are times when such a trade-off in uncertainty with sparser coverage is justified upon deployment.

![Figure 4.13: Indication of user position for outdoor path](image)

Table 4.6: Successful detection of tags A–H for the outdoor experiment shown in Figure 4.13

<table>
<thead>
<tr>
<th>Position</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
<th>H</th>
<th>AtnL</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>4</td>
</tr>
<tr>
<td>2</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>4</td>
</tr>
<tr>
<td>3</td>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td>4</td>
</tr>
<tr>
<td>4</td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td>5</td>
</tr>
<tr>
<td>5</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
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<td>X</td>
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<tr>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
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<td>X</td>
<td>5</td>
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<td>7</td>
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<td></td>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>5</td>
</tr>
</tbody>
</table>
Table 4.7: Positional accuracy for the outdoor platform

<table>
<thead>
<tr>
<th>Position</th>
<th>Real X</th>
<th>Real Y</th>
<th>Est X</th>
<th>Est Y</th>
<th>Error(m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5</td>
<td>3</td>
<td>5.05</td>
<td>2.44</td>
<td>0.50</td>
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<tr>
<td>2</td>
<td>8</td>
<td>3</td>
<td>8.89</td>
<td>2.56</td>
<td>0.99</td>
</tr>
<tr>
<td>3</td>
<td>11</td>
<td>3</td>
<td>12.92</td>
<td>3.40</td>
<td>1.96</td>
</tr>
<tr>
<td>4</td>
<td>17</td>
<td>3</td>
<td>17.37</td>
<td>2.66</td>
<td>0.50</td>
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<td>5</td>
<td>20</td>
<td>3</td>
<td>19.31</td>
<td>3.04</td>
<td>0.69</td>
</tr>
<tr>
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<td>23</td>
<td>3</td>
<td>22.91</td>
<td>2.94</td>
<td>0.10</td>
</tr>
<tr>
<td>7</td>
<td>26</td>
<td>3</td>
<td>25.09</td>
<td>3.42</td>
<td>1.00</td>
</tr>
</tbody>
</table>

4.4.7 Analysis of the Relationship between Attenuation Ranges and Distance

Figure 4.14 shows six of the eight geographic ranges of the reader power attenuations. These boundaries were obtained using multiple readings at various distances in an open field, and for different tags. As mentioned in previous sections, power attenuation is the core technique in the proposed system. Therefore, 108 samples were taken at distances of 1, 5, 10, 15, 20 and 25 m and in random sequence, in order to evaluate the reliability of power attenuation as a quantised distance measure. The results in Table 8.4 show that there were only seven incorrect samples (shown by the false columns) among the 108 samples.

The method is that a tag is presented at a certain distance, and should be detectable for all levels corresponding to that range and greater. So a tag positioned at 5 m would be detectable for all ranges beyond attenuation range 1, but not range 1 at 2.5 m, as per the legend in Figure 4.14.
### Table 4.8: Evaluation of detection reliability

<table>
<thead>
<tr>
<th>Distance (m)</th>
<th>True +ve</th>
<th>False −ve</th>
<th>True −ve</th>
<th>False +ve</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>18</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>5</td>
<td>15</td>
<td>0</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>10</td>
<td>8</td>
<td>4</td>
<td>6</td>
<td>0</td>
</tr>
<tr>
<td>15</td>
<td>9</td>
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<td>9</td>
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</tr>
<tr>
<td>20</td>
<td>5</td>
<td>1</td>
<td>12</td>
<td>0</td>
</tr>
<tr>
<td>25</td>
<td>2</td>
<td>1</td>
<td>14</td>
<td>1</td>
</tr>
</tbody>
</table>

### 4.4.8 Analysis of the Relationship between the Received Signal Strength Indicator and Distance

The main technique of the proposed positioning system (NAAB) is a combination of power attenuation and the RSSI. The experiments showed that power attenuation was reliable but a higher degree of accuracy was achieved when power attenuation was combined with RSSI. One very important advantage is that the AtnL is automatically adjusted in the reader for positioning purposes, rather than using fixed reader sensitivity.

The effect of distance on RSSI was tested, and revealed a rough inverse linear relationship between RSSI (measured in dB) and short distance (up to 10 m) as shown in Figure 4.15. When the reader detects more than one tag at the same AtnL, this means all detected tags are in the same range. Similarly, the RSSI technique is useful to differentiate a closer tag from a distant one.

In contrast, RSSI failed to work in many cases by itself for wider ranges (more than 10 m) as shown in Figure 4.16, which shows a vaguely negative exponential relationship. The proposed positioning system is not based on using RSSI by itself, but on a combination of RSSI and attenuation control techniques, particularly for the wider range.
Figure 4.14: The geographic range representing the relationship between power attenuation and distance

Figure 4.15: The near-linear relationship between distance and RSSI for short range

Figure 4.16: The linear relationship between distance and RSSI breaks down for wider ranges
4.5 Summary

This chapter has presented a new technique to assist BVI people to reach their destination in both indoor and outdoor environments using a wide-range active RFID system. The mobile reader has eight power AtnLs and the geographic range of each level was calculated. A successful detection rate of 93.5% was achieved, as well as a false positive rate of 1%. Further, a combined technique of power attenuation and RSSI was formulated to identify locations to assist BVI people to reach their destination accurately.

To evaluate this technique, two case studies were conducted: the first was inside a building and was designed to assist a user to reach a particular laboratory door in our school, achieving a very high success rate where error rates were less than 0.5 m in all cases; the second was designed to help blind people indicate their position accurately on a pedestrian path, achieving an error rate of around 1 m in almost all cases.

The RFID reader used (RFCode M220) has a significant advantage in that it is omnidirectional, but this advantage causes a usability disadvantage in term of guiding blind users to their destination, where they are mis-led in many cases. For instance, when the user is in a corridor and the system correctly indicates the nearest two tags, the system at its current stage cannot recognise which door is on the left side and which is on the right side. To address this limitation, the QR-code technique was integrated into the system. Each door was identified with a unique ID in the RFID tag and the same ID in the QR-code as well. Thus, the user can detect a QR-code tag to get an accurate navigational instruction: ‘turn left’, ‘turn right’ or ‘you are in front of ... ’, and so on. Integration of QR-code into the positioning system is discussed in detail in the following Chapter.
Chapter 5: Integrated Positioning System Using Active RFID and QR-code

Two of the main services that the NAAB system provides are positioning and navigation: for more detail about navigation refer to Chapter 6. Positioning is responsible for indicating the current position of the user, and navigation is responsible about guiding the user to reach their destination. An investigation of positioning using RFID technology by itself, and associated limitations, is presented in Chapter 4, hence the aim of this chapter is to present an integrated positioning system using active RFID and QR-code, which resolves concerns about using RFID technology alone.

5.1 Introduction

The RFID reader used here has a significant feature in that it is omni-directional, so it detects the tag at any direction whether the tag is located in the front, behind, on the left side or on the right side of the user. The reader is able to detect a tag in any direction but cannot determine the orientation of the detected tag. Therefore, this chapter aims to present a solution to that problem, by integrating a QR-code with RFID. The main purpose of supplementing RFID positioning with a QR-code system is to produce a usable positioning system for BVI people.

QR-codes, an abbreviation of quick-response code, were invented in 1994 by Denso Wave (Wave 2010). It was designed for high-speed component scanning to track vehicles during manufacture (Furht 2011). A QR-code is a type of matrix barcode or two-dimensional barcode developed for the automotive industry in Japan (Wave 2010). It was subsequently used for further applications either within or external to the automotive industry, due to its fast readability and greater storage capacity compared to standard barcodes. Such applications have included product tracking, item identification, time tracking, document management and general marketing (Denso 2011).

The systems that have been designed for navigation purposes in indoor environments to
assist BVI people can be placed into two groups: the first is based on scene analysis and the second is based on using a set of equipment. Both techniques have limitations in terms of practical usability:

- The disadvantage of the scene analysis technique is that has a long processing time and this delay may be reflected in navigation practical usability. Therefore, NAAB does not intend to scan the surrounding area at all times looking for QR-codes, but after the current position of the user is indicated based on RFID technology then NAAB starts to search for QR-codes within 2 m only. The benefit of integrating QR-codes is that it addresses the directionality issue, which NAAB cannot do based on RFID technology itself. Another benefit of using QR-codes is to increase accuracy of the system from ~2 m, without QR-code.

- The disadvantage of the equipment-based approach is that most solutions require expensive infrastructure.

The proposed use of QR-codes is not intended to replace the use of canes, but to provide an independent positioning system at less than 1-m resolutions and provide blind users with very precise navigation information inside buildings with the smallest amount of required equipment. Therefore, the proposed system been designed to be used in addition to the cane and dog, where it provides navigation, which the cane does not, or waypoint interpretation, which the dog cannot do.

NAAB could work based on RFID alone, but there is a significant limitation related to lack of directionality, so the proposed system has been supplemented by integration of QR-codes to resolve this disadvantage and achieve more precision and therefore produce a usable navigation prototype system to assist BVI people.

5.2 Background and Related Work

Previous research produced for navigation purposes to assist BVI people can be classified into two groups in terms of its use of optical sensors. The first group includes systems based on scene analysis, which then use image-processing algorithms such as edge detection and object recognition for the purposes of positioning and navigation. These techniques are reasonable, but the required processing time may affect practical
navigation usability (e.g. Ali & Nordin 2010; Dunai et al. 2013; Sun et al. 2012). Sun et al. (2012) used lamps on the ceiling as landmarks to indicate the position of the camera, but the lamps need to be distributed uniformly. Ali and Nordin (2010) introduced the SLAM method, which uses a scale-invariant feature transformation (SIFT) representation of the scene (as clouds of SIFT feature on the map) and they produced a new electronic cane that contains a camera: the system computes weights of SIFT features of the site view of the scene environment, and cloud construction gives the estimated position and direction of the blind person. Dunai et al. (2013) produced an object-detection device to assist blind people to navigate safely. For situation awareness, Ko et al. (2011) used speeded-up robust features (SURF) from the input images then compared them with the template data to be indexed using the vocabulary tree, following which the most relevant images were selected. Karacs et al. (2008) used a database to describe the surrounding environment to blind people.

The second group contains the systems that require various equipment and specific infrastructure, such as those based on GPS, RFID and Bluetooth or a combination of these technologies. An example is Retscher and Fu (2010), who proposed a continuous positioning system based on a combination of RFID and the inertial navigation system. Chang and Wang (2010) proposed an architecture based on Bluetooth tags and scanning PDAs. Gallagher et al. (2012) indicated position based on Kalman filters, which fuse data from different sensors (WiFi chipset, accelerometers and a magnetic field sensor). Cruz et al. (2011) proposed a navigation system based on Bluetooth. Yang et al. (2011) produced an integrated system involving communication satellite location/cell location (CSL/CL) for navigation in indoor environments. Dodson et al. (1999) used a 35-mm² GPS and compass.

5.3 Overview of the Use of QR-code for Positioning

The proposed system aims to assist BVI people to indicate their positions and navigate them to their desired destinations with minimal equipment required.

5.3.1 The System Components
The proposed system requires only three elements:

- Printed QR-code to store location information, embedded inside red circles (see Figure 3.7). There are two benefits of using a red circle: first to render the QR-code easily detected from a distance (up to 3 m); and second, to distinguish the positioning QR-code from any irrelevant QR-codes that may be in the vicinity.

- An optical sensor, which is built in to a smartphone, tablet or whatever mobile portable device the system needs to detect and decode QR-code.

- A positioning app responsible for three tasks. First, to inform the user about a QR-code available in the surrounding area based on the circle-detection feature. To increase the efficiency of the system, NAAB looks not only for a red plane, since white circles also have a red plane. Rather, it looks for red-plane circles that are not visible in the blue or green plane (see Algorithm 2, below). It then applies the circle-detector algorithm on that plane and calculates the size of that detected circle. Second, based on the size of the detected circle and Equation 5.1, the distance is estimated between that circle and the user in their current location to guide them towards the QR-code so they can scan it. Third, the system decodes the QR-code to provide users with positioning information. There is two benefits to this information: it describes the surrounding environment to the user, and is used for navigation purposes to aid the user to reach their destination, as discussed in the next chapter.

5.3.2 The Sequence of Steps involved in Positioning Using QR-code

The positioning service aims to indicate the current position of the user, both at the starting point of the route and for tracking purposes until the user reaches their destination. All location information was encoded in QR-codes embedded inside circles as shown in Figure 3.7, to be detected from a longer distance. To achieve that goal, the system performs the sequence steps as shown in Figure 5.1. First, the system detects a circle using the Hough circle-detection algorithm (Xu et al. 1990) following steps presented in Algorithm 2 below. Figure 5.2 shows the original image of a QR-code on the left side and the detected circle on the right side. Then the user is provided with the calculated distance between themself and the circle. Finally, the user approaches that circle to decode the QR-code and thus indicate their current position.
Algorithm 2 Circle Detection Algorithm

1: read the image
2: convert to HLS colour space
3: extract red lines (H = 0.8 to 1.0 and 0.0 to 0.2 Set this to 1, set rest to 0)
4: applying Hough circle detector algorithm
5: for 1 to NoOfDetectedCircles do
6: indicate the maximum circle
7: calculate size belonging to the biggest circle
8: end for
9: return the maximum size
10: calculate distance based on eq. 5.1

Figure 5.1: The sequence of positioning steps using QR-code

5.4 The Efficiency of Using QR-code for Positioning

NAAB was developed in Visual Studio 2010 using C# language, and QuickMark is the software used to decode QR-codes. In the following section, evaluation issues using QR-codes for positioning will be discussed.

Figure 5.2: The left image represents the original image of a QR-code and the right image represents the circle detected by the Hough circle-detector algorithm
5.4.1 Evaluation of Positioning

All position information was encoded in QR-codes, and the range needed to decode QR-codes is ~1.5 m. The QR-code was embedded inside a circle to be easier to detect from longer distances, around 3 m: the system estimates the distance between the detected circle and the user based on the size of the detected circle, then provides that information to the user so that they can come closer to decode the QR-code. The circle was detected effectively from 3 m or less on a wide angle of 120°. All circles used have to be the same size. To generate Equation 5.1, which represents the ratio between the distance and the size of the circle (shown in Figure 5.3), 39 images of the circle were taken at a variety of distances ranging from 25 cm to 3 m:

\[ f(X) = a \times X^b \]  

where \( f(X) \) represents the distance and \( X \) represents the size of a detected circle. For evaluation purposes, >100 tests were conducted to evaluate circle recognition and the accuracy of distance estimation between the user and a QR-code, as follows:

- Evaluation of circle recognition: the rate of true positive detection was 98% and the rate of false positive detection was <1%.

- Evaluation of distance estimation between the user and QR-code: as shown in Figure 5.4, the maximum error in the ratio between the size of the circle and the distance was ±2 cm.


**Figure 5.3:** The ratio between the size of a detected circle and the distance between the circle and the camera.

**Figure 5.4:** The degree of accuracy of distance estimation equation.

### 5.5 Positioning Using the Integration of RFID and QR-code

The RFID positioning system by itself lacks an orientation feature. Also, trying to find QR-code everywhere is a difficult task for a blind person. Therefore, the aim of this thesis is to produce an integrated system of RFID combined with QR-codes, in which RFID technology is used for initial positioning and then QR-codes are used for exact positioning including orientation. For instance, when the user needs a toilet, they can query the system for that POI. The system may indicate that there is a toilet 3 m away from the current position of the user, which is the information may produced based on
RFID technology using the proposed positioning algorithm. However, that information is insufficient for the user to reach that destination, so they must start scanning the surrounding area to find a QR-code that would help determine their location and orientation precisely, to provide them with useful navigational instructions to that destination, such as ‘turn left then walk to the end of corridor then turn right and walk for five steps to find the toilet on your left side’. During the trip as the user moves from point to point, at each point the system tracks the user using RFID, the QR-code confirms that the user is following the right path and the system informs them with highly accurate navigational instructions. More details about how the navigation system works are provided in the following chapter. Another example of the benefit of combining QR-codes with the proposed system is that if the user is standing in the range of a tag belonging to a toilet, the system can use RFID to give instructions, such as ‘1.5 m to the toilet’, but it is challenging for the blind user to know which direction they should travel to reach that toilet, and where the door of the toilet is located.

By integrating RFID and QR-code, these problems could be resolved: the system describes the surrounding area to the user using RFID technology and then the user scans for a QR-code to obtain exact positioning information. In the previous example, when the system confirms that a toilet is 1.5 m away from the user it is not difficult for the user to search for and decode the QR-code in a range less than 2 m, especially if all QR-codes are distributed at a standard known height.

The core features of RFID (as discussed in Section 3.2.1) are:

- It works independently in all directions (is omnidirectional) because the field of view of the reader and tag is 360°.
- The RFID reader carried by a user is a mobile device, so it is suitable for navigation purposes.
- The range of the reader used here is up to 70 m, with accuracy of around 2 m.

The main features of QR-code are:

- It is an extremely low-cost technique; in fact it is free other than the cost of
printing QR-codes on A4 paper.

- It is a high-accuracy technique: when the user decodes a QR-code they will definitely be given the correct positioning information.
- QR-code is a good solution to resolve concerns about directionality of RFID.

5.6 Summary

This chapter has discussed an integration positioning technique of RFID and QR-code developed to assist BVI people to indicate their position precisely. The proposed positioning system uses a combination of a wide-range active RFID system and QR-code for navigation purposes. The positioning system aims to determine the current position of the user, and the navigation system aims to use that positioning technique to determine and describe the most suitable path for users to assist them to reach their desired destination.

The following chapter describes in detail how this positioning technique has been employed in a navigation system.
Chapter 6: Navigation Using an Integrated System

The aim of this chapter is to present an integrated navigation system called NAAB, which was developed based on the integration of positioning systems as discussed in Chapters 4 and 5. The main concept of NAAB depends on integration of QR-code and long-range active RFID. The focus of this chapter is on production of an inexpensive integrated navigation system to assist BVI people to navigate independently in indoor environments.

6.1 Introduction

Navigation applications are improving over time, both for indoor and outdoor environments. Most applications have been designed for sighted people. In contrast, navigation for BVI people still requires substantial improvement, particularly for indoor environments. Therefore, this thesis aims to produce an inexpensive navigation service to assist BVI people in indoor environments using a combination of QR-code and long-range RFID. The system produced has two main tasks: first, it determines the current position of the user precisely and second, it guides the user to their desired destination.

To achieve the first task, the system uses QR-code or RFID technology as discussed in the previous chapter. The advantage of RFID is that it works independently and accuracy is increased when combined with QR-codes. The system detects a QR-code in the surrounding area, estimates accurately the distance to that code and finally scans (decodes) that code and reads the embedded position information. In the case of failure to detect the QR-code for any reason, the system is able to indicate the current position of the user based on determining the nearest RFID tag.

6.2 Infrastructure Design

The proposed integration system based on RFID and QR-code is shown in Figure 1.2. The RFID device was carefully chosen because it has many advantages, such as a wide range up to 70 m, omnidirectionality, reader mobility, and Bluetooth and USB
interfaces. Also, QR-code is an inexpensive technique and treats the orientation limitation of RFID technology by indicating the orientation of the user to increase the benefit and accuracy of the navigation system.

All QR-codes and RFID tags were distributed at known locations, which were included in the database belonging to a particular building. Each tag identifies a specific location such as an office, toilet, lift, entrance or exit. The height of the QR-codes from the ground was 1.8 m and the height of RFID tags was approximately 2 m, on wooded doors in most cases, as shown in Figure 6.1. Tags were also deployed in the corners of the building to serve as indicator tags. The purpose of these tags was tracking and detection of deviation as explained in detail in the following section. The RFID tags were classified as either identification or indicator tags.

Figure 6.1: The RFID components (test set showing mobile reader and a tag above the door) and concept design
6.3 Methodology and Algorithms

It is assumed that when the user enters a building, their mobile device is provided with positioning information for that building using any available communication method, which may be WiFi or Bluetooth. A description of this task was omitted from this thesis because it is not the focus. Instead, an XML file was used in the database to position the Distributed Systems and Networking research group at RMIT University, where the initial experiments were conducted (see Figure 6.2).

6.3.1 Data Required for the Trip

As shown in Figure 6.3, the proposed navigation system requires two specific data points to generate the suggested path: the starting point and the destination. The starting point, indicated using the current position algorithm, is based on decoding a QR-code or using the closest RFID tag algorithm, summarised in Algorithm 3 (and described in the following section). The destination is recognised based on the user’s speech, and then transformed from voice to text and processed by the system.
6.3.2 Current Position Algorithm

To indicate the user’s current position, the system determines which tag is closest to the user. The system assumes that the user is located in a position near the closest tag to them. The positioning data of the closest tag, rather than the user’s actual position, can then be used because the relative localisation data are sufficient in this scenario.
6.3.3 Shortest Path Algorithm

After the preferred path is indicated by a user, the shortest path is calculated based on the Dijkstra algorithm (Dijkstra 1959), and the waypoints from the starting point to the destination are determined including the source indicator tag and the destination indicator tag. The waypoint represents the point at which the user takes a navigational action, such as a left or right turn.

6.3.4 Error-detection Algorithm

An inverse relationship between distance and RSS has been used in this research. The source and destination indicator tags are used for tracking purposes; therefore, the RSS that belongs to a source indicator tag should decrease during the trip (as shown in Figures 6.6 and 6.7). This is because the distance between the RFID reader carried by a user and the source indicator tag will have increased. The signal that belongs to the destination indicator tag should also increase synchronously. Therefore, an error may be detected in four ways as shown in Algorithm 4: first, if the signal belonging to the source indicator tag did not decrease; second, if the signal belonging to the destination indicator tag did not increase; third, if any unexpected tags were detected (unexpected tag refers to any tag other than the waypoints); and finally, if users are absent from the range of a waypoint at the expected time. In this case, after a certain time an error returns and the system tries to find out where the user is located, based on speed factors.

---

**Algorithm 3 Determination of Closest Tag**

1: {estimation the current position by indication the closest RFID tag}
2: for range = 1 to range = 8 do
3:     stop the reader
4:     Clear the detected tags list tagList.Clear
5:     adjust the range of the reader belong to the current range
6:     Run the reader
7:     tagList ← detectedTagsRSS
8:     if only one tag detected then
9:         closestTag ← detectedTagRSS
10:    else
11:        Find the closest tag which belongs to highest RSS
12:    end if
13: end for
14: {or estimation the current position by decoding QR-code in surrounding area}

---
and the length of the segment.

Figure 6.4: The connections and distance between nodes belonging to the map shown in Figure 6.2

Algorithm 2 Error Detection
1: \([\text{SrcIndID}, \text{ArrayOfIDsOfWayPoints}, \text{DestIndID}] \leftarrow \text{GetTripDATA()}
2: \text{repeat}
3: \quad \text{UpdateTagIndicatorData each 3 Sec}
4: \quad \text{SrcIndRSS}\_\text{previous} \leftarrow \text{SrcIndRSS}\_\text{current}
5: \quad \text{DestIndRSS}\_\text{previous} \leftarrow \text{DestIndRSS}\_\text{current}
6: \quad \text{if SourceIndRSS is increasing then}
7: \quad \quad \text{return ERROR and calculate alternative route}
8: \quad \text{else if DestIndRSS is decreasing then}
9: \quad \quad \text{return ERROR and calculate alternative route}
10: \quad \text{else if UnexpectedTag is detected then}
11: \quad \quad \text{return ERROR and calculate alternative route}
12: \quad \text{else if Reader not in the expected range on time then}
13: \quad \quad \text{return ERROR and calculate alternative route}
14: \quad \text{else}
15: \quad \quad \text{keep going to the destination}
16: \quad \text{end if}
17: \text{until Reach Destination Or Error occurred}
6.3.5 Route-tracking Algorithm

The proposed system provides a tracking service to users as shown in Algorithm 5, assisting them to reach their desired destination by providing them with navigational voice instructions. If an error occurs, the system recognises this and recalculates an alternative path based on the user’s current position. As mentioned in the previous section, error detection is based on tag indicators, expected waypoints and estimated time to reach each waypoint for each segment of the trip. The estimated time to reach each waypoint is based on speed and distance between a pair of waypoints in the suggested path. According to LaPlante and Kaeser (2007), the walking speed for pedestrians is 3.5 ft sec\(^{-1}\), or 1.06 m sec\(^{-1}\). Therefore, the required time is estimated based on Equation 6.1:

\[
time_{\text{required}} = \text{SpeedFactor} \times \text{Distance} \tag{6.1}
\]

<table>
<thead>
<tr>
<th>Algorithm 5 Route Tracking</th>
</tr>
</thead>
<tbody>
<tr>
<td>1: SpeedFactor (\leftarrow) 1.06 INITIALIZE();</td>
</tr>
<tr>
<td>2: ([\text{Source, Destination, Distance, Direction}] \leftarrow \text{GETTripData}());</td>
</tr>
<tr>
<td>3: repeat</td>
</tr>
<tr>
<td>4: (\text{intSrc} \leftarrow \text{Source});</td>
</tr>
<tr>
<td>5: (\text{intDest} \leftarrow \text{Destination});</td>
</tr>
<tr>
<td>6: (\text{intDistance} \leftarrow \text{Distance});</td>
</tr>
<tr>
<td>7: (\text{intDirection} \leftarrow \text{Direction});</td>
</tr>
<tr>
<td>8: {Estimate time to reach the next waypoint};</td>
</tr>
<tr>
<td>9: (\text{timeToNextWayPoint} \leftarrow \text{intDistance} \times \text{SpeedFactor});</td>
</tr>
<tr>
<td>10: (\text{timervalue} \leftarrow \text{timeToNextWayPoint});</td>
</tr>
<tr>
<td>11: (\text{timer.Enabled();});</td>
</tr>
<tr>
<td>12: (\text{timer.Start();});</td>
</tr>
<tr>
<td>13: run closest tag Algorithm 3 after expected time</td>
</tr>
<tr>
<td>14: return (closestTagcurrent);</td>
</tr>
<tr>
<td>15: if closestTagcurrent (==) intDest then</td>
</tr>
<tr>
<td>16: {go to next segment if any left and repeat the step};</td>
</tr>
<tr>
<td>17: if nextNode (\neq) Null then</td>
</tr>
<tr>
<td>18: node (\leftarrow) nextNode</td>
</tr>
<tr>
<td>19: else</td>
</tr>
<tr>
<td>20: Destination Reached</td>
</tr>
<tr>
<td>21: end if</td>
</tr>
<tr>
<td>22: else</td>
</tr>
<tr>
<td>23: return ERROR Occurred;</td>
</tr>
<tr>
<td>24: break;</td>
</tr>
<tr>
<td>25: end if</td>
</tr>
<tr>
<td>26: until There are no segments remaining in the path</td>
</tr>
</tbody>
</table>
Figure 6.5: The indicator tag scenario. The first segment is from office 18 to the entrance and the second segment from the entrance to office 33.

Figure 6.6: The received signal strength belonging to indicator tag star1 and tag star2 in Figure 6.5 when the movement was from star1 towards star2. The upper figure represents the source indicator tag (star1 signal) and the lower figure contains signals belonging to the destination indicator tag (star2).
Figure 6.7: The received signal strength belonging to indicator tag star1 and tag star2 in Figure 6.5 when the movement was from the entrance (star2) towards Office 018 (star1). The upper figure represents source indicator tag (star2) and the lower figure contains signals belonging to the destination indicator tag (star1).

6.4 Indoor Navigation Test

The proposed system aims to provide navigation service to assist BVI people. Throughout this research, the system produced was evaluated for three parameters: reliability of shortest path prediction, evaluation of indicator tag technique and accuracy of positioning. Features such as voice recognition are used to recognise the user’s desired destination and instructions can then be transferred into text for use in the programme. The calculated path shown in Figure 6.8 can be used by the visually impaired, and voice instructions can guide blind users to their destination. As described in the interface in Figure 6.8, there are three buttons, indicating ‘Where am I?’; ‘What is my exact location?’ and ‘Go To’. These buttons have been designed to work by touching them or by voice commands using voice recognition. ‘Where am I?’ is used to activate the closest tag algorithm and identifies the user’s current location, which would be activated when the user touches that button or says ‘my position’. The second button ‘What is my exact location?’ feature calculates the coordinates of the estimated location of the user using the coordinate system of the XML file and downloaded map. This feature is more suitable for navigation in outdoor environments. The purpose of the ‘Go To’ button is to calculate the preferable shortest path to the user’s selected destination.
Figure 6.8: The interface of the indoor navigation system programme: in this sample, the current position was room 18 and the destination was room 33, so the instruction was ‘please turn left then walk for 11 steps to find the entrance facing you’ as the first segment.

6.4.1 Reliability of Shortest Path Prediction

This navigation system guides users through the preferable shortest path, which is calculated using the Dijkstra algorithm (Dijkstra 1959). In Figure 6.9, the dashed line represents the generated path and the solid arrows represent another longer path. The components Dijkstra requires to generate the shortest path are start point, nodes (called here waypoints) shown in Figure 6.4, distance between nodes and destination. All data are included in the database as an XML file (see Figure 6.10) provided to users upon entry to the building. The starting point represents the current position, which is indicated by using the closest tag algorithm or by decoding the closest QR-code, and the desired destination is determined by the user. In-between nodes and distances are extracted from the database and the connection distance represents the weight used by the Dijkstra algorithm to vote among available routes. Figure 6.10 shows part of the connections between nodes in the XML file. When the starting point is identified successfully, the system is capable of producing the shortest path 100% of the time. The current position of the user may be mistakenly indicated as a result of interference from signals from RFID tags. To avoid this kind of error, the minimum distance between each pair of tags should be >2 m. This measurement represents the average of the
narrowest range of the RFID reader. Also, by integration of QR-codes in the positioning system, this kind of error has been completely avoided.

Figure 6.9: The interface of the indoor navigation system programme. The dashed line represents the generated path calculated by the system using the Dijkstra algorithm (Dijkstra 1959), the solid arrows represent another path for the same start point and same destination, which was ignored because it is longer

```xml
</assets>
<directions>
<path source="00251613" destination="00251609"
    direction="turn right then walk 9 steps then find next tag on left side"
    distance="9"></path>
<path source="00251609" destination="00251613"
    direction="turn left then walk 9 steps then find next tag on right side"
    distance="9"></path>
</directions>
</taggroups>
</RFTrack>

Figure 6.10: An excerpt from an XML file showing typical directions between nodes
6.4.2 Indicator Tag Scenario Test

The proposed system uses RFCode, the RFID device used for navigation purposes by researchers such as Ruiz et al. (2012), who found a strong relationship between RSS and distances of up to 12.5 m, as this result confirmed in our experiments which presented in Figure 4.16. Therefore, this feature has been used in the system proposed here for early error detection. To evaluate the efficiency of the error-detection algorithm based on the indicator tag technique, two tags (represented by star1 and star2 in Figure 6.5) were distributed in the corners. The signals transmitted by these tags were then used for error detection and tracking of the user. In the first case, the user walked from tag star1 to tag star2. In this instance, tag star1 represented an indicator source tag and its signals (shown in the upper part of Figure 6.6) decrease in almost all cases. Tag star2 represents destination indicator tag and the signals from that tag increased (as shown in the lower part of Figure 6.6) because the reader was moving towards it and the distance between the reader and that tag decreased. This experiment was repeated 10 times and three readings were taken for each tag each time. To confirm the results, the experiment was repeated with the same tags moving in the opposite direction, from star2 towards star1. In other words, tag star2 represented the source indicator tag and tag star1 represented the destination indicator tag. The signals for this experiment are shown in Figure 6.7, with the signals from tag star2 decreasing and those from tag star1 increasing. A success rate >90% was achieved.

As shown in Figure 6.5, the black rectangles represent identification tags and the stars represent indicator tags. All tags are the same but they have been classified based on their purpose in the system, where each identification tag identified a particular position and indicator tags were used for error-detection purposes. Identification tags were deployed on the doors of the offices and the indicator tags were distributed in the corners. Once the user starts moving towards their destination, the system analyses the signals from indicator tags. For each segment of the path, the system concentrates on the signals of the source and destination indicator tags to detect a wrong path from the first metre. According to Algorithm 4, when the user walks on the track correctly, the signal belonging to the source indicator tag should decrease and the signal of the destination indicator tag should increase (as shown in Figures 6.6 and 6.7). As a case study (see Figure 6.5) the user moved from office 18 to office 33, so the starting point is office 18.
and the destination is office 33. The shortest path contained two segments: the first from office 18 to the entrance, and the second from the entrance to the destination. At the first segment in this example, the source indicator tag was the tag represented by star1, and the destination indicator tag was the signal belonging to tag star2, in the opposite corner. Figure 6.11 illustrates the behaviour of these signals. At the second segment of the same example, the source indicator tag became the tag that was represented by star2 and the destination indicator tag was the tag represented by star4. Figure 6.12 shows the signal of these tags when the user was in the second segment, where the dashed line represents the destination indicator tag signal for both segments in Figures 6.11 and 6.12.

![Figure 6.11: The dashed line represents the signal belonging to the destination indicator tag (star2) and the solid line represents the source indicator tag (star1) of the first segment in the path shown in Figure 6.5](image)

6.4.3 Accuracy of Positioning Test and Justification

One of the features of the RFCode reader is that it can change its range via eight pre-programmed ranges. The highest width of the narrowest range is 1.5–2.5 m, so to get a higher level of accuracy the distance between each pair of RFID identification tags should be at least 2 m, and the maximum distance between each pair of RFID indicator tags should be 12 m, to get a meaningful RSS for tracking and error-detection purposes. Each position on the map should be identified by one identification RFID tag and one QR-code that includes a unique ID.
6.5 Summary

This chapter presented a new technique to assist BVI people to reach their destination in indoor environments using an integrated system of QR-codes and wide-range active RFID technology. Three algorithms—positioning, error detection and tracking—were presented. The accuracy of positioning using RFID was around 2 m and this error disappeared almost completely following integration of QR-codes. The new error-detection technique reached a success rate of >90%, detected errors as they happened and helped the system to reroute the user using alternative paths to their desired destination. The proposed system has a tracking feature based on sensing the user’s current position and providing them with a voice navigational instruction after they reach the next waypoint on the shortest calculated path. This instruction is based on an estimate of the time required to reach a point at walking speed.

Further, the proposed navigation system enables the user to select their preferred path, for example, when their destination is on another level the system may ask the user the following question: ‘Do you want to avoid stairs?’, if there is a lift available in the building.
One kind of error explored in the study concerned misidentification of the user’s position. This error may occur if there are two RFID tags very close together. To avoid this problem, it is suggested to distribute RFID tags with at least 2 m between each pair, and further accuracy of positioning has been achieved with the integration of QR-codes, which also solved the concern of orientation of the RFID system used.

The navigation system was implemented and reached a very high rate of success in generating the shortest path in indoor environments. Therefore, for evaluation purposes the system was implemented and tested in a real environment on real BVI participants, with highly satisfactory results as presented in the following chapter.
Chapter 7: Blind User Response to NAAB

In Chapter 6, the navigational system (NAAB) was presented. The system was built upon two technologies: RFID tags and QR-codes. It was tested by sighted people and reached a high level of satisfactory results identifying the current position of the user with an accuracy of less than 2 m in most cases, and guiding users safely to a desired destination. The new positioning technique is based on line-of-sight QR-code detection, and non-line-of-sight signal attenuation of active RFID tags using a wearable reader. The aim of this chapter is to present some user feedback from the perspectives of blind people. A significant outcome of the usability test on blind participants presented herein is that the system has to work in an integrated manner in order to achieve the requirements of users.

7.1 Introduction

The purpose of usability testing is to contribute to the production of a more usable navigation system for blind people. The developed system aims to guide blind people and assist them to reach their desired destinations. Therefore, the aims of this test are to discover the limitations of the system from the perspective of blind users and to evaluate the satisfaction of real users in relation to the developing navigational system.

One of the most significant rehabilitation steps for people who have recently become blind, or have low vision, is for such people to regain their ability to navigate and react to their immediate environment independently and therefore to feel that they are in control again (Science Daily 2007). It was this that motivated the development of a system using both line-of-sight and non-line-of-sight technologies to give the user both passive and active feedback about their position. The scenario for the proposed system is summarised in Figure 7.1, where the cubes represent the hardware components—active RFID, QR-code and Kinect—and the rounded rectangles represent the main service algorithms of the system. The navigation process follows three steps: (1) the system indicates the initial position of the user as a start point using an RFID algorithm based on the technique of attenuation control; (2) the user is recommended to scan the
surrounding area using a camera to detect QR-codes using a built-in QR-code reader application; and (3) the navigation application determines the most preferable route for the user and then starts providing voice instructions. Route calculation is based on Dijkstra’s (1959) algorithm, which identifies the shortest path between two points (the current position and the destination).

Figure 7.1: The scenario of the proposed navigational system

The system was described in detail in Chapters 4, 5 and 6 and initial testing was performed in the office area shown in Figure 6.2. The system achieved highly successful results in identifying the current position of the user and guiding that user to various destinations within the domain shown in Figure 6.2. Therefore, the author was enthusiastic about applying the system on real blind participants, and this represents the second stage of usability testing. Human Ethics approval for this part of the study, to be conducted on real blind subjects in Saudi Arabia, was provided by RMIT. The participants were eight completely blind male students between 17 and 20 years of age. The path was established in an indoor school gymnasium, and QR-codes were printed
on A4-size paper and attached along with RFID tags, on pillars at various points in the room (see Figure 7.2 and Figure 7.3. The distance between each pair of pillars was measured and the system adapted for that environment. All tests were conducted during a school day in a real-life scenario. Participants were asked to carry a laptop and to hang the RFID reader in their pocket. Figure 7.4 shows one participant in the experiment navigating following NAAB instructions.

![Figure 7.2: The positions of pillars where RFID tags and QR-codes were distributed and used for usability testing purposes during the second stage of testing](image)

![Figure 7.3: The RFID tags and QR-codes in the school where the usability test was conducted](image)
7.2 Related Work

Many navigational technologies have been developed to aid BVI people (e.g. Balakrishnan et al. 2005; Calder 2009; Choudhury et al. 2004; Nagarajan et al. 2004; 2002; 2003; Xia et al. 2011; Wong et al. 2003). Much research has been conducted into computer scene understanding at both a low and high level, using many individual modalities such as the navigation tool proposed by Mihajlik et al. (2001), which is based on connecting sound generation to a navigation system using a digital signal processor, and ultrasonic echolocation, which has been applied successfully in mobile robots with a 3D sound-generation technique. Another attempt presented by Balakrishnan et al. (2005) is ETAs. An ETA is similar to Mihajlik’s device in that both use ultrasonic waves to detect obstacles, but ETAs aim to identify objects specifically for visually impaired users. Later research by Nagarajan et al. (2004) investigated a vision sensor camera to capture images and then process these images and convert them to sound. Most of this research has used a grey-level technique to identify objects in images—the NAVI system (Nagarajan et al. 2004) being a well-known example of this approach.

7.3 Planning the Test

Requests from participants have been designed considering a simple task such as walking from point 2 towards point 3 along the same line as shown in (A) in Figure 7.5,
to more complex tasks: for instance, navigating from point 9 to point 2, shown in (E) in Figure 7.5. This concept was used to give the participants the chance to become more familiar with the system. It is believed that training on the system is a necessary requirement for new users to enjoy its full benefits.

![Figure 7.5: The test routes from the simple ‘A’ to more complex ‘E’](image)

Participants were asked to undertake the following tasks:

- Identify their destination. As shown in Figure 7.6(A), low-vision people may be able to indicate their destination by clicking the ‘Go To’ button, but a voice recognition feature has been added to the system so that blind people can communicate their desired destination via verbal commands.

- Make an error. Each participant was asked to commit a deliberate error, such as turning left instead of following instructions from the system to turn right. The purpose of this was to evaluate the error-detection feature as shown in Figure 7.6(C), and to test the ability of the system to recalculate an alternative path to guide the user from their current incorrect location back to their target destination successfully.
• Recognise when they have arrived, by seeing or hearing the message shown in Figure 7.6(B).

• Apply the QR-code navigation system alone. Each participant was asked to walk to five different destinations using the QR-code alone, by pointing the camera in the right general direction.

• Apply the RFID navigation system alone. Each participant was asked to do the test again using just the RFID technology, where pointing was unnecessary, but location was slightly more error prone.

• Apply the integrated system of RFID and QR-code to do the test again and navigate towards a variety of destinations.

• Answer eight questions regarding usability of the system.

![Figure 7.6: Interface of the navigation programme, where A represents the start interface, B represents the final stage when the user reaches the destination successfully, and C represents an error-detection feature](image)

7.4 Reporting Results

After participants completed the requested navigational tasks, they were asked to answer questions described in the following sections.
7.4.1 Trust in the System

The average confidence in reaching destinations by using the navigation system with QR-codes alone was 3.875 out of 5, which increased using the RFID system to 4.25 out of 5. The average trust was 4.75 out of 5 using the integrated system as shown in Figure 7.7. Half of the participants were more trusting of the RFID system to help them reach their destination. Three participants trusted the RFID and QR-code systems equally and only one participant preferred the QR-code over the RFID system. An integrated system was more trusted by most participants.

![Figure 7.7](image)

**Figure 7.7: Q1 Do you feel that you were guided well to reach the destinations?**

Grading 1 (Unsatisfactory) to 5 (Excellent)

7.4.2 User Tracking During the Trip

The system estimates the required time to reach each waypoint in a trip to track the user for error-detection purposes. The required time is calculated based on a standard walking speed of approximately 1 m sec$^{-1}$ as confirmed by LaPlante and Kaeser (2007). The average satisfaction with the required time calculation method was similar for QR-code, RFID and the integrated system where the average overall was ~4 out of 5, as shown in Figure 7.8.
7.4.3 Error Detection and Path Recalculation

This question relates to the error-detection feature and enabled an examination of the degree to which participants believed that the system was able to recalculate an alternative path to guide them to their destination. As shown in Figure 7.9, the average satisfaction of participants regarding the QR-code system was 3.375 out of 5 and the average level of satisfaction increased with the RFID system to 4.25 of 5. Using the integrated system, satisfaction increased to 4.75 out of 5 for error detection and successful rerouting of participants to their destinations.

Figure 7.9: Q3 When the programme told you there was an error, did you understand what the system asked you to do next (1=not at all, 5=very much)?
7.4.4 The Importance of Training

Almost every participant gave a score of 4 or 5 out of 5 regarding the benefit of training on the system. All participants believed that training is required and helpful for the systems (QR-code, RFID and integrated) so they gave the same scores for all systems regarding this question, as shown in Figure 7.10.

Figure 7.10: Q4 Do you feel you got more confident using the system over time (1=not at all, 5=very much)?

7.4.5 Requirements for Improvement

After participants performed all tasks they were asked: ‘Can you suggest any improvements?’ Most suggestions were with respect to voice instructions, in terms of language and volume level. Around one-third of the participants preferred to hear Arabic instructions, and three-quarters of participants found it difficult to hear the instructions because of the background noise in the school.

7.4.6 Satisfaction Regarding Mode of Instruction

The instructions were the same for all designs of the system (QR-code, RFID and integrated) so all participants gave the same score for their levels of satisfaction regarding the way in which the instructions were delivered to them: only two participants gave 1 of 5 regarding the way of instructions as shown in Figure 7.11, which means that participants were relatively dissatisfied with the mode of instruction.
It is believed that language and volume level were mainly responsible for this lack of satisfaction.

![Graph showing satisfaction levels for different systems](image)

**Figure 7.11: Q6 Do you believe that the instructions the system provides need to be improved (1=Happy with it, 5=Much improvement needed)?**

### 7.4.7 Perspectives of Participants Regarding RFID, QR-code and the Integrated System

Three of the participants preferred to use the RFID navigation system. In contrast, all other participants believed that the integrated system (RFID + QR-code) was more beneficial and useful for them (see Figure 7.12). All participants reported that using QR-code by itself was difficult compared with the integrated system, so none of them preferred the QR-code navigation system. Also, in responses to Q1 we found participants trusted RFID and the integrated system more than QR-code. Therefore, circles around QR-codes were added to make them easier to detect from a greater distance.
Figure 7.12: Q7 With which of the systems are you more comfortable: the QR-code system or the RFID system? Or do you prefer both of them? Why?

7.4.8 Preferred Application Method

As shown in Figure 7.13, two participants hoped to use this navigation system and receive the navigational instructions via spectacles or headphones. The other participants preferred to have this navigation system installed as an application on their smartphones.

Figure 7.13: Q8 If we turned this system into a product that you can buy, would you prefer it as a mobile phone app or as spectacles that can speak into your ears?

7.5 Summary

The chapter presents a user test of a designed navigational system based on active RFID technology and QR-codes. The system has been tested in two stages: first by sighted people for debugging purposes and secondly by blind people for usability. With respect
to the results of the usability test, the majority of blind participants preferred to use an integrated system of RFID and QR-codes. Because the active RFID system works independently, its accuracy is less than 2 m and its range is up to 70 m, to increase precision of positioning information the user needs to start scanning in that 1-m area to detect QR-codes, which are very difficult for the blind to detect without the assistance of RFID. Therefore, from a blind user’s perspective, RFID has the advantage that it works independently and the advantage of QR-code is that it makes users more confident and gives them trust in the system that includes QR-codes. Hence, most participants believed that the integrated system provides higher precise navigational instructions to them.
Chapter 8: Additional Services to NAAB

Previous chapters presented positioning and navigation services to assist BVI people. The positioning service presented in Chapters 4 and 5 aims to assist BVI people to indicate their location. The navigation service presented in Chapter 6 aims to produce a navigation system (NAAB) designed to guide BVI users to their desired destination. Blind users’ perspectives regarding NAAB were presented in Chapter 7.

8.1 Introduction

The purpose of this chapter is to introduce further services to the navigation system presented in the previous chapters. This chapter consists of two parts: the first part presents a service to help BVI people to cross streets safely; and the second discusses how to detect obstacles in front of blind users, predict paths of these obstacles to determine which ones may intersect the path of the user, and then warn the user about it. Therefore, what distinguishes this service from other obstacle-avoidance systems is that it notifies BVI users only about obstacles that may intersect their path, rather than informing users about all obstacles ahead of them. The advantage of this algorithm is that it reduces the amount of information that BVI users receive, particularly in a crowded environment.

8.2 Crossing Streets Safely

The aim of this technology is to present a service for BVI people to assist them to cross the street independently. The presented approach provides the user with significant information such as detection of pedestrian crossing signals from any point of view, when the pedestrian crossing signal light is green, the detection of dynamic and fixed obstacles, predictions of the movement of fellow pedestrians, and information on objects that may intersect the user’s path. The approach is based on capturing multiple frames using a depth camera attached to a user’s headgear. This section discusses the efficiency of using the SURF algorithm for object recognition for the purposes of blind people assistance. The system predicts the movement of objects of interest to provide
the user with information on the safest path to navigate and information on the surrounding area. Evaluation of this approach on real-sequence video frames resulted in 90% detection of human obstacles and more than 80% for other related objects.

8.2.1 Overview and Basic Concept

The provided system components are Kinect and GPS. Microsoft’s Kinect sensor is attached to a helmet, the power is supplied by a battery pack and the Kinect sensor is connected to a laptop for the processing task. Kinect was chosen because it provides two kinds of calibrated images as shown in Figure 8.1: a depth image and a colour image. Depth images contain a grey level, which represents the distance between objects and the Kinect sensor. Using the Microsoft-supplied API, there is a linear inverse relationship between the value of pixels as a grey level and the estimated distance, where darker objects represent objects that are further from the camera, and lighter objects represent those closer to the camera. Using Kinect the system can reach %98.4 accuracy of objects detection as confirmed by Xia et al. 2011. The system could be can estimate the distance between the camera and the object with high accuracy.

![Figure 8.1: Colour and depth image from Kinect](image)

8.2.2 The System

The system aims to assist BVI people to cross the street safely. It guides a user to the closest pedestrian signal using GPS then guides them to the exact location of a pedestrian crossing signal using the normal camera built into Kinect. The SURF algorithm (Bay et al. 2008) was chosen because it is invariant in scale and rotation. Figure 8.2 summarises the architecture of the system. It has been divided into part A as a preparation stage, and part B as the execution stage. The SURF algorithm requires target and model images to generate target models, which are used to detect target
objects in captured images. The final goal of stage A is to establish a list of target models that the system needs to load in order to identify its targets. Since target models can be location dependent, the system is able to obtain them from cloud-based services.

*Pedestrian Crossing Signal Detection*

After the GPS device guides a user to the pedestrian signal, the system guides the user to the precise location of the pedestrian crossing signal platform, so that they are ready to cross when the signal allows. To make pedestrian crossing signal detection successful from any presentation angle between 0 and 45°, a new model has been designed based on nine targets from different presentation angles. Along with the affine invariance property of the SURF algorithm (Bay et al. 2008), this provides a degree of pose independence to the recognition process.

![Figure 8.2: The system architecture](image-url)
Figure 8.3: Relationship between number of targets and percentage of successful matching

As shown in Figure 8.3, there is a positive relationship between percentage of successful detections of pedestrian signals and the number of target models, from one to nine. When 100 random frames were applied on one model, a positive match was achieved in only around 12% of cases. In contrast, when the number of used target models was increased to nine, the positive match rate jumped to 72.5%. Because the nine chosen models cover most presentation angles, the percentage of matching for more than nine models increased only slightly. A sample of experiments appears at Figure 8.4.

Figure 8.4: Steps of detection of a pedestrian crossing signal
Determination of Consent to Cross Street

When a visually impaired person wants to cross the street, they listen for the clicker sound emitted by many pedestrian crossing signals, which indicates when it is safe to cross the street. However, sometimes the noise of the city makes it difficult for the user to determine which clicker refers to which light, and sometimes they do not work at all. In addition, not all crossings have the clicker facility. The system described here can help the user in these circumstances, as it uses the clicker sound as secondary evidence for the light state. When a user is facing a pedestrian crossing, they will hear the crossing sound and the system will tell them whether the signal is green or not.

![Figure 8.5: Crossing signal models](image)

The system can distinguish the green signal from the red signal based on its colour and its template using the SURF algorithm, where the green signal uses a man with his legs apart (see Figure 8.5a) to represent a person walking and the red signal shows a man standing still (see Figure 8.5b). To detect the red man signal, the system removes all colour spaces except red then applies the SURF algorithm on that image. If the red man is not detected the same procedure is repeated with the green and green space. The results are shown in Table 8.1. In addition, to evaluate the ability of the system to distinguish between the green walking man (Figure 8.5c) and the green arrow (Figure 8.5d), the green template matching algorithm was performed on two kinds of image. The result is shown in Figure 8.6: the sum of squared differences for the green man signal is always less than the sum of squared differences for the green arrow. Less difference indicates a better match. The system was found to successfully distinguish the green man from the green arrow in all 15 random samples.
Figure 8.6: The red line represents the sums of the squares of the absolute differences between pixels in the images containing signals of the green man and the corresponding pixels in the green man model. The dashes represent the difference in degree of matching between the green man and green arrow models.

Table 8.1: Overall detection results

<table>
<thead>
<tr>
<th>Detection</th>
<th>Green man</th>
<th>Red man</th>
<th>Human head</th>
</tr>
</thead>
<tbody>
<tr>
<td>True positive</td>
<td>86%</td>
<td>82%</td>
<td>90%</td>
</tr>
<tr>
<td>True negative</td>
<td>95%</td>
<td>91%</td>
<td>–</td>
</tr>
</tbody>
</table>

Human Detection

After the system gives the user permission to cross, it provides information about surrounding objects. Humans were chosen in this case because they are the most common objects at a pedestrian crossing.

Using an approach similar to that of Xia et al. (2011), but using a SURF algorithm rather than template matching, the system detects humans based on a model of a head, as shown in Figure 8.7. This way a blind person can use other humans starting to cross the road as yet further verification. This was found to be an efficient method because head boundaries are similar in almost all people and do not differ between situations because the head boundary from the front is exactly the same as the head boundary from the back and sufficiently similar from the side. Around 90% successful detection in a 2-m range was achieved.
Figure 8.7: (a) Depth image, (b) edges detected using the Canny method, (c) after small objects are removed, (d) distance map of captured frame, (e) head template, (f) distance map of head template, (g) marked target

Prediction of Movement of Pedestrians

The objective of this research is to enhance the safety of visually impaired people in cluttered environments, in this case when they are crossing the road. Therefore, when the system detects objects (humans) in front of the user, it will predict the movement of these objects and notify the user when an object is blocking or may block their path. However, if the system notifies the user about all the objects surrounding him, this could be noisy. Therefore, the system is enabled to classify objects in front of the user into two types: objects that are coming towards the user and objects going away.

The system then provides the user with more information on objects coming towards them. The classification of objects in front of the user is done by tracking the 3D coordinates of an object’s (the head) location over time. When the Z distance becomes shorter, from frame to frame, this indicates that the object is approaching, and vice versa. Being provided with continuous information and unique sounds for each nearby object’s features, distance and movement, the user is relied on to classify and judge, for example, people moving with them across the road and people moving the other way.
Figure 8.8 shows the system test result for three people and successfully predicts and classifies their movements. The sound is based on this gradient and on object features.

![Graphs showing system test results.](image)

**Figure 8.8: Prediction of movement of surrounding objects: (a) distance of object from observer; (b) velocity**

### 8.3 Improvement of Object-avoidance Technique

There have been many portable navigation and obstacle-avoidance systems proposed for the blind over recent years, but they have generally assumed for simplicity that the obstacles are static. The system proposed here adds a vital feature by helping the blind user to avoid obstacles whose movement threatens to intersect their path; that is, to avoid collisions. Hence, the proposed service is a navigation system for the user that is able to include both fixed and moving objects. Moreover, the system has the ability to estimate the proximity of the user to other moving objects and tell them where they will intersect, in addition to identifying the user’s path. The proposed system is a gadget that provides 3D information: the Microsoft Xbox Kinect. The success rate of the new algorithm in indicating the possibility of intersection between moving objects and the blind user was 93.33%.

### 8.3.1 Background and Related Work

Evading obstacles is not a strange concept, so discussion about how to achieve this has occurred since the 1950s. Previous studies that have explored this field consider two
issues: blind people assistance and robotics. The focus of the current study is entirely on blind people. Helping blind people navigate on their own is a difficult task, especially bestowing the ability of avoiding obstacles in their surroundings. Some researchers have made inroads to reducing the associated distress (e.g. Innet & Ritnoom 2009; Song & Huang 2001). Innet and Ritnoom (2009) incorporated the IR sensor into the electronic white stick and Song and Huang (2001) fashioned an algorithm of optical flow approximation for real-time avoidance of obstacles. However, both these systems help the user to avoid all objects, whether or not they will intersect with them. Other researchers have utilised 3D information with the help of Kinect for obstacle evasion to help visually impaired people (e.g. Khan et al. 2012; Mann et al. 2011; Zollner et al. 2011). Zollner et al. (2011) suggested a system to detect objects and their position in front of the user, and also gauge the distance between surrounding objects and the user. Khan et al. (2012) proposed a similar service that can also detect precisely the position of detected obstacles. Of the three proposed systems (Khan et al. 2012; Mann et al. 2011; Zollner et al. 2011), none could distinguish objects that would intersect with the path of the user from those that would not. Since all of them try to help the users avoid close objects.

The aim of this study is to create a system that has the ability to detect obstacles ahead of the user and notify them about the objects that are most likely to intersect their path. This reduces the quantity of unwanted information provided to the user, based on technology (Kinect) that has previously been utilised and shown to work (Khan et al. 2012; Mann et al. 2011; Zollner et al. 2011).

**8.3.2 The System Scenario**

The Kinect sensor was selected on the basis of its valuable features. It has the ability to detect humans and provides both 3D and depth data views, as shown in Figure 8.9. Currently, the proposed scheme can distinguish a moving human ahead of the user as a priority object in motion within the user’s surroundings. When the project is completed in the future, it will be able to detect more kinds of obstacles.
As portrayed in Figure 8.10, detected people are categorised into two groups. The first is people who are not intersecting with the user’s path; hence, the user does not need information about them. As a result, the amount of information required by the user has been trimmed from the system. The user only receives information concerning people that will intersect with their path. In order to attain this goal, the system requires that it tracks the detected people to give an approximation of their paths, based on coordinates provided by Kinect.

By comparing the current location of the detected individual marked as A in Figure 8.11, with their subsequent location over time (noted as A–B, A–C, A–D, A–E, A–F and A–G) an approximation of their path can be made. As shown in Figure 8.11, when people move in a direction in the form of A–B, A–C, A–D, A–E and A–G, they will not traverse the path of the user. Therefore, the system will not notify the user even if they are close to them: for instance, in the case of A–F in the same illustration. Kinect offers 3D coordinates for the people detected: X, Y and Z. To approximate the path of a detected person, only X and Z are needed, where Z represents the distance between the user’s Kinect and the person. A positive X value symbolises the right side ahead of Kinect and negative X represents the left side of Kinect. When Z and X both approach zero, this implies that the person will transect the path of the user, otherwise they will not because they are moving away or are moving in a direction parallel to the user.
Figure 8.10: Object classification flow chart to inform users only about objects that may intersect their path

Figure 8.11: The field of view of Kinect is categorised into three ranges: DFR, RR and LR. The role of the proposed algorithm is to predict the paths of detected objects to identify those that will intersect the path of the user and inform the user about them. Using this technique, the system will produce an alarm about objects only with paths like A–F, to reduce the amount of unnecessary information the user receives
8.3.3 Proposed Moving-obstacle-avoidance Algorithm

The key notion of this algorithm is the detection of objects ahead of the blind user, tracking the path of different objects, and notifying the user of the objects that may intersect their path. The unique feature of the algorithm is cutting back the quantity of information the user receives. For example, if the object is ahead of the user and moving in a parallel direction, this implies that the object will not intersect and thus the system will not inform the user. Many previous studies have been undertaken in order to help blind people evade obstacles, but they all have the following restrictions:

- They aim to avoid fixed objects.
- They present the user with both wanted and unwanted information regarding objects ahead of them.

The suggested Algorithm 6 addresses these issues as follows. Kinect is designed to detect up to four persons, and assigns them X, Y and Z coordinates, where X is positive is the person is on the left side and negative if on the right side, of the user. Z values represent the space between Kinect and the person. Every second, Kinect produces 30 frames, so there will be 30 values for X and Z per person per second. The use of average values reduces the number of provided values. To predict the path of obstacles in front of the user, two values of X and Z were taken for comparison, as shown in rows 1 and 3 of Algorithm 6. As can be seen in Figure 8.11, Kinect’s field of view is divided into three parts. The first part is DFR, which has a width of 80 cm in the range of +40 to −40 on the X-axis. An object within this range has a high chance of intersection with the user unless the person is drifting away from the user’s path, which is denoted by the values of Z. If the obstacle is impending, the distance between Kinect and the obstacle will decrease, and vice versa. In order to provide the user with information in this area, two conditions must be met, as appears in rows 4 and 5 in Algorithm 6. Also, when the average value of X is out of DFR, the obstacle may intersect the path of the user when it meets the condition that appears in row 11 in Algorithm 6.
Algorithm 6 avoiding of moving obstacles

1: \( \text{Average}Z_1 \leftarrow \text{Average}ofZ(), \text{Average}X_1 \leftarrow \text{Average}ofX() \)
2: \{to track obstacles the values of X and Z reading again after short period\}
3: \( \text{Average}Z_2 \leftarrow \text{Average}ofZ(), \text{Average}X_2 \leftarrow \text{Average}ofX() \)
4: \textbf{if} \( \text{Average}ofX \) is in \( \text{DFR} \) \textbf{then}
5: \hspace{1em} \textbf{if} \( \text{average}valueofZ \) is decreasing \textbf{then}
6: \hspace{2em} Triggers an alarm and depicts the course and space to the user.
7: \hspace{1em} \textbf{else}
8: \hspace{2em} Ignorance of the obstacle.
9: \hspace{1em} \textbf{end if}
10: \textbf{else}
11: \hspace{1em} \textbf{if} both the average values of X and Z going towards zero \textbf{then}
12: \hspace{2em} Trigger an alarm and notify the user on the direction.
13: \hspace{1em} \textbf{else}
14: \hspace{2em} Ignorance of the object
15: \hspace{1em} \textbf{end if}
16: \textbf{end if}

8.3.4 Experiments and Evaluation

In order to assess the algorithm in the three experiments, 20 samples have been taken for each case.

Avoiding Obstacles in DFR

Table 8.2: Moving obstacle avoidance if the detected people were in DFR range

<table>
<thead>
<tr>
<th>True Positive</th>
<th>False Positive</th>
<th>True Negative</th>
<th>False Negative</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>0</td>
<td>10</td>
<td>0</td>
</tr>
</tbody>
</table>

The first experiment represents the detection of the object (a person) and its path prediction if the obstacle is within the DFR range. In this study, a person moved towards the Kinect 10 times, with the outcome noted in Table 8.2. The ‘true positive’ column shows the number of times the system succeeded in detecting the person and notifying the user. The second column represents the number of times it failed to notify the user about the person. Another 10 samples were conducted for a scenario where the person was within the DFR range, but was not facing the Kinect and was walking in a parallel direction, so that they would not intersect the path of the user. In this case, the system should detect that person but not notify the user about them. The results are shown in
the last two columns of Table 8.2: the number of times the person was detected and their path forecast correctly and the user was not notified about that person because the system recognised the person was leaving. In the first case, the success rate of prediction for a person in DFR was 100%.

**Prediction of Movement of Obstacles in RR**

**Table 8.3: Moving obstacle avoidance if the detected people were in RR range**

<table>
<thead>
<tr>
<th>True Positive</th>
<th>False Positive</th>
<th>True Negative</th>
<th>False Negative</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>0</td>
<td>8</td>
<td>2</td>
</tr>
</tbody>
</table>

The second experiment involved prediction of movement of an object (a person) detected within the RR. The person in motion in this location will either be facing towards the Kinect or away from it. The experiment assumes that a person located within the RR range but facing away from the Kinect will not intersect with the path of the user. However, a person facing the Kinect might intersect with the path of the user. The first and second columns of Table 8.3 represent the people that would intersect with the path of the user. The third and fourth columns represent the samples in which the system detected a person in the user’s path but did not give a warning. It achieved a success rate of 100% for predicting intersection, and an 80% prediction rate for people walking within the RR range but not intersecting with the path of the user.

**Prediction of Movement of Obstacles in LR**

**Table 8.4: Moving obstacle avoidance if the detected people were in LR range**

<table>
<thead>
<tr>
<th>True Positive</th>
<th>False Positive</th>
<th>True Negative</th>
<th>False Negative</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>0</td>
<td>8</td>
<td>2</td>
</tr>
</tbody>
</table>

The third experiment involved people detected within the LR, with the outcome achieved shown in Table 8.4.

The total success rate of avoiding obstacles was 93.33%, and produced the wrong
expectation only four times out of the 60 samples (see Table 8.5).

<table>
<thead>
<tr>
<th>True Positive</th>
<th>False Positive</th>
<th>True Negative</th>
<th>False Negative</th>
</tr>
</thead>
<tbody>
<tr>
<td>30</td>
<td>0</td>
<td>26</td>
<td>4</td>
</tr>
</tbody>
</table>

**8.4 Summary**

In this chapter, a new system was presented that aims to assist BVI people to cross the street safely. The proposed system detects a pedestrian crossing signal and together with the clicking emitted by the pedestrian crossing, this gives the blind user greater confidence at crossing signals. Further, it detects human objects, determines their movements and then notifies the user about those that may intersect their path.

The second part of the chapter presented and assessed an improved algorithm to avoid moving obstacles. That algorithm aims to detect obstacles in the trajectory of blind users and notify them only about obstacles that will intersect their path. This study presents an algorithm that helps BVI people to evade objects in motion using Kinect. The proposed algorithm is capable of predicting and tracking detected objects. Following the prediction paths for obstacles, the algorithm can distinguish between objects that may or may not intersect the path of the user. The major advantage of the suggested algorithm is that it provides the user only with useful information. In three experiments involving 60 samples, the algorithm achieved a success rate of 93.33% in object evasion and provided <10% of unnecessary information to the user. The path approximation for moving objects in Kinect’s surroundings achieved impressive results.
Chapter 9: Conclusions and Future Directions

9.1 Conclusions

The main goal of this thesis was to develop an integrated navigation system to assist BVI people to navigate independently in indoor environments. The proposed system consists of two main parts: positioning and navigation. The positioning system aims to indicate the current position of the user for two purposes: (1) to inform the user about their current position when needed, and (2) to indicate the current position of the user for tracking purposes, so that in case the user misses the suggested path the system can recognise this and consequently guide the user to an alternative path based on their current location. The navigation system is designed to guide BVI people to their desired destination. Finally, assistance for blind people to cross streets safely and avoid obstacles in their path has been added to the navigation system as further services.

9.1.1 An Integrated Positioning System

The proposed positioning system is based on integration of QR-code and long-range active RFID. A novel positioning algorithm was described in Chapter 4, based on a combination of RSS and attenuation control of the RFID reader; 1-m accuracy was achieved. Further, the system was built to assist blind people, so the design of the system considered blind user needs in all functions. For example, a feature to recognise verbal instructions was inserted into the system, and a limitation of the positioning system in terms of usability by blind users was discovered and resolved to increase the efficiency of the proposed system: orientation concerns with the chosen RFID system were resolved by integrating QR-code.

The RFID device was selected because it has important properties, such as long range (up to 70 m), omnidirectionality (it transmits in all directions), a mobile reader, and the ability to change its range by controlling signal attenuation of the reader. Due to this feature, the system can sort group of tags based on the distance between them and the reader where the reader represents the user’s position because it would be carried by the
user at all times. Although omnidirectionality is an advantage of the device because it increases the efficiency and usability of the system, this feature may cause misorientation concerns for blind users. Integration of QR-code to the proposed system resolved that concern and increased its accuracy.

9.1.2 An Integrated Navigation System

The positioning system presented in Chapters 4 and 5 was developed to apply in the navigation system presented in Chapter 6. The navigation system (NAAB) was designed to guide BVI users to their destination precisely via their more preferred route. For instance, if the destination is located on a different level of the building so that the user would have to use stairs or a lift to reach that destination, the system would ask the user to indicate their preferred mode and then would calculate the shortest path between the user and that destination based on the Dijkstra (1959) algorithm.

NAAB has a deviation-detection feature developed to explore the deviation from the first metre the user deviates from the suggested path based on active RFID tags called ‘indicator’ tags. These indicator tags are distributed in the corners to cover all corridors inside the building and are used as smart sensors that can estimate the direction the user proposes to walk and detect when the user goes the wrong way: successful results were achieved in this regard.

9.1.3 Usability Test

To ensure the usability of NAAB, various experiments were conducted with the help of eight blind participants. Each participant was asked to do the test three times, navigating first using QR-code, second using RFID and finally using the integrated system. They were also asked to commit a deliberate error to evaluate the deviation-detection algorithm. Two techniques were developed to detect the deviation: one based on the required time to reach each waypoint in a trip and the based on an indicator tag algorithm not included in the tests. Finally, participants were asked to answer eight questions via a questionnaire designed to improve the usability of the system: the analysis of their responses was presented in Chapter 7.
9.1.4 Street Crossing and Anti-collision

Chapter 8 presented two further services for BVI people: crossing the street safely and avoiding moving obstacles that may intersect with their path of travel.

NAAB can be summarised as providing four services to BVI users: (1) indicating their position; (2) directing them to a particular destination; (3) protecting them from any potential risk by predicting the paths of surrounding moving obstacles; and (4) assisting them to cross the street safely.

9.2 Future Work

Based on the theoretical and experimental work carried out during this research, it is recommended that further research should be done to improve the efficiency of NAAB to address the following points:

- The system should be produced as a complete package in one mobile device such as a smartphone, watch or helmet, not the multiple parts used in this thesis as shown in figure 1.1.
- In a crowd, only the author’s voice matters to NAAB but the voice recognition needs significant training. Therefore, simplify the voice recognition task to the user will be taken into account in future. Alternative user input methods should also be explored (such as haptic or touch based).
- The Hough circle-detection algorithm (Xu et al. 1990) has been used to detect QR-code easily from further distances. The circle would look like an ellipse at a narrow angle, so modifying the circle-detection algorithm to enable it to detect ellipses would represent a significant improvement to the system.
- Avoidance of obstacles should be generalised to avoid objects other than humans, as NAAB currently provides.
- It would be a significant idea to integrate a magnetometer to overcome the directional issues particularly when there is no QR code within scanning range.
- Because of the walking speed varies greatly from person to person, the system should take that into account as a significant improvement of the system.
Bibliography


G. Balakrishnan, G. Sainarayanan, R. Nagarajan and S. Yaacob 2005, ‘Stereo image to stereo sound methods for vision based ETA’, in 1st International Conference on


O. Cruz, E. Ramos and M. Ramirez 2011, ‘3D indoor location and navigation system
based on Bluetooth’, in 21st International Conference on Electrical Communications and Computers, pp. 271–277, IEEE.


visually impaired people’, in *34th Annual Conference of IEEE Industrial Electronics*, pp. 2982–2987, IEEE.

J. F. Oliveira 2013, ‘The path force feedback belt’, in *8th International Conference on Information Technology in Asia*, pp. 1–6, IEEE.


B. Prudhvi and R. Bagani 2013, ‘Silicon eyes: GPS–GSM based navigation assistant for visually impaired using capacitive touch braille keypad and smart SMS facility’, in *World Congress on Computer and Information Technology*, pp. 1–3, IEEE.


D. Wave 2010, QR-code features. QR-Code. Com, viewed 30 October 2014


Fourth International Conference on Information, Communications and Signal Processing, volume 2, pp. 734–737, IEEE.


