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A NEAR FIELD COMMUNICATION FRAMEWORK FOR INDOOR NAVIGATION: DESIGN AND DEPLOYMENT CONSIDERATIONS

by

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DECLARATION

I, Wilson Evuarherhe Sakpere, declare that the contents of this thesis represent my own unaided work, and that the thesis has not previously been submitted for academic examination towards any qualification. Furthermore, it represents my own opinions and not necessarily those of the Cape Peninsula University of Technology.

W.E. Sakpere	**28th September, 2015**
Signed	**Date**

ABSTRACT

Navigation systems are known to provide time and location information for easy and accurate navigation in a specified environment. While Global Positioning System (GPS) has recorded a considerable success for navigating outdoors, the absence of GPS indoors has made orientation in an indoor environment challenging. Furthermore, existing technologies and methods of indoor positioning and navigation, such as WLAN, Bluetooth and Infrared, have been complex, inaccurate, expensive and challenging to implement; thereby limiting the usability of these technologies in less developed countries. This limitation of navigation services makes it difficult and time consuming to locate a destination in indoor and closed spaces. Hence, recent works with Near Field Communication (NFC) has kindled interest in positioning and navigation.

While navigating, users in less developed nations face several challenges, such as infrastructure complexity, high-cost solution, inaccuracy and usability. However, this research focuses on providing interventions to alleviate usability challenges, in order to strengthen the overall accuracy and the navigation effectiveness in stringent environments through the experiential manipulation of technical attributes of the positioning and navigation system in indoor environments. Therefore, this study adopted the realist ontology and the positivist epistemological approach. It followed a quantitative and experimental method of empirical enquiry, and software engineering and synthesis research methods. The study entails three implementation processes, namely map generation, positioning framework and navigation service using a prototype mobile navigation application that uses the NFC technology. It used open-source software and hardware engineering tools, instruments and technologies, such as Ubuntu Linux, Android Software Development Kit, Arduino, NFC APIs and PandaBoard. The data was collected and the findings evaluated in three stages: pre-test, experiment and post-test.

Our approach and findings revealed that the capability of NFC in leveraging its low-cost infrastructure of passive tags, its availability in mobile devices and the ubiquity of the mobile device provided a cost-effective solution with impressive accuracy and usability. Based on the outcome of the positioning and navigation study with NFC, the positioning accuracy (i.e. the distance between the mobile device and the NFC tag) was less than 9 cm. The prototype navigation system used on an android emulator and a mobile device showed that the usability improved after the post-test from 44% to 96% based on the feedbacks given by respondents who tested the application in an indoor environment. Furthermore, the evaluation and findings in this work showed that NFC is a viable alternative to resolve the challenges identified in previous solutions and technologies.

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Now unto the King eternal, immortal, invisible, the only wise God, be honour and glory for ever and ever.

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DEDICATION

To the memory of my late father, Chief Lawrence Sakpere.

To my golden mother, Mrs Mary Sakpere.

To that person who has struggled through life with no one to lean on and yet believes in his/her ingenuity to overcome life's challenges; and did overcome.

This, is to you trio.

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LIST OF ABBREVIATIONS

Abbreviation	Clarification
ADT	Android Development Tools
AOA	Angle of Arrival
API	Application Programming Interface
CPU	Central Processing Unit
CSS	Cascading Style Sheet
DOLPHIN	Distributed Object Locating System for Physical-space Internetworking
DVI	Digital Visual Interface
EEPROM	Electrically Erasable Programmable Read-Only Memory
ETSI	European Telecommunications Standards Institute
GPS	Global Positioning System
GSM	Global System for Mobile Communications
HDMI	High-Definition Multimedia Interface
HF	High Frequency
HTML	HyperText Markup Language
HTTP	HyperText Transfer Protocol
I2C	Inter-Integrated Circuit
IC	Integrated Circuit
IDE	Integrated Development Environment
IMU	Inertial Measurement Unit
INS	Inertial Navigation Systems
IR	Infrared
ISO	International Organization for Standardization
JDK	Java Development Kit
JIS	Japanese Industry Standard
JOSM	Java OpenStreetMap
JVM	Java Virtual Machine
LCD	Liquid-Crystal Display
LED	Light-Emitting Diode
LF	Low Frequency
LLCP	Logical Link Control Protocol
LSB	Least Significant Byte
MSB	Most Significant Byte
NDEF	NFC Data Exchange Format

Abbreviation	Clarification
NFC	Near Field Communication
OS	Operating System
OSHW	Open-Source Hardware
OSM	OpenStreetMap
OSS	Open-Source Software
P2P	Peer-to-Peer
PC	Personal Computer
PCB	Printed Circuit Board
PCD	Proximity Coupling Device
PDA	Personal Digital Assistant
PICC	Proximity Inductive Coupling Card
PNG	Portable Network Graphics
QR	Quick Response
RAM	Random-Access Memory
RF	Radio Frequency
RFID	Radio-Frequency Identification
RSS	Received Signal Strength
RSSI	Receiver Signal Strength Indicator/Indication
RTD	Record Type Definition
SDHC	Secure Digital High Capacity
SDK	Software Development Kit
SMP	Symmetric Multiprocessing
SMS	Short Message Service
SPI	Serial Peripheral Interface
SRAM	Static Random-Access Memory
TCP	Transmission Control Protocol
TDOA	Time Difference of Arrival
TOA	Time of Arrival
TOF	Time of Flight
UHF	Ultra-High Frequency
UI	User Interface
UID	Unique Identifier
URI	Uniform Resource Identifier
URL	Uniform Resource Locator
URN	Uniform Resource Name

Abbreviation	Clarification
USB	Universal Serial Bus
UWB	Ultra-Wideband
Wi-Fi	*See WLAN*
WLAN	Wireless Local Area Network
XML	Extensible Markup Language

LIST OF PUBLICATIONS

The following publications have been peer-reviewed and published in a book chapter and a conference proceeding respectively.

1. Sakpere, W. E. & Adeyeye, M. O. 2015. Can Near Field Communication Solve The Limitations in Mobile Indoor Navigation? In Lee, I. (ed.). *RFID Technology Integration for Business Performance Improvement*, Hershey, PA: IGI Global: 52-79.

2. Sakpere, W. E. & Adeyeye, M. O. 2013. A Near Field Communication Framework for Indoor Navigation. In Volkwyn, R. (ed.). *Proceedings of Southern Africa Telecommunication Networks and Applications Conference (SATNAC) 2013*, Stellenbosch, 1-4 September 2013. 459-460.

If you get 1 out of 5 right then you must be brilliant. If you get them all right, it is probably because you are not being ambitious enough.

- Felipe Ortiz de Zevallos

CHAPTER ONE: INTRODUCTION

1.1 Introduction

With the advent of mobile devices, computing has become increasingly mobile, ubiquitous and context-aware (Aker & Mbiti, 2010; Reddy *et al.*, 2010). The mobile phone, including the Smartphone, is the most popular and widely used mobile device today (Oliver, 2009; Dinh *et al.*, 2013). By comparing contemporary analogue phones with limited audio exchange functionality in fixed locations, it was discovered that multi-functional mobile phones are fast becoming irreplaceable devices (Oliver, 2009; Reddy *et al.*, 2010; Dinh *et al.*, 2013). A Smartphone in particular has built-in computational applications and internet access, combining the features of a mobile phone and a Personal Digital Assistant (PDA), which can perform multi-functional tasks (Lane *et al.*, 2010; Dinh *et al.*, 2013). In addition to the audio exchange functionality, for example, a mobile phone enables a user to exchange video, pictures and textual data in the form of a short message service (SMS) and electronic mails (emails) (Ruggiero & Foote, 2011; Shearer, 2011:6-20; Narasimhan & Leblois, 2012). The mobile phone also enables the user to network over social media platforms, such as Facebook, Twitter, LinkedIn and other social media (Aker & Mbiti, 2010; Lane *et al.*, 2010; Reddy *et al.*, 2010).

Furthermore, the mobile phone is used by students and academia to collaborate on projects and assignments via voice calls, texts, messaging, conferencing and as a learning tool among students on campuses (Narasimhan & Leblois, 2012; Aker & Mbiti, 2010). The mobile phone has helped students to collaborate and carry out assignments using different learning applications, and by accessing the internet for information (Aker & Mbiti, 2010; Lane *et al.*, 2010). In addition, the mobile phone is used to listen to music and to watch videos for relaxation and pleasure purpose (Narasimhan & Leblois, 2012). The mobile phone can be used to locate a destination via a mapping application that would help students to navigate within the campus (Hansen *et al.*, 2013). The mobile phone has indeed become an important device for everyday activity.

However, these mobile devices can only function effectively within an ideal situation and environment (Aijaz *et al.*, 2013). For instance, communicating through voice and textual means is dependent on the availability of network (Aker & Mbiti, 2010; Dinh *et al.*, 2013). In addition, accessing learning environments online and downloading useful applications are dependent on network or Wi-Fi availability (ibid.). Likewise, using a mobile phone to navigate in an outdoor environment is dependent on uninterrupted access to satellite signals and network or Wi-Fi availability. In buildings where network or Wi-Fi availability is almost non-existent, users will find it difficult to do much on the mobile phone (Aijaz *et al.*, 2013). Such difficulties are mainly encountered in indoor environments, basements and underground environments of large buildings (Ozdenizci *et al.*, 2011). These difficulties make internet access and the use of certain applications challenging. Hence, the mobility and ubiquity of the mobile device has made it a popular personal device, which has many uses including navigation. Navigation in indoor environments, which is the focus of this study, has become as popular as outdoor navigation.

The rest of the chapter is organised as follows: Section 1.2 begins with the subject of this research in a context. This is followed by an overview of outdoor and indoor navigation in section 1.3. Section 1.4 explores the various technologies that have been used for indoor orientation. Section 1.5 presents the Near Field Communication (NFC) technology and how it may play a role in this research. Section 1.6 presents the statement of the research problem and a conceptualisation of the research problem of the study, while section 1.7 presents the research aim and objective. Section 1.8 delves into the research questions that this study will investigate, while section 1.9 presents the research approach of the study. The conceptual model, which shows the various variables of this study and the relationship among them, is discussed in section 1.10. Section 1.11 highlights various terms and concepts that are used prevalently in this thesis. This is followed by the structure of the thesis in section 1.12. Finally, the chapter ends with a summary and conclusion in section 1.13.

1.2 Framing the Context

As a central concept in networks technology, ‘navigation’ facilitates people’s movement from a departure point to a destination. Between departure and destination, a whole lot of activities take place. In navigation, three factors help in determining the successful orientation of an individual. They are the current position of a user (where am I?), the destination of the user (where am I going?) and the best path or route from the current position to the destination (how will I get there?). The succeeding story illustrates this succinctly.

> *Jake is new in Cape Town, South Africa. He has looked forward to being there for a while now. He will be resuming at the Cape Peninsula University of Technology (CPUT), Cape Town campus to study for his master’s degree. On his first day of school, he checked the location of the school on the google maps application on his smartphone. Taking a cab, he got to school without hassles. While trying to locate the department he was going to, he stopped someone and asked for directions. The person responded that he was new and therefore does not know*

> *the place. Fortunately, he asked a security personnel who was close by. The security personnel described the place and Jake set out to locate the department. After about seven minutes of trying to locate the place, he asked a fellow student nearby who told him that it is few blocks behind. He had missed the correct building. Becoming irritated, he went back. On getting to the building, he asked for the departmental office from a nearby student who described it to him. Finally, he located the department in which he was to resume.*

Many people go through this kind of scenario to locate a destination. The individual in question has to first understand, plan, and know the current position, the path or route, the process and the presumed destination. Then, the correct known information will help to locate the destination. Locating a destination is an activity we consciously and unconsciously engage in from day to day. Getting to that destination is dependent on knowing how to get there and how long it takes to get there, even when we find ourselves in a place we do not recognise or are not familiar with. This whole process is usually referred to as navigation.

1.3 Navigation

The word navigation has its root in Latin and is derived from the words 'navis' meaning ship and 'agere' meaning to drive, move or direct (Sonnenberg, 1988; Hofmann-Wellenhof *et al.*, 2011). The definition of navigation is as diverse as its activity. Sonnenberg (1988:42) defined navigation as, "the process of directing the movements of a vehicle successfully from one point to another." In Hoppen *et al.* (1990:950), navigation is defined as the movement of an object (car, ship, airplane or mobile robot) along the path of a navigation process from an actual position to a pre-defined goal in an unknown environment. Seo *et al.* (2006:247) defined navigation as "all the related theories and technologies for obtaining position, velocity and attitude of a vehicle". In addition, Hofmann-Wellenhof *et al.* (2011:2) noted that navigation deals with "moving objects (mostly vehicles) and involves trajectory determination and guidance". These definitions relate navigation to vehicles or objects and not humans.

Furthermore, Li and Tsuji (1999:686) defined navigation as "the process of determining and maintaining a course or trajectory from one place to another". Prasad and Ruggieri (2005:1) defined navigation as, "the process that drives a person during his or her movement between two points, enabling an ancient dream of the human race: the knowledge of position at any given time." Kaplan and Hegarty (2006:1) defined navigation as "the science of getting a craft or person from one place to another". Dodiya and Alexandrov (2008:171) defined navigation as "the process by which people control their movement using environmental cues and artificial aids such as maps so that they can achieve their goals without getting lost". In János and Matijevics (2010:319) and Santos *et al.* (2010:820), navigation is defined as the process or activity of accurately ascertaining one's position, planning a route and following that route within an unknown environment. These definitions took into account that humans and objects can be involved in the navigation process.

Gioia (2014:3) defined navigation as "the science of determining position and direction on and near the Earth surface". This definition does not take into consideration navigation in the sea, in the air and in space. However, certain points are common to all these definitions of navigation. They are determination of the initial position or departure point of the object or person, knowledge of the destination point of the object or person and, the information necessary to determine the best path or route from the initial position to the destination. These three points are the major determinants in navigation that must be taken into consideration before orientation may begin (Beecher, 2004). They help the traveller in arriving at the destination, and on time.

For the purpose of this study, navigation is defined as the process of successful orientation by a human, object or vehicle from a point of departure through a pre-determined and well-planned path or route to a desired or known destination in outdoor, indoor and even more challenged spaces without inhibitions or quality-loss.

1.3.1 Outdoor Navigation

In the general sense, navigation is an activity that dates back to as far as humans have been in existence (Prasad & Ruggieri, 2005; Grewal *et al.*, 2007). Originally, navigation was used to describe the movement of ships on sea (Prasad & Ruggieri, 2005). In modern times, it has included much more such as human, car, robot, airplane and spaceship navigation. The goal of navigation is to move from an initial position through a pre-determined path or route to a destination successfully (ibid.).

Early humans used natural landmarks and celestial elements like wind, mountains, trees, sun, moon and stars as guide while navigating on land and sea (Beecher, 2004; Titterton & Weston, 2004). These elements helped them to calculate and determine their movement eastwards, westwards, southwards or northwards. Travelling on sea was a major means of navigation in ancient times. In the 15th century, Christopher Columbus did his explorations by travelling mainly on sea using celestial elements, and navigation maps and tools (Prasad & Ruggieri, 2005; World Book Inc., 2013). The use of maps and charts evolved from celestial elements when people began to draw landmarks to keep detailed records for directions (Titterton & Weston, 2004; Prasad & Ruggieri, 2005). Over time, tools that helped in achieving a more accurate navigation timing were developed. They include the hourglass, cross-staff, astrolabe, sextant, quadrant and compass among others (World Book Inc., 2013). The use of these tools evolved as the methods of navigation evolved.

The introduction of air navigation brought new challenges with it (Hofmann-Wellenhof *et al.*, 2011). Locating a position in the air was more difficult than on land, which could lead to an aircraft getting lost (Prasad & Ruggieri, 2005). Thus, inventors developed tools that made positioning and navigation faster and more accurate (Powers & Parkinson, 2010; Hofmann-Wellenhof *et al.*, 2011). Such tools include the compass, crystal oscillator for radio navigation, dead-reckoning processes and automated positioning systems (ibid.). However, these ancient methods of navigation had their difficulties (Beecher, 2004; Hofmann-Wellenhof *et al.*, 2011). Positioning and navigation was not accurate and easy to use. It involved a lot of guesswork resulting in complexities and sometimes failure such as losing one's way. For example, Christopher Columbus made an error during one of his explorations when he got to the Americas; he thought he had arrived in Asia and named the place the Indies (Prasad & Ruggieri, 2005; World Book Inc., 2013). In addition, the orientation to a destination takes time since there is no certainty of the exact navigation route (Prasad & Ruggieri, 2005).

Advancements taking place in marine and land navigation led researchers to work on navigating in space (Prasad & Ruggieri, 2005). Navigating in space has its own challenges with respect to positioning and navigation. However, the possibilities of traveling in space inspired researchers (ibid.). These researchers attempted varied approaches to determine positions on the Earth using orbiting satellites (Pace *et al.*, 1995; Whitlock & McCaskill, 2009). Successes recorded led to the development of the Global Positioning System (GPS), which is eventually used in many new applications including outdoor positioning and navigation (Grewal *et al.*, 2007; Hofmann-Wellenhof *et al.*, 2012; Duncan *et al.*, 2013). With traffic road signs and billboards as conventional means of navigating outdoors, locating a destination, and helping a user understand current position on the route of orientation, the advent of the GPS has transformed navigation into a simplified activity (Tjan *et al.*, 2005). Users have the choice of using conventional and/or technological means of navigation.

Areas of application of the GPS include land, marine, air and space (Sonnenberg, 1988:42). Hofmann-Wellenhof *et al.* (2011:375) stated some specific areas of navigation applications. They include location-based services (integrating navigation with communication and information), mobile robotics (complementing navigation with computer science and mechanical engineering), mobile mapping (combining navigation with imaging and geo-referencing), pedestrian navigation (mainly user-focused) and indoor navigation (focused on highly demanding indoor environments). The GPS may be integrated in these application areas. GPS is mainly used for tracking, timing and positioning of which navigation is a part (Whitlock & McCaskill, 2009).

Furthermore, because position determination is a major problem in a wide range of positioning and navigation applications and systems, the GPS has been widely adopted for outdoor use due to its accuracy, precision and effectiveness (ibid.). However, there is no such acceptance with indoor positioning and navigation systems (Van-Diggelen, 2009; Löhnert *et al.*, 2010). This is due to buildings and walls that serve as obstacle to the satellite's signals.

1.3.2 Indoor Navigation

Following the numerous success of the GPS outdoors, the challenge was shifted to the provision of such services for the indoor environment (Mautz, 2012). Indoor navigation has generated interest in users and researchers, shifting position computation from outdoors to indoor spaces. As a result, several applications have been developed to aid indoor services. Mautz (2012:7) pointed out that, "the ability to locate objects and people indoors remains a substantial challenge, forming the major bottleneck preventing seamless positioning in all environments." Thus, navigating indoors with mobile devices became an interesting subject in recent years. In this research, the focus is on pedestrian navigation in indoor environment (indoor navigation).

Indoor navigation is a subject that has been studied over the years using variety of techniques and technologies (Storms, 2009; Serra *et al.*, 2010; Hammadi *et al.*, 2012; Zinkiewicz, 2012; Fallah *et al.*, 2013). Gu *et al.* (2009) posit that an indoor navigation system consists of a network of devices used in locating objects or people inside a building. Upon knowing where something or someone is, activities such as tracking and position determination can be done with the information (Liu *et al.*, 2007; Gu *et al.*, 2009). The early indoor navigation systems involved using sensors, which consist of transmitters and receivers, for tracking and positioning (Want *et al.*, 1992; Fukuju *et al.*, 2003; Minami *et al.*, 2004). Either of the transmitters or receivers could be fixed while the other is on the user who is in motion. Similarly, recent indoor navigation systems use mobile phones for positioning and navigation (Liu *et al.*, 2013; Rossi *et al.*, 2013; Vicent, 2013).

Over the past decade, mobile phones have been used in indoor navigation research (Serra *et al.*, 2010; Link *et al.*, 2011; Hammadi *et al.*, 2012; Retscher & Hecht, 2012). Mobile indoor navigation involves an individual finding his/her way around within indoor spaces to arrive at a desired destination using an interactive navigation system in a mobile device (Hammadi *et al.*, 2012). It involves the use of a mobile device, an installed navigation application in the mobile device, map of the indoor space of the building and a database to store map data. Navigating in large buildings, such as museums, airports, malls, hospitals and campuses, with an indoor navigation system guides a user to a preferred destination without hassles and without wasting time. However, the different techniques and technologies that have been used so far in indoor navigation implementation have limitations and are discussed in section 1.4 below.

1.4 Positioning Technologies

Determining the current position of a user is the most important and yet challenging in indoor positioning (Mautz, 2012). Without the current location, planning or re-routing a path to the destination is difficult with any device; thus, navigation becomes cumbersome. Likewise, when a pedestrian does not know where he/she is while trying to locate a destination without a device, it is difficult to know the exact route to take towards the destination. The individual is therefore lost. In order for this not to happen, certain techniques could be used to know an individual's current location. For example, celestial bodies, natural landmarks, points-of-interest or known buildings and technical means can be used.

The various technologies that have been used to investigate and classify positioning in indoor navigation are Infrared (IR), Ultrasound/Ultrasonic, Audible sound, Magnetic, Optical and Vision-based, and Radio Frequency (RF) (Liu *et al.*, 2007; Gu *et al.*, 2009; Koyuncu & Yang, 2010; Nuaimi & Kamel, 2011). These investigations are based on cost, accuracy, privacy, usability and complexity of the technology used, while the classification is based on the main medium used to determine location (Gu *et al.*, 2009; Mautz, 2009; Fallah *et al.*, 2013). The technologies, their benefits and limitations are expounded in the succeeding sub-sections.

1.4.1 Infrared (IR) Positioning System

As one of the earliest indoor positioning systems, the Active Badge, which is an IR positioning system, use IR signals to determine the position of objects or people (Aitenbichler & Muhlhauser, 2003; Lee & Song, 2007). The Active Badge system (Want *et al.*, 1992) is a widely recognised IR system for the location of objects or people wearing a badge due to its low cost (Ekahau, 2005; Mautz, 2012). The badges transmit signals with a unique code every 15 seconds. The periodic signals provide information about their location to a centralised location (server) through a network of IR sensors (Mautz, 2012). Gu *et al.* (2009) pointed out that this system is beneficial for the following reasons: active badges and sensors are cheap, resulting in a low-cost system; active badges carried by users are lightweight; and battery life is good. While there is no doubt that the cost of IR positioning system is low, its coverage range and accuracy are limited. Hence, an IR system would need several receivers to improve its accuracy (Ekahau, 2005; Mautz, 2012). As a result, this will lead to infrastructure complexity and high cost of the overall solution; scaling the solution can also become costly over time (Ekahau, 2005). In addition, line-of-sight problems exist between sender and receiver, hence reducing the usability of the system (Ekahau, 2005; Huang & Gartner, 2010). For example, the interference of IR waves with fluorescent light and sunlight. For this reason, it is necessary to explore other supplementary and even alternative indoor positioning systems such as Ultrasound positioning system.

1.4.2 Ultrasound/Ultrasonic Positioning System

Unlike the IR positioning system with low accuracy because of line-of-sight issues, the Ultrasound positioning system achieves much higher accuracies (Lorincz & Welsh, 2007). Hence, developing a positioning system using ultrasound signals will address some concerns affecting the IR system.

Ultrasound signals are used by bats to navigate at night (Gu *et al.*, 2009; Gudra *et al.*, 2011; Mautz, 2012). This inspired researchers to design positioning and navigation systems using ultrasonic signals. Ultrasound positioning systems include the active bat (Koyuncu & Yang, 2010; Woodman & Harle, 2010), cricket system (Priyantha, 2005) and dolphin system (Fukuju *et al.*, 2003; Minami *et al.*, 2004). They involve the use of ultrasonic tags or nodes on users and objects. These tags or nodes serve as receivers or transmitters; when one is stationary or fixed, the other will be in motion (Holm, 2012; Medina *et al.*, 2013). Gu *et al.* (2009) and Xiao *et al.* (2011) posit that the tags carried by users are small and convenient with a good battery life. Hence, users do not need to change the batteries frequently; and the tags are convenient to carry. In addition, they noted that the system is scalable for implementation in a large building, and thus offering efficient performance and low-cost deployment. However, despite the efficient performance, noise and multipath effects led to a degradation in the system's accuracy (Gu *et al.*, 2009; Fallah *et al.*, 2013; Medina *et al.*, 2013). In addition, the large number of sensors deployed results in a complex and costly system (Gu *et al.*, 2009). These limitations affect the usability of the ultrasound positioning system. Hence, the need to improve on the system has led to discovering other positioning systems such as the Audible Sound positioning system.

1.4.3 Audible Sound Positioning System

While the Ultrasound positioning system suffers from complexity and high cost, the Audible Sound positioning system reduces cost due to the use of mobile devices. Beep, one of the earliest Audible Sound positioning systems, consist of sensor networks and end user mobile devices (Mandal *et al.*, 2005; Rishabh *et al.*, 2012; Rossi *et al.*, 2013). Since most mobile devices are able to emit audible sound, the use of audible sound eliminates the need for additional infrastructures (Gu *et al.*, 2009; Rishabh *et al.*, 2012; Liu *et al.*, 2013; Rossi *et al.*, 2013). Liu *et al.* (2013) pointed out that the audible sound system uses acoustic sound to measure distance by calculating the time of flight for sound pulses. The acoustic sensors, which are mounted in the building, are connected to a central server through a wireless network (Gu *et al.*, 2009; Rossi *et al.*, 2013). These sensors receive audible sound from the user's mobile device and send these data to the central server through the wireless connection for position computation (Gu *et al.*, 2009; Liu *et al.*, 2013). After computing the device's position, the server sends the position information to the mobile device (ibid.). While the use of mobile devices which act as transmitters tend to reduce cost, the use of sensors with a wireless network raises the cost of the system. In addition, a room-level accuracy is achieved in this system (Gu *et al.*, 2009). However, since an audible sound does not have a high penetration ability, audio transmission issues such as interference, noise, reflection and low penetration power through walls and obstacles, have a negative effect on the system's accuracy (Liu *et al.*, 2013). As a result, the accuracy of the system tends to fluctuate, though minimally.

1.4.4 Magnetic Positioning System

Magnetic positioning system is an old way of position measuring and tracking that is based on previous works on magnetic fields, the earth's magnetic field and the compass (Li *et al.*, 2012). The loggerhead sea turtle, pied flycatcher and spiny lobster are animals that use the earth's magnetic field for position determination and navigation (Boles & Lohmann, 2003; Lohmann *et al.*, 2007; Lohmann, 2010; Lohmann *et al.*, 2012). This has helped researchers understand how animals use magnetic signals for positioning and navigation; and that understanding has helped in the development of the magnetic positioning system. Magnetic positioning system involves the use of magnetic signals for position determination (Blankenbach *et al.*, 2012; Kim *et al.*, 2012). It consists of fixed transmitters and receivers mounted on the user. The receivers receive magnetic signals from the transmitter and send the position information to a centralised location for position determination. Compared with the previous positioning systems discussed, the magnetic positioning system has high accuracy; and does not suffer from non-line-of-sight (Gu *et al.*, 2009; Chung *et al.*, 2011). However, one issue with the magnetic positioning system is that there is a limited coverage (Li *et al.*, 2012; Mautz, 2012). This limitation affects the efficiency and robustness of the system, despite its high accuracy. In order to improve the coverage range, an increase in magnetic sensors and infrastructures may be needed to cover sufficient areas, hence increasing the complexity and cost of the system (Li *et al.*, 2012).

1.4.5 Optical and Vision-based Positioning System

The Optical and Vision-based positioning system involves determining the position of a person or an object in a building with the aid of a mobile sensor or camera carried by the user (Klopschitz *et al.*, 2010; Mautz & Tilch, 2011). It can be done in two ways. Firstly, a mobile phone camera gets the visual information, as posited by Chang *et al.* (2007) and Vazquez-Briseno *et al.* (2012), using Quick Response (QR) code. With QR code, Chang *et al.* (2007) posit that it is easy to deploy because of its low cost. However, positioning is not real-time despite the fact that the mobile device is being tracked (Chang *et al.*, 2007). The position determined is the position of the marker. The markers are distributed around the navigation environment and position is determined by placing the mobile device in close proximity to the marker (Kim & Jun, 2008). Secondly, Augmented Reality (AR) gets the visual information, as posited by Klopschitz *et al.* (2010), by seamlessly overlaying a user's view with location information linked to an image database in a centralised location or server. The server performs optical marker detection, image sequence matching and location recognition (Klopschitz *et al.*, 2010; Vazquez-Briseno *et al.*, 2012). Mautz and Tilch (2011) pointed out that the server transmits the recognized location information to the mobile device; hence, enabling real-time positioning and navigation.

Compared to the previous positioning systems discussed, the simplicity with which the QR code works made it a viable system for indoor positioning. However, the accuracy depends on the range of the marker position to the device, and the range depends on the resolution of the device's camera (Lukianto & Sternberg, 2011). If the resolution of the device's camera is not good enough, it can negatively influence the accuracy and performance of the system. With the real-time positioning and navigation of the AR, orientation is effective. However, significant amount of computing power may be required to perform image matching by upgrading the server, thereby affecting performance (Lukianto & Sternberg, 2011). Upgrading the server may result in an increase in infrastructure cost, as well as maintenance cost. Generally, the accuracy of the optical and vision-based positioning system is low (Klopschitz *et al.*, 2010). In addition, the system suffers from interference from multiple effects, bright light and significant accumulative errors which could lead to poor performance (ibid.).

1.4.6 Radio Frequency (RF) Positioning System

Radio Frequency positioning systems consist of Bluetooth, Ultra-wideband (UWB), Wireless Sensor Network (WSN), Wireless Local Area Network (WLAN) and Radio-Frequency Identification (RFID) (Gu *et al.*, 2009; Huang & Gartner, 2010; Deak *et al.*, 2012; Fallah *et al.*, 2013). The advantage of this technology is that radio waves can penetrate walls and other obstacles, resulting in a larger coverage area (Gu *et al.*, 2009). In addition, RF-based positioning systems can reuse existing RF infrastructures, resulting in cost reduction. Radio wave-based methods work in two ways: by proximity detection, in the case of RFID tags, and by measuring the received signal strength indicator (RSSI) of installed infrastructure nodes such as WLAN, UWB, Bluetooth or WSN (Lukianto & Sternberg, 2011). With respect to positioning with RSSI, Gu *et al.* (2009:22) pointed out that in challenged indoor spaces, location fingerprinting or RSSI employs characteristics, such as received signal strength (RSS) and location information of transmitters, to determine the position of a user or an object effectively. This attests to the effectiveness of RFID. However, there are still limitations due to the complicated and complex nature of indoor environments. The various RF positioning systems possess unique strengths and limitations, and the succeeding sub-sections highlight them.

1.4.6.1 Bluetooth-based Positioning System

Bluetooth-based positioning systems locate and track objects and people inside a building by providing real-time location data of radio and mobile phone users using Bluetooth beacons connected to a LAN (Diaz *et al.*, 2010), which is similar to the audible positioning system’s setup. However, a drawback encountered by Bluetooth-based positioning methods is that device discovery is inherently a slow process, thus impacting negatively on its accuracy and performance (Subhan *et al.*, 2011; Bekkelien, 2012).

1.4.6.2 UWB-based Positioning System

The UWB-based positioning system sends ultra-short pulses to transmit signals that have the magnitude of bandwidth (Meissner *et al.*, 2013). UWB can operate across a broad area of the radio spectrum and achieve a precise indoor positioning (Liu *et al.*, 2007; Mautz, 2012). It has high penetrating power, low-power consumption and good positioning accuracy (Gu *et al.*, 2009; Mautz, 2012; Deak *et al.*, 2012). The use of more UWB readers and their strategic placement could reduce the effect of signal impairments, such as interference and multipath, which make close proximity use with Wi-Fi networks and other RF signals possible (ibid.). However, UWB makes use of technologies that are not in line with existing standards. Hence, its public use is not certain (Canovic, 2007; Mautz, 2012). Due to the use of more UWB readers to improve performance, UWB could be expensive to scale and battery use could be costly (Mautz, 2012; Deak *et al.*, 2012).

1.4.6.3 WSN-based Positioning System

The WSN-based positioning system is based on Angle of Arrival (AOA), Time of Arrival (TOA), Time Difference of Arrival (TDOA) and Received Signal Strength Indication (RSSI), and it consists of a large number of sensors fixed in pre-defined locations (Gu *et al.*, 2009; Giorgetti *et al.*, 2012). The location of a person or object can be determined by sensor signals (Niewiadomska-Szynkiewicz, 2012). Positioning systems based on RSSI are preferred for measuring signal strength because of its low cost (Wang *et al.*, 2009; Robles *et al.*, 2012). The low cost of the sensors facilitate scalability and parallel computation as demonstrated by Mao *et al.* (2007) and Yun *et al.* (2009). However, Robles *et al.* (2012) noted that WSN positioning systems are challenging to implement because the sensors are limited with respect to transmission range, computing resources and processing power. If several sensor nodes try to know their position at the same time and send the positioning information through the network, the performance of the system may be impeded (Yick *et al.*, 2008; Robles *et al.*, 2012).

1.4.6.4 WLAN-based Positioning System

The WLAN-based positioning system could use existing WLAN infrastructures in indoor environments to determine a user's position (Cypriani *et al.*, 2009; Vicent, 2013). Vicent (2013) pointed out that the calculation of a user's location is done in two phases, namely the offline phase and the online phase. In the offline phase, grid points are computed at different locations in the building, each with a list of RSSI values for visible access points at that particular location (Mautz, 2012; Vicent, 2013). In the online phase, the grid points are used to compute the most feasible position of the user (ibid.). This process is known as fingerprinting and is a time consuming process (Gu *et al.*, 2009).

In recent times, more attention is given to the WLAN technology for positioning because of its better performance and non-requirement of line-of-sight (Mautz, 2012). The accuracy of location estimations in WLAN positioning is based on measuring the intensity of the received signal strength or on fingerprinting (Wang & Jia, 2007; Mautz, 2012). Hence, position determination using WLAN technology has the advantage of performing indoors and outdoors, whereas GPS can only work outdoors. However, since the positioning techniques based on RSS could sometimes be less accurate (Sayrafian-Pour & Perez, 2007), the accuracy of the WLAN positioning system is low. Although these are viable systems in improving distance estimation, speed and accuracy are still of great concerns (Wang & Jia, 2007). Besides, wireless information access is not readily available in less developed countries due to the high cost of equipment, high cost of deployment and password protected access.

1.4.6.5 RFID-based Positioning System

RFID is an automatic identification process of objects through radio interface (Renaudin *et al.*, 2007; Grover & Berghel, 2011). It is similar to the QR code or barcode in operation except that the barcode is replaced with an electronic microchip attached to an antenna and the identification process is by radio instead of optics (ibid.). An RFID system consists of three main components namely tag, reader and server. The RFID tags can be classified into two, namely the active tag and the passive tag (Grover & Berghel, 2011). An active tag is a battery-powered transceiver and thus has a wider transmission range, hence reducing the number of tags required for an installation. On the other hand, a passive tag, which has a shorter transmission range, does not use a battery; it gets its power source from the reader’s signal before it can respond with information (Grover & Berghel, 2011; Fallah *et al.*, 2013).

RFID positioning systems are usually used in complex indoor environments (Saab & Nakad, 2011). They can be classified into active and passive RFID positioning systems (Mautz, 2012). In an ‘active’ positioning system, either the reader or active tags can be mounted within the building. That is, either of them can be mobile while the other is stationary (Mautz, 2012). The same concept can also be used in the ‘passive’ positioning system with the reader and passive tags (ibid.).

The strength of the RFID positioning system, especially in its active use, lies in its larger coverage area and use of fewer hardware when compared with other technologies (Gu *et al.*, 2009). On the other hand, the strength of the RFID positioning system in its passive use lies in its low cost, since passive tags are cheaper than active tags and do not use batteries (Wang & Katabi, 2013). However, for the passive positioning system, Gu *et al.* (2009:23) pointed out that, “the proximity and absolute positioning techniques need numerous infrastructure components installed and maintained in the working area of an RFID positioning system.” Therefore, making the tag mobile and the reader stationary at various points could lead to a complex installation and hence high cost for the passive RFID positioning system. However, when it is compared with the active system, its cost is lower (Fallah *et al.*, 2013). The active system is known to be expensive because of the use of active tags (Gu *et al.*, 2009). The limitation with active tags is that their batteries need to be replaced from time to time, hence increasing cost (Fallah *et al.*, 2013). Table 1.1 below shows a comparison between active and passive tags.

Table 1.1: Comparison of Active and Passive tags

Description	Active Tag	Passive Tag
Power	Battery-powered	No Battery
Signal Strength	High	Low
Required Signal Strength from Reader	Low	High
Transmission Range	Wide	Short
Storage	128 kb (Larger)	128 b (Smaller)
Tag Life	Long	Short
Cost	High	Low
Size	Large	Small
Operation	Transmitters	Receivers

1.5 Near Field Communication (NFC)

NFC is an interesting technology that has emerged in recent years. It is an RFID-based short-range wireless technology that aids contactless communication between NFC mobile devices, and NFC tags and contactless smart cards in close proximity of not more than 10cm (Benyó *et al.*, 2010; Minihold, 2011; Coskun *et al.*, 2012). NFC is often referred to as high frequency RFID that can be embedded in mobile devices (Want, 2011). It operates on the 13.56 MHz frequency and supports data transfer rates of 106Kbit/s, 212Kbit/s and 424 Kbit/s, and higher rates are expected in the future (Agrawal & Bhuraria, 2012; Al-Ofeishat & Al Rababah, 2012). NFC works in four ways, namely Phone to phone, Phone to device, Phone to tag and Phone to reader (ibid.). For two devices to communicate using NFC, one device must have an NFC reader/writer while the other could be an NFC reader or tag.

NFC is standardised in International Organization for Standardization (ISO), Ecma International and European Telecommunications Standards Institute (ETSI) (Minihold, 2011; Coskun *et al.*, 2012). It has two communication terminals, namely the initiator and the target (ibid.). The initiator starts the communication process while the target receives the initiator's request and responds accordingly (Al-Ofeishat & Al Rababah, 2012; Coskun *et al.*, 2012). Similarly, two communication modes exist in NFC, namely passive mode and active mode (Al-Ofeishat & Al Rababah, 2012; Coskun *et al.*, 2012). In the passive communication mode, the initiator is active and the target is passive while in the active communication mode, both initiator and target are active as they communicate (Al-Ofeishat & Al Rababah, 2012; Coskun *et al.*, 2012).

Furthermore, there are three main operating modes in NFC, namely Reader/Writer mode, Card Emulation mode (ISO14443) and Peer-to-Peer (p2p) mode (ISO18092) (Benyó *et al.*, 2010; Agrawal & Bhuraria, 2012; Coskun *et al.*, 2012). In Reader/Writer mode, an NFC device acts as a Proximity Coupling Device (PCD) (Mulliner, 2009; Minihold, 2011). The NFC device reads/writes data in NFC passive tags, which can also be embedded in public posters, displays and products (Benyó *et al.*, 2010; Minihold, 2011). The NFC reader emits electromagnetic field that powers and reads the content of the passive tag (Coskun *et al.*, 2012). In Card Emulation mode, an NFC device acts as a Proximity Inductive Coupling Card (PICC) or smart card (Mulliner, 2009; Minihold, 2011). In other words, an external reader reads the content of the NFC chip, which is the same as that of a contactless smart card (Coskun *et al.*, 2012; Minihold, 2011). This makes NFC a good medium for contactless transactions without changing existing infrastructures. The p2p mode enables a link-level communication between NFC devices (Mulliner, 2009; Agrawal & Bhuraria, 2012). An initiator interacts with a target in order to share data, exchange business cards, documents, photos or other types of personal information in p2p data transfers (Benyó *et al.*, 2010; Minihold, 2011). In this research, the Reader/Writer mode is adopted because the NFC device is used to read data stored in passive NFC tags.

The advantages of NFC technology are that mobile devices can be used both as information storage and an NFC reader; NFC is also compatible with existing RFID infrastructures, existing RFID tags and contactless smart cards (Coskun *et al.*, 2012). Furthermore, the transmission range of NFC is so short that when a user separates two devices, the communication between the devices is broken (Al-Ofeishat & Al Rababah, 2012; Coskun *et al.*, 2012). This is a technical limitation in that the reader will not require too much energy to communicate with the tag, which is ideal for mobile phones. In addition, since NFC technology has a very short range of operation, it is hard to eavesdrop. Indeed, NFC has inherent security and does not suffer from privacy and security concerns; it raises the bar for security, performance and convenience (Coskun *et al.*, 2012). Since the number of mobile devices integrated with NFC is growing every year (GSMA, 2012; Iglesias & Uribe, 2012:60-63; Clark, 2014), NFC is an ideal technology that can be used to aid the development of pervasive, ubiquitous and context-aware systems (Huang & Gartner, 2010).

NFC is useful in mobile payment, authentication and access control, data transfer between NFC devices and in unlocking a service (such as opening another communication link for data transfer like in Bluetooth or Wi-Fi) (Miraz *et al.*, 2009; Benyó *et al.*, 2010; Minihold, 2011). In addition, NFC is useful in ticketing and accessing digital information (read contents from smart poster to NFC phone, download maps from smart poster to NFC phone, record location like a parking spot in NFC phone) (ibid.).

1.5.1 NFC Forum

The NFC Forum (NFC Forum, n.d.) is a non-profit industry association formed by leading players in the mobile communications, semiconductor and consumer electronics industries (Gallo, 2011). The Forum promotes, implements and standardises the use of NFC technology by developing specifications that will ensure interoperability among devices and services (Minihold, 2011; Rosati & Zaverucha, 2011). The NFC Forum has issued various specifications for NFC (Katzman & NFC Forum, 2006; Coskun *et al.*, 2012). These include NFC Data Exchange Format (NDEF), Record Type Definition (RTD), Logical Link Control Protocol (LLCP), connection handover, and operation specifications for four tag types (Want, 2011; Coskun *et al.*, 2012; Innovision Research and Technology, 2013). The NDEF, which consists of header fields and a payload field for the actual data, defines a common data format between NFC-compliant devices and tags (Rosati & Zaverucha, 2011; Want, 2011). The payload data is formatted according to the type of information and it stores such information as URI, SMS or text (ibid.). NDEF messages may be up to 4KB, but are limited by tag memory restrictions (Want, 2011; Innovision Research and Technology, 2013).

The RTD specifies rules for building standard record types (Want, 2011). It provides an extensible structure for the identification of the type of data in an NDEF message by defining a record structure and record type, and identifying the semantics of the data (ibid.). Rosati & Zaverucha (2011:3) pointed out that, “the RTD architecture is very flexible and designed to facilitate any NFC interaction.” Hence, five specific RTDs (Text, Uniform Resource Identifier - URI, Smart Poster, Generic Control, and Signature) exist for building standard record types (Rosati & Zaverucha, 2011; Want, 2011). In addition, the LLCP defines a protocol to support p2p communication between two NFC devices, while the connection handover defines how to establish a connection using other wireless communication technologies (Coskun *et al.*, 2012). The operation specifications for four tag types define how to read NDEF data from or to NFC tags

(Agrawal & Bhuraria, 2012; Coskun *et al.*, 2012). The NDEF, RTD (particularly URI) and operation specifications for tag types are used in this research.

Furthermore, a URI is a string of characters used to identify names or resources on the Internet in a uniform format (Berners-Lee *et al.*, 2005; Rosati & Zaverucha, 2011). It can be classified as a uniform resource locator (URL) or uniform resource name (URN) or both (Berners-Lee *et al.*, 2005). However, a URI may refer to all or part of a URL or URN (ibid.). The URL refers to the method used to obtain a representation either through the description of the primary access mechanism or through the network location (Berners-Lee *et al.*, 2005; Rosati & Zaverucha, 2011). On the other hand, the URN identifies a resource by name in a particular namespace (ibid.). A URI, which can also represent SMS or text, typically describes the mechanism used to access the resource, the specific computer on which the resource is located and the specific name of the resource on the computer (Berners-Lee *et al.*, 2005).

1.5.2 NFC Tag

An NFC tag, often referred to as a smart tag, is a passive device that contains a small microchip with an antenna (Minihold, 2011; Coskun *et al.*, 2012). It has a small amount of memory that can store a small amount of data in NDEF (Minihold, 2011; Rosati & Zaverucha, 2011). NFC tags are receivers that have a short transmission range (Grover & Berghel, 2011; Fallah *et al.*, 2013). The NFC tag can contain the position information, such as coordinates, at a point of a building (Fallah *et al.*, 2013). It actually contains the URI or Unique Identifier (UID) of the map data location.

Furthermore, NFC tags can be either rewritable or read-only (Gallo, 2011; Innovision Research and Technology, 2013). Rewritable tags are those that can perform read and write functions. URI and position information can be written in such tags (Gallo, 2011). On the other hand, read-only tags are those that allow read functions only (Gallo, 2011; Innovision Research and Technology, 2013). Several manufacturers produce RFID transponder chips for use in such tags, with user-accessible memory of about 2 KB (Grover & Berghel, 2011; Rosati & Zaverucha, 2011). The NFC reader identifies such tags appearing in the reader’s RF field by a unique serial number or UID that is programmed and locked in the tag at the factory (Innovision Research and Technology, 2013). The locked UID, which is small in memory, is the only information that can be read from the tags (ibid.). Since the read-only NFC tag cannot contain the position information and URI of the map data location, the UID of the NFC tag is associated with the position information and URI in the navigation application’s code. In addition, the tag is generally stationary and stuck to the wall while the reader is mobile.

NFC tags are passive, and can be referred to as passive RFID tags as well (Rosati & Zaverucha, 2011). However, not all passive RFID tags are NFC tags. Passive tags primarily operate at three frequency ranges as stated below (Grover & Berghel, 2011; Want, 2011):

- Low Frequency (LF): 125 kHz – 134 kHz
- High Frequency (HF): 13.56 MHz
- Ultra-High Frequency (UHF): 856 MHz – 960 MHz

NFC devices operate at the same high frequency (13.56 MHz) as HF readers and tags (Want, 2011). Passive read-only NFC tags are used in this research because of their simplicity of use and low cost. For the experiment with the RFID reader in section 4.2.1 of chapter four, low frequency tags with 125 kHz range were used, while for the NFC shield experiment in section 4.2.2 of chapter four, high frequency tags at 13.56 MHz were used.

Furthermore, one of the specifications issued by the NFC forum for NFC-compliant devices is the operation specifications for four tag formats which defines how to read NDEF data from or to NFC tags (Want, 2011; Coskun *et al.*, 2012; Innovision Research and Technology, 2013). The four tag formats are type 1 tag, type 2 tag, type 3 tag and type 4 tag (Gallo, 2011; Minihold, 2011; Rosati & Zaverucha, 2011). The NFC forum's tag type specifications ensure compatibility between NFC tags and NFC devices. The standards and protocols of the NFC tag format is based on RFID standards as outlined in ISO14443, ISO18092 and JIS X 6319-4 (FeliCa) (Minihold, 2011; Rosati & Zaverucha, 2011). FeliCa is a contactless RFID smart card system based on the Japanese Industry Standard (JIS) and developed by Sony (Want, 2011). It is not an internationally standardised product but is compliant with ISO18092 (Innovision Research and Technology, 2013).

Type 1 tag is based on ISO14443A and is available from Innovision Research & Technology (Topaz) (Innovision Research and Technology, 2013). It utilises a simple memory model with memory availability of 96 bytes for user data (Gallo, 2011; Rosati & Zaverucha, 2011). The memory structure is divided into blocks containing 8 bytes each (NFC Forum, 2011a). Each block is numbered from 0 to 14 for static memory structure (ibid.). It is a very cost-efficient tag for a wide range of NFC applications (Innovision Research and Technology, 2013).

Type 2 tag is also based on ISO14443A and is available from Philips (MIFARE UltraLight) (Innovision Research and Technology, 2013). They are the most common tag type. The memory structure is divided into blocks containing 4 bytes each, with each block numbered from 0 to 15 for static memory structure (Gallo, 2011; NFC Forum, 2011b). The number associated with a block is also called block number, and the 4 bytes inside each block are numbered from 0 to 3 (NFC Forum, 2011b). For each block, byte 0 is the Most Significant Byte (MSB) and byte 3 is the Least Significant Byte (LSB) (ibid.).

Type 3 tag is based on FeliCa, and operates at a higher data rate of 212 kbit/s (Innovision Research and Technology, 2013). It has a larger memory with a contactless Integrated Circuit (IC) chip that has built-in memory and memory access functions (ibid.). The basic unit of information used in memory management is called a block, with each block having a fixed size of 16 bytes (NFC Forum, 2011c). The number of memory blocks available depends on the chip hardware (ibid.). Each tag contains a management data called System Information. This tag type is rarely used (Gallo, 2011).

Type 4 tag is an open tag that is compatible with ISO14443A/B and is available from a number of manufacturers, including Philips (MIFARE DESFire) (Rosati & Zaverucha, 2011; Innovision Research and Technology, 2013). It provides a flexible file system with different files and access types including data integrity checks and encryption options as some of the main features (NFC Forum, 2011d). It offers a large memory addressing capability with read speeds of between 106 kbit/s and 424 kbit/s (Gallo, 2011; Innovision Research and Technology, 2013). Table 1.2 below shows a comparison of the four tag types.

Table 1.2: Summary and comparison of NFC tag types

	Type 1 tag	**Type 2 tag**	**Type 3 tag**	**Type 4 tag**
Compatible Products	Innovision Topaz	NXP NTAG203, NXP Mifare UL, NXP Mifare UL-C	Felica	NXP DESFire, NXP SmartMX-JCOP, Calypso
Manufacturers	Innovision	Philips	Sony	Philips, etc.
Standards	ISO14443A	ISO14443A	JIS X 6319-4	ISO14443A/B
Memory Size	96 Bytes, 512 Bytes	48 Bytes, 64 Bytes, 192 Bytes, 2 KB	1 KB, 4 KB, 9 KB	2KB, 4KB, 8KB, 32KB
Speed	106 kbit/s	106 kbit/s	212 kbit/s	Up to 424 kbit/s
Unique Identifier	Yes	Yes	No	Yes
Cost	Low	Low	High	High

1.5.3 NFC Positioning System

There are growing numbers of applications where a form of short-range wireless communication is needed (Agrawal & Bhuraria, 2012; Al-Ofeishat & Al Rababah, 2012). These applications include those for mobile payment, ticketing, peer-to-peer transfer and navigation among others. One short-range technology that can meet this need is NFC (Al-Ofeishat & Al Rababah, 2012). Figure 1.1 below shows the architecture of NFC as it exists in an NFC mobile device.

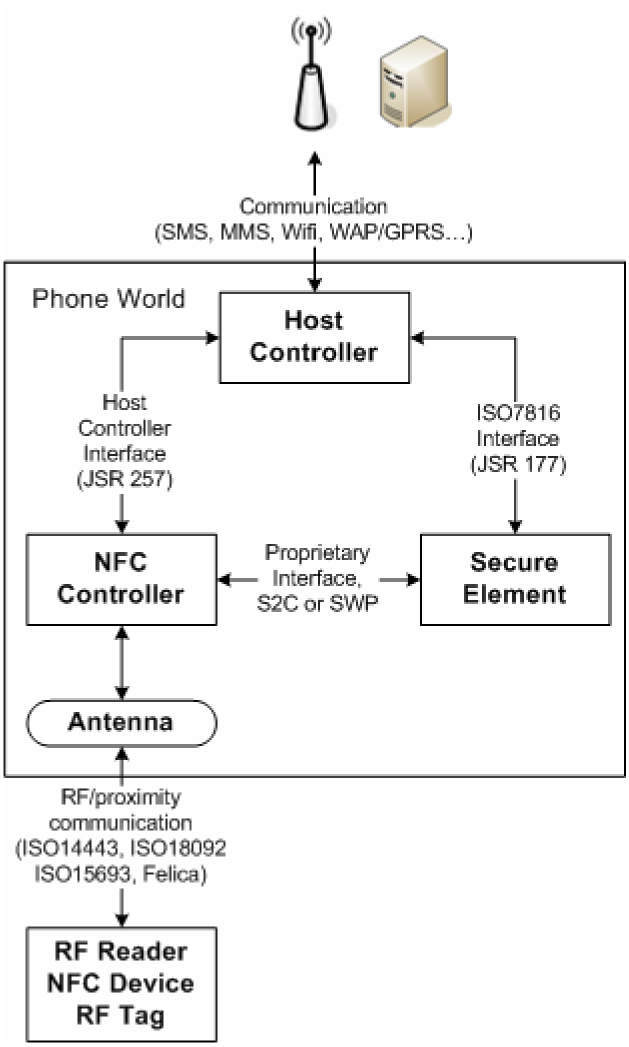


Figure 1.1: Architecture of NFC integrated in a mobile device (Miraz *et al.*, 2009)

The NFC positioning system consists of three main components, namely a passive tag, reader and database (Hammadi *et al.*, 2012). While the reader, which is an NFC mobile device, reads the content of the passive tag, the database is a centralised location where indoor map data of a building is stored (Ozdenizci *et al.*, 2011; Hammadi *et al.*, 2012). NFC positioning system is a novel area in indoor positioning that is gradually gaining traction. The NFC positioning system involves a user tapping an NFC mobile device to NFC tags spread within a building in order to determine current position (Ozdenizci *et al.*, 2011). A user entering a building for the first time and needs help in finding a destination can tap the NFC tag at the entrance with a mobile device. The map data of the building is downloaded from the database via mobile network or Wi-Fi and displayed on the navigation system in the mobile device (Ozdenizci *et al.*, 2011; Hammadi *et al.*, 2012). The position of the user is computed within the navigation system on the mobile device (Hammadi *et al.*, 2012), as opposed to the RFID system that computes position in a server. At the point where the user taps a tag, the location of the tag is taken to be the location of the user at that time. This is a simple, effective and accurate way of determining a location. In addition, reducing costs, as well as improving speed, accuracy and effectiveness, are the goals of developing a positioning system (Ozdenizci *et al.*, 2011; Hammadi *et al.*, 2012).

Furthermore, an NFC positioning system is similar to an RFID-based positioning system (also discussed in section 2.3.6.5 of chapter two). The difference is mainly in the distance of communication, the use of mobile devices by NFC and the position computation in a server by the RFID system. Likewise, the NFC positioning system is similar to the Cricket architecture and the optical-based system (also discussed in sections 2.3.2 and 2.3.5 of chapter two respectively) with respect to its mode of working. Just like NFC, Cricket works and preserves the privacy of the user, while the optical system uses a mobile device with QR code. However, the difference between NFC and these systems is that NFC positioning system is RF-based, while Cricket is Ultrasound-based and the optical system is marker-based. In addition, Cricket does not require a mobile device while the optical system does not preserve privacy, as position is determined in the server. The major disadvantage with the NFC positioning system is that there is no automatic update of a user’s position. In other words, there is no real-time positioning during navigation.

In summary, despite the fact that each of the RF-based positioning systems possesses unique problems, there are however those that are common to all of them. Both the range (coverage) and signal for radio waves are limited. They are also prone to disturbance, as certain electronics, storms and even organic matters can disturb or distort radio signals. As an RF signal travels through the air and other mediums in an indoor environment, it exhibits certain behaviours or propagation effects such as absorption, reflection, scattering, refraction, interference, multipath and attenuation (Mautz, 2012). These behaviours are signal impediments that affect a signal’s transmission between two locations thereby causing significant loss and degradation of the received signal (Ekahau, 2005; Mautz, 2012). Their effects could sometimes be unhelpful and have a negative effect on performance and accuracy (ibid.). To improve performance and accuracy, more infrastructures may be required and this could lead to an increase in system complexity and an increase in cost. Scaling the solution could also lead to high cost.

Furthermore, despite the studies carried out on indoor positioning and navigation, researchers gave more attention to the WLAN technology for positioning because of the advantages associated with the technology as highlighted in sections 1.4.6.4 and 2.3.6.4 of chapter two. However, due to the complexity, high cost and inaccuracy of this technology indoors, researchers tend to favour the hybrid model (Wang & Jia, 2007; Wang & Cheng, 2011; Galván-Tejada *et al.*, 2013) to compensate for the limitations of single model positioning technologies. The hybrid model is a combination of two or more positioning technologies and/or positioning techniques. It is complex and expensive but improves accuracy significantly. In addition, Wang and Jia (2007) carried out a study using the hybrid model for a WLAN Positioning System. This model made use of propagation modelling and fingerprinting modelling (Liu & Wang, 2010; Vathsangam *et al.*, 2011). As a result, the solution suffers from high complexity, low speed and low accuracy (Yim *et al.*, 2008).

1.6 Statement of the Research Problem

Navigation, a very vital activity in human existence, helps people, animals and objects to move from one place to another in order to fulfil the purpose of their existence. Thus for this purpose, Global Positioning Systems (GPS) have been widely adopted for outdoor navigation. It is precise and effective in positioning and navigation assistance (Whitlock & McCaskill, 2009). However, GPS has not been able to support indoor navigation, an important navigation environment for pedestrians (Renaudin *et al.*, 2007; Van-Diggelen, 2009; Seco-Granados *et al.*, 2012). This limitation of GPS indoors makes it difficult for pedestrians to navigate accurately in indoor environments with GPS especially when they are new in such environments. This has led to other technologies being used to develop indoor navigation systems. Despite the use of these technologies, challenges are still experienced in indoor spaces (Huang & Gartner, 2010; Retscher & Fu, 2010). These challenges include complexity of infrastructures, leading to high cost of deployment, accuracy problems and usability concerns (Han *et al.*, 2010; Ivanov, 2010). For example, to navigate indoors using prevalent mobile devices with existing methods of navigation such as WLAN, the need for unrestricted WLAN access arises. This makes it difficult in less developed countries where WLAN access may be restricted. In addition, Huang and Gartner (2010) posited that current indoor navigation and positioning systems use radio signals that suffer from signal impairments.

Furthermore, Han *et al.* (2010) noted that the implementation of an indoor location recognition system at a low cost is the biggest challenge that has not been solved. Bachrach and Taylor (2005:284) also pointed out that implementing a navigation system must cost as little as possible while still producing satisfactory results. In other words, designers must actively work to minimise the power cost, hardware cost and deployment cost of a navigation system (Bachrach & Taylor, 2005). The fact that current researches on indoor positioning and navigation are focused on solutions for more developed countries makes it even more challenging to implement in less developed countries. These persisting issues have not been satisfactorily addressed. By rethinking the approach to implementing an indoor navigation system, with the user being the focus, the limitations and problems can be significantly resolved. One approach to address these concerns would be the use of Near Field Communication (NFC) technology. Although a number of factors have been suggested as important elements influencing the success of indoor navigation, the impact of cost, accuracy and usability is significant (Ozdenizci *et al.*, 2011). However, little attention has been given in literature on the cost, accuracy and usability of NFC technology for an effective indoor navigation system.

1.6.1 Research Problem

Technology has provided the opportunity to resolve indoor navigation challenges, such as accuracy in determining the current position of a user, finding the shortest possible path to a destination, the intended destination of a user and creating an innovative indoor map, all at a minimal cost. Despite the unique benefits offered by various indoor navigation technologies to aid the movement of pedestrians in indoor environments, challenges still exist with respect to complexity, cost, accuracy, privacy and usability. Hence, users who find themselves in a new environment using existing indoor navigation technologies to locate a destination do so within the limitations of such technologies. Although some works (Bolz, 2011; Ozdenizci *et al.*, 2011; Hammadi *et al.*, 2012) have been proposed regarding the use of NFC in indoor navigation, no clear implementation has been shown concerning its usability in challenged spaces of less developed countries.

1.7 Research Aim and Objective

Mobile technologies as built-in wireless innovations have become the core of modern communication for social, business and learning functions. However, usability seems to be hindered in certain indoor and closed terrains, thereby limiting the benefits and uses of these innovations. Hence, **the aim** of this study is to investigate and evaluate the usability and full potential of NFC technology as an enabler of indoor positioning and navigation in challenged spaces of less developed countries. **The objective** is to identify innovative ways of improving a positioning and navigation system in indoor and closed spaces, in order to contribute towards a more effective and productive use of mobile navigation applications.

In view of the aforementioned, this research has been narrowed down to the following:

1. Map Generation: This intends to create map data to be used with the indoor navigation system. An open-source platform is considered for the implementation of the system. It addresses the statement, “How will I get there?” mentioned in section 1.2.
2. Positioning Framework: This part intends to determine accurate positioning using RFID/NFC tags. It tackles the statement, “Where am I?” mentioned in section 1.2. This attempt will investigate NFC for positioning accuracy and performance purposes.
3. Navigation Service: The goal here is to build a good and interactive user interface for the indoor navigation system that addresses the statement, “Where am I going?” mentioned in section 1.2. This will investigate NFC for usability and functionality purposes.

1.8 Research Question

How should the use of NFC improve support and effectiveness of an indoor navigation system in less developed countries, with regard to cost, accuracy and usability?

1.8.1 Research Sub-Questions

1. Why are the existing positioning and navigation technologies still experiencing challenges?
2. How can the NFC technology influence cost in an indoor navigation system?
3. How should the NFC technology improve accuracy in an indoor navigation system?
4. How should the NFC technology improve usability in an indoor navigation system?

1.9 Research Approach/Method

There are various approaches and methods used when conducting research. The methods commonly used are qualitative and quantitative research methods.

1.9.1 Qualitative and Quantitative Research

According to Creswell (2014), qualitative research is more exploratory in nature. It involves procedures such as interviews and participant observations and views (Bhattacherjee, 2012; Babbie, 2013; Creswell, 2014). Qualitative research helps researchers to study social and cultural phenomena (Bryman, 2012; Schutt, 2012; Monette *et al.*, 2014). It is mainly based on qualitative data, and the researcher is the primary data collection instrument (Flick, 2009; Creswell, 2014; Bryman, 2012). Quantitative research, on the other hand, is concerned with numerical methods and analyses (Singh, 2007; Bhattacherjee, 2012; Creswell, 2014). It can be deductive (theory-driven, hypotheses-testing, verification-oriented or confirmatory) or experimental (Babbie, 2013; Singh, 2007). The objective of quantitative research is to develop and employ mathematical models, theories and/or hypotheses regarding phenomena (Babbie, 2013; Creswell, 2014; Monette *et al.*, 2014). Quantitative research is generally carried out using scientific methods that include the following steps (Bhattacherjee, 2012; Creswell, 2014; Singh, 2007):

- The development of models, theories and hypotheses of what the researcher expects to find
- The development of instruments and methods for measuring the data gathered
- The use of experimental control and manipulation of variables
- The process of collecting data
- The process of modelling and analysing the data
- The process of evaluating the results

1.9.2 Software Development Method (SDM)

Software Development Method (SDM) is a major paradigm in the field of software engineering that has been widely adopted by the industry (Jayaswal & Patton, 2006; Boehm, 2007). Much research and publications have been conducted on software development methods and approaches, and these methods have evolved over time (Ruparelia, 2010; Bhuvaneswari & Prabaharan, 2013). Hence, there is no single best process for developing software (Dooley, 2011:8). A software development approach guides a developer through the software development process (Jayaswal & Patton, 2006; Geambaşu *et al.*, 2011). It is important to decide on the kind of model that best suits a particular project before a model can be chosen (Dooley, 2011). Furthermore, in order to develop a software, the developer usually chooses a software development approach and applies the guidelines that the selected approach provides to some variables (Geambaşu et al., 2011; Ruparelia, 2010). The main variables of software development projects are cost, time, features and quality (Dooley, 2011:16). The use of development methods have resulted in significant reduction in the number of failed or uncompleted software projects, while the cost and development time of software projects have decreased (Boehm, 2007; Geambaşu *et al.*, 2011).

Every software development undergoes a Software Development Life Cycle (SDLC) no matter how large or small it is (Jayaswal & Patton, 2006; Dooley, 2011). SDLC is a process that describes the planned activities at each stage of a software development (Boehm, 2007; Ruparelia, 2010). It involves a detailed plan describing how to design, develop, test and maintain quality software, and how to transition from one stage to the next (ibid.). SDLC describes a methodology for improving the quality of software and the development process (Geambaşu et al., 2011; Ruparelia, 2010). SDLC usually consists of the following stages: conception/planning, requirements gathering, design, building/ implementation, testing and deployment (Jayaswal & Patton, 2006; Dooley, 2011; Ruparelia, 2010). With each of these steps supported by different approaches, a development process could compress or combine some of these steps (ibid.). Figure 1.2 below shows a representation of the various steps of SDLC.

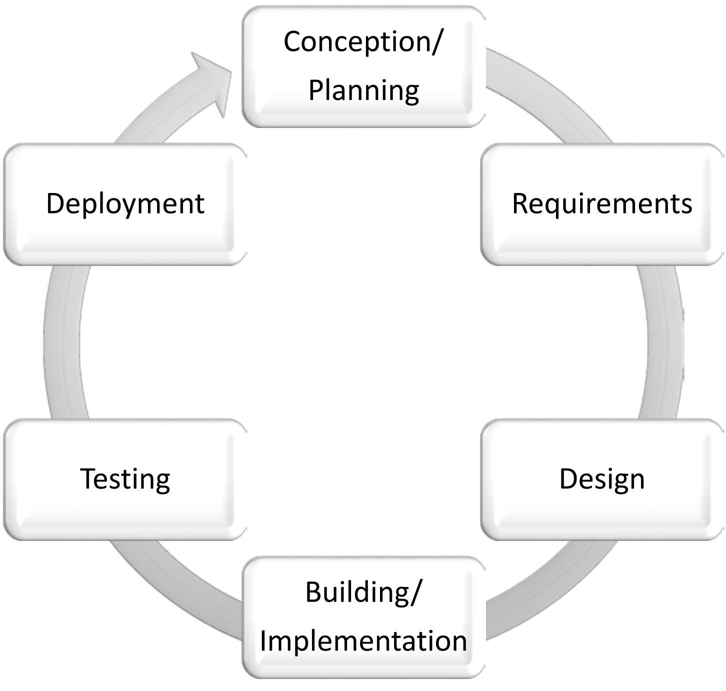


Figure 1.2: Graphical representation of the various stages of SDLC

Furthermore, various SDLC models are employed during software development processes. These models follow a distinct series of steps meant to ensure success in the software development process. They include code and fix model, waterfall model, V model, iterative model, incremental model, spiral model, big bang model, agile model, Rapid Application Development (RAD) model and prototyping model (Jayaswal & Patton, 2006; Boehm, 2007; Dooley, 2011; Ruparelia, 2010).

Code and fix is a very simple type of model consisting mainly of two steps namely, write code and fix code bugs (Jayaswal & Patton, 2006; Boehm, 2007; Dooley, 2011). It is implemented in the early days of development with little or no initial planning. Code and fix model is suitable for small projects or prototypes that are not intended to be foundational to future developments (ibid.).

Waterfall and V model are sequential and traditional SDLC models (Boehm, 2007; Ruparelia, 2010). They are sequential in the sense that the next phase starts only after the completion of the first phase (ibid.). These models are suitable for projects with very clear requirements that will not change dynamically in the course of development (Jayaswal & Patton, 2006; Dooley, 2011).

Iterative, incremental and spiral models are more accommodative in terms of change (Boehm, 2007; Ruparelia, 2010). They are suitable for projects where the requirements are not well defined (Jayaswal & Patton, 2006; Dooley, 2011). They allow for incremental refinement of a project through each iteration (Jayaswal & Patton, 2006; Boehm, 2007; Dooley, 2011).

Big Bang model is a simple model that does not follow any specific process (Bhuvaneswari & Prabaharan, 2013). It requires little or no planning with no formal testing phase. This model is suitable for small, practice or academic projects (ibid.).

Agile model is widely accepted in the software industry (Bhuvaneswari & Prabaharan, 2013). It delivers in good time using a combination of iterative, incremental and prototype approaches (Dooley, 2011; Bhuvaneswari & Prabaharan, 2013). User interaction and feedback is important in Agile, which is a realistic approach to software development with little planning required (ibid.). Implementing new changes can be done at a minimal cost and time because of the frequency that new increments are produced (Bhuvaneswari & Prabaharan, 2013; Ruparelia, 2010).

RAD and Prototyping models are modern techniques that help in understanding requirements in a better way early in the project cycle while focusing on short development time (Geambaşu et al., 2011; Bhuvaneswari & Prabaharan, 2013; Ruparelia, 2010). These techniques provide the look and feel of a working application to users in order to get feedback. The feedback is used to iterate the application for improvement (ibid.).

In practice, more than one model can be combined into a single project. A project can be started with a particular model while introducing other models within the project to refine the project.

1.9.3 Summary

The general approach employed in this research involves the practical and empirical manipulation of technical artefacts (i.e. use of experiments), with end users' feedback on the navigation application. Thus, the qualitative approach is not suitable for this study because this study is not based on social observations. In fact, the qualitative approach is a poor way of evaluating design usability (Nielsen, 2012b). Therefore, this research is conducted with a software development method supported with a quantitative approach for user interaction and feedback. In addition, two software development methods, which are iterative and prototyping models, were used. The use of these models supports usability.

1.10 Research Conceptual Model

The conceptual model below shows the various variables of this study and the relationship among them. The mobile device is the core of all the variables. It communicates with the tag through the NFC architecture within it. The NFC tag contains information about the location of the map data. When the mobile device retrieves this information, it is able to download the map data and display it in the navigation system. Thus, a user would be able to locate his/her destination.

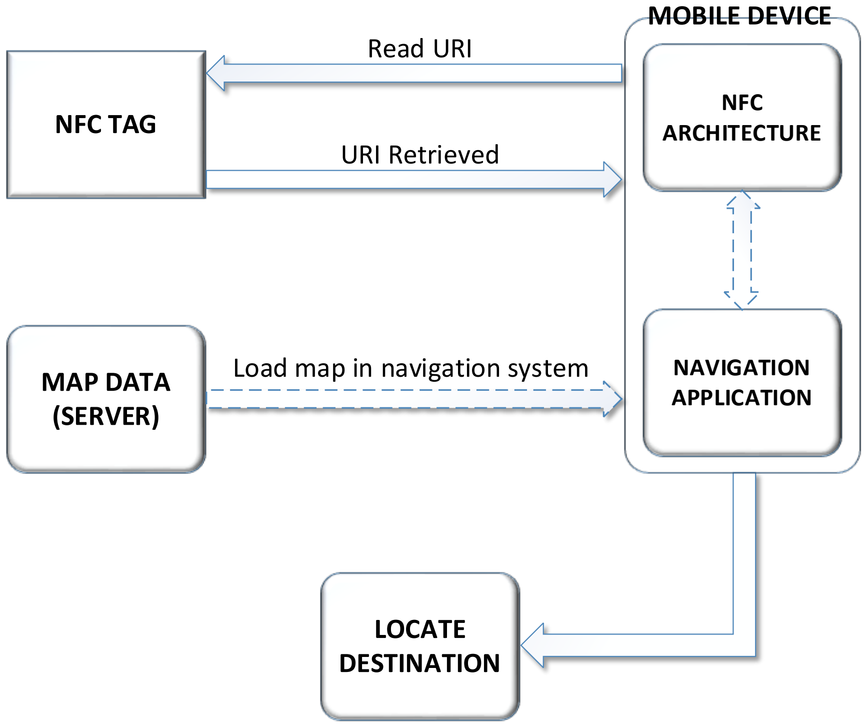


Figure 1.3: Conceptual model of navigation system

1.11 Clarification of Terms

While all terms are defined as they are used in the thesis, this section highlights the most prevalent (key) terms and defines their meaning as used in this document. The most predominant terms in this study include Navigation, Mobile Devices, Global Positioning System, Positioning, Accuracy (of a position), Complexity, Cost, Usability, Privacy and Design.

1.11.1 Navigation

The term “Navigation” is defined extensively in section 1.3. However, some clarifications are made here. Beecher (2004) used a synonymous term known as wayfinding, which is defined as, “the process of determining path or route between an origin and a destination.” She notes that navigation involves following that route. The term “Navigation” is a modern connotation for wayfinding. Dodiya & Alexandrov (2008) pointed out that navigation tasks consist of two main components, namely Wayfinding and Travel. Travel refers to the movement from origin to destination (Dodiya & Alexandrov, 2008). Navigation does not only involve determining a path between an origin and a destination, it also involves determining initial location and destination within an environment before orientation commences (János & Matijevics, 2010; Santos *et al.*, 2010; Gioia, 2014). In mobile devices, this environment is the map used. Hence, in this research, navigation takes into consideration the current location of a traveller, the destination and the path required to travel from a point of departure to a destination.

1.11.2 Mobile Devices

Mobile devices are personal devices that are used to share ideas and information while multitasking (Sarker & Wells, 2003; Pettit & Kukulska-Hulme, 2007; Sharma *et al.*, 2013). For example, they are used in learning, teaching, social communication, voice, text and data communication, entertainment, accessing information on the internet and accessing Wi-Fi among others. Some mobile devices are more powerful than others are, and this allows users to do more during use. Mobile devices include, but not limited to, cell phones, smartphones, PDAs, tablet, e-readers, palmtops, laptops, MP3 players and GPS receivers (Pettit & Kukulska-Hulme, 2007; Sharma *et al.*, 2013). In this research, mobile devices refer to devices such as smartphones and tablets only because of the unavailability of NFC technology in other mobile devices. In addition, they are used as readers.

1.11.3 Global Positioning System (GPS)

GPS is a space-based Global Navigation Satellite System (GNSS) that makes use of GPS receivers, like Garmin and TomTom, for timing, positioning and navigation purposes in an outdoor environment (Prasad & Ruggieri, 2005; Whitlock & McCaskill, 2009). It is one of three GNSSs in operation; the other two are Global Navigation Satellite System (GLONASS) and Galileo developed by Russia and Europe respectively (Prasad & Ruggieri, 2005; Grewal *et al.*, 2007; Seco-Granados *et al.*, 2012). GPS was originally developed by the United States military for military purposes, however it has since been discovered to be of significant benefit to civilians in a variety of applications (Grewal *et al.*, 2007; Van-Diggelen, 2009; Whitlock & McCaskill, 2009; Seco-Granados *et al.*, 2012). In this research, GPS is discussed mainly in relation to its positioning and navigation uses.

1.11.4 Positioning

Hofmann-Wellenhof *et al.* (2011) defines a position as a set of coordinates related to a well-defined coordinate reference value. Hence, positioning is the process of determining the location or position of a person, place or object by employing positioning techniques within a network. Positioning takes into consideration the initial or current position, speed and direction of movement as new or current position is computed real-time, and the time it takes to move between initial and current positions. In this research, position and positioning refers to current position of a user vis-à-vis the NFC tag since navigation is not real-time.

1.11.5 Accuracy

The accuracy of a position is an important factor of positioning and navigation systems (Liu *et al.*, 2007; Niewiadomska-Szynkiewicz, 2012). Ochieng et al (2003:53) defined accuracy as "the degree of conformance of an estimated or measured position at a given time to a defined reference value." The reference value is a true value, if known, or some agreed-upon standard value, all other things being equal (Ochieng *et al.*, 2003). Pradhan *et al.* (2009:233) defined accuracy as the likelihood that an object is within a certain range or a defined reference value. Liu *et al.* (2010) defined accuracy as, "the expected Euclidean distance between the location estimate and the actual location of an unknown node." Nuaimi & Kamel (2011) noted that, the "accuracy of a positioning system is the closest calculated position that can be achieved to a target object." Different systems provide different accuracies. The accuracy of some is in the range of metres while the accuracy of others is in the range of centimetres, with the centimetre range more accurate than the metre range (Hofmann-Wellenhof *et al.*, 2011; Fallah *et al.*, 2013). Generally, the higher the accuracy, the better the system performance (Liu *et al.*, 2007). In this study, the accuracy of a position is defined as the degree of conformance of a user's or object's estimated or measured position to a certain range or reference value.

1.11.6 Complexity

The complexity of a positioning system can determine the strength of the accuracy and cost of the system. Liu *et al.* (2007:1072) noted that, the "complexity of a positioning system can be attributed to hardware, software, and operation factors." When a system is deployed in a large area, it could lead to hardware complexity as multiple devices and infrastructures are installed. In order to improve the accuracy of a system, the number of hardware devices could also increase, which then results into complexity (Gu *et al.*, 2009). In addition, scaling a system also results in hardware complexity as more hardware devices are added to the system (ibid.). Niewiadomska-Szynkiewicz (2012:284) noted that the hardware complexity of range-based systems is much more than that of range-free systems. On the other hand, software complexity is because of the computing intricacy of positioning algorithms (Niewiadomska-Szynkiewicz, 2012). It also depends on the number of positioning algorithms and techniques combined and used in a system. In addition, range-based positioning algorithms are usually more complex than range-free algorithms, as more algorithmic computation is needed in range-based algorithms. Furthermore, the complexity of operational factors is because of computational processes, computational time, memory used and power source. Therefore, in this study, complexity refers to the combined hardware, software and computational processes of the positioning and navigation system.

1.11.7 Cost

Cost is one of the most important variable in any project that depends on a variety of factors including complexity (Liu *et al.*, 2007). According to Grewal *et al.* (2007:334), cost includes acquisition cost, operations cost and maintenance cost. Similarly, Liu *et al.* (2007:1072), Gu *et al.* (2009:18), Liu *et al.* (2010:284), Mautz (2012:20) and Niewiadomska-Szynkiewicz (2012:285) posit that the cost of a positioning system is influenced by installation costs, maintenance costs, computational costs, and hardware and software costs. In positioning and navigation systems, the higher these variables become, the costlier the system in general (Gu *et al.*, 2009). In addition, the higher the accuracy of a system, the higher the complexity, and hence the higher the cost of the system. In this study, cost refers to a combination of installation costs, computational costs, hardware and software costs, and maintenance and operations costs.

1.11.8 Usability

Usability is a necessary consideration for software designs and applications. It is a quality possessed by many designs and applications, and yet is lacking in many others (Rubin & Chisnell, 2008). As a result, present-day best practices spend a notable amount of a design project's budget on usability (Nielsen, 1993; Nielsen, 2012b). Rubin and Chisnell (2008) define usability as when, “the user can do what he or she wants to do the way he or she expects to be able to do it, without hindrance, hesitation, or questions.” The ISO 9241-11 standard defines usability as, “the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use.” (International Organization for Standardization, 1998; Barnum, 2011; Quesenbery, 2013). These definitions cover the very essential elements (specified users, specified goals and specified context of use) and focus on the critical components of usability (effectiveness, efficiency and satisfaction). In addition, Nielsen (2012) defines usability as, “a quality attribute that assesses how easy user interfaces are to use.” He notes that usability refers to methods for improving ease-of-use during the design process. Further to that, Nielsen attributes this definition of usability to five quality components, namely learnability, efficiency, memorability, errors and satisfaction. Similarly, Quesenbery (2013) expanded the three components of ISO 9241 into what she calls the five dimensions of usability (5Es) namely, effective, efficient, engaging, error tolerant and easy to learn. Nielsen and

Quesenbery's classification extend the critical ones of the earlier definitions. Thus, for a system to be termed usable, it should be useful, efficient, effective, error tolerant, satisfying, memorable, learnable, and accessible (Rubin & Chisnell, 2008).

Furthermore, the goals and objectives of usability are typically defined in quantifiable terms of one or more of these components (Rubin & Chisnell, 2008). In fact, there are many other components such as simplicity, comprehensibility, usefulness and utility (functionality or flexibility) (Nielsen, 2012b). However, there is a trade-off between usability and utility (flexibility). As the flexibility of a system increases the usability of the system decreases, and vice-versa (Lidwell *et al.*, 2011). Flexibility or functionality refers to whether a design or system has the needed features (Nielsen, 2012b). Flexible designs are more complex and as a result are generally more difficult to use (Lidwell *et al.*, 2011). The flexibility-usability trade-off exists because flexibility accommodates a wide range of design requirements, resulting in compromises and complexity (ibid.). In essence, flexibility results in high cost, while usability saves cost (Nielsen, 2012b). Therefore, balancing the trade-off between usability and functionality will result in a useful system (Lidwell et al., 2011; Nielsen, 2012b).

In this study, usability is defined as the quality that assesses the extent to which an application can be used by specified users to achieve specified goals in a specified context of use with effectiveness, efficiency, satisfaction, usefulness, memorability, learnability, accessibility, simplicity, comprehensibility, and functionality. The usability evaluation is conducted by means of a formal user testing and evaluation, with the application made to navigate indoors only, while cutting off other functionalities.

1.11.9 Privacy

Privacy is an important factor of security requirements. It is a complex concept that has been found to be difficult to define (Westin, 1968; Pearson & Charlesworth, 2009; Koontz, 2013). Westin (1968) defined privacy as "the claim of individuals, groups, or institutions to determine for themselves when, how, and to what extent information about them is communicated to others." In a general sense, Pearson (2009) defined privacy as, "a fundamental human right that encompasses the right to be left alone". People do not want to be tracked to the point that others know every information about their private lives or when they do not want their location to be monitored. This made Ann Cavoukian, who was once the Information and Privacy Commissioner of Canada, to develop the concept known as "Privacy by Design". She postulated seven foundational principles of the concept. Privacy by Design refers to "the philosophy and approach of embedding privacy into the design specifications of various technologies" (Cavoukian, 2009). In this study, privacy is used in the sense of data and user protection, and applied in the technology innovation.

1.11.10 Design

Design is a multi-faceted concept used in every field of endeavour in one way or another. In effect, it has different meaning in different disciplines like Art, Engineering, Fashion, Social Science and Software Development among others. As a result, a number of terms, which include service design, user-centred design, structured design, interactive design et cetera, have been used to describe design in the various fields. Design can be artistic, technical, mechanical, psychological and commercial (Head, 2000). In an interview with Victor Hwang, Todd Johnston – a designer – defined design as, “to mark out a pattern as a means of making meaning of an experience.” (Hwang, 2014). In social research, a research design is not just a work plan; it ensures that the data collected answers the research question as clearly as possible. In this discipline, design involves “the intersection of philosophy, strategies of inquiry and specific methods.” (Creswell, 2014). It is defined as, “the formulation of a plan for collecting relevant data”, a plan for arranging elements in such a way as to best accomplish a particular purpose (Miller, 2005; Creswell, 2014). However, the use of design in this thesis refers to its use in Software Development as discussed in section 1.9.2.

1.11.11 Developed and Developing Countries

According to the United Nations Statistics Division, “there is no established convention for the designation of "developed" and "developing" countries or areas in the United Nations’ system” (United Nations, 2013). In fact, the developed and developing designations are used mainly for statistical purposes and not as derogatory expression to some countries’ well-being (United Nations, 2013; International Monetary Fund, 2015). However, the designations “developed” and “developing” have been used to differentiate between a more advanced economy and an emerging one. A developed country can be referred to as an independent nation that has a highly matured economy and an advanced technological structure when compared with that of less industrialised nations (The World Bank, n.d.). The economic criteria used for this designation include per capita income, Gross Domestic Product (GDP), Gross National Product (GNP), industrialisation, widespread infrastructure, Human Development Index (HDI) and general standard of living (The World Bank, n.d.; International Monetary Fund, 2015). HDI is a comparative measure of poverty, literacy, education and life expectancy, among other factors. Developed countries are also called industrialised or more economically developed countries, and they have high economic criteria. On the other hand, a developing country can be referred to as a nation that has an immature industrial base, economy and technological structure (The World Bank, n.d.). Developing countries are also called less developed or third world countries, and they have low economic criteria (Mankiw, 2012:543-544). In this research, the term “less developed countries” is used to refer to developing countries with low and emerging economic criteria.

1.12 Structure of the Thesis

This section contains the organisation of the thesis, which is divided into six chapters and followed by references and appendices. The thesis is organised as follows:

Chapter one begins with an introduction that informs the reader about positioning, navigation and mobile technologies. It contains the background, statement of the research problem, research problem, research aim and objectives, research questions, research approach and method, and conceptual model of the research. The chapter rounds off with the clarification of terms, thesis structure and conclusion.

Chapter two reviews the existing literature on the status of indoor positioning and navigation techniques and technologies. It analyses the working of these techniques and technologies, stating their advantages and disadvantages in their unique scenario when implemented, and evolving gradually through the state-of-the-art.

Chapter three discusses the research approach and methodology used in this study and why it is appropriate. This leads to an explanation of the research method and design, and how they will be applied. It proceeds with an overview and analysis of various applications, components and technologies – map generation, positioning component and navigation component – used in the course of this study with the aid of free open-source software and hardware. Finally, the first stage of the experiment design process, known as pre-test, is presented.

Chapter four presents the service design and implementation of the study. The preliminary experiments involving the RFID reader, NFC shield and Arduino, as well as the navigation service description are presented. This is followed by the main experiment, which involves the manipulation of the prototype application’s code. It also presents the final test of the study known as post-test.

Chapter five contextualises the findings of the test done and presents the evaluation and discussion of the prototype application. It reviews the research sub-questions and assesses the deployment and usability test of the prototype application.

Finally, chapter six concludes the study and presents a summary of the chapters, together with specific contributions of the study and recommendations for future work.

1.13 Chapter Conclusion

The discussion in this chapter offers a general overview of the study, namely the need for a simple, accurate, usable and cost-effective solution for indoor positioning and navigation. While indoor navigation applications have a great deal of potential to aid users' interaction and orientation with mobile devices, a user-friendly solution is critical to their success. Addressing complexities, usability issues and high cost in indoor navigation systems has received little attention in research. Hence, this research focuses on reducing complexity and cost, and improving usability in an indoor navigation system to aid orientation in indoor environments, a development that will be beneficial to less developed countries. The research problem, aim, objectives, questions, approach, data collection and analysis methods were highlighted. The research approach used a quantitative and experiment method of empirical enquiry, and software engineering and synthesis research methods. Furthermore, important terms and concepts used in the thesis were clarified and explained. The outline of the thesis was also explicitly stated. A comprehensive discussion of the research outline is presented in the succeeding chapters, with the literature review that provides a detailed analysis for the study presented in the following chapter, chapter two.

CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

The aim of this study was to investigate and evaluate the usability of NFC technology as a convenient and cost-effective means for indoor navigation in challenged spaces of less developed countries. In line with a roadmap painted in chapter one – towards this end, a literature survey on indoor positioning techniques, which consists of signal metrics and positioning algorithms, and the existing positioning and navigation technologies in which these metrics are applied, is presented in this chapter.

In effect, there has been a steady and exponential growth in the research and use of positioning and navigation technology outdoors in recent years. Based on this success achieved outdoors, there has been various attempts to implement these technologies indoors and this has led to various studies in this space. Several technologies have been proposed and implemented to improve positioning and navigation indoors. Among these technologies are the ones discussed in section 1.4 of chapter one. Most of the techniques, algorithms and constituents of these technologies have been very much around, as they are implemented outdoors. However, how they fare indoors is different from outdoors altogether. This has spurred researchers into discovering ways to make life easier for people while navigating in indoor spaces. The outcome of these researches has resulted in observed inhibitions in the various technologies, which have in essence affected performance.

Although these technologies were introduced in chapter one, a state-of-the-art of these technologies in indoor navigation and their use in various scenarios and environments is presented in this chapter. Section 2.2 begins with an overview of indoor positioning techniques, highlighting the principles and the importance of the signal metrics and positioning algorithms. Section 2.3 delves into the various existing technologies, which include Infrared (IR), Ultrasound/Ultrasonic, Audible Sound, Magnetic, Optical/Vision-based and Radio Frequency (RF). Each of these technologies are reviewed and discussed, with a detailed information on their performances and challenges. The unique challenges of the various technologies provide the inspiration for the study presented in this thesis leading to its major contributions. Finally, Section 2.4 summarises the chapter and provides concluding remarks.

2.2 Indoor Positioning and Techniques

Over the years, indoor navigation has been studied using a variety of algorithms, technologies and techniques to improve positioning (Serra *et al.*, 2010; Hammadi *et al.*, 2012; Zinkiewicz, 2012). Despite the limitations of these technologies and techniques, which has caused researchers to continuously search for better ways to determine a position determination, there have been significant improvement in navigation research (Storms, 2009; Fallah *et al.*, 2013). Such improvements include an increase in position accuracy and performance, and a reduction in cost of deployment of the navigation systems (Storms *et al.*, 2010; Fallah *et al.*, 2013). However, challenges still exist in indoor positioning systems (Trigony, 2012), in that no single system is able to provide a complete solution.

In indoor positioning systems, 'positioning techniques' are used to determine and estimate the position of sensor nodes to improve positioning accuracy (Gu *et al.*, 2009; Nuaimi & Kamel, 2011). These techniques help users to have easy access to position and navigation information. A number of algorithms and techniques exist for obtaining bearing, range or proximity information based on signal measurement or metrics (Amundson & Koutsoukos, 2009). The algorithms used in positioning systems translate recorded signal metrics into distances and angles, and then computes the actual position or location of a target object (Huang & Gartner, 2010). Thus, a user is able to use the position information in a navigation system during a navigation activity (Nuaimi & Kamel, 2011). In addition, the position information can be used to track objects. To determine the position of a user, the two positioning techniques used are signal characteristics/metrics and positioning algorithm (Huang & Gartner, 2010).

2.2.1 Signal Metrics and Properties

Positioning systems can be classified by the signal measurement and/or metric techniques they employ (Amundson & Koutsoukos, 2009; Huang & Gartner, 2010). Signal metrics are geometrical parameters consisting of properties such as angle, distance and signal to measure an object's position using calculations (ibid.). In general, there are various methods of measurement or metric techniques (Amundson & Koutsoukos, 2009; Nuaimi & Kamel, 2011). However, the prevalent metric techniques are Angle of Arrival (AOA), Time of Arrival (TOA), Time Difference of Arrival (TDOA) and Received Signal Strength Indication (RSSI).

2.2.1.1 Angle of Arrival (AOA)

AOA is the angle and distance calculated relative to two or multiple reference points through the intersection of direction lines between the reference points (Amundson & Koutsoukos, 2009). The calculation of the angle and distance is used to estimate and determine the position of a transmitter, and the information is used for tracking or for navigation purposes (ibid.). With AOA, a position can be determined with few sensors for two-dimensional (2D) or three-dimensional (3D) positioning (Brás *et al.*, 2012). In practice, however, few sensors absolutely require AOA information, though several sensors are capable of using it when present (Liu *et al.*, 2007). In addition, the hardware tends to be complex and expensive.

2.2.1.2 Time of Arrival (TOA)

While AOA's measurement is angle-based, the measurement of TOA is mainly distance-based. TOA is sometimes called Time of Flight (TOF) (Brás *et al.*, 2012). The definition and meaning of both TOA and TOF explicitly points this out. TOA is the time taken by a signal to arrive at a receiver from a fixed transmitter, with the transmitter as the reference point (Nuaimi & Kamel, 2011). On the other hand, TOF is the time taken for a signal to take off from a transmitter to a receiver, with the receiver as the reference point (Hazas & Hopper, 2006). It thus behoves to conclude that TOA and TOF are the same because the time in both cases is the same. Furthermore, TOA uses the absolute time of arrival at the receiver rather than the measured time difference between departing from a transmitter and arriving at the receiver (Xiao *et al.*, 2011). Thus, the distance between the transmitter and the receiver can be directly calculated from the TOA, and position can be determined with the information (Liu *et al.*, 2007). TOA provides high accuracy but at a cost of higher hardware complexity (Brás *et al.*, 2012), hence TDOA is meant to eliminate the hardware complexity limitation.

2.2.1.3 Time Difference of Arrival (TDOA)

Just like TOA, TDOA is also a distance-based metric. TDOA determines the relative position of a mobile transmitter based on the difference in the propagation time of arrival of the transmitter and multiple reference points or sensors (Liu *et al.*, 2007). In other words, TDOA measures the difference in TOA at two different sensors and thus eliminates the need to know when the signal was transmitted (Amundson & Koutsoukos, 2009; Nuaimi & Kamel, 2011). When the position of the mobile transmitter is known, tracking can be effected with this information (Brás *et al.*, 2012). As an improvement on TOA, TDOA eliminates the modification of the transmitter for absolute arrival time

(Amundson & Koutsoukos, 2009). Just like TOA, TDOA provides high accuracy as well (Xiao *et al.*, 2011).

2.2.1.4 Received Signal Strength Indication (RSSI)

Unlike the angular and distance-based metrics, RSSI is a measure of the power level of the received signal strength (RSS) present in a radio infrastructure that can be used to estimate the distance between mobile devices (Subhan *et al.*, 2011). In other words, the RSSI approach measures the signal attenuation of transmitted signals to calculate the signal strength reduction or loss due to propagation, hence distance between mobile devices can be estimated (Subhan *et al.*, 2011). Through the estimation, position information can be acquired (Brás *et al.*, 2012). RSSI is the relative RSS in a wireless environment, the higher the RSSI the better the signal quality (Liu *et al.*, 2007). However, in indoor environments where it is difficult to obtain line-of-sight, the RSSI and positioning may be affected by multipath and shadow, hence decreasing accuracy (Liu *et al.*, 2007; Xiao *et al.*, 2011).

In brief, the signal metric is an important element in determining position, as it will be required in the calculation and estimation of a position. The signal metric used with a positioning algorithm goes a long way in determining the potency of the positioning technique. Hence, to use the most appropriate metric, it is important to understand positioning algorithms.

2.2.2 Positioning Algorithms

Positioning algorithms specify how to calculate the position of a target object (Gu *et al.*, 2009). In other words, these algorithms translate the recorded signal metrics into distances and angles, and then computes the actual position of a target object (Huang & Gartner, 2010). For example, when the distance between a target object and the reference points is estimated, the algorithm calculates and determines the position of the object (Gu *et al.*, 2009). Both the signal metric and the positioning algorithm work together to determine the position of an object (Huang & Gartner, 2010). The positioning algorithm processes the signal metric and outputs a position. Furthermore, the various positioning algorithms improve the accuracy of a determined position (Gu *et al.*, 2009). The accuracy of the information gathered on the position depends on the correctness of the signal metric value (ibid.). In addition, positioning algorithms have unique advantages and disadvantages, hence using more than one type of positioning algorithm at the same time will improve position accuracy and performance (Liu *et al.*, 2007). Therefore, several techniques exist for determining position using bearing, range, or proximity information based on signal measurement (Chawathe, 2008; Mautz, 2012). However, the main algorithmic techniques used in positioning are triangulation, trilateration, proximity and scene analysis, and the various signal metrics are applied within corresponding positioning algorithms (Liu *et al.*, 2007; Chawathe, 2008; Nuaimi & Kamel, 2011; Deak *et al.*, 2012; Mautz, 2012).

2.2.2.1 Triangulation

Triangulation (or angulation) uses the geometric properties of triangles to estimate the position of a target object by computing angular measurements relative to two known reference points (Chawathe, 2008; Zhang *et al.*, 2010). In other words, the position of the target object is found by the intersection of two pairs of angle direction lines, a method known as direction finding (Liu *et al.*, 2007; Zhang *et al.*, 2010; Fallah *et al.*, 2013). AOA is used to compute the distance between direction lines or fixed points to locate the object (Liu *et al.*, 2007). The position of the object is determined by calculating the position of a transmitter based on the angle and distance relative to the reference points (Amundson & Koutsoukos, 2009). Furthermore, when two or three reference points are used to determine position, it results in a simple and low-cost system (Liu *et al.*, 2007; Gu *et al.*, 2009). However, when the coverage area is wider with multiple reference points, position determination may contain some errors that may result in a decreased accuracy (Gu *et al.*, 2009). In addition, the hardware requirement for a wide coverage area tends to be complex and expensive (Gu *et al.*, 2009). Moreover, triangulation is often assumed to be synonymous with trilateration, however both terms are actually different (Chawathe, 2008).

2.2.2.2 Trilateration

Just like triangulation, trilateration (or lateration) also uses the geometric properties of triangles to estimate the position of a target object (Liu *et al.*, 2007; Subhan *et al.*, 2011). However, in this case, distance measurements relative to three known reference points are used to determine position by computing the attenuation of the transmitted signal (Amundson & Koutsoukos, 2009; Liu *et al.*, 2010; Zhang *et al.*, 2010; Nuaimi & Kamel, 2011). On the other hand, multilateration is similar to trilateration except that four or more points are used in multilateration (Chawathe, 2008; Diaz *et al.*, 2010; Mautz, 2012). The position of the target object is determined using TOA to measure the time taken by a signal to arrive at a receiver from a transmitter (Nuaimi & Kamel, 2011). Also, TDOA, which is an improvement on TOA, is used in some instances. TDOA measures the difference in TOA at two different receivers, and determines the relative position of the transmitter based on the difference in the propagation time of signals (Xiao *et al.*, 2011).

This results in high accuracy like TOA, but at a cost of higher hardware complexity (ibid.). The accuracy depends on the signal received and the environmental conditions (Subhan *et al.*, 2011).

2.2.2.3 Proximity

Unlike triangulation and trilateration, proximity does not give an absolute or relative position estimation because it only provides position information (Liu *et al.*, 2007; Gu *et al.*, 2009). To provide the information, a grid of antennas with known positions is used to determine position (Liu *et al.*, 2007; Gu *et al.*, 2009; Nuaimi & Kamel, 2011). When a mobile device is detected in motion, the closest antenna is used to calculate its position (ibid.). But if the mobile device is detected by more than one antenna, the antenna with the strongest signal is used to calculate its position (Gu *et al.*, 2009; Nuaimi & Kamel, 2011). The position of the mobile device is determined using RSSI, which is generally used in proximity to estimate the distance between mobile devices in order to acquire the device's position information (Xiao *et al.*, 2011). Getting the device's position is beneficial in location-based services and applications such as tracking and navigation (Gu *et al.*, 2009). In addition, proximity is applied in systems using IR, RFID and Bluetooth, and yet requires little calibration effort (Liu *et al.*, 2007; Harle, 2013). However, there is the need for larger spread of readers to achieve a reliable and a wider coverage area (Harle, 2013). This large concentration of readers could lead to complexity and high cost.

2.2.2.4 Scene Analysis and Fingerprinting

Unlike the previous three algorithms, the position estimation in Scene Analysis is done independent of angle or distance. As one of the important elements of the positioning technology under analysis in this thesis, Scene Analysis collects information or features from a scene or observation and then estimates the position of an object by matching or comparing the collected information with the one in an existing database (Liu *et al.*, 2007; Nuaimi & Kamel, 2011). This information collected is also known as a fingerprint, which is a unique characteristic or signature that distinguishes a scene from another (ibid.). Thus, the Scene Analysis algorithm is also referred to as location fingerprinting or simply as fingerprinting, which is an RSS-based algorithm, in wireless or RF networks (Liu *et al.*, 2007; Nuaimi & Kamel, 2011; Mautz, 2012). The fingerprinting method uses a database of RSS values to determine the position of a Wi-Fi device in a Wi-Fi coverage area (Wang & Jia, 2007).

As reflected in application sections 2.3.5 and 2.3.6, location fingerprinting matches the fingerprint of some characteristic of a signal that is location dependent (Liu *et al.*, 2007). Location fingerprinting can be done in two phases, namely offline and online (Liu *et al.*, 2007; Yim *et al.*, 2011; Brás *et al.*, 2012). In the offline phase, an environment within a building is surveyed and grid points are computed at different locations in the building (Liu *et al.*, 2007; Yim *et al.*, 2011). Each grid point has a list of RSSI values for visible access points at the locations (Yim *et al.*, 2011; Brás *et al.*, 2012). Furthermore, the respective position information and signal strengths from the different locations are collected for position estimation purposes (Liu *et al.*, 2007). The accuracy obtained by this method is higher than the RF-based indoor positioning technique that determines object position based on RSS, presented by Subhan *et al.* (2011). In the online phase, grid points and collected position information compute the most feasible position of the object (Liu *et al.*, 2007; Yim *et al.*, 2011).

Fingerprinting has a better positioning accuracy and performance when compared with propagation (Wang & Jia, 2007; Yim *et al.*, 2008). However, the offline stage requires a significant amount of effort and time to build the coordinate signal strength maps for each WLAN and to update the RSS map of the WLAN when there is a change in position (Wang & Jia, 2007; Gu *et al.*, 2009; Yim *et al.*, 2011). In general, the challenges of fingerprinting are mainly the time consuming process and the high computational cost (Liu *et al.*, 2007; Yim *et al.*, 2008). As a result, fingerprinting suffers from high cost, high complexity and low speed (Yim *et al.*, 2008). In addition, due to the fact that the positioning techniques based on RSS could sometimes be less accurate (Yim *et al.*, 2008; Yim *et al.*, 2011), robust methodologies that could be implemented on a low-cost infrastructure is required (Sayrafian-Pour & Perez, 2007). Areas of application of scene analysis or fingerprinting are in the RF-based systems such as WLAN and optical and vision-based systems such as IR and camera-based ones (Kemper & Linde, 2008).

2.3 Existing Technologies

Having adequately introduced and discussed indoor positioning techniques such as the signal metrics and properties as well as the positioning algorithms in section 2.2, this section discusses technologies in which these techniques are applied. Given that positioning and navigation development employ variety of algorithms and techniques, navigation technologies vary in their application. While many technologies have evolved for positioning and navigation, the prevalent ones for indoor environments are the focus of this section.

According to Mautz (2012), determining the current position of a user is the most important and yet challenging in indoor positioning. Without the current location, planning or re-routing a path to the destination is difficult with any device; thus, navigation becomes cumbersome. Additionally, when a pedestrian does not know where he/she is while trying to locate a destination without a device, it is difficult to know the exact route to take towards the destination. The individual is considered lost. In order for this not to happen, certain technologies and techniques help in determining an individual's current location. For example, celestial bodies, natural landmarks, points-of-interest or known buildings, radio signals and satellite signals aid position determination.

Furthermore, investigating and classifying positioning while navigating indoors have required various technologies that include Infrared (IR), Ultrasound/Ultrasonic, Audible sound, Magnetic, Optical and Vision-based, and Radio Frequency (RF) (Liu *et al.*, 2007; Gu *et al.*, 2009; Koyuncu & Yang, 2010; Nuaimi & Kamel, 2011). These investigations are based on accuracy, performance, cost, usability, privacy and complexity of the technology used, while the classification is based on the main medium used to determine location (Gu *et al.*, 2009; Mautz, 2009; Fallah *et al.*, 2013). In addition, all positioning and navigation systems are techniques driven. Therefore, starting with the infrared positioning system, their benefits as well as limitations are expounded in the succeeding sub-sections.

2.3.1 Infrared (IR) Positioning System

The early indoor positioning systems were used for positioning and tracking purposes. One of such systems is the Active Badge, which studies have shown can be used for position determination (Want *et al.*, 1992). The Active Badge system is a widely recognised Active IR positioning system for the location of objects or people wearing a badge or tag (Ekahau, 2005; Mautz, 2012). The system uses IR signals to determine the position of objects or people, and is made up of a network of IR sensors linked by wires and connected to a centralised location or server (Want *et al.*, 1992; Mautz, 2012). Although, the infrared sensors are low-cost, researchers, such as Gu *et al.* (2009) and Mautz (2012), tend to agree that the IR positioning system as a whole is expensive. In general, the Active IR positioning system is beneficial because of its good battery life, cheap sensors and badges, and lightweight badges carried by users (Gu *et al.*, 2009). In addition, the Active Badge determines a position by using the TOA and trilateration positioning techniques discussed in section 2.2.

Furthermore, the desire to develop a system without the use of badges or tags motivated Kemper and Linde (2008) to propose a passive IR indoor positioning system based on passive thermal IR sensors known as thermopiles, a proposal that was implemented by Hauschildt and Kirchhof in 2010. The passive IR positioning system consists of thermal infrared sensors that measures the thermal radiation emitted by any human within its range. This is possible because the temperature of the human skin differs from room temperature in indoor environments. However, the system has limitations just like the Active IR system. Because humans are not the only source of heat in indoor environments, other heat sources could influence the signals received by the IR sensors (Kemper & Linde, 2008; Hauschildt & Kirchhof, 2010). For example, light bulbs, computers, electronic devices and so forth, could influence the heat signals and thus affect the performance and accuracy of the system (ibid.). In concluding their study, Hauschildt and Kirchhof (2010) posit that limitations that affect performance and accuracy still exist in the IR system.

While there is no doubt that the implementation of the IR positioning system at room level is at a very low cost, its coverage range and accuracy are limited (Aitenbichler & Muhlhauser, 2003; Lee & Song, 2007). For a large space implementation, an IR system would need several receivers to improve accuracy (Ekahau, 2005; Mautz, 2012). As a result, this will lead to infrastructure complexity and high cost of the overall solution; scaling the solution can also become costly over time (Ekahau, 2005). The cost factor however, is not the only limitation. Technical limitations, including the line-of-sight problems, exist between sender and receiver, hence reducing widespread usability of the system (Ekahau, 2005; Huang & Gartner, 2010). For example, the interference of IR waves with fluorescent light and sunlight. Due to these factors, researchers explored other approaches of indoor positioning such as ultrasound that could cater for the limitations in the IR system.

2.3.2 Ultrasound/Ultrasonic Positioning System

Just like the IR positioning system, the Ultrasound positioning system has high accuracy at room level. Some Ultrasound positioning systems use either narrowband or broadband signals that have shown high-accuracy level during implementation. Ultrasound positioning systems involve the use of ultrasonic tags or nodes on users and objects. These tags or nodes serve as receivers or transmitters; when one is stationary or fixed, the other will be in motion (Holm, 2012; Medina *et al.*, 2013). The widely known Ultrasound positioning systems include the Active Bat (Koyuncu & Yang, 2010; Woodman & Harle, 2010), Cricket system (Priyantha, 2005) and Dolphin system (Fukuju *et al.*, 2003; Minami *et al.*, 2004).

2.3.2.1 Active Bat

The study on the Active Bat began with the work of Ward *et al.* (1997); further work was done by Woodman and Harle (2010). The Active Bat system consists of receivers, transmitters and a centralised location or server for position computation. Just like in the IR system, a network of wires link the receivers fixed on the ceiling, with the network of receivers connected to the server. The ultrasonic tag (or transmitter) broadcast signals while the receiver processes the signals one at a time to prevent interference. However, the study by Woodman and Harle (2010) developed a system where the receiver can process signals received from transmitters concurrently without the risk of interference. Just like the IR Active Badge, Active Bat uses the trilateration and TOA positioning techniques to determine the position of a tag.

According to the survey carried out by Gu *et al.* (2009) and Xiao *et al.* (2011), the ultrasonic tags carried by users are small, convenient and have a good battery life. Hence, users do not need to change the batteries frequently. In addition, the Active Bat system has good accuracy at room level. However, it is not scalable for implementation in a large building. This is because the receiver or sensor processes the signal one at a time and a large number of tags will need to be deployed. Therefore, implementation on a large scale will degrade accuracy, and performance due to noise and multipath effects (Gu *et al.*, 2009; Fallah *et al.*, 2013; Medina *et al.*, 2013). The large number of sensors deployed will result in a complex and costly system, with privacy concerns still an issue because of the server that computes position (Gu *et al.*, 2009).

The study by Woodman and Harle (2010) concurs with the views of these surveys. However, their alternative experimental system was scalable unlike the Active Bat system, meaning that it can be implemented on a large scale conveniently, because the sensors process signals concurrently and not one at a time. Furthermore, other newer Ultrasound positioning systems address some of the issues in the Active Bat system. For example, Medina *et al.* (2013) gave a summary of their study using trilateration and TOA techniques to improve positioning accuracy and performance. Holm (2012) used the trilateration, TOA and RSS techniques to improve accuracy and coverage area, and hence scalability. Lopes *et al.* (2012) made use of TOA and broadband ultrasonic transducers, as against the narrowband ultrasonic transducers that the afore-discussed systems use, to improve accuracy on a large scale. With the exception of the Cricket system discussed in the subsequent section however, none of these systems addresses the privacy issue.

2.3.2.2 Cricket System

Unlike the Active Bat system with low user privacy because of the use of a server, the Cricket system provides higher user privacy. It improves upon the Active Bat system by using a combination of ultrasound and RF for position determination that is performed locally on the mobile device (Priyantha, 2005; Xiao *et al.*, 2011). In addition, the Cricket system uses TOA, TDOA and trilateration techniques to locate a target (Priyantha, 2005; Gu *et al.*, 2009).

The study on the Cricket System began with the work of Priyantha *et al.* (2000). Their goal was to develop Cricket, a location-support system for mobile and location dependent applications in indoor environments. In other words, Cricket does not track or monitor user location but help devices to know their position and discover where they are. This eliminates the use of a server for position computation. A similar study by Randell and Muller (2001) focused on a low-cost indoor positioning system using a single RF transmitter and four ceiling mounted ultrasound transmitters to compute user position autonomously at room level.

According to Priyantha *et al.* (2000) and Priyantha (2005), the Cricket system consists of nodes known as 'Cricket nodes'. The Cricket nodes are mobile or static devices installed within the positioning network. They are the ultrasound transmitters (beacons) and receivers (listeners). The beacons are active and fixed to the ceiling or wall of a building while the listeners are passive and attached to target objects or people for position determination. In order to determine position, the beacons transmit messages to the listener intermittently while the listener, listening for transmissions, uses the information to determine its position.

A number of studies have attempted to implement the Cricket system in an indoor navigation scenario. For example, Priyantha *et al.* (2001) designed and implemented the Cricket compass system, which consists of active beacons and passive sensors or receivers. The transmitted signal from the beacons enables position estimation and movement direction of the mobile device. The Cricket compass system aids orientation within a building (Priyantha *et al.*, 2001), but determining position while navigating is not real-time. While the compass system introduces orientation with the Cricket system, implementing it on a large scale will result in complexity, high cost and deployment difficulties. This is because of the number of sensors that will be required to improve accurate position estimation and orientation.

In addition, Miu (2002) designed and implemented a precise indoor mobile navigation system, known as CricketNav, using the Cricket indoor location-support system. CricketNav consists of active beacons, passive receivers and the Cricketserver. The Cricketserver processes and estimates the user position real-time during navigation (Miu, 2002). Miu (2002:18) pointed out that, "the CricketServer normally runs in the handheld device attached to the Cricket listener but it can also run on the network to free up scarce CPU cycles on the handheld." Based on this deduction, implementing the Cricketserver in the handheld device is sufficient for testing and for research purposes. However, in order to implement the system on a large scale or for commercial purposes, running Cricketserver in a server is required, which of course raises privacy concerns.

Another navigation system that uses the Cricket indoor location-support system is the one developed by Smith *et al.* (2004). This system involves tracking active and passive mobile architectures. In the active architecture, receivers at known locations estimate the distances to a mobile device based on the active transmission from the device. In the passive architecture, active beacons periodically transmit signals to a passive mobile device that estimates the distances to the beacons. In the active architecture, real-time tracking and navigation takes place while in the passive architecture tracking and navigation is not real-time. However, the passive architecture scales better. The advantages and limitations of both architectures led Smith *et al.* (2004) to focus on a hybrid system where both architectures are integrated to capitalise on the strengths of both. However, with such a system there is always a trade-off. Smith *et al.* (2004) did observe that tracking a moving device in this hybrid system is harder than the active architecture. In order to attain fast real-time tracking, the active architecture is more suitable but comes at the cost of reduced scalability, high cost and privacy concerns.

Furthermore, Priyantha *et al.* (2000) posit that Cricket is the result of five design goals in mind. These goals are user privacy, decentralised administration, network heterogeneity, low-cost and room-sized granularity. Priyantha (2005) further clarified these goals as user privacy, scalability, ease of deployment and configuration, small form factor and accuracy respectively. In essence, the development of Cricket addresses problems associated with user privacy, scalability, deployment and configuration, cost and accuracy. In addition, the Cricket system uses a less number of transmitters fixed on the ceiling and addresses the issue of fault tolerance by using RF signals as a second method of proximity positioning if enough transmitters are not available (Priyantha *et al.*, 2000; Priyantha, 2005; Gu *et al.*, 2009). The system is scalable for implementation in a large building and offers efficient performance and low-cost deployment as a location-support system (ibid.). In general, Cricket provides user privacy by locally performing position calculation in the located object. However, Cricket-related systems have shown that deploying Cricket on a large scale and space for navigation purposes will result in complexity, in that additional infrastructures are used to improve convenience, accuracy and performance. Because of the increase in infrastructural usage, the cost of the system increases. In addition, while the positioning accuracy of these systems is efficient at room level, scaling them at a wider coverage area could result in lower positioning accuracy because of the computational increase in the components. This could therefore lead to poor performance. As an alternative, the Dolphin system is explored in section 2.3.2.3 below.

2.3.2.3 Dolphin System

Dolphin (Distributed Object Locating System for Physical-space Internetworking) is another ultrasound positioning system, based on a hop-by-hop locating mechanism and broadband signals (Fukuju *et al.*, 2003; Minami *et al.*, 2004). Fukuju *et al.* (2003) and Minami *et al.* (2004) carried out the study on Dolphin. However, work on this area of ultrasound positioning system began with studies such as that of Hazas and Ward (2002). The position principle of the Dolphin is similar to that of active bat and cricket, using TOA, TDOA and trilateration techniques for position determination just like the Cricket.

The Dolphin system consists of nodes with RF, ultrasound transmission function and one-chip Central Processing Unit (CPU) (Fukuju *et al.*, 2003; Minami *et al.*, 2004). The two types of nodes used are reference node and normal node. Dolphin knows the location of a few nodes, and requires only a few pre-configured reference nodes for locating all other nodes in the system (ibid.). Using RF and ultrasound transmission function, the remaining nodes can determine their location based on the location of reference nodes. A reference node transmits RF signal, which contains predetermined position of the reference node, and ultrasonic pulse to other nodes (Fukuju *et al.*, 2003; Minami *et al.*, 2004; Gu *et al.*, 2009). The other nodes start internal pulse counter on receiving the RF signal. As soon as the internal pulse counter stops, the nodes compute distances to the reference node on receiving the ultrasonic pulse (ibid.).

One distinguishing factor of the Dolphin system is the use of ultrasound broadband signals (Hazas & Hopper, 2006). The broadband technique is able to overcome some limitations of the narrowband technique used by other ultrasound positioning systems. For example, the broadband technique is able to perform better than the narrowband in the presence of noise and multipath effect (Hazas & Ward, 2002; Hazas & Hopper, 2006). The study by Hazas and Ward (2002) focused on a positioning system using ultrasound broadband signals against narrowband signals. The transmitter and receiver prototype of this system, collectively referred to as Dolphin, were designed using electronic components and broadband ultrasonic transducers. This has helped the system to overcome limitations such as processing signals one at a time. With the broadband ultrasound technique, signals are transmitted concurrently, that is, multiple access transmission (Hazas & Hopper, 2006).

Other works that have employed this approach are the studies by Hazas and Ward (2003), Hazas and Hopper (2006) and Herbert and Georg (2011). The study by Hazas and Hopper (2006) is identical to that of Hazas and Ward (2002). Their study used the same process and methods, achieved the same results, and have the same advantages and limitations as that of Hazas and Ward (2002). Hazas and Ward (2003) focused on a privacy-oriented location system that allows users with mobile ultrasound receivers to determine their position autonomously within the Dolphin system. The autonomous position determination guarantees privacy and improves accuracy. However, it is doubtful that this autonomous system is implementable on a large scale. On the other hand, the study of Herbert and Georg (2011), an ultrasound indoor positioning system that supports the locating of many static and mobile devices, focused on a low-cost system that improves position accuracy. Just like other Dolphin systems, this system uses a server and hence raises privacy concerns.

The advantage of the Dolphin system is that it requires only a few nodes to determine all the position of nodes, hence improving performance. However, one general problem that is inherent in this system is low accurate positioning caused by multipath effects and line-of-sight (Gu *et al.*, 2009; Fallah *et al.*, 2013; Medina *et al.*, 2013). In some cases, privacy concern is an issue with regard to where a server stores and computes users' position information.

In general and based on the afore-discussed, the ultrasound signal's characteristics, such as slow propagation signal speed when compared with speed of light, negligible penetration in walls and low-cost of transducers, make it interesting for studies in indoor positioning systems. The advantages of the ultrasound positioning system when compared with other positioning systems include improved accuracy and performance, low-cost and scalability. For example, the active bat exhibits good accuracy and performance, Cricket exhibits good accuracy, low-cost and user privacy, and Dolphin exhibits good performance and scalability. CricketNav exhibits good accuracy as well as low-cost and scalability. Most of these advantages are exhibited at room level.

On the other hand, implementing on a large scale will degrade the advantages in this system. Ultrasonic positioning systems are expensive to deploy and maintain on a large scale. They are usually inexpensive at room level. For example, the Active Bat system involves the deployment and configuration of many fixed sensors when implementing on a large scale, which is time consuming. The same goes for Cricket and Dolphin systems. This deployment results in complexity and high cost in instances where a server is involved. In addition, ultrasound systems suffer from multipath effects such as noise, reflection and interference. Hence, system accuracy and performance is degraded.

2.3.3 Audible Sound Positioning System

Unlike the Ultrasound positioning system, which has a limited range because of high attenuation while propagating in the air, the Audible Sound positioning system is not limited in range (Rishabh *et al.*, 2012). Audible Sound positioning system is a system where the position of a person or an object is determined in a building by using audible sound waves through sound cards of standard devices (Mautz, 2012; Fallah *et al.*, 2013). Examples of such a system are Beep, BeepBeep, Guoguo and Roomsense as demonstrated in the studies of Mandal *et al.* (2005), Peng *et al.* (2012), Liu *et al.* (2013) and Rossi *et al.* (2013) respectively. Other examples include the studies of Höflinger *et al.* (2012), Rishabh *et al.* (2012) and Sertatil *et al.* (2012). The working operation of these systems is the same despite the fact that they consist of different but similar hardware and architecture.

The studies of Mandal *et al.* (2005), Höflinger *et al.* (2012), Rishabh *et al.* (2012), Liu *et al.* (2013) and Rossi *et al.* (2013) consist of mobile devices (e.g. mobile phone), acoustic receivers, central server and wireless network. The mobile device acts as a transmitter that sends sound to the receivers, with each acoustic receiver having a processing unit, a wireless network interface card and a microphone for detecting acoustic signals (Höflinger *et al.*, 2012; Liu *et al.*, 2013). When a mobile device requests for a position, the device's speaker transmits an acoustic signal that is detected by the acoustic receivers. The receiver estimates the TOF/TOA of the acoustic signal and sends it to the central server, along with the position information of the receiver through the wireless network. With this information, the central server computes the position of the mobile device and sends the information to the mobile device. While the mobile device acts as a transmitter in the positioning system of these studies, the usage of the mobile device differs in the study of Rishabh *et al.* (2012). The mobile device, in this case, acts as the receiver through the device's microphone.

Furthermore, the studies of Peng *et al.* (2012) and Sertatil *et al.* (2012) consist of speakers (signal generator), microphones (signal detector), central server and wireless network. Although, Peng *et al.*'s system is mainly a software-based solution, it uses hardware infrastructures nonetheless. In this configuration, the speakers transmit acoustic signals to compute the distance between the speakers and the microphone (receiver). The receiver detects the acoustic signals and uses the computed distance to perform TOF/TOA measurement of the signal. The central server receives the measurement via the wireless network and calculates the position of the device using trilateration (Peng *et al.*, 2012; Sertatil *et al.*, 2012).

In general, the Audible Sound positioning system has the potential to provide a high positioning accuracy at a low cost (Gu *et al.*, 2009). However, if high accuracy will be maintained in a system, more sensors will be needed; more so when the acoustic signal is weak (Mautz, 2012). Hence, the complexity and cost of the system rises. Furthermore, because interference, noise, reflection, low update rate, attenuation of signals, limited bandwidth of microphone and low penetration power through obstacles affect audible sound signals, system performance is also negatively impacted (Fallah *et al.*, 2013; Liu *et al.*, 2013). In addition, though privacy intrusion may be minimised in some systems, it is not eradicated; hence, privacy remains a concern (Liu *et al.*, 2013).

2.3.4 Magnetic Positioning System

Magnetic positioning is an old way of position determination and tracking, as evidenced in the study carried out by Raab *et al.* (1979), which is still relevant. This method of positioning is based on works on magnetic fields, the earth's magnetic field and the compass (Li *et al.*, 2012). Magnetic positioning system involves the use of magnetic signals for position determination within a magnetic field (Paperno *et al.*, 2001; Blankenbach *et al.*, 2012; Kim *et al.*, 2012). The system consists of fixed transmitters, and receivers that are mounted on the user or tracked object. The receivers receive magnetic signals from the transmitter and send the position information to a centralised location for position determination. However, there are systems that do not use these installed devices. Instead, they make use of the magnetic properties of pillars, steel structures, electric power systems, electronic appliances and other structures that exhibit some form of magnetic field (Gozick *et al.*, 2011).

According to Talcoth and Rylander (2011), magnetic positioning systems are implemented using two magnetic field types namely, static magnetic field and low frequency alternating magnetic field. Other variations of these magnetic field types are artificial magnetic field and electromagnetic field (Mautz, 2012), and static magnetic field and dynamic magnetic field (Gozick *et al.*, 2011). In the static or artificial magnetic field, magnetic field is generated with permanent magnets, or coils using Alternating Current (AC) or pulsed Direct Current (DC) (Talcoth & Rylander, 2011; Mautz, 2012). In the low frequency alternating or electromagnetic magnetic field, static charges produce electric fields and current produce magnetic fields to form electromagnetic field (Mautz, 2012). In addition, oscillating charges produce electric and magnetic fields (ibid.). In essence, these magnetic fields change dynamically from an electrical field or device (Gozick *et al.*, 2011). In the survey by Mautz (2012), he classified the studies surveyed into the following categories: systems using antenna near field, systems using magnetic fields from currents, systems using permanent magnets and systems using magnetic fingerprinting. Most studies fit into at least one of these categories.

While Raab (1979) describes a positioning and tracking system using three-axis magnetic dipole source and a three-axis magnetic sensor, Paperno (2001) focused on increasing the speed of the positioning and tracking system by using two-axis generation of a quasi-static rotating magnetic dipole source and three-axis magnetic sensor. These two studies are similar in that they both use mathematical method to attain their goal, and based on ‘systems using magnetic fields from currents’. The study by Paperno (2001) is an improvement of the study done by Raab (1979). The study involves the excitation of the magnetic source and the resultant sensor output. The excitation obtains information about the sensors’ position, and hence, enables accurate position determination and an increase in the tracking speed. As a result, there is a reduction in electromagnetic interference. Similarly, Arumugam *et al.* (2011), Talcoth and Rylander (2011) and Blankenbach *et al.* (2012) also based their studies on “systems using magnetic fields from currents”.

The study by Arumugam *et al.* (2011) involves the excitation of an emitting loop with a sinusoidal signal source to generate a ‘magnetoquasistatic’ field for positioning and tracking purposes. The generated field is analysed with complex image theory to improve accuracy and wide coverage area tracking. However, improving the accuracy over a wide coverage area resulted in some errors within close proximity. Hence, this led to the researchers’ study on the understanding of the source of the errors and how they can be mitigated (Arumugam *et al.*, 2011).

On the other hand, Talcoth and Rylander (2011) focused on the optimisation of sensor positions of a magnetic tracking system by using an analytical model, where magnetic dipoles approximate the transmitting and sensing coils of the system. The analytical model uses the Fisher information matrix (FIM) and the concept of D-optimality to formulate a performance measure and to compare the sensor array layout. Generally, more sensors in a system results in improved accuracy. However, the more the number of sensors used the higher the system cost, complexity and configuration time (Talcoth & Rylander, 2011). Hence, the motivation to optimise sensor position should improve coverage area by a sensor and thus reduce the number of sensors used. However, since optimising the sensor positions involve performance measurement, optimisation problem formulation, sensor selection and the number of sensors used, the configuration time of a sensor is likely to increase and degrade a system's performance.

In the study of Blankenbach *et al.* (2012), a 3D indoor positioning system was developed based on DC artificial magnetic fields generated by active magnetic coils. By capturing the coils' magnetic field with a passive magnetometer, the position of a mobile device is determined. The magnetic field is able to penetrate buildings and obstacles without signal propagation error or multipath effects. However, the accuracy of the system depends on the signal quality of the coils' magnetic field. In addition, if the range between the sensor and the mobile reference point is too large, the accuracy and performance of the position estimation is degraded.

Furthermore, the study by Song *et al.* (2009) is an example of 'systems using permanent magnets'. The study involves a magnetic localisation and orientation system for tracking the movement of a wireless capsule. The capsule, with a permanent magnet embedded in it, generates a magnetic field that is sensed by the magnetic sensors around it as magnetic signals. Thus, the magnetic sensors are able to measure the magnetic signals, and compute the capsule's position by using the Levenberg-Marquardt (LM) algorithm and least squares curve fitting method. As a result of using this algorithm and method, the magnetic system is able to have a good accuracy and good performance, with its application area being the medical and health related field (Talcoth & Rylander, 2011; Mautz, 2012).

Another category of the classification of studies in the magnetic positioning system is 'systems using magnetic fingerprinting'. Fingerprinting is used because of non-line-of-sight signal (Li *et al.*, 2012). The works of Storms *et al.* (2010), Chung *et al.* (2011), Gozick *et al.* (2011), Kim *et al.* (2012) and Li *et al.* (2012) fall under this category. The approach of Storms *et al.* (2010) made use of the distinctive nature of magnetic field variations in indoor environments to estimate position and navigation path of a vehicle. To estimate the position successfully, a map of the magnetic field intensities of the environment, three-axis magnetometers and Kalman filter algorithm are used. This resulted in a good accuracy level for the system; however, certain errors existed when using a map of an entire area.

On the other hand, Chung *et al.* (2011) made use of disturbances of the Earth's magnetic field and that of structural steel elements in a building to design an indoor positioning system. Their study entails investigating the characteristics of magnetic field fingerprints, the performance of the positioning system using the fingerprints and its implementation in a pedestrian navigation system. In the navigation system, a mobile object collects magnetic fingerprints while navigating and sends it through HyperText Transfer Protocol (HTTP) or serial port Universal Serial Bus (USB) cable, which then goes to a server. The server compares the received fingerprints with the map fingerprints in the server, and returns the estimated position of the object. Hence, positioning and navigation is accomplished. The system has wide coverage area capability; however, errors and costs increase as the coverage area increases (Li *et al.*, 2012). In addition, significant effort and time is required for system configuration and setup, with a fair accuracy and performance (ibid.).

Furthermore, Gozick *et al.* (2011) and Kim *et al.* (2012) used a mobile phone and building structures to aid positioning and navigation. The building structures act as landmarks and guideposts within the system. The navigation system involves collecting and analysing the magnetic field at various points inside a building, using the built-in accelerometer, magnetometer and gyroscope of the mobile device. A developed measurement system collects measured data to aid magnetic map generation for positioning and navigation purposes. To determine a user's position, Kim *et al.* (2012) used the Monte Carlo Localisation (MCL) algorithm that is based on a particle filter method. In addition to that, they made use of software development methods to develop an application that will run in the smartphone, activate the sensors and record the sensor readings. The magnetic field variations inside the building is used as magnetic fingerprints to identify landmarks, corridors and rooms effectively; thus, the system does not require additional infrastructures (Gozick *et al.*, 2011; Kim *et al.*, 2012; Li *et al.*, 2012). However, certain fluctuations and errors exist in the measurement of the magnetic field (Kim *et al.*, 2012; Li *et al.*, 2012). Hence, accuracy and performance is degraded especially on a large-scale implementation.

In general, the magnetic positioning system has high accuracy and does not suffer from non-line-of-sight errors between magnetic sensors and the tracked object (Gu *et al.*, 2009; Chung *et al.*, 2011; Mautz & Tilch, 2011). However, one issue with the magnetic positioning system is that of limited coverage (Li *et al.*, 2012; Mautz, 2012). This limitation affects the efficiency and robustness of the system, despite its high accuracy. In order to improve the coverage range, an increase in magnetic sensors and infrastructures may be needed to cover sufficient areas, hence increasing the complexity and cost of the system (Gu *et al.*, 2009; Li *et al.*, 2012). In addition, systems using the fingerprinting method are influenced by steel and metal structures within the building (Li *et al.*, 2012).

2.3.5 Optical and Vision-based Positioning System

The Optical and Vision-based positioning system is a system where the position of a person or an object is determined in a building by identifying a marker or image that is within view, with the aid of a mobile sensor or camera in a mobile device carried by the user (Klopschitz *et al.*, 2010; Mautz & Tilch, 2011). The marker is a fixed object that has patterns used as a point-of-interest, or reference within the field of view of an imagery sensor such as a mobile camera (Saito *et al.*, 2007). Examples of a marker include barcodes, QR codes and fiducials among others. Optical and Vision-based positioning is mainly done in two ways namely, marker-based and Augmented Reality (AR) (Mautz, 2012).

2.3.5.1 Marker-based Method

In the marker-based method, a mobile phone camera gets visual information using markers, for example QR code, as posited by Chang *et al.* (2007), Mulloni *et al.* (2009), Vazquez-Briseno *et al.* (2012), George and Mazel (2013), Raj *et al.* (2013) and Basiri *et al.* (2014). The system consists of a mobile device with camera, QR code and server (Raj *et al.*, 2013; Basiri *et al.*, 2014). The camera of the mobile device is used to capture data by scanning the pattern of the QR code, while the server is used for tracking purposes and storing information such as floor plan map data for retrieval purposes when required (Chang *et al.*, 2007; Mulloni *et al.*, 2009; Barberis *et al.*, 2014).

While the focus of Chang *et al.* (2007) is on tracking individuals with cognitive impairments in smart environments, Mulloni *et al.* (2009) focused on scanning and updating position information of an environment in real-time in order to aid continuous navigation. In other words, the study by Chang *et al.* (2007) does not enable real-time navigation like that of Mulloni *et al.* (2009), but can track the movement of users at certain intervals of time. In the case of Raj *et al.* (2013), scanning the QR code gets the floor map URL and geo-location details. Hence, the floor map of the building is retrieved and used for navigation purposes (Raj *et al.*, 2013; Basiri *et al.*, 2014). However, navigation in this case is not real-time.

Compared to the previous positioning systems discussed, the simplicity with which the QR code works makes it a viable system for indoor positioning (Raj *et al.*, 2013; Basiri *et al.*, 2014). Chang *et al.* (2007) posited that it is easy to deploy because of its low cost. In addition, user privacy is protected because real-time positioning and update through a server does not exist for some solutions like the study of Raj *et al.* (2013). For some other solutions, the user position is not real-time despite the fact that the mobile device is being tracked (Chang *et al.*, 2007; Mulloni *et al.*, 2009; George & Mazel, 2013). The user position determined is the position of the marker. The markers are distributed around the navigation environment and position is determined by placing the mobile device in close proximity to the marker (Kim & Jun, 2008). For some solutions, real-time navigation is still achieved as shown in the study of Barberis *et al.* (2014). In addition, the accuracy of the system depends on the range of the marker position to the device, and the range depends on the resolution of the device's camera (Raj *et al.*, 2013). If the resolution of the device's camera is not good enough, it can negatively influence the accuracy and performance of the system (ibid.). On the other hand, the study by Barberis *et al.* (2014) does not require knowing the resolution and properties of the device's camera. However, these systems become more complex and the cost is higher because of additional infrastructures. These challenges led to the AR approach, which serves as an alternate method.

2.3.5.2 Augmented Reality (AR) Method

Just like the marker-based method, AR also consists of mobile device with camera, marker and server (Raj *et al.*, 2013; Basiri *et al.*, 2014). The camera of the mobile device is used to capture data by scanning the pattern of the marker, while the server is used for position calculation, position determination and real-time tracking and navigation (Chang *et al.*, 2007; Mulloni *et al.*, 2009; Vazquez-Briseno *et al.*, 2012). AR is the overlay of virtual objects with the real world by using visual markers or images for the purpose of positioning, tracking and navigation (Möller *et al.*, 2012). AR gets the visual information, as posited by Klopschitz *et al.* (2010), Mulloni *et al.* (2011) and Möller *et al.* (2012), by seamlessly overlaying a user's view with location information linked to an image database in a centralised location or server. The server performs optical marker detection, image sequence matching, location recognition and location annotation (Kim & Jun, 2008; Klopschitz *et al.*, 2010; Vazquez-Briseno *et al.*, 2012). Mautz and Tilch (2011) noted that the server transmits the recognized location information to the mobile device; hence, enabling real-time positioning and navigation.

In the studies by Mulloni *et al.* (2011) and Möller *et al.* (2012), they focused on improving the interface of an AR indoor navigation system so that navigation in indoor environments will be enhanced. In the course of navigation, information points such as markers are placed within the environment to aid accurate positioning and performance using activity-based instructions to guide users. Hence, there is a significant reduction in navigation errors. To achieve this, robustness, simplicity and usability are factors that are considered in the implementation process (Mulloni *et al.*, 2011; Möller *et al.*, 2012). Although most positioning and navigation systems use the marker-based approach, the study by Klopschitz *et al.* (2010) adopts a new approach that is "markerless-based". This approach uses available image features for matching and tracking purposes. Because matching image features in real-time could be difficult, the markerless-based approach uses some assumptions with respect to the camera of the mobile device (Klopschitz *et al.*, 2010).

Furthermore, real-time positioning and navigation is effective with AR when more markers and a server are used (Möller *et al.*, 2012). However, despite the improvement of AR over marker-based, significant amount of computing power may be required to perform image matching thereby increasing the complexity and affecting the performance (Klopschitz *et al.*, 2010). In addition, upgrading the server may result in increase in cost and cost of maintenance.

In general, the optical and vision-based positioning system uses the camera and processing power of a mobile device (Möller *et al.*, 2012). Modern mobile devices come with inertial sensors, such as accelerometers, gyroscopes and magnetometers, inbuilt in them. Hence, there is a reduction in the infrastructure installation (ibid.). In addition, this system reduces cost significantly when compared with some other positioning systems (Mulloni *et al.*, 2011). However, the system suffers from low accuracy, interference from multiple effects such as bright light and motion blur, and significant accumulative errors which could lead to poor performance (Klopschitz *et al.*, 2010; Möller *et al.*, 2012). In some cases, privacy concerns may be an issue since a server stores position information for tracking and navigation purposes.

2.3.6 Radio Frequency (RF) Positioning System

Radio Frequency positioning system is a positioning technology that uses RF signals and infrastructures to determine the position of a person or object for tracking and navigation purposes (Zhang *et al.*, 2010). The RF system has the benefits of its signal being able to penetrate walls and obstacles leading to a wider coverage area, as well as reusing existing RF infrastructures resulting in a relative cost reduction (Gu *et al.*, 2009;

Farid *et al.*, 2013). These benefits have attracted researchers to the RF positioning system thus resulting in its categorisation as proximity detection and RSSI measurement systems (Lukianto & Sternberg, 2011). These systems make use of the triangulation, trilateration or fingerprinting techniques (Gu *et al.*, 2009; Zhang *et al.*, 2010). However, limitations exist due to the complicated and complex nature of indoor spaces. The RF positioning systems are further categorised into Bluetooth, Ultra-wideband (UWB), Wireless Sensor Network (WSN), Wireless Local Area Network (WLAN), Radio-Frequency Identification (RFID) and Near Field Communication (NFC) (Gu *et al.*, 2009; Huang & Gartner, 2010; Deak *et al.*, 2012; Fallah *et al.*, 2013). The various RF positioning systems have unique strengths and limitations, and the succeeding sub-sections highlight them.

2.3.6.1 Bluetooth-based Positioning System

Bluetooth is a wireless technology that is used for short-range data exchange and Wireless Personal Area Network (WPAN) (Gomez *et al.*, 2012; Mautz, 2012; Wang *et al.*, 2013). Gomez *et al.* (2012), Mautz (2012) and Wang *et al.* (2013), among other researchers, have used mobile WPAN that utilise the RSS feature in a couple of implementations that include positioning. Bluetooth-based positioning system is a system that locate and track objects and people inside a building by providing real-time position information of radio and mobile phone users using fixed Bluetooth sensors connected to a LAN (Diaz *et al.*, 2010; Wang *et al.*, 2013). The positioning system consists of Bluetooth devices, Bluetooth tags or sensors, server and WLAN (Liu *et al.*, 2007; Deak *et al.*, 2012). Bluetooth devices that are within the range of the installed Bluetooth sensors are able to connect to the sensors, thus resulting in the sensor's communication of the device's ID to the server via WLAN (Gu *et al.*, 2009; Deak *et al.*, 2012). The server computes the position of the device and sends the information to the application running on the device (Deak *et al.*, 2012).

However, the studies of Feldmann *et al.* (2003), Chawathe (2008) and Bekkelien (2012) showed that position computation also occurs in the mobile device, thus improving user privacy. In this case, the Bluetooth sensors communicate with the server that stores the position information of the sensors, but the server does not compute position. The application in the mobile device requests the position information from the Bluetooth sensors before computing the position of the device with the information (Feldmann *et al.*, 2003; Bekkelien, 2012). In addition, the sensors are placed within the environment in such a way as to make their operation optimal.

Furthermore, the advantage of using Bluetooth in positioning systems lies in its high security, low-cost, low-power and small size (Gu *et al.*, 2009; Mautz, 2012). However, device discovery is inherently a slow process in the Bluetooth-based positioning methods, thus affecting real-time positioning, accuracy and performance, thereby making Bluetooth undesirable for tracking and navigation purposes (Chawathe, 2008; Subhan *et al.*, 2011; Bekkelien, 2012). In addition, due to the amount of infrastructures required, the cost of the system rises, with the use of the server raising privacy concerns (Deak *et al.*, 2012).

2.3.6.2 UWB-based Positioning System

UWB is a short-range high-speed radio technology for wireless communication with the ability to have a robust resistance to non-line-of-sight and multipath effects (Lee *et al.*, 2007; Mautz, 2012; Farid *et al.*, 2013). A variety of applications and positioning technologies has implemented this technology because of its high bandwidth (Gu *et al.*, 2009; Farid *et al.*, 2013). For example, De-Angelis *et al.* (2010), Luo and Law (2012) and Zwirello *et al.* (2012) have carried out studies on positioning technologies using UWB.

UWB-based positioning system can be classified into passive and active (Mautz, 2012). Passive UWB-based positioning system is a system that uses signal reflection, and not an attached UWB tag, to determine the position of a person or object by means of the principle of radar (ibid.). When a person moves within a room with known positions of installed UWB transmitters and receivers, the body of the person reflects the signals emitted by the transmitters. The receivers sense the reflected signals, and the position of the person is estimated using TOA, TDOA and trilateration techniques (ibid.).

On the other hand, active UWB-based positioning system makes use of a battery-powered UWB tag. The active UWB-based positioning system consists of UWB sensors (fixed), active UWB tags (mobile), central software controller and WLAN (Liu *et al.*, 2007; Gu *et al.*, 2009; Deak *et al.*, 2012). The system locates and tracks objects and people inside a building by transmitting ultra-short UWB pulses from the tracked active UWB tags to the fixed and networked UWB sensors (De-Angelis *et al.*, 2010; Meissner *et al.*, 2013). The sensors send the collected information via WLAN to the software platform, which then analyses, computes and displays the position of the UWB tags in real-time (Liu *et al.*, 2007; Gu *et al.*, 2009; Deak *et al.*, 2012). In addition, the tags transmit signals and they are located by using the TOA, TDOA and trilateration techniques (Deak *et al.*, 2012; Mautz, 2012; Zwirello *et al.*, 2012).

Furthermore, the application of UWB in indoor environments has the advantages of a long battery life for UWB tags, robust flexibility, high data rates, high penetrating power, low-power consumption and transmission, good positioning accuracy and performance, and little or no interference and multipath effects (Liu *et al.*, 2007; Luo & Law, 2012; Mautz, 2012). In addition, the use of more UWB sensors and their strategic placement could result in a wider coverage area, real-time tracking, better positioning accuracy and reduction of the effect of signal impairments (Gu *et al.*, 2009; Mautz, 2012; Deak *et al.*, 2012). However, UWB makes use of technologies that are not in line with existing standards; hence, its public use is not certain (Canovic, 2007; Mautz, 2012). In addition, UWB is expensive to scale because of the need to deploy more UWB sensors in a wide coverage area to improve performance (Mautz, 2012; Deak *et al.*, 2012; Farid *et al.*, 2013).

2.3.6.3 WSN-based Positioning System

Another technology employed in RF positioning systems is WSN. WSN is a group of collaborative sensors with communication infrastructures for monitoring and recording of physical or environmental conditions, such as temperature, sound, pressure, humidity, light and wind, for onward data organisation and transmission to a central location or server through a WLAN (Akyildiz *et al.*, 2002; Wang & Balasingham, 2010; Mautz, 2012). A WSN consists of few or several sensor nodes that are small, lightweight and portable (Yick *et al.*, 2008; Cheng *et al.*, 2012; Giorgetti *et al.*, 2012). Each sensor node consists of a sensing unit (transducer), processing unit (microcontroller), communication unit (radio transceiver) and power unit (power source) (Yick *et al.*, 2008; Potdar *et al.*, 2009; Giorgetti *et al.*, 2012). The transducer generates electrical signals depending on the physical or environmental condition detected; the microcontroller collects, processes and stores signal data taken from the sensor; the radio transceiver transmits data to and receives data from the server, while the power source of the sensor node is usually a battery (Akyildiz *et al.*, 2002; Potdar *et al.*, 2009; Wang & Balasingham, 2010).

Furthermore, the cost of the sensor node is variable and depends on its energy consumption, computational speed, bandwidth and memory (Akyildiz *et al.*, 2002; Wang *et al.*, 2009; Robles *et al.*, 2012). The sensor node, as well as the WSN that is used mainly for monitoring and tracking purposes, has its application prominent in consumer and industrial areas, which include health, traffic, automation, smart home and positioning (Yick *et al.*, 2008; Potdar *et al.*, 2009; Wang *et al.*, 2010; Cheng *et al.*, 2012). ZigBee, an IEEE 802.15.4 communication standard protocol, is a radio device that has been implemented as a sensor node in a WSN, networked through a WLAN (Potdar *et al.*, 2009; Wang & Balasingham, 2010; Giorgetti *et al.*, 2012; Robles *et al.*, 2012).

WSN-based positioning system is a system that determines and tracks the position of a person or an object using sensor signals from the measurements taken by networked sensor nodes fixed in known positions in a building (Gu *et al.*, 2009; Giorgetti *et al.*, 2012). WSN-based positioning systems can be basically implemented in two ways namely, range-based (distance-based) and range-free (connectivity-based) (Zhong & He, 2009; Cheng *et al.*, 2012). Range-based positioning systems use the signal metrics and properties measurement discussed in section 2.2.1 to estimate the distance between nodes (Kumar *et al.*, 2011; Chen *et al.*, 2013). For example, in the studies of Wang *et al.* (2009) and Motter *et al.* (2011), the range-based system was used. Wang *et al.* (2009) carried out a study to reduce the influence of distance errors between nodes on position accuracy using RSSI and more than three anchor nodes. Motter *et al.* (2011) used the IEEE 802.15.4 standard (ZigBee) and RSSI to determine the distance between nodes and to develop a positioning system of mobile nodes. The use of RSSI resulted in low complexity, low energy consumption, suitable communication range, relatively good accuracy and ease of deployment and configuration (Motter *et al.*, 2011). Generally, the range-based system has higher position accuracy than the range-free system. However, the range-based has a complex hardware configuration, which results in high cost (Zhong & He, 2009; Kumar *et al.*, 2011). Thus, a large-scale deployment is impractical, with the use of RSSI not being a good choice for accurate ranging in range-based positioning because of its low position accuracy compared to other approaches (Kumar *et al.*, 2011; Robles *et al.*, 2012).

On the other hand, range-free positioning systems do not use the signal metrics and properties measurement between nodes. It, however, uses a different kind of algorithms, the connectivity or proximity information of sensor networks and the existence of known nodes position, to estimate distance and position (Kumar *et al.*, 2011; Chen *et al.*, 2013). The study by Baggio and Langendoen (2008) focused on the information gathered by a sensor node to improve position accuracy using the Monte Carlo localisation algorithm, which does not require additional sensor node hardware. Likewise, Yun *et al.* (2009) proposed range-free positioning systems by using soft computing techniques and RSS to compute the proximity information of sensor nodes in relation to the known anchor node position. These systems are cost-effective when compared with the range-based approach (Baggio & Langendoen, 2008; Yun *et al.*, 2009). However, there is a trade-off with the range-free system. The range-free has fewer hardware and a low overall system cost, but a low system accuracy (Zhong & He, 2009; Kumar *et al.*, 2011; Chen *et al.*, 2013).

In general, WSN-based positioning algorithms determine the position of sensor nodes by using the knowledge of the absolute positions of a few sensors and inter-sensor measurements (Mao *et al.*, 2007; Yick *et al.*, 2008). One of the essential problems in sensor network applications is the localisation of non-anchor nodes for location-based services (Mao *et al.*, 2007). Thus, WSN-based positioning system is used to determine the position of the non-anchor nodes (Yick *et al.*, 2008; Yun *et al.*, 2009; Robles *et al.*, 2012). Furthermore, WSN-based positioning systems are challenging to implement because of the limitations experienced with the sensor node with respect to communication range, processing power, energy efficiency, responsiveness, robustness, self-configuration and computing resources (Robles *et al.*, 2012).

2.3.6.4 WLAN-based Positioning System

A WLAN is a wireless high-speed network that uses high frequency radio waves to connect and communicate between nodes and devices within a building or area to aid the mobility of users within the coverage area. Using the WLAN in a WLAN-based positioning system setup eliminates line-of-sight issues (Farid *et al.*, 2013). WLAN-based positioning system is a system that tracks and determines the position of a person or an object within a coverage area using the WLAN infrastructures (Mautz, 2012). The positioning system can use existing WLAN infrastructures to track or determine a user's position (Cypriani *et al.*, 2009). It consist of Wi-Fi devices, access points (APs) and server (Cypriani *et al.*, 2009; Tippenhauer *et al.*, 2009). WLAN-based positioning systems can be implemented in two ways, namely propagation and fingerprinting methods (Wang & Jia, 2007; Ma *et al.*, 2008; Yim *et al.*, 2008).

Propagation method is a mathematical model used in creating radio map and estimating RSSI values into geometrical parameters measurement, discussed in section 2.2.1, such as angle and distance (Ma *et al.*, 2008). Using calculations and appropriate positioning algorithm (usually trilateration), the geometrical parameters then compute the position of an object (Wang & Jia, 2007). For example, the studies by Mazuelas *et al.* (2009) and Nurminen *et al.* (2012) employ the propagation method. While Mazuelas *et al.* (2009) made use of RSS values and trilateration to determine position, Nurminen *et al.* (2012) used RSS, Bayesian statistical methods and a different set of algorithms, namely Metropolis-Hastings and Gauss-Newton algorithms, to determine position dynamically or real-time. An advantage of these implementations is that they are computationally light (Mazuelas *et al.*, 2009; Nurminen *et al.*, 2012). However, because

RSS is mainly used in propagation, it is difficult to fit the RSS distribution accurately using mathematical formula and it is difficult to estimate the distance due to localisation errors (Wang & Jia, 2007; Liu & Wang, 2010). Hence, fingerprinting became an alternative to solve these challenges.

The fingerprinting method is carried out in two phases, namely offline and online (Yim *et al.*, 2011). The offline phase is also referred to as training phase or calibration phase, while the online phase is also referred to as positioning phase or tracking phase or determination phase (Kaemarungsi, 2005; Jiang, 2012; Niu *et al.*, 2013). Fingerprinting and the operations of these phases have been discussed in section 2.2.2.4. The studies by Kaemarungsi (2005), Jiang (2012) and Niu *et al.* (2013) implemented WLAN fingerprinting for positioning. Kaemarungsi (2005) presented an analytical model of an indoor positioning system based on RSS location fingerprinting, for an efficient system design and deployment. A systematic study analyses the location fingerprint while the analytical model examines the relationship between the positioning system performance and parameters. The performance of the positioning system is dependent on the RSS and increase in the number of APs deployed. However, the increase in the number of APs can only be achieved up to a certain limit, after which the performance is inhibited (Kaemarungsi, 2005).

Similar to the study by Kaemarungsi, Jiang (2012) proposed an ‘accurate and efficient’ indoor positioning system based on WLAN fingerprinting. The fingerprinting method creates a probability distribution map of the RSS values measured at known positions in order to determine the position of a mobile device (Jiang, 2012). On the other hand, Niu *et al.* (2013) developed an ‘energy efficient’ WLAN fingerprinting positioning system using the ZigBee radio for the collection of WLAN RSS signals. While these systems exhibited an impressive positioning accuracy at room level, and improved performance by saving energy consumption, they however employ a time consuming process (Jiang, 2012; Niu *et al.*, 2013). Furthermore, because of the unique challenges experienced with both propagation and fingerprinting methods, Wang and Jia (2007) employed both the hybrid approach of propagation and the fingerprinting methods for a WLAN positioning system. The hybrid method takes advantage of the simplicity of the propagation method and the high positioning accuracy of the fingerprinting method, in order to deliver high positioning accuracy in the WLAN positioning system.

2.3.6.5 RFID-based Positioning System

RFID is an automatic identification process that uses RF wireless communication technology based on electromagnetic transmission between RFID readers and RFID tags for tracking purposes (Liu *et al.*, 2007; Grover & Berghel, 2011). The RFID reader queries and reads data from the tags, while the tags respond accordingly with the unique identification or information stored in it (Grover & Berghel, 2011; Mautz, 2012). The RFID tags are primarily classified into active and passive tags (Liu *et al.*, 2007; Fallah *et al.*, 2013). An active tag is a battery-powered transceiver and thus has a wider transmission range, hence reducing the number of tags required for an installation. On the other hand, a passive tag has a shorter transmission range because it does not use a battery; it gets its power from the reader's signal before it can respond with information (Grover & Berghel, 2011; Fallah *et al.*, 2013). The reader and tag, as well as a server for position computation, are used in an RFID-based positioning system (Bouet & Dos Santos, 2008; Li & Becerik-Gerber, 2011).

An RFID-based positioning system is a system that tracks and determines the position of a person or an object using an RFID reader via radio waves. It can be classified into active and passive RFID positioning systems (Mautz, 2012). In the active positioning system, active tags are mounted within the building while the reader is mobile (Mautz, 2012). For example, in the works of Ni *et al.* (2003) and Wang *et al.* (2007), an active positioning system with the active tags stationary and the reader mobile, was implemented. Because the active tags use batteries, they have wider coverage area, and hence fewer tags are used compared with the passive system (Ni *et al.*, 2003; Wang *et al.*, 2007; Gu *et al.*, 2009). However, the use of the expensive active tags increases the cost of the active system. Similarly, in the passive positioning system, passive tags are mounted within the building while the reader is mobile. Examples of such systems can be found in the works of Bekkali *et al.* (2007), Wilson *et al.* (2007), and Saab and Nakad (2011). The passive tags in this case do not use batteries (Wilson *et al.*, 2007; Mautz, 2012; Wang & Katabi, 2013). Hence, the tags are cheaper than the active tags, making the overall system less costly than the active system (Bekkali *et al.*, 2007; Saab & Nakad, 2011; Fallah *et al.*, 2013).

Finally, having presented a state-of-the-art discussion of the various positioning technologies, Table 2.1 below shows a summary of the indoor positioning systems using low, medium and high as comparative metrics.

Table 2.1: Summary of Indoor Positioning Technologies

Technology	Technique	Algorithm	Accuracy	Cost	Complexity	Scalability	Privacy/Security	Real-Time
Infrared	Trilateration	TOA/TDOA	Medium	Low	High	Medium	Low	Yes
Magnetic	Triangulation	AOA/TOA	High	High	High	Low	Low	Yes
Optical and Vision-based	Scene Analysis & Proximity	RSSI	Low	Medium	Medium	Low	Low	Yes
Audible Sound	Trilateration	TOA	Medium	Medium	Medium	Medium	Low	Yes
Ultrasound/Ultrasonic								
Active Bat	Trilateration	TOA/TDOA	Medium	Medium	Medium	Medium	Low	Yes
Cricket	Triangulation	AOA	Medium	Low	Medium	Medium	High	No
CricketNav	Triangulation	AOA/TOA	Medium	Medium	Medium	Medium	Medium	Yes
Dolphin	Trilateration	TOA/TDOA	Medium	Low	Medium	Medium	Low	Yes
Radio Frequency								
Bluetooth	Fingerprinting	RSSI	Low	Medium	Medium	Medium	Medium	Yes
UWB	Trilateration	TOA/TDOA	High	Medium	Medium	Medium	Low	Yes
WSN	Fingerprinting	RSSI	Medium	Medium	Medium	Medium	Low	Yes
WLAN	Fingerprinting	RSSI	Low	Medium	High	Medium	Low	Yes
RFID	Fingerprinting	RSSI	Low	Medium	Medium	High	Low	Yes

2.4 Chapter Conclusion

This chapter set out to do a literature survey on existing positioning and navigation technologies, as well as the positioning techniques employed in these systems. Existing works and technologies have been clearly outlined, taking note of their functions and significance in relation to metrics such as the complexity, cost, accuracy, usability, and user preference to privacy of the technology. A survey of key authors and their dominant work, the leading methods employed, as well as the analysing technologies and emergent innovations in the field constitute the core of this chapter. Furthermore, a comprehensive discussion of best practices, milestones and related challenges of positioning and navigation technologies and innovations has been given to offer insight on the subject of investigation in this chapter.

In summary, this chapter has outlined the study of indoor positioning techniques that improve positioning. These techniques include the application of signal metrics and properties, such as AOA, TOA, TDOA and RSSI, as well as positioning algorithms, such as triangulation, trilateration, proximity, and scene analysis/fingerprinting that influence the positioning accuracy, cost, usability and other metrics as well. Furthermore, the technologies in which these techniques are applied were detailed and discussed. Since variations of positioning technologies may be infinite, only those innovations that are most relevant to the purpose of this investigation have been explored in this chapter. The technologies explored include IR, which uses IR signals to determine the position of objects or people wearing a tag within a network of IR sensors; Ultrasound/Ultrasonic, which uses narrowband or broadband signals to determine the position of objects or people wearing ultrasonic tags; and Audible sound, which uses audible sound waves generated with sound cards of standard devices. In this case, the user carries a mobile device that acts as a transmitter instead of wearing a tag as compared to IR or Ultrasound. Other technologies include Magnetic, which uses magnetic signals for position determination of people or objects wearing receivers within a magnetic field; and Optical and Vision-based, which uses the camera and processing power of a mobile device to determine the position of a person or object by identifying a marker or image with the aid of a mobile sensor or camera. Finally, the RF technology uses RF signals and infrastructures to determine the position of a person or object wearing a tag or transmitter in an active scenario or using signal reflection in a passive scenario.

It is on this background that a discussion of the methodology, applications, components and services used in this research work is based. This is discussed in the subsequent chapter, chapter three.

CHAPTER THREE: RESEARCH METHODOLOGY

3.1 Introduction

Building from the literature background on positioning techniques, and positioning and navigation technologies in chapter two, this chapter outlines a research methodology and the techniques used. It also outlines the process of enquiry, which were followed in the research presented in this thesis.

To this effect, the chapter begins with an outline of a research approach, methodology and technique in section 3.2. This is followed, in section 3.3, by the discussion of applications, components and services that best fit the positioning and navigation technology project and function as applied in this experiment work. Free open-source software and hardware were used to achieve this purpose. At this point, a test of the first stage of the study as shown in the experiment design, known as pre-test, is provided in section 3.4. The chapter ends with a summary and conclusion in section 3.5.

3.2 Research Approach and Methodology

A research problem in this study was that current technologies and methods of indoor positioning and navigation are complex. They tend to be inaccurate, expensive and difficult to implement in challenged spaces of less developed countries, thereby limiting the usability of these technologies. As such, the objective of the investigation was to explore improvements to the current indoor positioning and navigation systems, by developing a prototype mobile application (app). The aim was to strengthen the accuracy and navigation effectiveness even in stringent environments through the experiential manipulation of the technical attributes of the positioning and navigation systems. For this reason, the study falls under the realist ontology, and the positivist epistemological approach (Mlitwa, 2011), using experiment methods and techniques of empirical enquiry (Babbie, 2013).

Experiment research can be conducted in laboratory or field settings using three major components, namely independent and dependent variables, pre-testing and post-testing, and experiment and control apparatus (Babbie, 2013; Monette *et al.*, 2014). Bhattacherjee (2012:38,83) defined an experiment method as one that seeks to test the hypothesis, in order to establish causation in a tightly controlled setting by directly manipulating independent variables to observe their effect on a dependent variable (Mlitwa, 2011). Experiment methods are used to investigate phenomena that examine cause-effect relationships, where the independent variable is the cause and the dependent variable is the effect (Bhattacherjee, 2012; Babbie, 2013). An experiment method usually follows four minimum steps. Firstly, the identical sampling units are identified, selected and are divided into the control and the experiment apparatus. Secondly, both the control and experiment apparatus are placed under identical conditions, and are subjected to a similar pre-test for validity control. A pre-test is the measurement of the effect of the state of a dependent variable, in both the control and the experiment apparatus before the experiment (Bhattacherjee, 2012; Babbie, 2013). Thirdly, the experiment apparatus is subjected to a stimulus (an independent variable). Fourthly, the experiment apparatus as well as the control apparatus are subjected to a post-test, which is the re-measurement of the dependent variable in the subject after its exposure to the experimental stimulus (ibid.). Changes in the post-test results will reflect the effect that the stimulus may have had (if any) on the experiment apparatus (Mlitwa, 2011).

Since the nature of the problem under investigation pertained to technical innovations whose functioning depends on varying qualities and quantities of factors, the experiment method was considered more relevant (Babbie, 2013; Monette *et al.*, 2014). Table 3.1 below illustrates the experiment methodology and techniques applied in this study, as elaborated in subsequent paragraphs and sections.

Table 3.1: Experiment Design

	Pre-test	**Experiment**	**Post-test**
Control Apparatus	- Tested usability of the application - Observed some inhibitions	No experiment	- Tested usability of the application - Observed some inhibitions
Experiment Apparatus	- Tested usability of the application - Observed some inhibitions	- Manipulated the code of the navigation application in order to address inhibitions	- Tested usability of the application - Observed improvement over inhibitions

As illustrated in Table 3.1 above, the experiment apparatus is the sample unit that is exposed to one or more experimental stimulus. The control apparatus on the other hand is the sample unit that is not exposed to any experimental stimulus, and yet is identical to the experiment apparatus (Babbie, 2013; Monette *et al.*, 2014). The control apparatus in the case of this study, according to Table 3.1, is the developed application based on taglocate (Bolz, 2011) and smartcampus (Hansen *et al.*, 2013). It was only the experiment sampling unit, which was checked by pre-testing prior to the experiment, that was exposed to the stimulus (Bhattacherjee, 2012; Nielsen, 2012b). In this study, the experimental stimulus refers to the manipulation of the application's code for the improvement of the navigation app. Any differences observed between the control apparatus and experiment apparatus on one hand, and between the pre-test and post-test on the other hand are attributed to the effect of the experimental stimulus (Bhattacherjee, 2012; Nielsen, 2012b; Babbie, 2013). The experiment is considered successful if the post-test outcome is more favourable than the pre-test (Nielsen, 2012b). Hence, the validity of experiment research depends on how well the experimental stimulus is manipulated (Bhattacherjee, 2012).

Furthermore, the hypothesis in this experiment was that the usability of the artefact depends on metrics such as complexity, cost, accuracy and privacy. In essence, usability is the dependent variable while complexity, cost, accuracy and privacy are metrics that can be used to measure usability after the manipulation of the independent variables. The purpose of the experiment, therefore, was to test the validity of this hypothesis by developing a prototype mobile application (subject) and manipulating it with the experimental stimulus (independent variables). This, however, required an understanding of the tools and services employed in this research, which are presented in the following section.

3.3 Applications, Components and Navigation Service

To obtain a good outcome in any experiment research, solid preparatory work in an operational empirical site is a prerequisite. To this end, the researcher started by identifying, and ultimately acquired, appropriate tools in the form of applications such as Mapwarper, OpenStreetMap (OSM) and Java OpenStreetMap (JOSM) editor that were to be used in the experiment. Other applications include Ubuntu Linux 12.04 Operating System (OS), Android Software Development Kit (SDK), Java SDK, Eclipse Integrated Development Environment (IDE) and SerialPort-Server. The researcher also needed to source for the necessary hardware components such as RFID/NFC tags and toolkits, PandaBoard, Arduino and Samsung Galaxy SIII Smartphone. Virtually all the applications and components used in this research are open source.

3.3.1 Free Open-Source Software and Hardware

In order to realise a low-cost implementation without infringing on proprietary copyright software, it was necessary to utilise free open-source software and hardware. Open-source software (OSS) is a software that is publicly developed and available in native source code, and can be freely used and modified by anyone (Mtsweni & Biermann, 2008). Using OSS is cost-effective, time-efficient, reduces expended effort significantly and delivers quality software at a significantly low cost and restriction (Lotito & Mazzocchi, 2012; Riehle & Berschneider, 2012). OSS used in this research include Mapwarper, OSM, JOSM editor, Ubuntu Linux 12.04 OS, Android SDK, Java SDK, Eclipse IDE and SerialPort-Server. On the other hand, Open-Source Hardware (OSHW) refers to physical equipment or tools whose design is publicly developed and made available so that anyone can use, modify and distribute, giving people the freedom to control and share technology and knowledge (Ackermann, 2009; Acosta, 2009). OSHW use readily available components and materials, standard processes, open infrastructures, unrestricted content, and open-source design tools (Pearce, 2012). OSHW used in this research include PandaBoard, Arduino, Parallax RFID Reader and NFC Shield. OSHW are used with the positioning component, while OSS is used in the map generation and navigation process.

3.3.2 Map Generation

The Engineering building of the Cape Peninsula University of Technology (CPUT), Cape Town Campus is used in this research as the test or implementation site. The site is referred to, henceforth, as the test-bed. The floor plan of the second floor of the Engineering building of CPUT that is used in this research is shown in Figure 3.1 below.

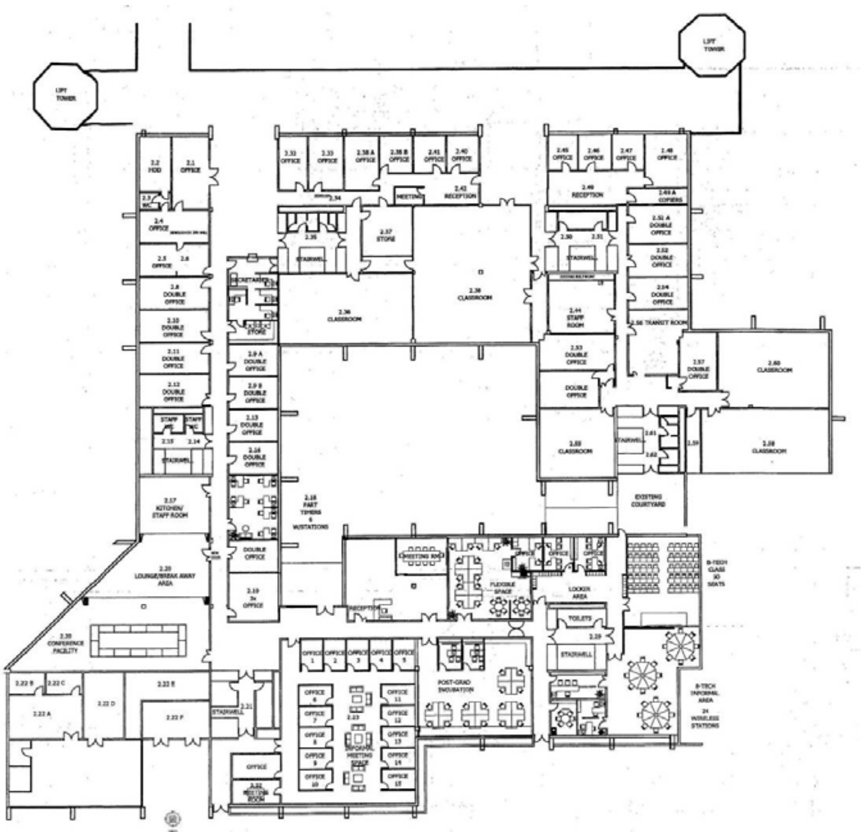


Figure 3.1: Sectional view of second floor engineering building

Furthermore, to navigate indoors using a mobile device, a map data is required for both path and position representation. OSM, which is an open-source platform, serves as the map database and is used to process map data. OSM is a free wiki-style collaborative map of the world that anyone can create, edit and contribute to the data (Haklay & Weber, 2008; Bennett, 2010; Ramm *et al.*, 2011). The map of the test-bed building is in OSM; hence, porting applications and tools with OSM is easily achievable. MapWarper and JOSM editor are tools used in generating, creating and editing the map of the floor plan of the test-bed building as illustrated in the subsequent sections below.

3.3.2.1 MapWarper

In order to be able to use the map data in a mobile device, an online map rectification utility named 'MapWarper' is used to rectify the map. Figure 3.2 below shows a screenshot of MapWarper with the floor plan of the test-bed building.

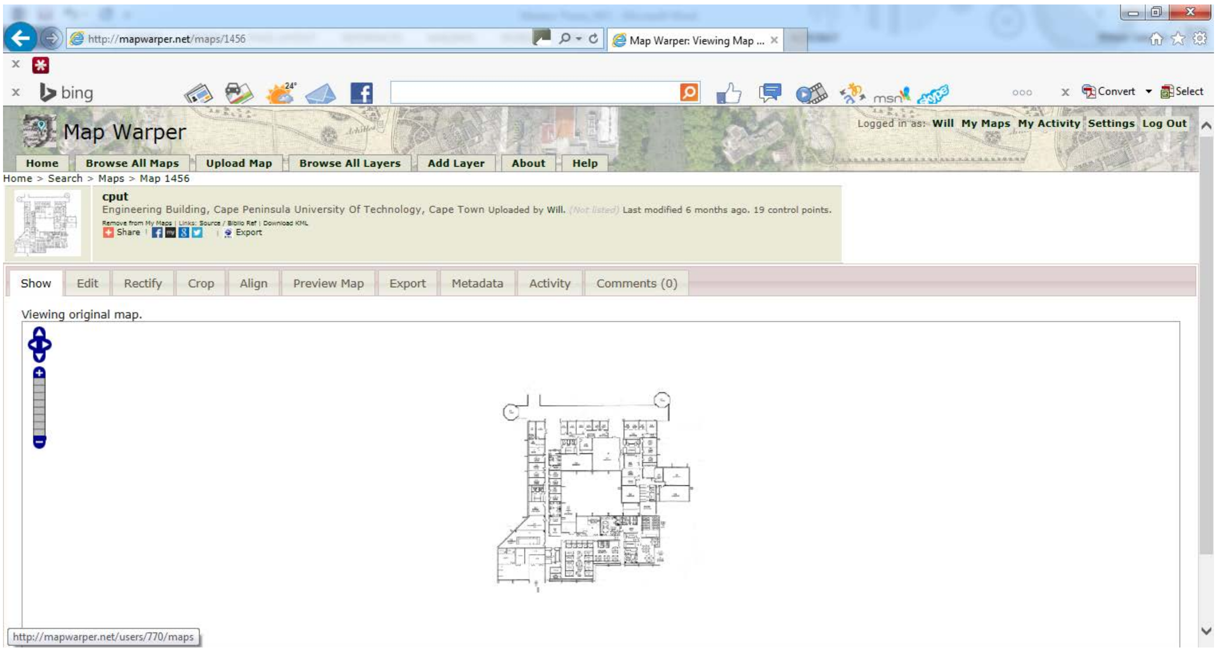


Figure 3.2: Screenshot of MapWarper with the floor plan of the test-bed

MapWarper is a web-based open-source map warping, geo-rectification and geo-referencing application. The map image of the floor plan of the test-bed building is uploaded to http://mapwarper.net for rectification and warping of the image to the base map of the test-bed building as displayed on OSM. The map to be rectified is placed side by side with the base map. Nineteen (19) control points are created on the map image, with each point corresponding to the same position on the base map as shown in Figure 3.3 below.

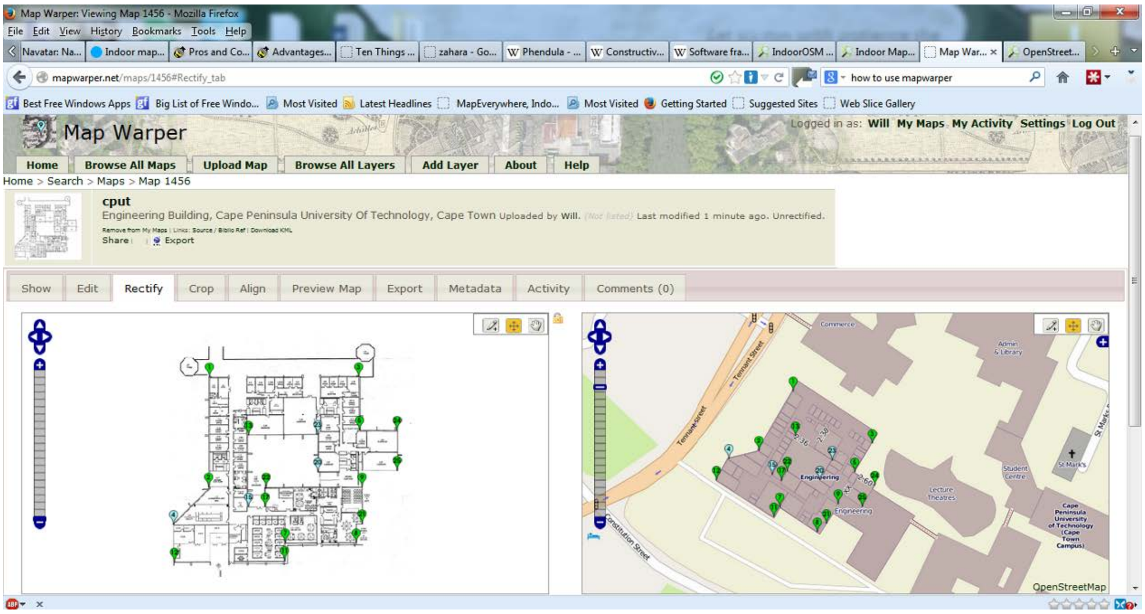


Figure 3.3: Screenshot of the image rectification

As soon as there are enough control pins added, the map is rectified or warped by clicking on the rectify button. The warped map is displayed over the base map and the corresponding image is shown in Figure 3.4 below. Thereafter, the rectified map is exported as a PNG file to the JOSM editor for further processing.

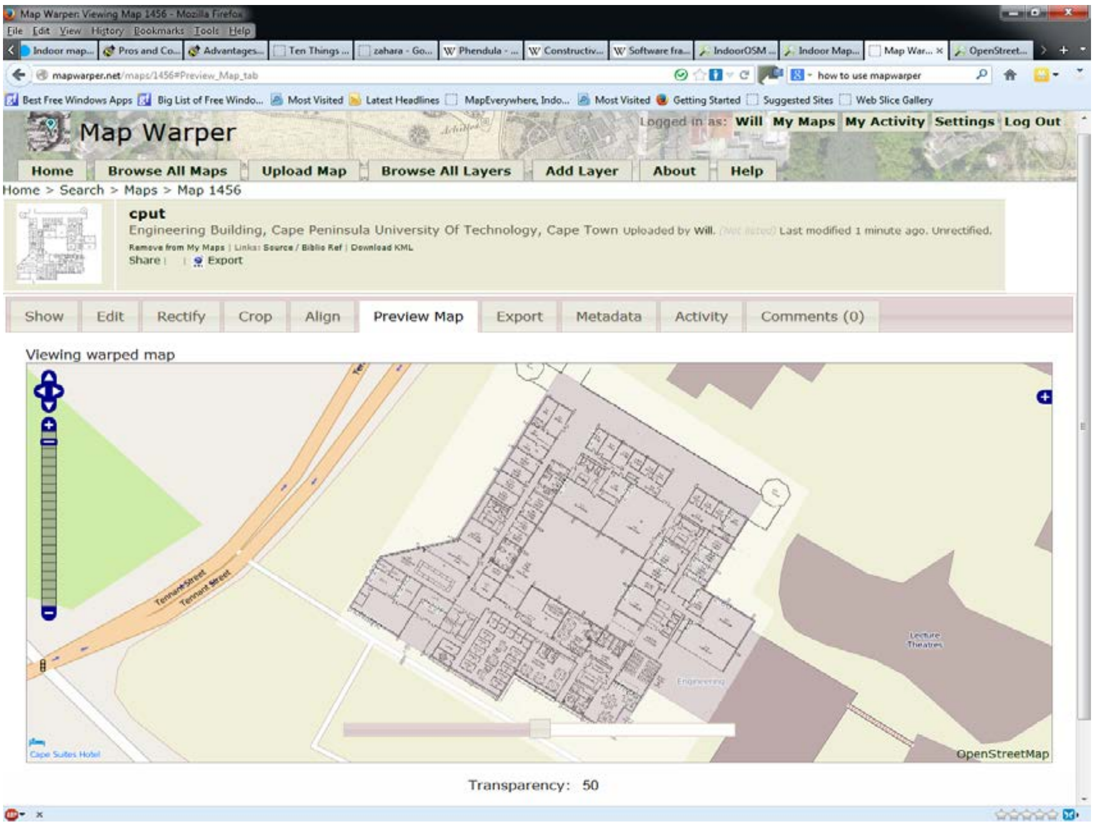


Figure 4.4: Screenshot of the warped image

3.3.2.2 JOSM Editor

After the map has been rectified in MapWarper, it is imported and edited in JOSM editor. JOSM editor is an OSM offline editor tool that can be used to create and edit indoor maps. The data edited in JOSM can be uploaded to the OSM server for further use. Figure 3.5 below shows a screenshot of the test-bed building floor plan in JOSM editor as viewed in OSM.

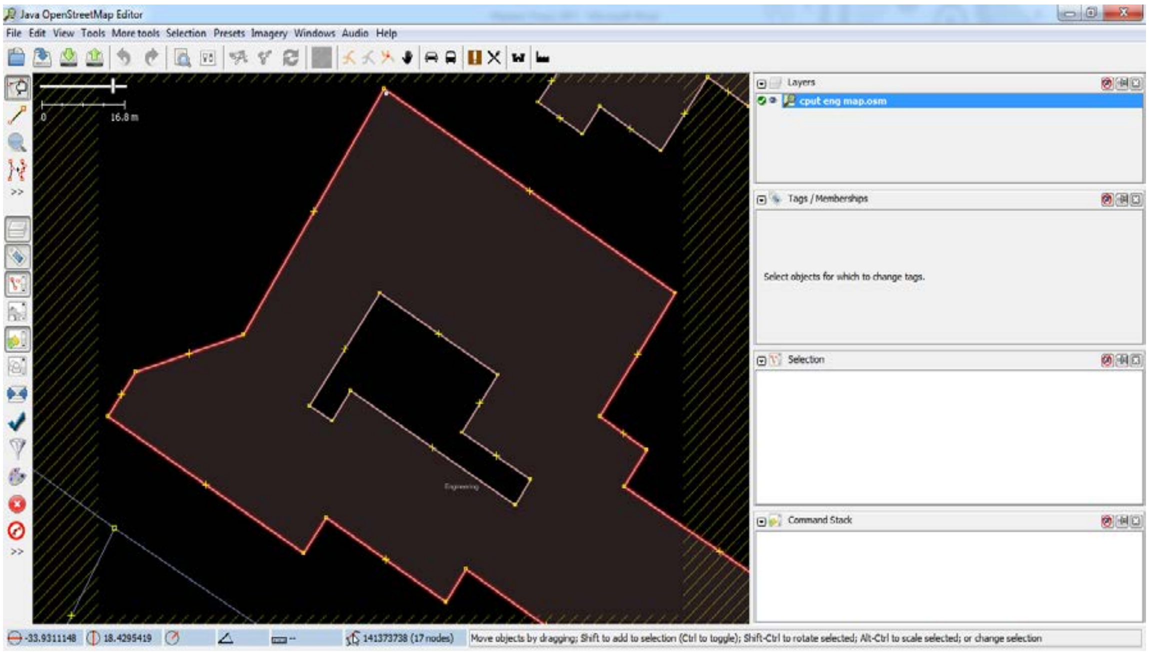


Figure 5.5: Screenshot of JOSM Editor showing the test-bed footprint

The piclayer plug-in is installed in the JOSM application in order to simplify the creation of indoor maps with the JOSM editor. The exported rectified PNG image from MapWarper is uploaded into JOSM. By using the tools available in JOSM, the edges of the image are tagged and aligned to the OSM map of Figure 3.5. The corresponding image is shown in Figure 3.6 below.

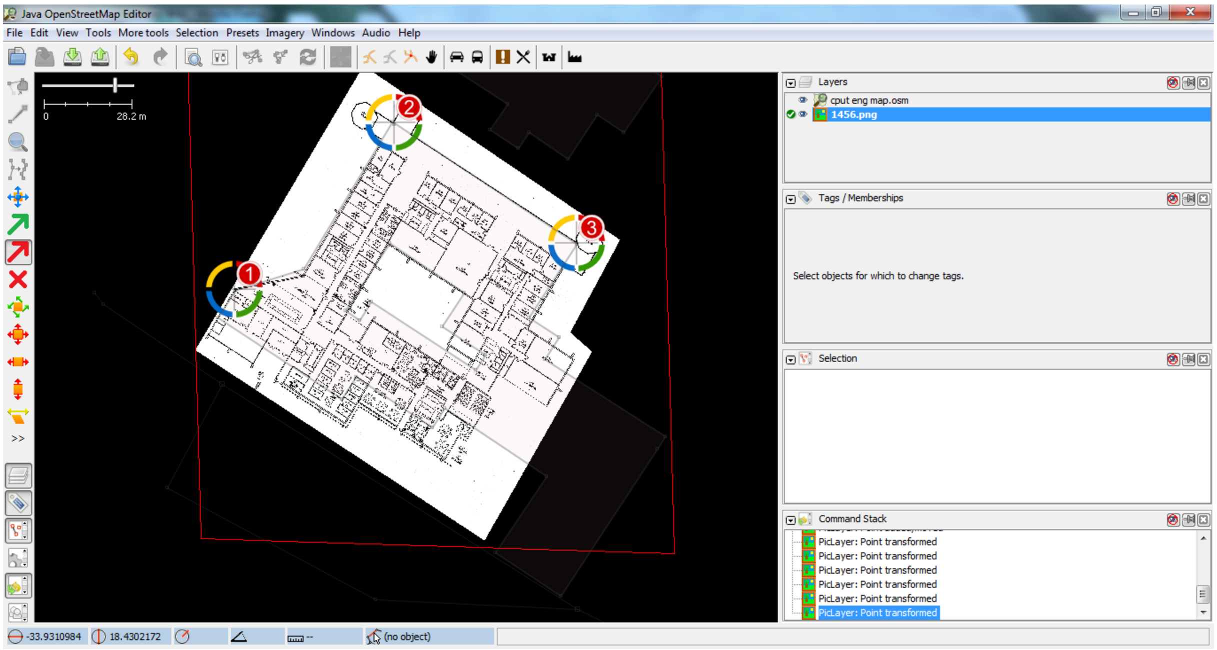


Figure 6.6: Screenshot showing map tagging

With the edges tagged and aligned, the rooms, doors, corridors and paths that would be used in the navigation application are mapped accordingly as shown in Figure 3.7 below.

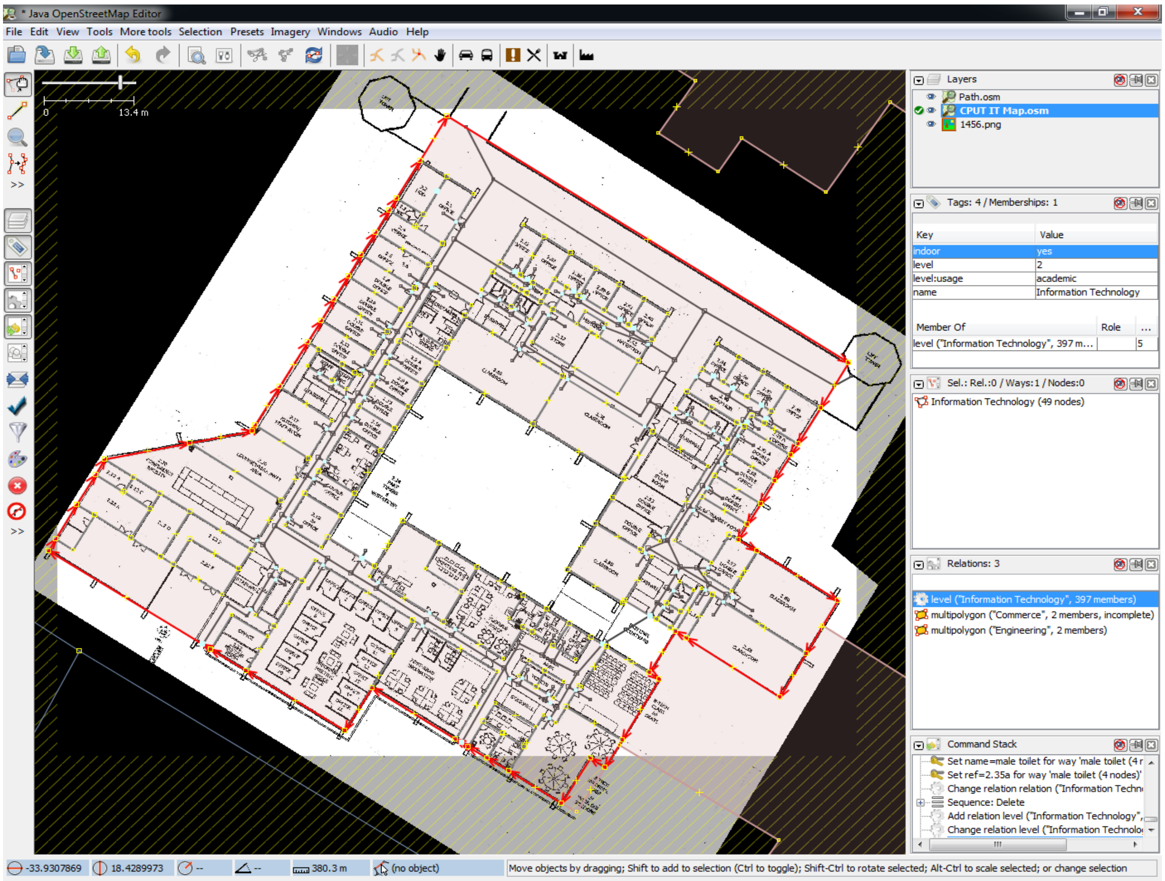


Figure 3.7: Screenshot of the floor plan nodes and links

Thereafter, the nodes and links are computed and the map data was created. This is shown in Figure 3.8 below. These map data present details about the rooms, doors, corridor and path.

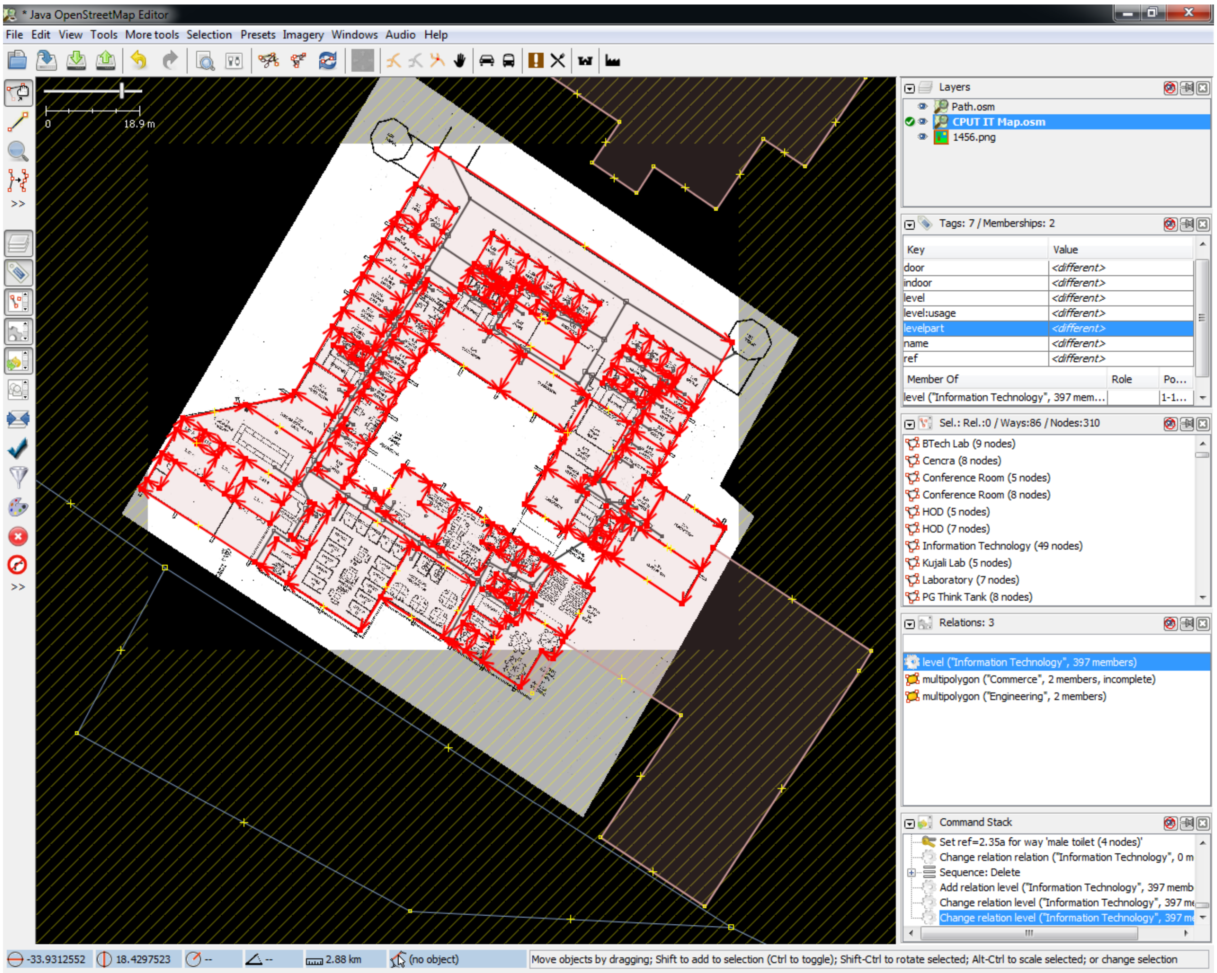


Figure 3.8: Screenshot of rooms' and doors' nodes and links

The map data of the test-bed building is then exported as an XML file. This XML file, as well as the XML file of the path representation discussed in the following sub-section, is used in the coding of the navigation application.

3.3.2.3 Path Preparation

The JOSM editor is also used to create the indoor path representation or route applied by the positioning component. The navigation path that will be used by a user to determine the best possible path for navigation is created. The path is shown in Figure 3.9.

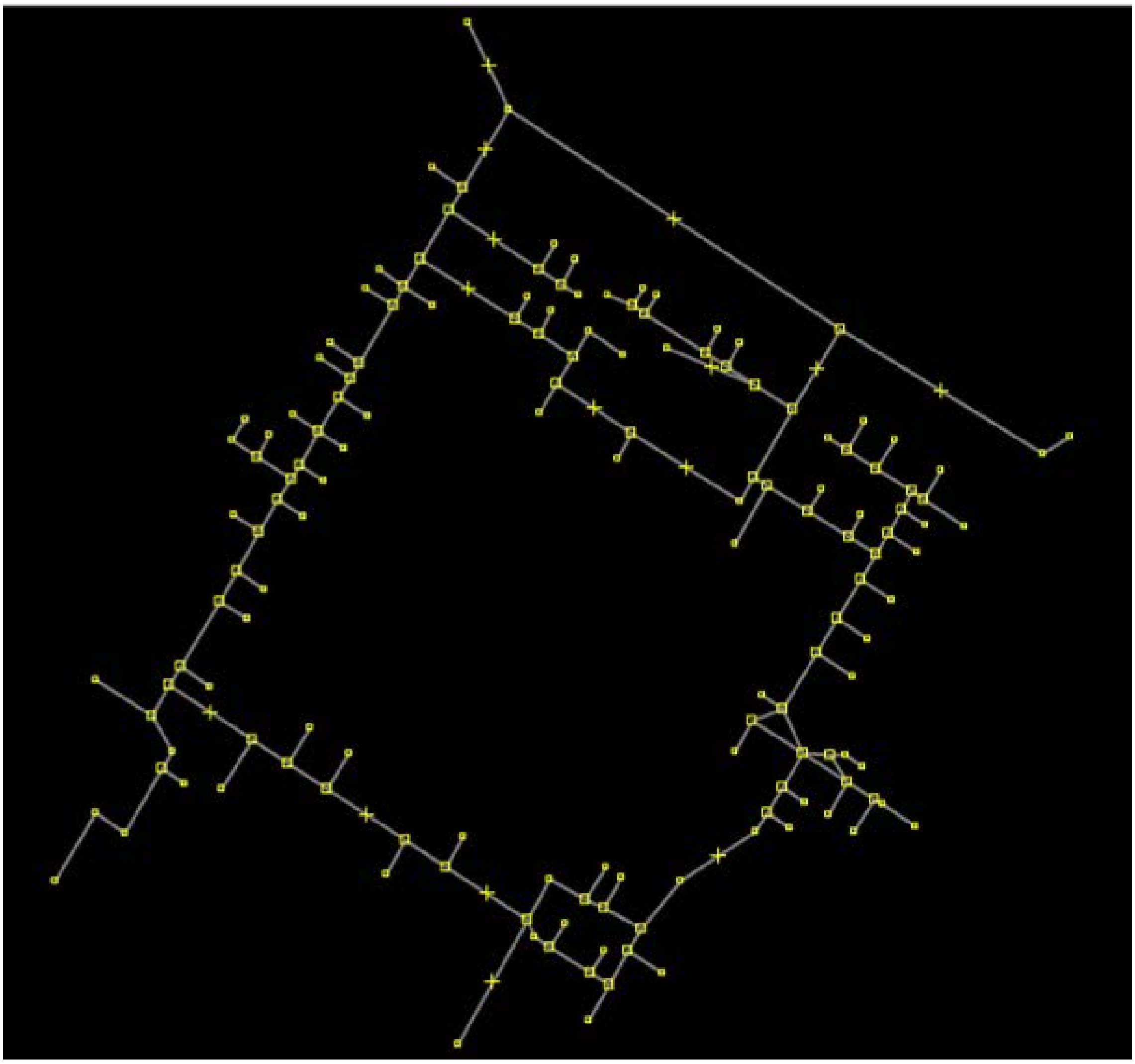


Figure 3.9: Navigation path and nodes

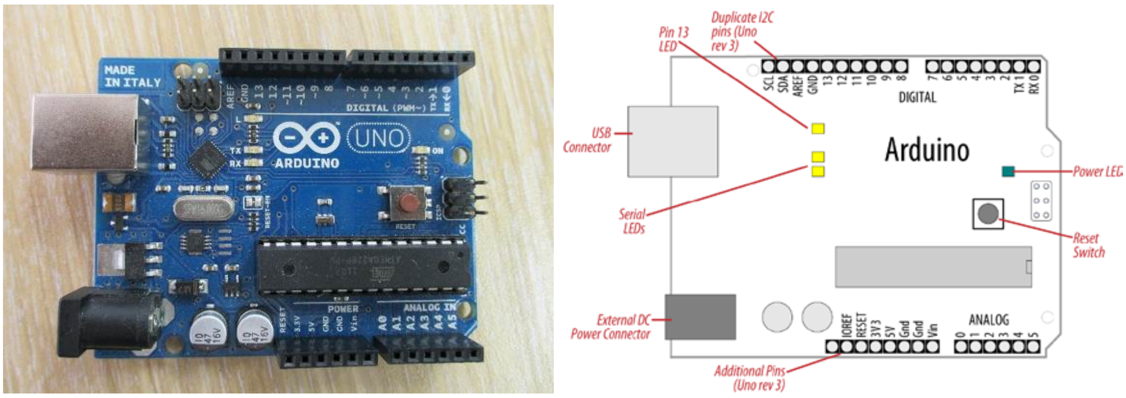
The path of the test-bed building is exported as an XML file, and used in the navigation application's code.

3.3.3 Positioning Component

Having created and generated the map and path data, the researcher prepared the hardware components for the preliminary experiment. Due to the nature of the experiment, the proximity technique is applied with the positioning components. The components include Arduino, Parallax RFID reader, NFC Shield and RFID/NFC tags.

3.3.3.1 Arduino

Arduino is an open-source microcontroller board based on flexible, easy-to-use hardware and software. The hardware consists of an open-source board designed around an 8-bit Atmel AVR microcontroller or a 32-bit Atmel ARM. The Arduino platform was designed to provide a cheap and easy way to create devices that interact with their environment. Since Arduino is open source, any software, hardware or shields will be compatible with it. Arduino can be used with a reader, and connected to a computer to retrieve and send data back and forth. Once this data activity is achieved with this setup, it can be replicated in the main experiment for the navigation service. With different variants of Arduino available, the two variants used in this work are Arduino Uno and Arduino Duemilanove. Figures 3.10 and 3.11 below show pictorial representation of the Uno and Duemilanove.



(a) (b)

Figure 10.10: Arduino Uno

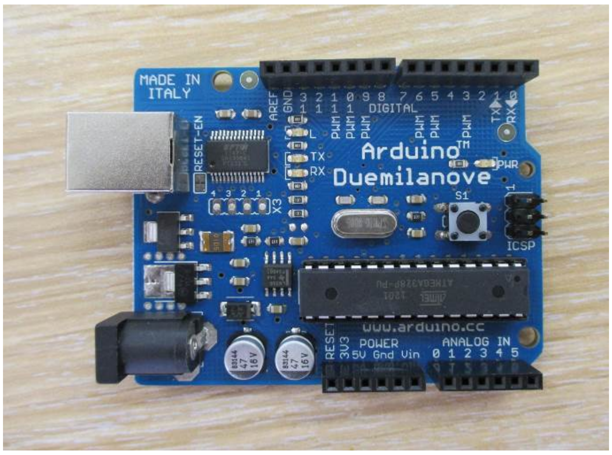


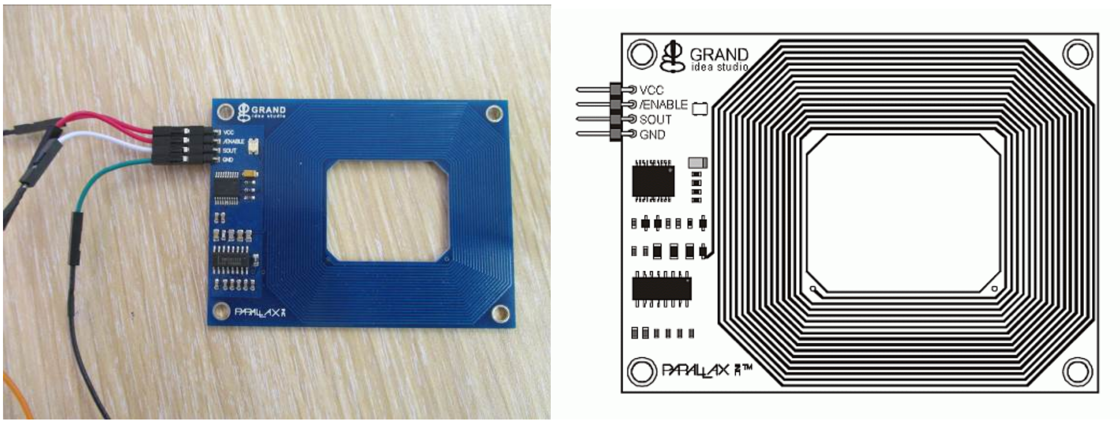
Figure 11.11: Arduino Duemilanove

The Uno and the Duemilanove use a bootloader called Optiboot, which frees flash memory and enables faster boot. They use a standard 28-pin chip attached to an IC socket. The Uno and Duemilanove both use the Atmega328 USB-to-serial converter chip but do not use the FTDI USB-to-serial driver chip that enables the USB chip with the ability to re-flash its firmware to make Arduino show up on the Personal Computer

(PC) as another device. The Arduino board is made up of an Atmel AVR microprocessor, a 16 MHz crystal or oscillator, a 5V linear regulator, 31.5 KB of usable Flash memory, 2 KB of Static Random-Access Memory (SRAM) and 1 KB of Electrically Erasable Programmable Read-Only Memory (EEPROM). Other modules include 14 digital input/ output (I/O) pins, 6 analog inputs, a USB connector for serial data communication and a power connector. The board can be powered using the USB connection. With this sort of specification, performance should not be a problem. The challenge will be in ensuring a smooth communication between Arduino and the RFID/NFC reader, which is demonstrated in section 4.2 of chapter 4.

3.3.3.2 Parallax RFID Reader

Having compatibility with the Arduino platform, the Parallax RFID Reader module is a fully integrated low-cost device for reading passive RFID transponder tags. It has a 2400 baud serial interface and is compatible with 125 kHz tags (ISO14443). When using RFID tags with the reader, the tags are held parallel to the front or back surface of the module. If the tag is held perpendicularly or angularly to the module, there may be poor distance reading. Hence, for the navigation process, holding devices perpendicularly or angularly is avoided. In addition, the reader reads only one tag at a time to avoid tag collisions from the use of more than one tag that may lead to false detection or inability to detect any of the tags. Figure 3.12 below shows a pictorial representation of the RFID reader.



(a) **(b)**

Figure 12.12: Parallax RFID Reader

Furthermore, the RFID Reader can be integrated into any design using only four connections as shown in Table 3.2 below.

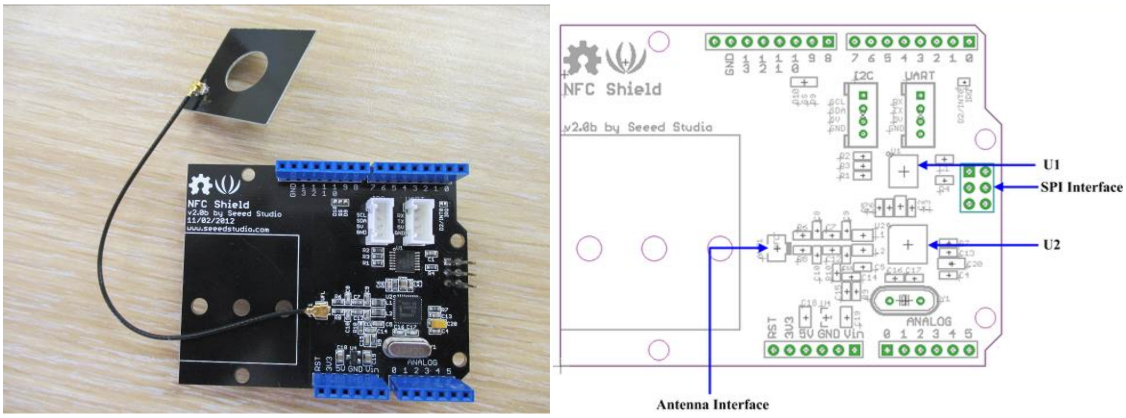
Table 3.2: Parallax RFID Reader serial pin features

Pin	Pin Name	Type	Function
1	VCC	P	System power, +5V DC input.
2	/ENABLE	I	Module enable pin. Active LOW digital input. Bring this pin LOW to enable the RFID reader and activate the antenna.
3	SOUT	O	Serial Out. TTL-level interface, 2400bps, 8 data bits, no parity, 1 stop bit.
4	GND	G	System ground. Connect to power supply's ground (GND) terminal.
Note: Type – I = Input, O = Output, P = Power, G = Ground			

The parallax RFID reader is designed in such a way that when the reader is connected and powered up and in an idle state, its Light-Emitting Diode (LED) will be green. However, when it is searching for or communicating with a compatible tag and in an active state, its LED will be red. The "VCC" pin is connected to a 5V DC supply input while the "/ENABLE" pin is connected to a digital output which activates the RFID reader. When the reader is powered up and the "/ENABLE" pin is in a LOW state, the reader enters the active state. When the "/ENABLE" pin is in a HIGH state or not connected, the reader enters the idle state. The "SOUT" pin is connected to a digital input while the "GND" pin is connected to the system power supply ground terminal.

3.3.3.3 NFC Reader (NFC Shield)

Similar to the working principle of the RFID reader, the NFC readers only initiate communication with passive NFC tags. The PN532 NFC Shield with Arduino Duemilanove (Atmega 328) are used in this research because of their compatibility with each other. In addition, the shield works with NFC/RFID type 1 to 4 tags. NFC readers are incorporated into mobile phones, tablets, laptops, computer devices and payment terminals. A pictorial representation of NFC Shield is shown in Figure 3.13 below.



(a) (b)

Figure 13.13: PN532 NFC Shield

The NFC shield features a highly integrated transceiver module PN532 chipset which is the same chip that is embedded in most mobile phones and devices with NFC. The chipset is very powerful that it can read and write to tags at 13.56 MHz, and serve as an NFC tag. An independent printed circuit board (PCB) antenna, which can easily be detached, is attached to the shield. The shield requires a 5V DC power source. U1, in Figure 3.6b is a quad buffer IC, U2 is PN532 NFC controller IC, Serial Peripheral Interface (SPI) communicates with Arduino, and the antenna interface reads tags. NFC shield is designed to use Inter-Integrated Circuit (I2C) or SPI communication protocols. However, the model of NFC shield used in this research uses the SPI interface and protocol.

3.3.3.4 RFID/NFC Tag

Since NFC devices operate at the same frequency (13.56 MHz) as HF readers and tags, read-only passive NFC tags are used in this experiment because of their simplicity and low-cost. In order to determine position information, two passive tag types of frequency 125 kHz and 13.56 MHz are acquired. For the experiment with the RFID reader, low frequency tags at 125 kHz range are used, while high frequency tags at 13.56 MHz are used for the NFC shield experiment. In addition, tag type 2 (discussed in section 1.5.2) is used in this work. A pictorial representation of tags used in this experiment is shown in Figure 3.14 below.

(a) (b)

Figure 14.14: RFID/NFC Tag

3.3.4 Navigation Component

Having generated the map and acquired the positioning components, the researcher made use of applications and tools for the navigation process. The navigation tools and components include PandaBoard, SerialPort-Server, Android SDK, Eclipse IDE and Samsung Galaxy SIII Smartphone.

3.3.4.1 PandaBoard

In order to be able to test the navigation application in a tablet device, the PandaBoard is used for evaluation purposes. PandaBoard is an open low-power, low-cost, single-board mobile development platform based on Open Multimedia Applications Platform 4 (OMAP4) application processors. It has a GSM module for mobile communication, and sensors (gyroscope, accelerometer) for detecting orientation. An expansion board when used with a PandaBoard acts as a mobile device by providing an LCD screen for display. A PandaBoard with an extension board is used in this experiment. Figure 3.15 below shows a pictorial representation of a PandaBoard with an extension board.

Figure 15.15: A PandaBoard with an extension board

PandaBoard is a community supported development platform that supports various Linux-based operating systems such as Android, Ubuntu and Mozilla Firefox OS. PandaBoard features a TI OMAP4430 processor clocked at 1 GHz and a dual-core ARM Cortex-A9 MPCore with Symmetric Multiprocessing (SMP) at 1 GHz each. It has 1 GB low-power DDR2 Random-Access Memory (RAM) and delivers full 1080p multi-standard high-definition (HD) video with support for HD 3D encode/decode. Its board can output video signals via Digital Visual Interface (DVI) and High-Definition Multimedia Interface (HDMI) interfaces. It has 3.5 mm audio connectors and a low-power audio chip with optimised power and audio management. A PandaBoard's primary storage is an SD Card slot allowing up to 32 GB Secure Digital High Capacity (SDHC) cards. It includes wired and wireless Ethernet, Bluetooth connectivity and two USB 2.0 ports.

3.3.4.2 SerialPort-Server

SerialPort-Server will make a device, like Arduino and PandaBoard, a web server. Considerations in choosing a web server include how well it works with the OS and other servers, its ability to handle server-side programming, its security characteristics, publishing, search engine and site building tools that may come with it. A serial port server is a port redirector device that transfers data between a computer serial port (COM port) and an Ethernet LAN. It includes the underlying software necessary to access device servers that provide remote serial devices.

3.3.4.3 Android SDK

The Android SDK is a set of development tools used by developers to build, test, debug and package applications (apps) for the Android platform. The Android SDK includes sample projects with source code, development tools, a debugger, an emulator, application program interface (API) documentation, tutorials and libraries, which are used to build Android applications written in the Java programming language. The Java Development Kit (JDK) is also installed with the Android SDK. The SDK is used to write Android programs in the command prompt or via an Android app. However, the common method is by using an IDE. The IDE has a graphical interface that enables developers to perform development tasks faster. The Eclipse IDE with the Android Development Tools (ADT) plug-in is used.

3.3.4.4 Eclipse IDE

In order to be able to develop a robust navigation application, the Eclipse IDE is used. Eclipse is an extensible open-source IDE for developing applications using the Java programming language and other programming languages such as C, C++, Python, PHP, PERL, Ruby etc. It is a robust and full-featured platform with highly integrated tools. One of such tools is the Android Development Tool (ADT), which is a plug-in that allows Eclipse to be used as a development tool for Android.

3.3.4.5 Mobile Device Frontend

Although, PandaBoard is used as a mobile device frontend, it is even more beneficial to use a mobile device frontend to measure a user's preference. Mobile device frontend refers to the device's interface through which a user will directly interact with the navigation application. It can also be referred to as the client side of the program. The various technologies that are available for mobile devices are shown in Table 3.3 below.

Table 3.3: Mobile Device Frontend Technologies

	Apple iOS Phones	Blackberry OS Phones	Google Android Phones	Mozilla Firefox OS Phones	Windows OS Phones
Core Technologies (Operating System)	Hybrid Unix kernel (optimised Mac OS X with Cocoa Touch Layer)	BB OS (Java Virtual Machine, JVM) and BB10 (QNX Unix kernel)	Monolithic Linux Kernel (Dalvik modified JVM)	Monolithic Linux Kernel (Gecko)	Monolithic Windows CE kernel (Windows Phone 7), Hybrid Windows NT kernel (Windows Phone 8)
Documentation and License	Proprietary	Proprietary	Free and Open-Source (Apache License 2.0, Modified Linux kernel under General Public License v2)	Free and Open-Source (Mozilla Public License)	Commercial Proprietary Software
Frontend Technologies	C, C++, Objective-C, Swift	C, C++, HTML, CSS, JavaScript	C, C++, Java	C++, HTML5, CSS, JavaScript	C, C++, .NET
Backend (Database) Technologies	Web SQL Database, IndexedDB	Web SQL Database, IndexedDB	Web SQL Database, IndexedDB	Web Storage, IndexedDB	Web Storage, IndexedDB

From Table 3.3, Android and Firefox OS are free and open-source mobile device frontends built on the Linux core. The navigation application can be developed for the various frontends shown in the table such as Android, iOS, BlackBerry, Windows Phone OS and Firefox OS. However, the Android frontend was used in this research because it allows for so many possibilities and flexibilities in customising a mobile device to suit the user. Although Firefox OS, a recent entrant into the mobile device space by Mozilla, is fit for use in this study, Android is nonetheless used because of its wide acceptability, popularity and usage. The Firefox OS will be considered for future work.

3.3.4.6 Path Representation

Difficulties encountered in indoor path finding are due to unfamiliarity with the interior orientation of a building. The more complex the interior of a building is, the more complex it is to navigate in (Mohammadi, 2011; Aebi, 2012). Apart from finding the current position of a user, the navigation path and the destination of the user are two important considerations in navigation. Determining the destination can be achieved by using certain points of interest. However, finding a suitable path for navigation involves the process of mapping in graph theory and finding the shortest path to the destination (Herman *et al.*, 2000; Franz *et al.*, 2005; Jensen *et al.*, 2009; Höcker *et al.*, 2010). A graph consists of a collection of links and nodes while a path is the length of an origin to a destination. Where the fastest route outdoors may not be the shortest, the same cannot be said for indoors. Most times the fastest path indoors is the shortest path, unless the shortest path is not navigable. The path is said to be the shortest path if it has the shortest length from among all paths that originates from a source node and ends at other nodes within the graph (Głąbowski *et al.*, 2013). To find the shortest path indoors, Dijkstra’s algorithm is commonly adopted (Chao & Hongxia, 2010; Mohammadi, 2011; Aebi, 2012; Dramski, 2012; Huang *et al.*, 2013). This is because of its method of finding the shortest distance linking two points, and its ability to be terminated as soon as the shortest path to the destination node has been attained (Jasika *et al.*, 2012; Murota & Shioura, 2013).

The succeeding sections delve into the pre-test aspect of the experiment design as discussed in the preceding section (in Table 3.1).

3.4 Pre-test

As stated in Table 3.1 of section 3.2, this test was meant to compare the control apparatus and experiment apparatus, and determine the design inconsistencies. NFC, being a technology based on RFID, is the main technology used in the implementation of the navigation application since it is installed in mobile devices. Hence, the codes of taglocate (Bolz, 2011) and smartcampus (Hansen *et al.*, 2013) applications were extended in this research and used as the control and experiment apparatus.

The purpose of the pre-test was to help improve the effectiveness, responsiveness and the look and feel of the application ultimately. To this effect, ten statements of a questionnaire were posed on five respondents who participated in the test. These respondents are Master's and PhD students and researchers of the Computer Science discipline, given their familiarity with application design and development. The choice of five respondents is based on Nielsen's suggestion to "identify a design's most important usability problems, rather than run a big and expensive study" (Nielsen, 1993; Nielsen, 2012a; Nielsen, 2012b). Thus, resources are conserved, and it is easier to review the design and fix the usability flaws as they are identified. In addition, the information acquired from the questionnaire is not for statistical purposes but for application refinement purposes. The questionnaire statements are: Q1). The app had a clear, clean and explicit interface. Q2) The app minimized the number of steps it took to complete tasks. Q3) Information presented on screen was easy to comprehend. Q4) Information needed for a specific task was grouped together on a single screen. Q5) Alerts were only presented at appropriate times. Q6) I found the application prototype to be easy to use. Q7) The menu items were well organized and functions were easy to find. Q8). The buttons were well organized and easy to find. Q9) Navigating around the application screen was very easy. Q10) My overall impression of the application prototype is very positive. The participants were encouraged to provide honest opinions regarding the usability of the application.

Appendix C shows the questionnaire each participant answered. The questionnaire is an economical way of collecting data, and offering the opportunity to gather information about the research component within a limited time. Table 3.4 below shows a summary of the respondents' responses to the questionnaire.

Table 3.4: Pre-test Data

	Q1	**Q2**	**Q3**	**Q4**	**Q5**	**Q6**	**Q7**	**Q8**	**Q9**	**Q10**
Participant A	N	A	A	N	D	A	N	D	A	N
Participant B	N	SA	A	A	N	A	N	D	N	A
Participant C	D	A	A	A	D	N	A	N	N	N
Participant D	SD	A	N	A	SD	A	N	A	N	N
Participant E	N	N	A	A	N	A	N	A	A	N
Note: Strongly Agree (SA); Agree (A); Neutral (N); Disagree (D); Strongly Disagree (SD)										

For the purpose of this research, strongly agree and agree responses are considered as positive feedback. However, responses that are neutral, disagree and strongly disagree are considered as negative feedback. Hence, the experiment or manipulation of the subject of investigation is done considering the neutral, disagree and strongly disagree responses. Each question is now analysed below.

3.4.1 First Question

The first statement in the questionnaire is, 'The app had a clear, clean and explicit interface', with Figure 3.16 below showing the data based on this first question.

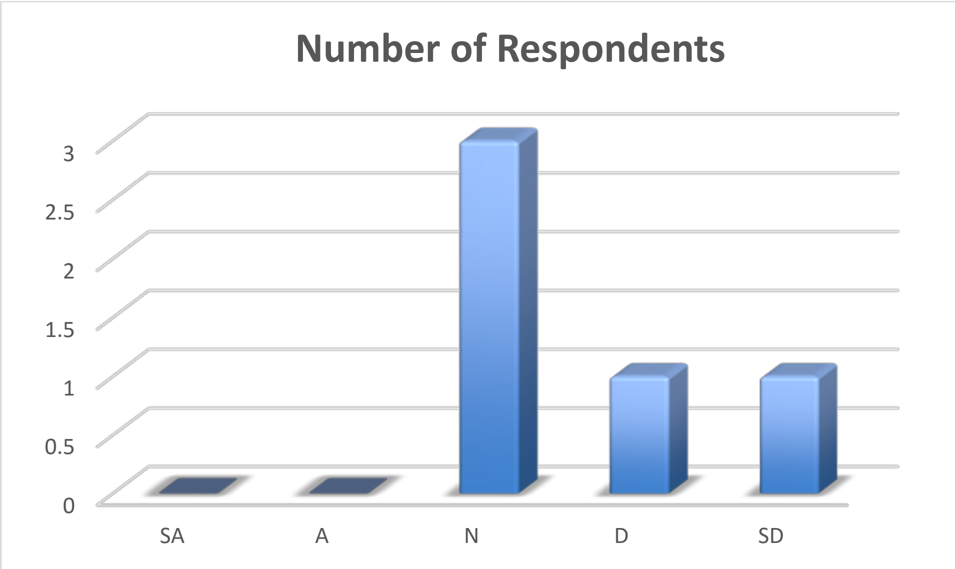


Figure 3.16: Response to the first question of the pre-test

According to data in Figure 3.16, only 40% of respondents felt that the quality of the interface was compromised when the app is used in the indooor environment of the test-bed building. The remaining 60% neither agreed nor disagreed (were indifferent). While reasons for indifference could vary, perhaps ranging from a lack of understanding of the question or the inability to familiarise themselves with the context of the question, the 40% positive responses gathered explain limitations in the usability of the app. This clearly suggested an inadequacy of the interface, and that it required improvement.

3.4.2 Second Question

The second statement in the questionnaire pertained to time-efficiency usability aspects, where respondents were required to indicate whether 'The app minimised the number of steps it took to complete tasks'. Response patterns on this question are outlined in Figure 3.17 below, and clarified in subsequent paragraph below the graphical illustration.

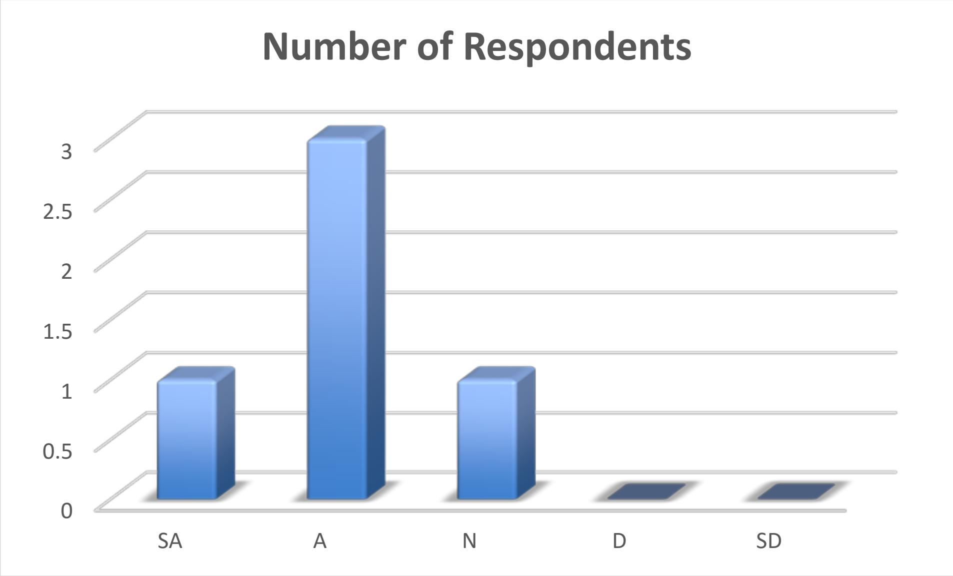


Figure 3.17: Response to the second question of the pre-test

Unlike the first question, the majority of participants gave decisive responses to the second question based on the data in Figure 3.17. 80% of the respondents agreed that the app minimised the number of steps taken to perform tasks, with 20% neither agreeing nor disagreeing. This positive assessment suggests an acceptable (or even the perceived adequacy) efficiency of the app when used in the indoor environment of the test-bed building, meaning that the efficiency of the app was not a cause for concern. When compared with applications such as taglocate (Bolz, 2011) and IMG (Hammadi *et al.*, 2012), which require a number of steps to complete a task, there is an impressive improvement.

3.4.3 Third Question

The third statement in the questionnaire sought to test the clarity of information transmitted through the app. Under this question, respondents were asked to indicate whether 'Information presented on screen was easy to comprehend'. The response data for this statement is outlined in Figure 3.18 and elaborated further in the subsequent paragraph.

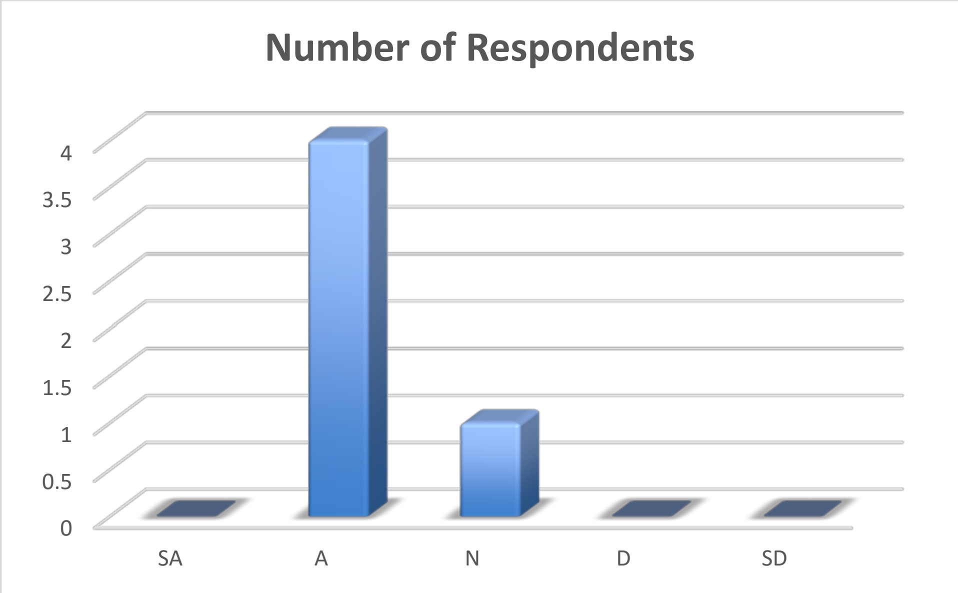


Figure 3.18: Response to the third question of the pre-test

According to data in Figure 3.18, the majority of respondents agreed that the use of the app in the indoor environment of the test-bed building did not compromise its efficiency in terms of the quality of information transmitted and displayed on the screen. About 80% of respondents agreed that information was easily comprehensible, with only 20% neither agreeing nor disagreeing to the statement. On this basis, it can be deduced that the use of the app under continuous motion was of acceptable efficiency, which did not call for an intervention.

3.4.4 Fourth Question

The fourth statement in the questionnaire has to do with the functionality of the app. Respondents were required to indicate if, 'Information needed for a specific task was grouped together on a single screen'. The data based on the fourth question is shown in Figure 3.19 below and expounded further in the subsequent paragraph.

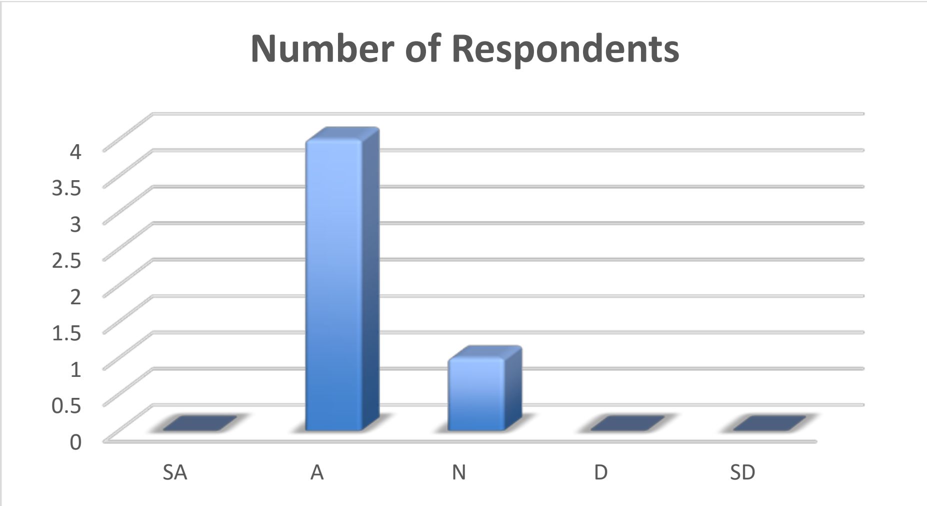


Figure 3.19: Response to the fourth question of the pre-test

Based on the data in Figure 3.19 and similar to the response of the previous question, 80% of respondents agreed that the information needed for a specific task was grouped together on a single screen while 20% neither agreed nor disagreed. This implied that the majority of respondents agreed that the functionality of the app balances its usability when used in the indoor environment of the test-bed building.

3.4.5 Fifth Question

The fifth statement in the questionnaire also has to do with how the app balances functionality with usability. Respondents specified how, 'Alerts were only presented at appropriate times'. The response data for this statement is shown in Figure 3.20 and elaborated further in the subsequent paragraph.

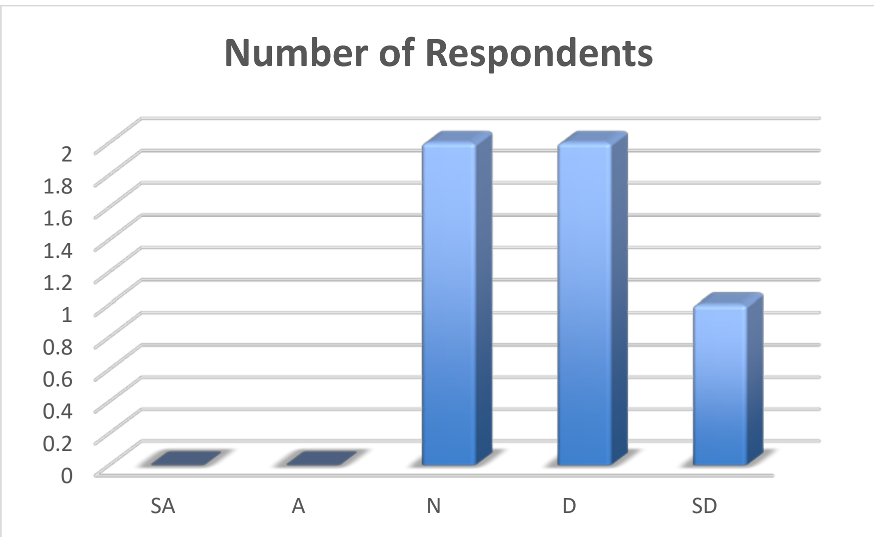


Figure 3.20: Response to the fifth question of the pre-test

Based on the data in Figure 3.20, 60% of respondents felt that the functionality of the app in relation with its usability did not help their orientation in the indoor environment of the test-bed building. The remaining 40% neither agreed nor disagreed with the functionality-usability trade-offs on the alerts presentation. This implies that under continuous motion and use of the app, the expected instructions were not forthcoming. Instead, unnecessary and irritating alerts were popping up. This is in connection with the fact that the app does not work real-time, given that the NFC technology itself does not support regular updating of user position. In effect, certain improvements that the app requires for vital alert presentation are necessary.

3.4.6 Sixth Question

The sixth statement in the questionnaire relates to ease-of-use usability features, where respondents were asked to state how, 'I found the application prototype to be easy to use'. The response data for this statement is shown in Figure 3.21 below, with further explanations in the subsequent paragraph below.

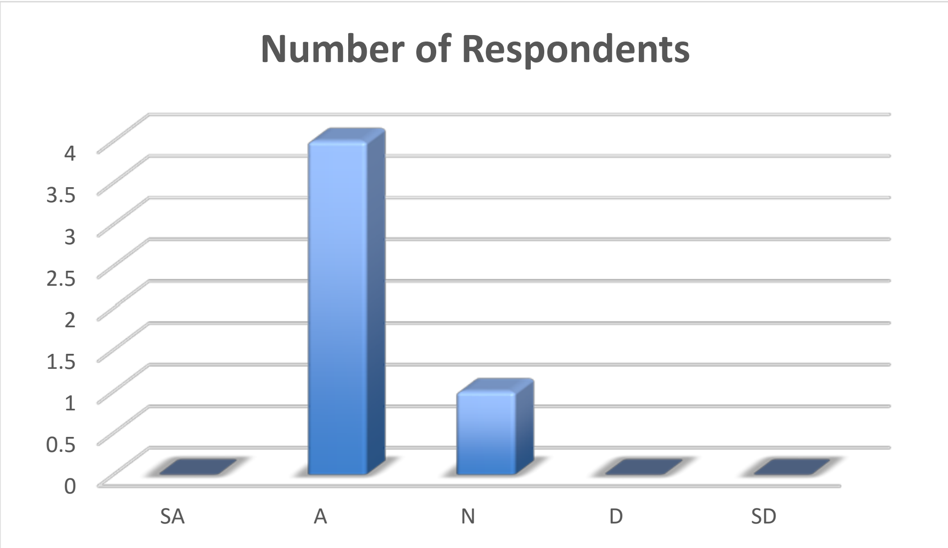


Figure 3.21: Response to the sixth question of the pre-test

According to data in Figure 3.21, which has a similar response as the third and fourth questions, 80% of respondents agreed that the application prototype is easy to use while 20% neither agreed nor disagreed. Based on the margin of this response, it can be concluded that the ease-of-use of the app under continuous motion in the indoor environment of the test-bed building was of acceptable proficiency.

3.4.7 Seventh Question

The seventh statement in the questionnaire pertained to the organisation of menu items and functions, so that orientation in the test-bed building is not impeded and thus improving usability. Respondents were required to specify if, 'The menu items were well organised and functions were easy to find'. The response data for this statement is shown in Figure 3.22 and elaborated further in the subsequent paragraph.

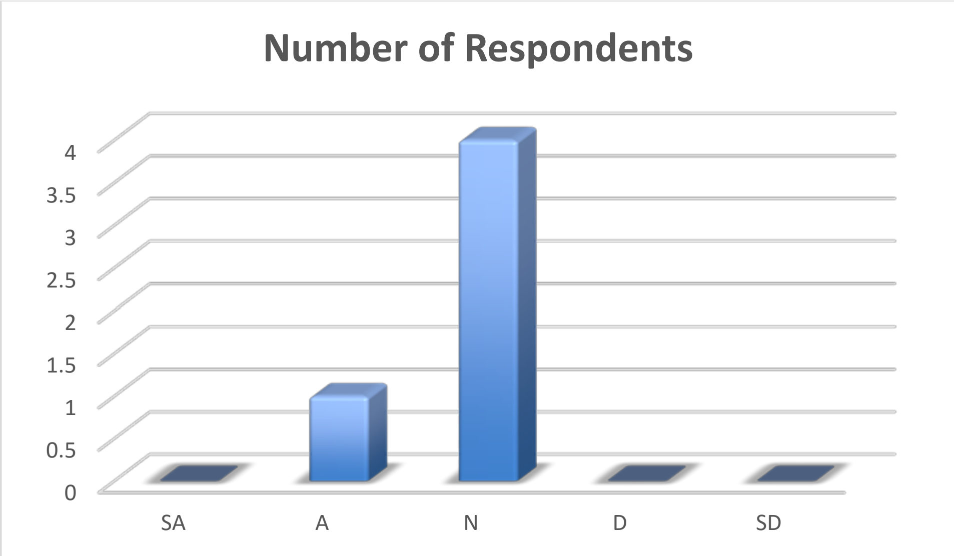


Figure 3.222: Response to the seventh question of the pre-test

According to data in Figure 3.22, only 20% of the respondents felt that the menu items were well organized and functions were easy to find as they navigate within the test-bed building. The remaining 80% neither agreed nor disagreed. While this neutrality could be as a result of individual differences or just lack of understanding of the interface menu items, it nonetheless portrays a setback for menu items and functions of the app. Hence, it signifies that the menu items and functions were not well organised for ease-of-use and thus requires improvement.

3.4.8 Eighth Question

The eighth statement in the questionnaire also relates to the organisation of the interface buttons of the app to reduce clutter on the screen. Respondents were required to specify if, 'The buttons were well organized and easy to find'. Response data to this statement is shown in Figure 3.23 and elaborated upon in the subsequent paragraph.

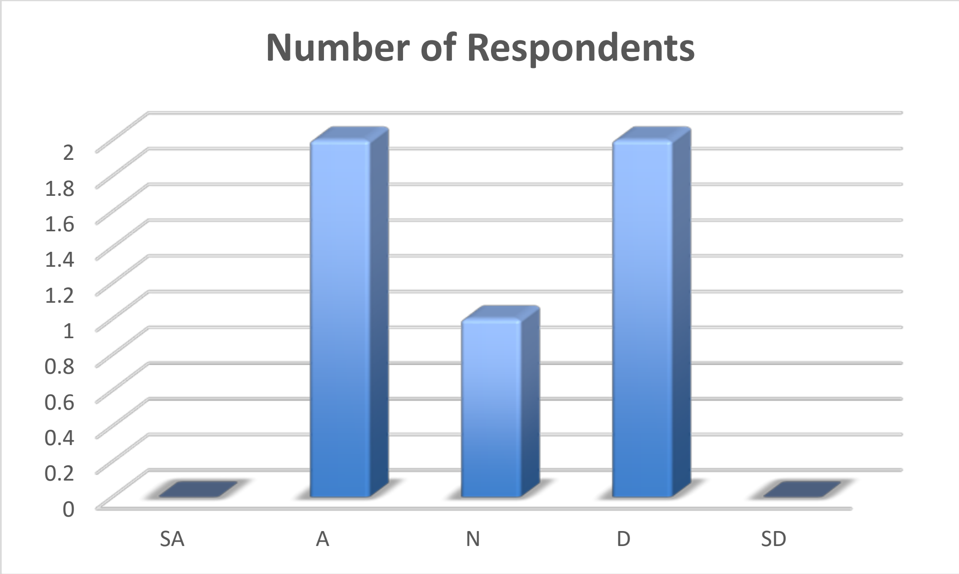


Figure 3.23: Response to the eighth question of the pre-test

Based on the data in Figure 3.23, 40% of respondents agreed that the buttons were well organized and easy to find while 40% of respondents disagreed that the buttons were well organized and easy to find during orientation within the test-bed building. The remaining 20% neither agreed nor disagreed. Unlike previous questions, this one is a close call due to the equal number of responses for the agreed and disagreed. However, to eliminate any iota of doubt, the 20% response was categorised with the 40% of the disagreed response. This way, the organisation of the buttons are addressed as needing improvement.

3.4.9 Ninth Question

The ninth statement in the questionnaire has to do with how the functionality of the app balances the usability in the course of orientation in the indoor environment of the test-bed building. In this statement, respondents were asked to indicate if, ‘Navigating around the application screen was very easy’. The response data for this statement is shown in Figure 3.24 below, and elucidated in the subsequent paragraph.

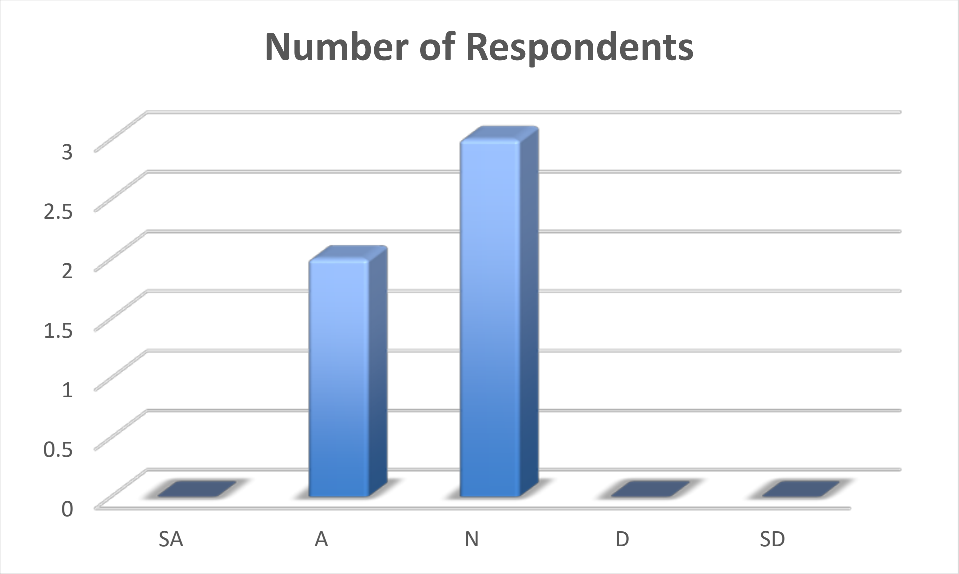


Figure 3.24: Response to the ninth question of the pre-test

According to the data in Figure 3.24, the majority of respondents felt that navigating around the application screen was clunky during orientation in the test-bed building. This implies that the functionality of the app was more than its usability. About 40% of respondents agreed that navigating around the application screen was very easy, while 60% of respondents neither agreed nor disagreed. It may be tempting to assume that since none disagreed, the app is usable. However, the neutral respondents might actually be disagreeing rather than agreeing. Hence, based on this margin, and to eliminate any iota of doubt, the navigation interface was perceived as requiring minor improvement.

3.4.10 Tenth Question

The tenth and final statement in the questionnaire is focused on the overall usability of the app while navigating in the indoor environment of the test-bed building. Under this statement, respondents were required to specify if, 'My overall impression of the application prototype is very positive'. The response data for this statement is shown in Figure 3.25 below, with an elucidation in the subsequent paragraph.

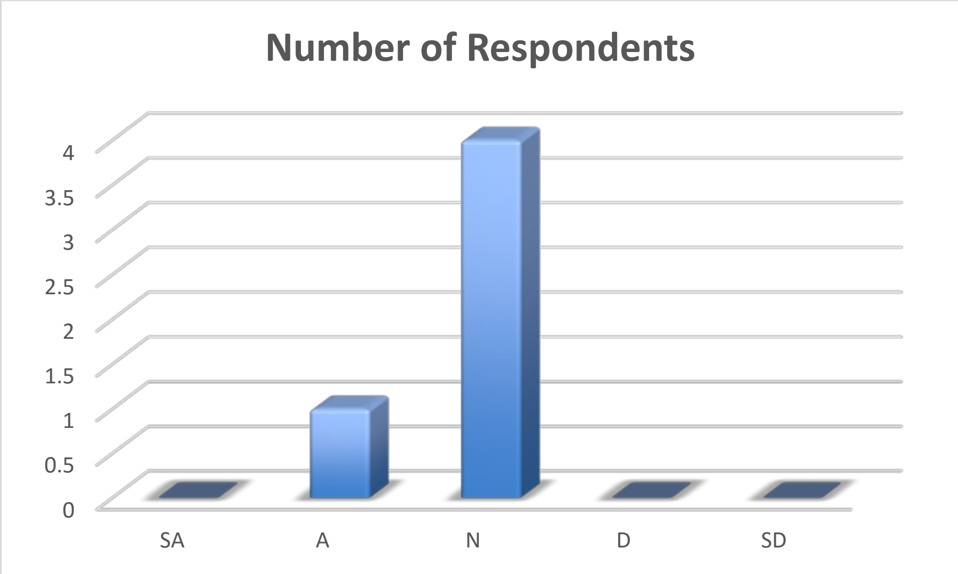


Figure 3.25: Response to the tenth question of the pre-test

According to the data in Figure 3.25, the majority of respondents, though optimistic, had reservations concerning the overall usability of the app. As many as 80% of respondents neither agreed nor disagreed that the overall impression of the application prototype is very positive. The remaining 20% of respondents agreed that the overall impression of the application prototype is very positive, with none disagreeing. Although it seemed positive that none disagreed, however, being the overall assessment of the app, it is expected that the response would be more positive than neutral or negative. Hence, the navigation app requires improvements and overhauls based on the responses of respondents.

A summary of the responses in the pre-test iteration is shown in Table 3.5 while the representation is shown in Figure 3.26 below.

Table 3.5: Summary of responses from Pre-test

	Q1 (%)	Q2 (%)	Q3 (%)	Q4 (%)	Q5 (%)	Q6 (%)	Q7 (%)	Q8 (%)	Q9 (%)	Q10 (%)	AVG (%)
Strongly Agree (SA)	0	20	0	0	0	0	0	0	0	0	2
Agree (A)	0	60	80	80	0	80	20	40	40	20	42
Neutral (N)	60	20	20	20	40	20	80	20	60	80	42
Disagree (D)	20	0	0	0	40	0	0	40	0	0	10
Strongly Disagree (SD)	20	0	0	0	20	0	0	0	0	0	4

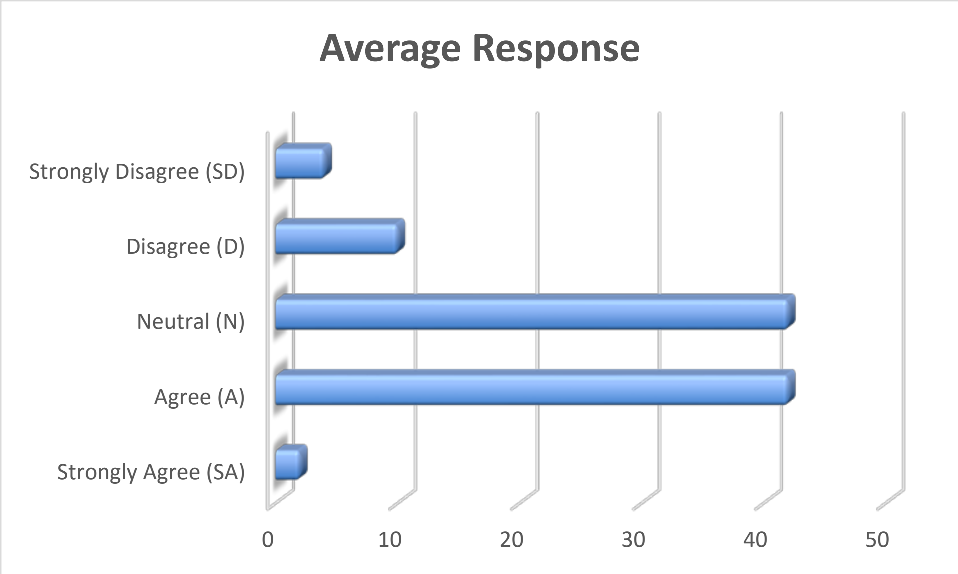


Figure 3.26: Representation of summary of responses from pre-test

From Figure 3.26, both the ‘agree’ and the ‘neutral’ responses are 42% each. Although the ‘neutral’ response may simply suggest indifference, it nonetheless adds no value to the quality of the app. Therefore, for the purpose of this study and to improve the application interface, the ‘neutral’ response is categorised with the ‘disagree’ and the ‘strongly disagree’ responses. Thus, adding the 10% of the ‘disagree’ and the 4% of the ‘strongly disagree’ to the ‘neutral’ responses, will give us 56%. This practically suggests that improvements and fixes are necessary to improve the overall usability and functionality of the application.

3.5 Chapter Conclusion

In this chapter, the approach and methodology employed in this research to achieve the objective of the study was presented, as well as the applications, components and navigation service employed in the indoor positioning and navigation system implementation. The experiment design that underpins this research was described and explained in order to have an understanding of the various stages in this study. Furthermore, a detailed presentation of the first stage of the experiment design was realised.

The chapter discussed the approach and the method employed, which is the experiment method and technique, and discussed why this is the case. In order to be able to carry out experiments, an understanding of the applications and components employed was necessary, and was presented. This research focuses on the use of free open-source software and hardware to reduce cost. In order to be able to understand the various applications and components, the discussion was divided into three parts, namely map generation, positioning component and navigation component. A detailed approach to these stages of implementation is documented in order to present the underlying principles of these components and technologies as applied in this research. The map generation method was explained based on map rendering with MapWarper, OpenStreetMap and JOSM editor. The positioning and navigation components introduced the various tools and technology employed. Having thoroughly explained the technical and technological elements of the research, their application was then presented and tested in the pre-test stage of the study. Although, experiment techniques are conducted in laboratory or field settings, this research uses the laboratory setting because of the technologies and instruments involved. The three stages of the experiment design employed in the study namely pre-test, experiment and post-test were presented. Pre-test was exhausted in this chapter, while experiment and post-test are implemented in the following chapter, chapter four.

CHAPTER FOUR: SERVICE DESIGN AND IMPLEMENTATION

4.1 Introduction

The objective of this study was to identify innovative ways of improving the positioning and navigation system in indoor and closed spaces, in order to contribute towards a more effective and productive use of mobile navigation applications. This chapter builds on the background of chapter two and chapter three, in order to present the processes and the outcome of the research. While the literature and theoretical foundations (chapter two) mapped the scientific basis for the investigation, chapter three outlined the research approach, methodology and techniques that were used in this study. For example, a positivist epistemological approach was used for this study. The study is an empirical investigation that uses the experiment technique as a research methodology.

After the initial pre-test on both the control and the experiment apparatus in chapter three, this chapter presents the stimulus manipulation of the experiment apparatus in order to explore the impact that the enhancements made on positioning technologies have on their navigation potential. This chapter builds on this background to present the components (and applications) used in the experiment in section 4.2. This is followed by a detailed outline of the actual experiment process in section 4.3., as well as a validation process in the form of the post-test in section 4.4. The chapter ends with the summary and conclusion in section 4.5.

4.2 Preliminary Experiment

Given the resource limitations (and budgetary constraints), the success of the project depends much on cost minimising strategies. Therefore, choice of tools for the experiment, such as the software applications, is very crucial. Thus, the open-source software and hardware technology applications were used to avert the software licence costs, thereby paving a way for the initial steps in the experimentation process. In order to achieve an efficient positioning and navigation in these experiments, it is important to determine a user's initial position accurately. Two preliminary experiments were carried out using RFID toolkit, NFC toolkit, Arduino board and Linux OS. This hardware-based approach supports the main application and is presented in the following sections.

4.2.1 RFID Reader and Arduino

The Parallax RFID reader is a low-cost method used for reading passive RFID tags. The RFID reader and the Arduino Uno board setup were used for two reasons. Firstly, to observe the interaction and performance between the reader and tags. The performance observed with this setup will help in ensuring a more improved replication with the prototype navigation application at the experiment stage. Secondly, it was done to read and capture the serial number or Unique Identifier (UID) of the tags. The UID is also useful at the experiment stage, because it is associated with the position information in the prototype navigation application. The Parallax RFID reader and Arduino Uno board were set up as shown in Figure 4.1 below.

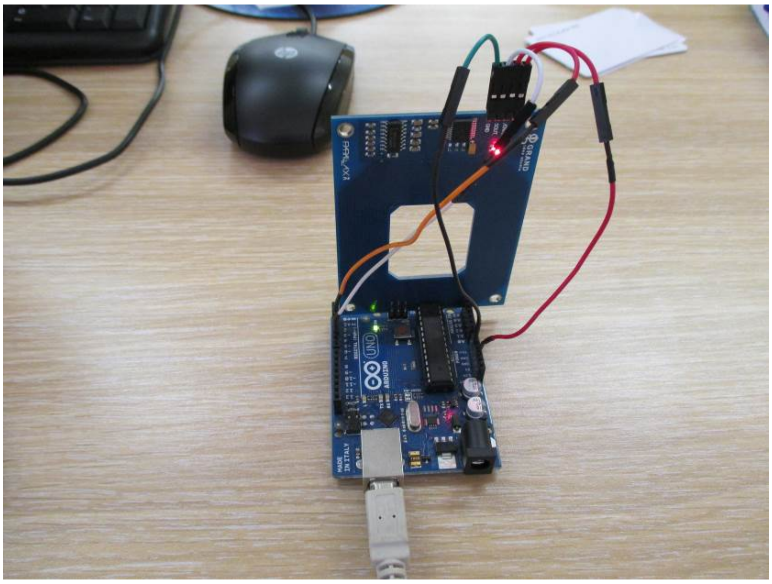


Figure 4.1: An RFID reader and Arduino board setup

From Figure 4.1, the setup shows that the reader and Arduino are connected and powered up. The setup was connected to the Ubuntu system via a USB connector. The LED of the reader is red, meaning that the reader is in an active state of searching and waiting for compatible tags within range as discussed in section 3.3.3.2 of chapter three. The reader is connected to Arduino with four jumper wires. The pin connection of the four jumper wires used in connecting the two devices is shown in Table 4.1 below.

Table 4.6: Pin Connection of RFID Reader to Arduino Uno board

RFID Reader	Arduino Uno Board
VCC	5 V
GND	GND
/ENABLE	DIGITAL PIN 2
SOUT	DIGITAL PIN 5

The RFID Reader can easily interact with any host microcontroller, such as Arduino, using only four connections as shown in Table 4.1. As discussed in section 3.3.3.2 of chapter three, the reader and Arduino pins are connected as shown in the table. In order for the RFID Reader and Arduino to interact, a set of code (known as sketch) was written, uploaded and verified in the Arduino IDE. The sketch is shown in Figure 4.2 below.

```
#include <SoftwareSerial.h>
        #define RFIDEnablePin 2
        #define RFIDSerialRate 2400
        #define RxPin 5
        #define TxPin 4
        SoftwareSerial RFIDReader(RxPin,TxPin);
        String RFIDTAG="";
        String DisplayTAG = "";

        void setup()
        {
                RFIDReader.begin(RFIDSerialRate);
                pinMode(RFIDEnablePin,OUTPUT);
                digitalWrite(RFIDEnablePin, LOW);
                Serial.begin(9600);
                Serial.println("Hello world!");
        }

        void loop()
        {
                if(RFIDReader.available() > 0)
                {
                ReadSerial(RFIDTAG);
                }
                if(DisplayTAG!=RFIDTAG)
                {
                DisplayTAG=RFIDTAG;
                Serial.println(RFIDTAG);
                }
        }

        void ReadSerial(String &ReadTagString)
        {
                int bytesread = 0;
                int  val = 0;
                char code[10];
                String TagCode="";

                if(RFIDReader.available() > 0) {
                  if((val = RFIDReader.read()) == 10) {
                    bytesread = 0;
                    while(bytesread<10) {
                      if( RFIDReader.available() > 0) {
                        val = RFIDReader.read();
                          if((val == 10)||(val == 13)) {
                            break;
                          }
                          code[bytesread] = val;
                          bytesread++;
                        }
                    }
                    if(bytesread == 10) {
                      for(int x=0;x<10;x++)
                        {
                          TagCode += code[x];
                        }
                        ReadTagString = TagCode;
                        while(RFIDReader.available() > 0)
                        {
                          RFIDReader.read();
                        }
                    }
                    bytesread = 0;
                    TagCode="";
                }
            }
        }
```

Figure 4.2: A sketch for an RFID used in Arduino

The sketch in Figure 4.2 uses the serial monitor on the Arduino IDE to output the reader data at a rate of 9600 baud. While bringing the RFID tag closer to the RFID reader, the reader senses the tag at a distance of 9cm, and the UID of the tag was displayed in the Arduino's serial monitor. The same process was applied to all the RFID tags to retrieve the UIDs and associate them with the position information in the prototype navigation application.

4.2.2 NFC Shield and Arduino

Just like the RFID reader, the NFC Shield and Arduino Duemilanove setup are a low-cost method used in reading NFC tags. The setup is implemented for the same reasons as the RFID's, but this time with the NFC instruments and Arduino. The UID of the NFC tags are retrieved when the NFC Shield reads the tags. The retrieved UIDs are associated with the position information in the code of the prototype navigation application. The NFC Shield and Arduino Duemilanove were set up as shown in Figure 4.3 below.

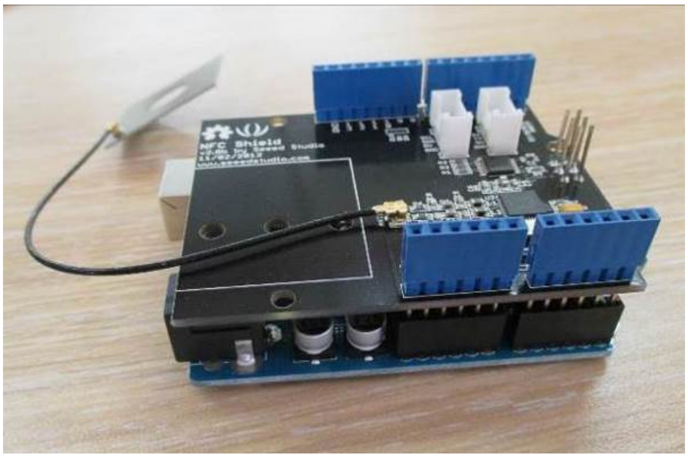


Figure 4.3: NFC Shield and Arduino Duemilanove setup

Figure 4.3 shows the setup of the NFC Shield and Arduino. In this setup, jumper wires are not required, as the Shield is connected to the Arduino socket by simply placing the pins of the Shield on the Arduino socket. The setup was connected to the Ubuntu system via a USB connector. The NFC shield uses the popular and powerful PN532 chipset, which is embedded in the majority of NFC mobile devices. The PN532 software library and NDEF library for NFC Shield were included in Arduino's library to ensure ease of communication between the Shield and Arduino. The library also provides API for reading passive NFC tags. A sketch was written, uploaded and verified in the Arduino IDE to aid interaction between the devices. The sketch is shown in Figure 4.4 below.

```
#include <PN532.h>
#define SS 10
#if defined(__AVR_ATmega1280__) || defined (__AVR_ATmega2560__)
      #define MISO 50
      #define MOSI 51
      #define SCK 52
#else
      #define MISO 12
      #define MOSI 11
      #define SCK 13
#endif

PN532 nfc(SCK, MISO, MOSI, SS);

void setup(void) {
      Serial.begin(9600);
      nfc.begin();
      uint32_t versiondata = nfc.getFirmwareVersion();
      if (! versiondata) {
            Serial.print("Didn't find PN53x board");
            while (1);
      }

      Serial.print("Found chip PN5"); Serial.println((versiondata>>24) & 0xFF, HEX);
      Serial.print("Firmware ver. "); Serial.print((versiondata>>16) & 0xFF, DEC);
      Serial.print('.'); Serial.println((versiondata>>8) & 0xFF, DEC);
      Serial.print("Supports "); Serial.println(versiondata & 0xFF, HEX);
      nfc.SAMConfig();
}

void loop(void) {
      uint32_t id;
      id = nfc.readPassiveTargetID(PN532_MIFARE_ISO14443A);
      if (id != 0) {
            Serial.print("Read card #"); Serial.println(id);
      }
}
```

Figure 4.4: A sketch for an NFC Shield used in Arduino

Similar to the RFID experiment, the sketch in Figure 4.4 uses the serial monitor on the Arduino IDE to output the Shield data at a rate of 9600 baud. The NFC tag was brought in close proximity to the NFC Shield, which sensed the tag at a distance of 7 cm, and then the UID of the tag was displayed in the Arduino’s serial monitor. The same process was applied to all the NFC tags. The reading of all the NFC tags was to ensure that they are functional, and for the purpose of retrieving the UIDs in order to associate them with the position information in the prototype navigation application. For the preliminary experiment, the UIDs were used in the HyperText Markup Language (HTML) code of the navigation service, which is discussed in the following sub-section. Table 4.2 below shows the RFID and NFC read-only tag description.

Table 4.7: RFID and NFC tag description

Card	Maximum Proximity/Range	Remarks
Parallax RFID tag	9 cm	Each tag has a unique 10 digit ID with 125 kHz operating frequency
Parallax NFC tag	7 cm	Each tag has a unique 10 digit ID with 13.56 MHz operating frequency

4.2.3 Navigation Service

With the map data prepared and the positioning components set up, the actual test process, which, for the purpose of this experiment, is referred to as the 'navigation service' is implemented. The focus of this experiment is on the use of the image file of the test-bed building in a web application (i.e. HTML and JavaScript). The SerialPort-Server was installed in the Linux system. It aids interaction between the web application and Arduino as illustrated in Figure 4.5 below.

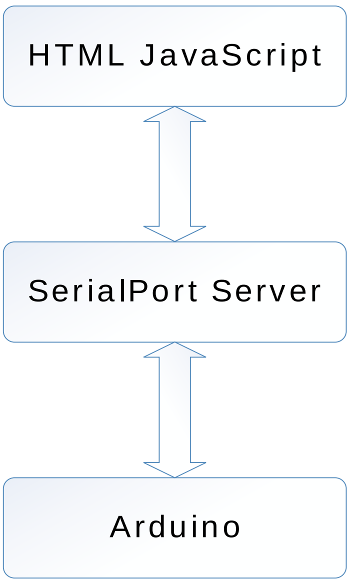


Figure 4.5: SerialPort and Arduino Interaction

The SerialPort is accessed via HTTP, WebSocket or Transmission Control Protocol (TCP) Socket using the script shown below in the Ubuntu Linux terminal window.

Run serialport-server

% serialport-server /dev/tty.usb-device

HTTP Interface

Read serialport

% curl http://localhost:8783

Write serialport

% curl -d 'hello!!' http://localhost:8783

WebSocket Interface

```
// JavaScript
var ws = new WebSocket("ws://localhost:8784");
ws.onmessage = function(e){
  alert(e.data);
};
ws.send('hello!!');
```

TCP Socket Interface

% telnet localhost 8785

The SerialPort provides accessibility and portability with the PandaBoard device. The following HTML code of Figure 4.6 was opened in a web browser and used for the preliminary experiment.

```
<html>
<head>
<title>Navigation System</title>
</head>
<body>
<script language="javascript">
        var ws = new WebSocket("ws://localhost:8784");
ws.onmessage = function(e){
  <!-- alert(e.data);//-->
if (e.data == "0100A62A86"){
document.images.location_map.src = "location_1.png";}
else if(e.data == "0000C04AC6"){
document.images.location_map.src = "location_2.png";}
else if(e.data == "0000C060BF"){
document.images.location_map.src = "location_3.png";}
};
//ws.send('hello!!');
</script>
<img src ="location.png" width="800px" height="600px" name="location_map">
</body>
</html>
```

Figure 4.6: The HTML code used in Navigation

The experiment involved the use of three NFC tags, their UID, which is associated with the position information, and the map data. When a tag is tapped to the reader in a range that is less than 10 cm, its position on the map is displayed. The same thing happens when the other tags are tapped to the reader on the navigation path. The display is as shown in Figure 4.7 below.

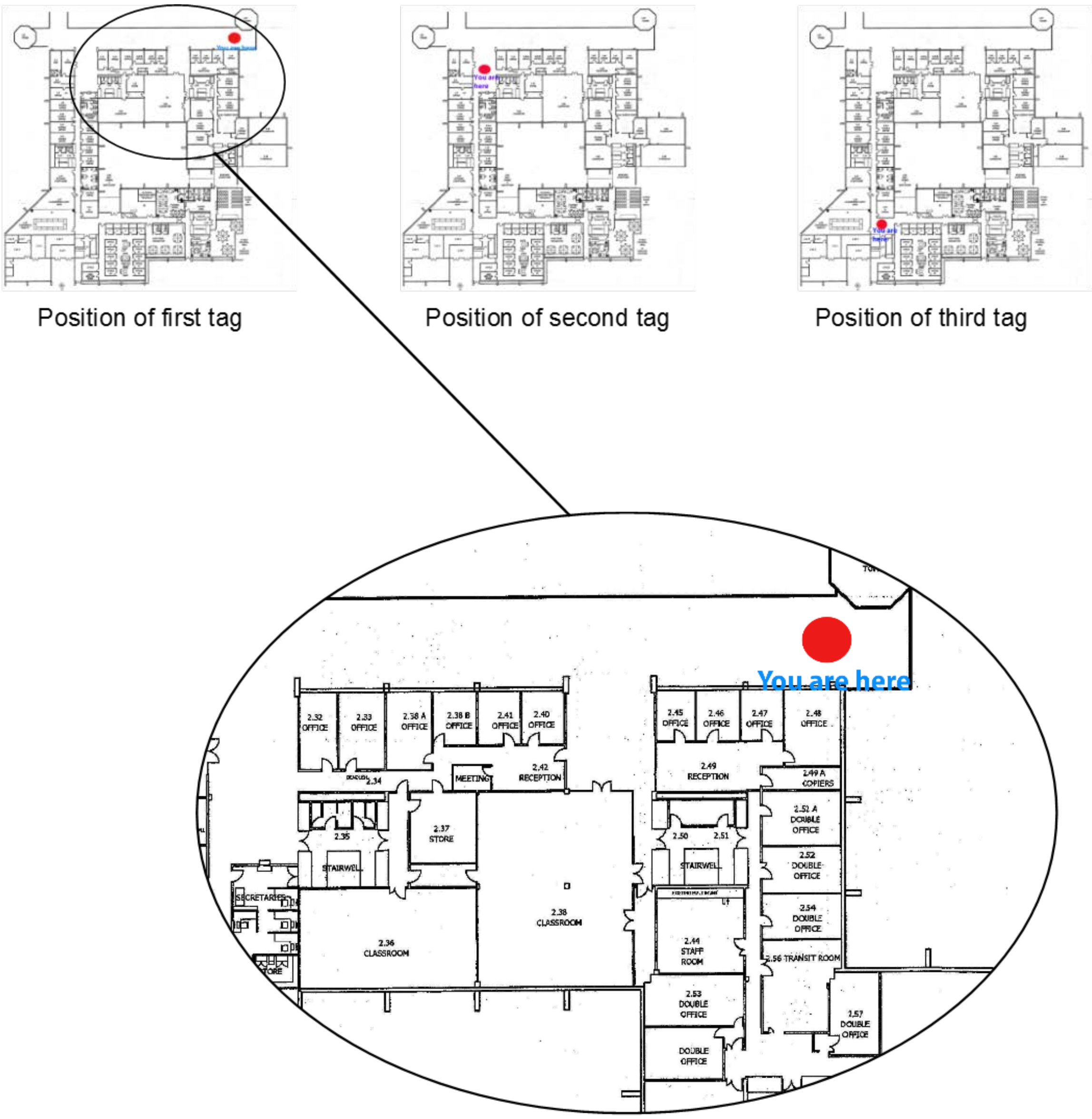


Figure 4.7: Illustration of Indoor Positioning and Navigation

This preliminary experiment was demonstrated in Cape Town at the ICTDevers' meeting, which comprises of industry technocrats, excellent faculty members and postgraduate students from the four universities in Western Cape, South Africa. As a follow-up to this preliminary experiment, an experiment in which the experimental stimulus is introduced is presented in the following section.

4.3 Experiment

The control apparatus and the experiment apparatus were compared and the outcome showed that they are the same. This is because the control and the experiment apparatus, according to Table 3.1 of section 3.2, did not undergo any alteration or manipulation. However, inconsistencies were observed at the end of the test. As a result, there is a need to introduce an experimental stimulus to the navigation service of the experiment apparatus to address the inconsistencies. The experimental stimulus herein refers to the manipulation of the application's code in order to improve the navigation application. In other words, tweaking and optimising the application's code. In order to know which aspect of the code to manipulate, the responses gathered from the pre-test are taken into consideration. For example, Table 4.3 below outlines a summary of the pre-test that was done in section 3.4. Column A of the table represents the sum of the 'strongly agree' and the 'agree' responses for each question, while column B represents the sum of the 'neutral', the 'disagree' and the 'strongly disagree' responses for each question. While the 'strongly agree' and the 'agree' responses are considered as positive feedbacks, the 'neutral', the 'disagree' and the 'strongly disagree' responses are considered as negative feedbacks. However, the 'strongly disagree' and the 'disagree' responses were given priority, in that order, so that more attention is spent on improving the areas that were flagged by these responses. Based on the responses of the respondents, the application's code was manipulated to address the inconsistencies raised.

Table 4.8: Summary of the pre-test outcome

	QUESTION	A	B
1	The app had a clear, clean and explicit interface	0	100
2	The app minimised the number of steps it took to complete tasks	80	20
3	Information presented on screen was easy to comprehend	80	20
4	Information needed for a specific task was grouped together on a single screen	80	20
5	Alerts were only presented at appropriate times	0	100
6	I found the application prototype to be easy to use	80	20
7	The menu items were well organized and functions were easy to find	20	80
8	The buttons were well organized and easy to find	40	60
9	Navigating around the application screen was very easy	40	60
10	My overall impression of the application prototype is very positive	20	80

From Table 4.3, the responses given to the tenth question, in which 80% of the responses are negative, show that the application needs to be improved entirely. The first, fifth, seventh, eighth and ninth questions also need improvements. These improvements were achieved with the Android emulator.

In the first question, where all the respondents agreed that the interface is complex because there are too many information and task for functionality purposes, the interface was made simple without trading away usability and functionality. For the fifth question, it was observed that unnecessary and irritating alerts were popping up. The alerts were minimised to the barest minimum as the application is very easy to understand and use. With respect to the seventh question, some menu items were removed so that the necessary functions will be easily identifiable. For the eighth question, the buttons in some of the screens seemed unnecessary and were removed, leaving only the necessary ones. For the ninth and tenth question, as well as the other questions that require little attention, the application was generally debugged to improve its look and feel. Then, it was tested before the final post-test.

Furthermore, the application is developed using the Java and Android SDKs, and the existing NFC APIs such as LinuxNFC and libNFC. The navigation application, herein referred to as NFCPUT InPoint, involves the use of a mobile device platform with the NFC and Android APIs, the NFC and Android libraries and a development platform, which is the Android emulator. The navigation application can be created for various platforms and phones given that they use various core and frontend technologies. However, since the Android platform is used in this study, the HTML code in Figure 4.6 is rewritten in the Java programming language as shown in appendix A, then compiled and bundled on the Android emulator and phone. The HTML code can also be used in Firefox OS phone since it is an open source platform, and its frontend is written in HTML5, JavaScript and Cascading Style Sheet (CSS).

The navigation service involves the application that reads the content of the NFC tag and translates it to a position on the map. Reading the contents of the tag and getting the position information involves associating the UID of the tag with a position of interest within the building in the application's code. This is achievable because each tag has a unique UID. For example, tag B's UID may be linked with Room 2.1 of the Information Technology department, while tag A's UID is linked to entrance A. Therefore, the application is able to display a position on the map of the test-bed building after getting the UID from the NFC tag, and plotting a route from the starting point (entrance A) to the destination (Room 2.1). However, in order to use the application, it has to be downloaded and installed on a mobile device. The download and the installation are a once-off procedure. Subsequently, the application will not need to access the Internet again to download the map of that building because it is saved to the device already. The device only accesses the internet when it needs to update the map or application. The user will then launch the application on the mobile device at every place where the service runs, in this case the Engineering Building at CPUT. Having downloaded the map data of the building with the application, it is displayed in the navigation application for the first time. In addition, the application can work offline when used at another time. A system flowchart of the navigation service is shown in Figure 4.8 below.

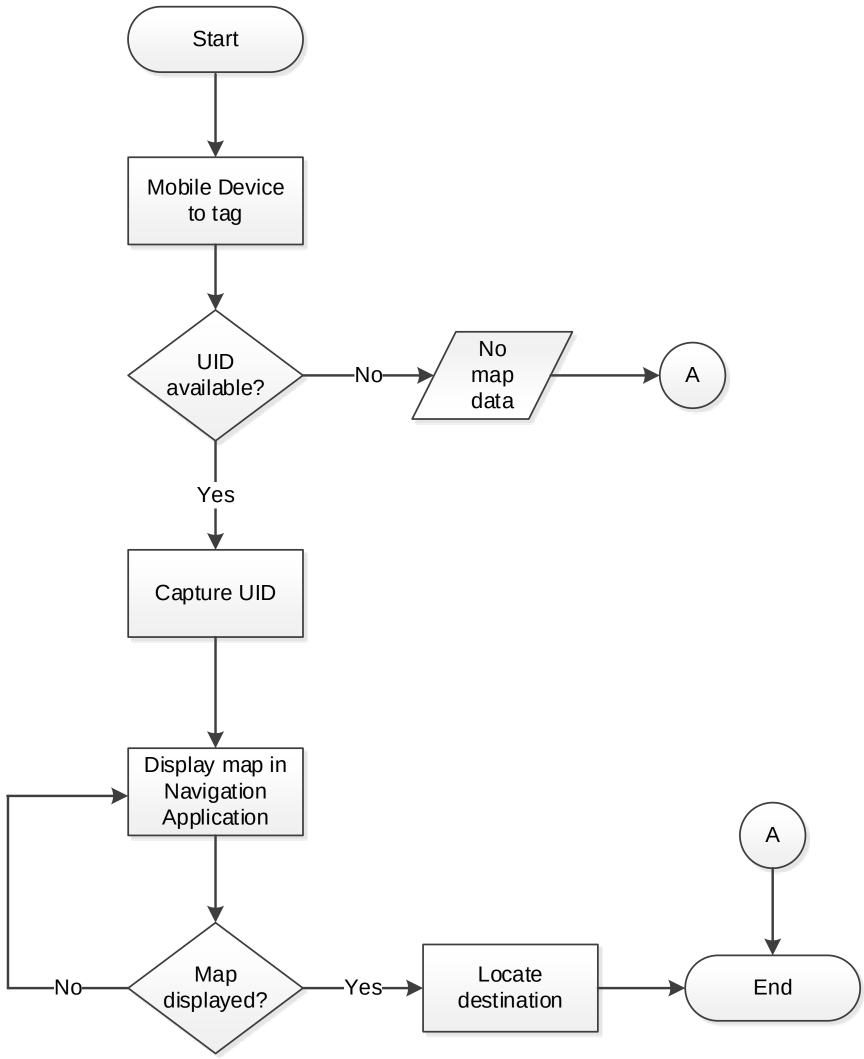


Figure 8.8: The flowchart of navigation service

From Figure 4.8, when the mobile device is tapped to the installed NFC tag at the entrance A while the application is running, it checks for the UID in the tag. If the UID is not linked with that position on the map, the application displays a “no map data” information. However, if the UID is linked, the current location of the user will be displayed in NFCPUT InPoint under “You are here” as shown in Figure 4.9 below.

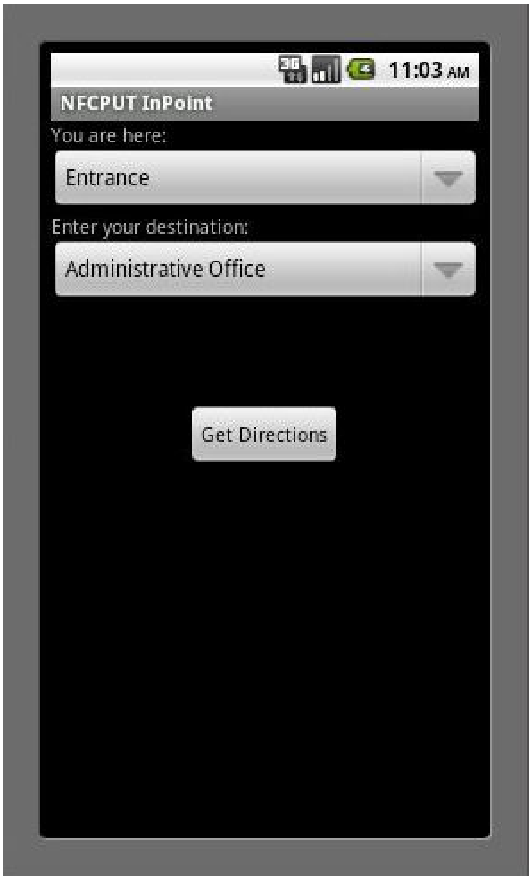


Figure 4.9: Navigation system at the point of entering destination point

From Figure 4.9, the questionnaire’s questions one (the app had a clear, clean and explicit interface), seven (the menu items were well organised and functions were easy to find) and eight (the buttons were well organized and easy to find) were addressed. The interface of the app appears to be clear, clean and explicit, bearing no complicated instructions. In addition, the menu items, functions and buttons have been reduced and well organised. A user is able to enter the destination from the drop-down arrow and click on ‘Get Directions’ button without worrying about the button to click which could have been caused if there are many buttons. On clicking the button, NFCPUT InPoint displays the map of the building as shown in Figure 4.10 below.

Figure 4.10: Navigation system showing map of test-bed building

From Figure 4.10, the app displays the map of the building on its interface and computes the shortest path from origin to destination. The speed with which the map is displayed on a mobile device is dependent on the performance of the device, which is dependent on factors such as the RAM size and processor speed, among others. On computing the shortest path from the current position to the destination, the map displays the navigation path as shown in Figure 4.11 below.

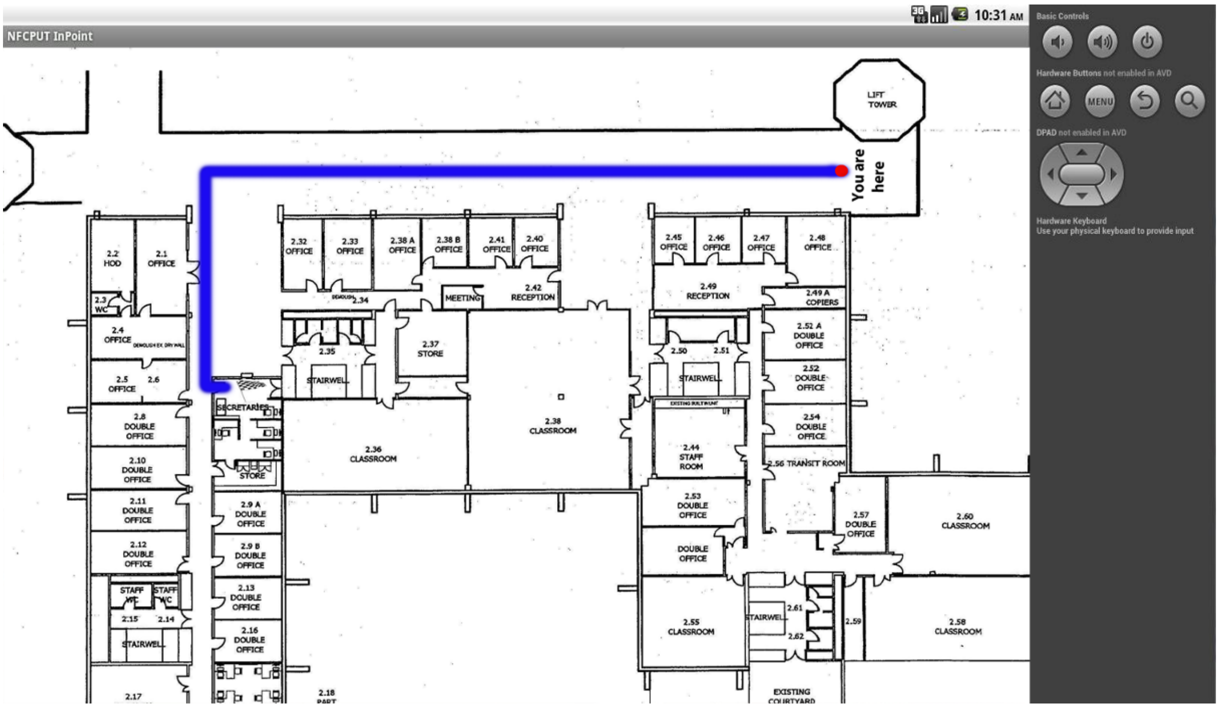


Figure 4.11: Map showing shortest route from current position to destination

From Figure 4.11, the navigation path shown on the screen will assist the user in navigating. However, there is no automatic update of the user's position. Instead, the user taps the mobile device to any NFC tag found on the navigation path to find out if the correct navigation path is still maintained. If the user veers off the navigation path and then taps an NFC tag on the way, the app detects a new position information outside the original path and then calculates a new path from the new position to the destination. The navigation activity diagram shown in Figure 4.12 below summarises the whole process.

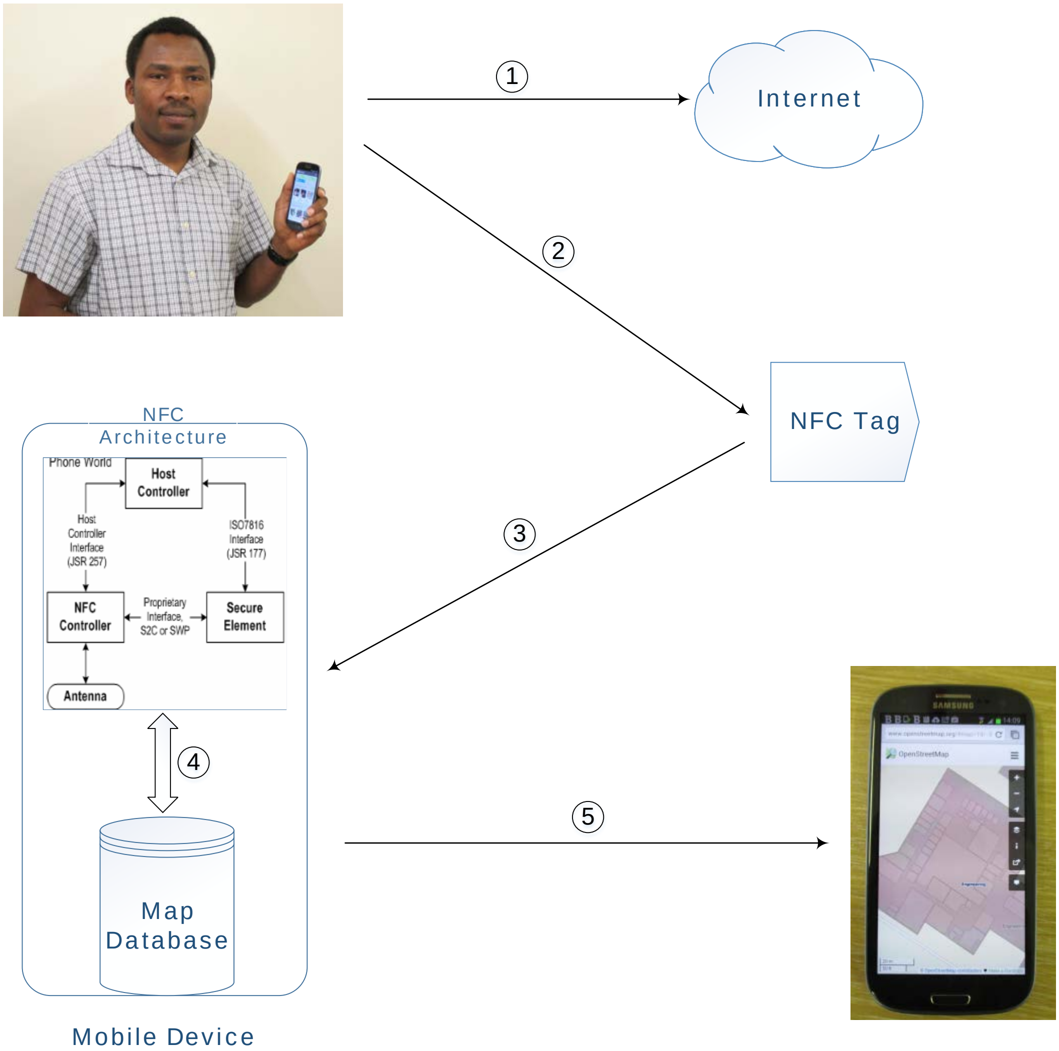


Figure 4.12: Navigation Activity Diagram

The navigation activity diagram is expounded below.

1. Download the navigation application from the internet and install it on mobile device.
2. Tap the NFC mobile device to the NFC tag to retrieve the UID information from tag.
3. The mobile device then retrieves the UID information, and associates the information with the position of interest on the map.
4. The saved map data interacts with the NFC architecture within the mobile device in order to determine the current position.
5. The current position is displayed on the map in the mobile device, and a path to the destination point is plotted in the navigation system.

Having manipulated the code of the navigation application to achieve an improvement with the navigation service, the researcher followed the above steps in order to test the application. The test outcome showed a significant improvement in the application in terms of performance and usability. Thereafter, the post-test was carried out using the same participants used for the pre-test to validate the researcher's inference.

4.4 Post-test

Based on the feedback of the first iteration or pre-test, the navigation application was tweaked, optimised and improved in the preceding section. The new and optimised application was evaluated in the same manner as the pre-test using the same set of questions. Table 4.4 below shows a summary of the respondents' responses to the questionnaire after the optimisation, with an analysis of the questions subsequently.

Table 4.9: Post-test Data

	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10
Participant A	SA	SA	A	SA	A	SA	A	SA	A	SA
Participant B	A	SA	A	SA	N	SA	A	SA	A	SA
Participant C	A	SA	A	SA	A	SA	A	A	A	A
Participant D	A	SA	A	SA	N	A	A	A	A	A
Participant E	A	SA	SA	SA	A	SA	A	A	A	SA
Note: Strongly Agree (SA); Agree (A); Neutral (N); Disagree (D); Strongly Disagree (SD)										

4.4.1 First Question

The first statement in the questionnaire is, 'The app had a clear, clean and explicit interface', with Figure 4.13 below showing the data based on this first question.

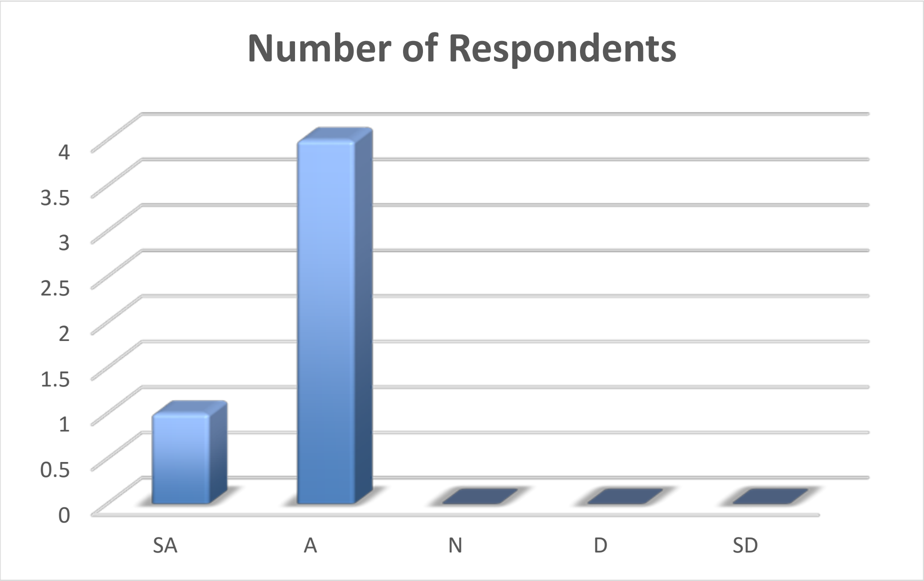


Figure 4.13: Response to the first question of the post-test

Based on the data in Figure 4.13, the respondents expressed their satisfaction with the interface of the app. About 20% and 80% of the respondents strongly agreed and agreed respectively that the app had a clear, clean and explicit interface. This implies that the quality of the interface is satisfactory. Hence, the interface has improved compared to when the pre-test was carried out, as pointed out in section 3.4.1.

4.4.2 Second Question

The second statement in the questionnaire is, 'The app minimised the number of steps it took to complete tasks'. The response data to this statement is shown in Figure 4.14 below.

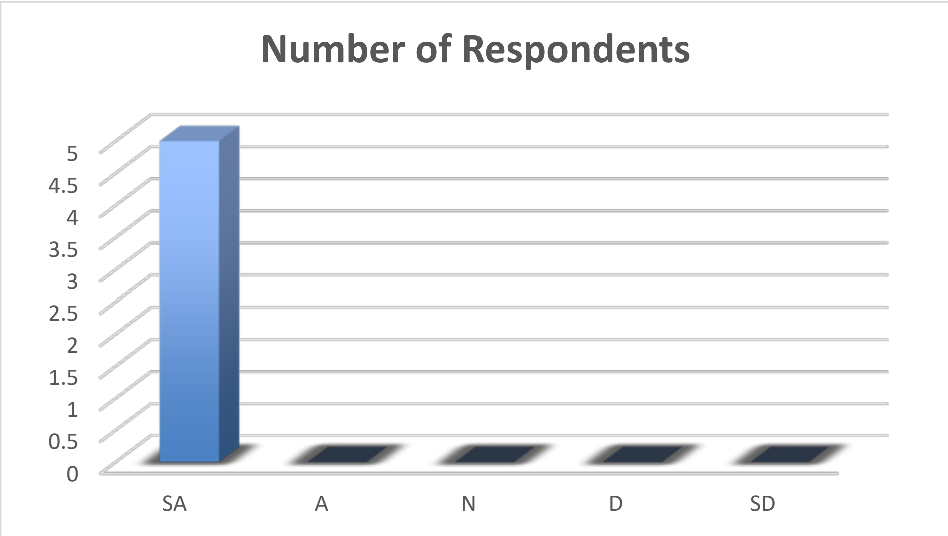


Figure 4.14: Response to the second question of the post-test

According to the data in Figure 4.14, 100% of the respondents strongly agreed that the application minimised the number of steps taken to perform tasks. This is in contrast with the pre-test result, where 20% of the respondents were indecisive. Hence, the outcome of this step yielded an excellent improvement compared with that of the pre-test in section 3.4.2.

4.4.3 Third Question

The third statement in the questionnaire is, 'Information presented on screen was easy to comprehend'. The response data to this statement is shown in Figure 4.15 below and expounded in the subsequent paragraph.

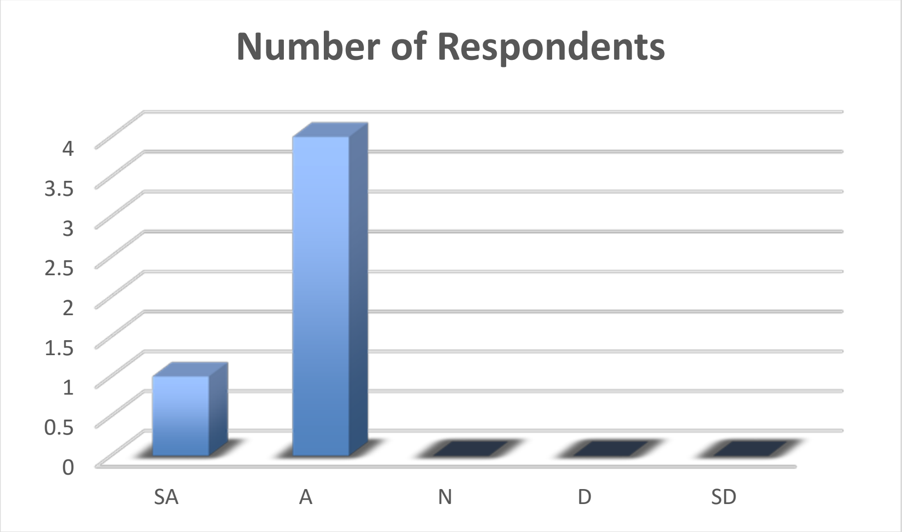


Figure 4.15: Response to the third question of the post-test

According to the data in Figure 4.15, all the respondents felt that the information presented on the screen was easy to comprehend. Just like the first question, 20% of the respondents strongly agreed that the information presented on the screen was easy to comprehend while 80% of the respondents agreed. Hence, the presentation of information on screen has improved compared with that of the pre-test in section 3.4.3.

4.4.4 Fourth Question

The fourth statement in the questionnaire is, 'Information needed for a specific task was grouped together on a single screen'. The response data to this statement is shown in Figure 4.16 below with an explanation in the subsequent paragraph.

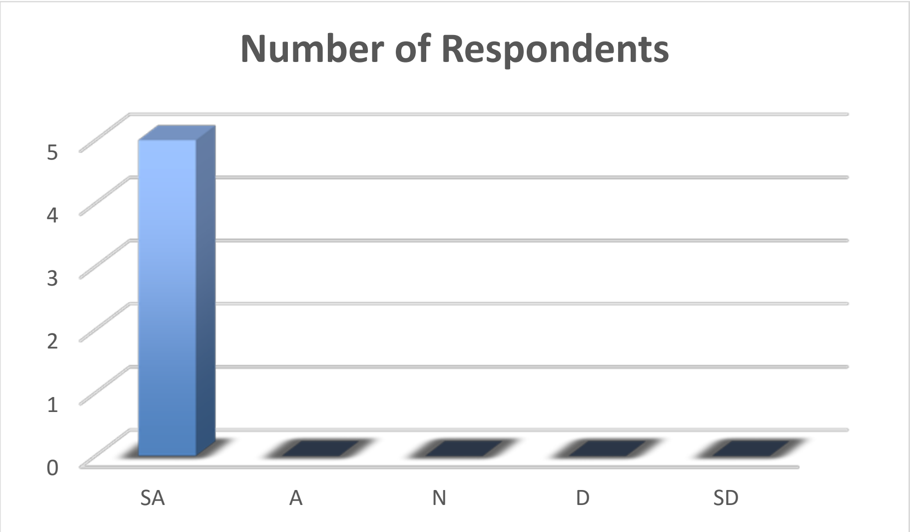


Figure 4.16: Response to the fourth question of the post-test

According to the data in Figure 4.16 and similar to the response of the second question, 100% of the respondents strongly agreed that the information needed for a specific task was grouped together on a single screen. This shows that the grouping of the information that are needed for a specific task was excellently executed compared with that of the pre-test in section 3.4.4.

4.4.5 Fifth Question

The fifth statement in the questionnaire is, ‘Alerts were only presented at appropriate times’. The response data to this statement is shown in Figure 4.17 below and elucidated in the subsequent paragraph.

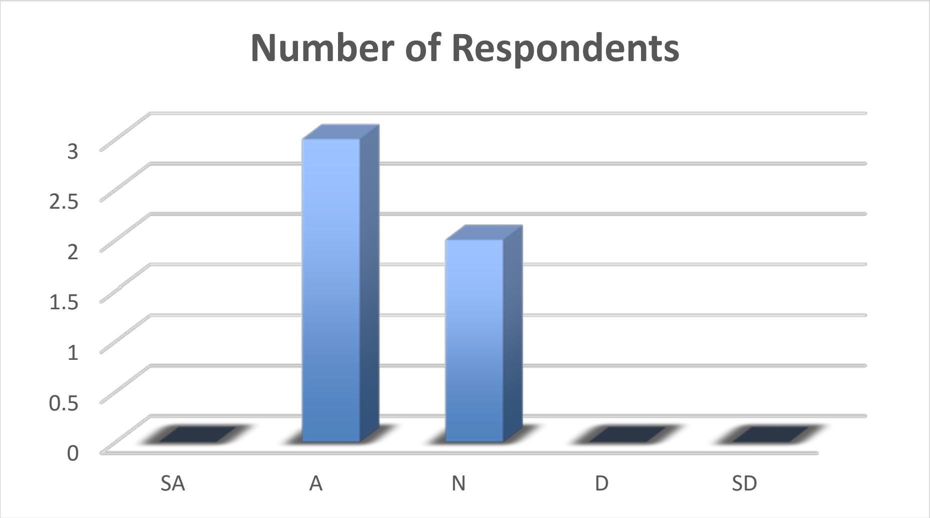


Figure 4.17: Response to the fifth question of the post-test

According to the data in Figure 4.17, 60% of the respondents agreed that alerts were only presented at appropriate times while 40% neither agreed nor disagreed. The indecision of the respondents can be connected to the fact that the app does not work real-time, and the NFC technology does not support regular updating of user position. Given this limitation, the usability of the app is not impeded as users are able to navigate following the navigation path. Furthermore, the use of alerts in a system is actually dependent on the user’s choice. Hence, the alert system, which help users with the main functionalities in the app, is acceptable when compared with that of the pre-test in section 3.4.5.

4.4.6 Sixth Question

The sixth statement in the questionnaire is, ‘I found the application prototype to be easy to use’. The response data to this statement is shown in Figure 4.18 below and elaborated in the subsequent paragraph.

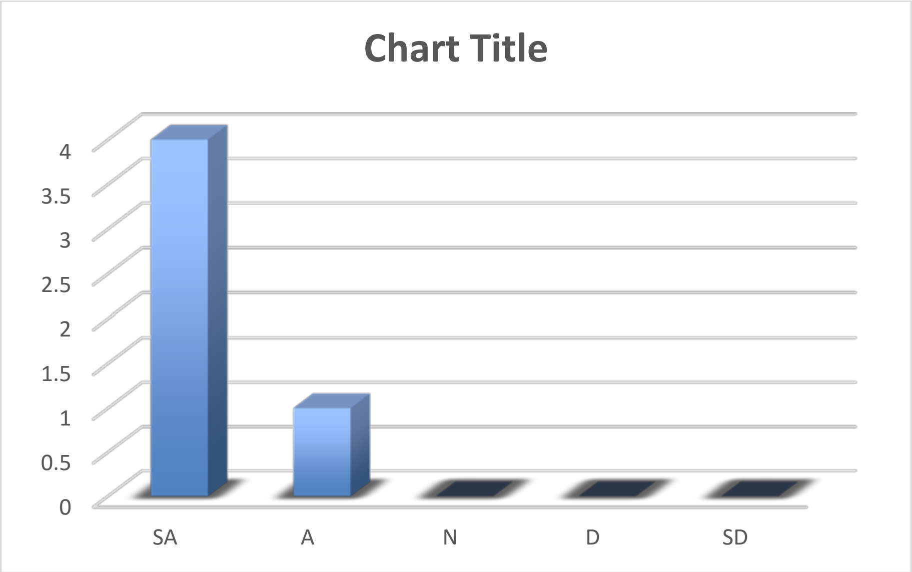


Figure 4.18: Response to the sixth question of the post-test

According to the data in Figure 4.18, all the respondents felt that the ease-of-use of the app is proficient. While 80% of the respondents strongly agreed that the application prototype is easy to use, 20% agreed. Hence, the ease-of-use of the application prototype is excellent compared with that of the pre-test in section 3.4.6.

4.4.7 Seventh Question

The seventh statement in the questionnaire is, ‘The menu items were well organized and functions were easy to find’. The response data to this statement is shown in Figure 4.19 below and clarified in the subsequent paragraph.

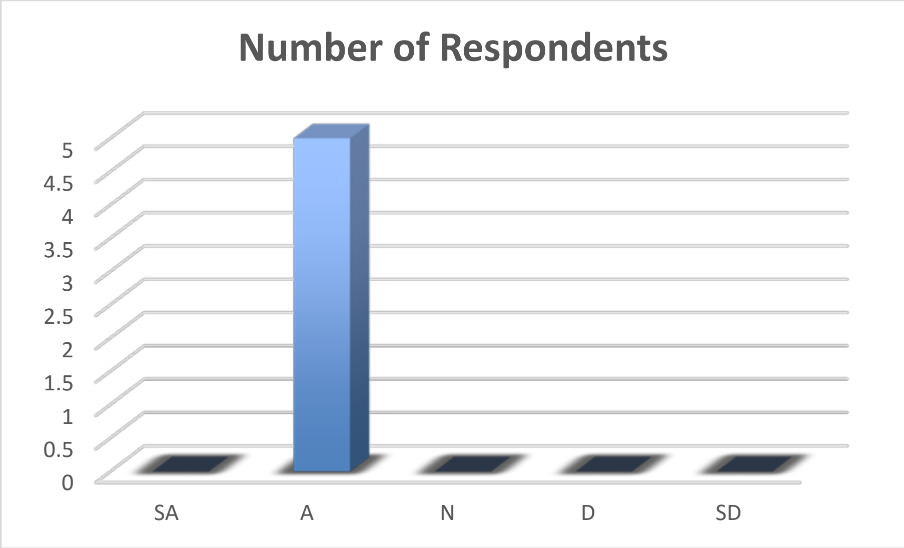


Figure 4.19: Response to the seventh question of the post-test

According to the data in Figure 4.19, 100% of the respondents felt that the quality of the menu items and the functionality of the app were usable. The positive outcome of the assessment confirms that the app is efficient and usable. Hence, the organisation and the functionality of the menu items made the app easy to use compared with that of the pre-test in section 3.4.7.

4.4.8 Eighth Question

The eighth statement in the questionnaire is, 'The buttons were well organized and easy to find'. The response data to this statement is shown in Figure 4.20 below with an elaboration in the subsequent paragraph.

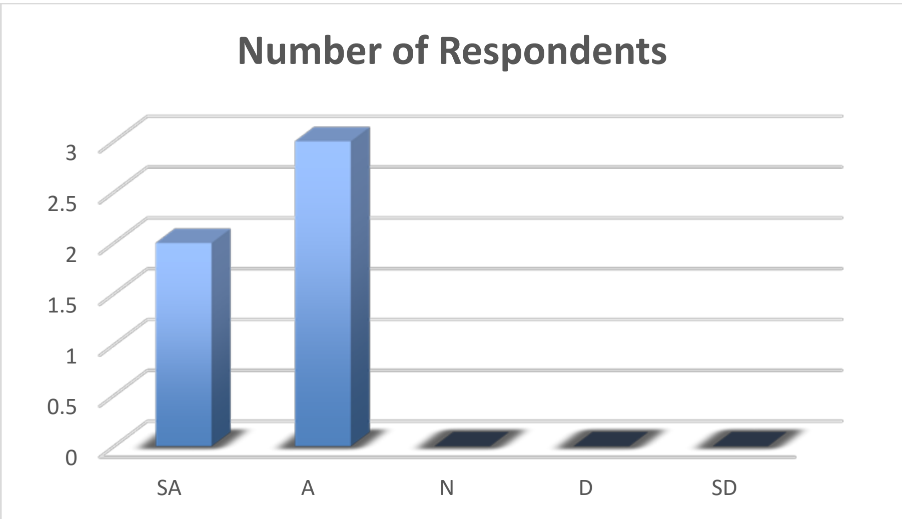


Figure 4.20: Response to the eighth question of the post-test

According to data in Figure 4.20, 40% and 60% of the respondents strongly agreed and agreed respectively that the buttons were well organized and easy to find. This implies that the usability of the app is acceptable. Hence, the organisation and the usability of the buttons has improved when compared with that of the pre-test in section 3.4.8.

4.4.9 Ninth Question

The ninth statement in the questionnaire is, 'Navigating around the application screen was very easy'. The response data to this statement is shown in Figure 4.21 below and elaborated in the subsequent paragraph.

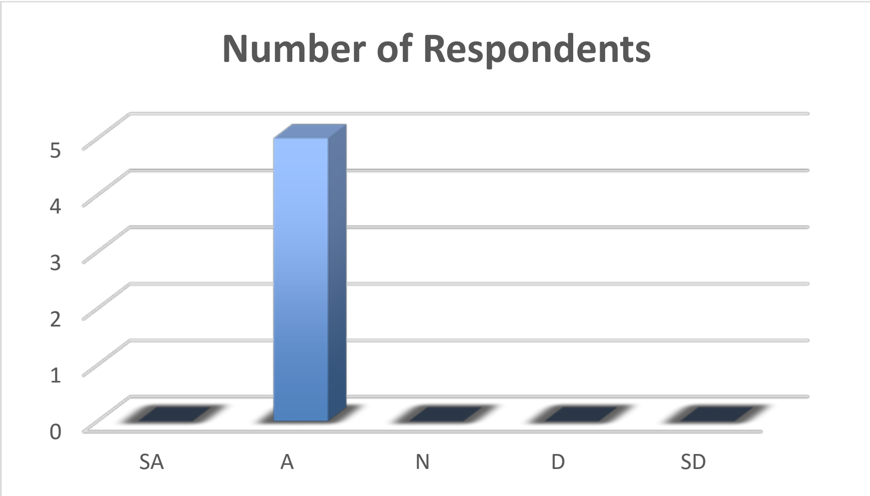


Figure 4.21: Response to the ninth question of the post-test

According to the data in Figure 4.21 and similar to the response of the seventh question, 100% of the respondents agreed that navigating around the application screen was very easy. This is in contrast with the pre-test result, where 60% of the respondents were neutral. This implies that the usability of the app has greatly improved. Hence, compared with that of the pre-test in section 3.4.9, the app interface has been enhanced.

4.4.10 Tenth Question

The tenth statement in the questionnaire is, 'My overall impression of the application prototype is very positive'. The response data to this statement is shown in Figure 4.22 below and elaborated in the subsequent paragraph.

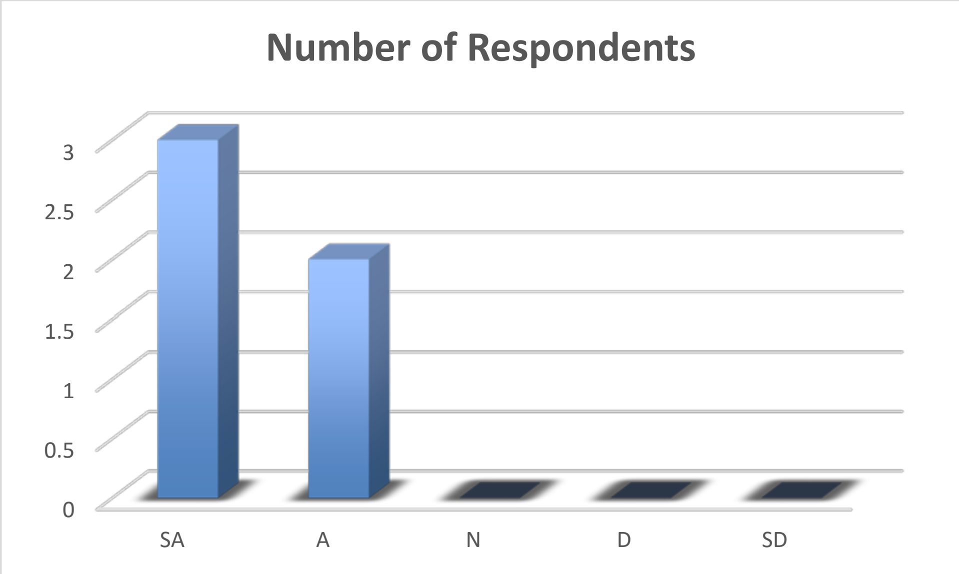


Figure 4.22: Response to the tenth question of the post-test

According to the data in Figure 4.22, all the respondents were satisfied with the generality of the appllication's usability. About 60% and 40% of the respondents strongly agreed and agreed respectively that the overall impression and the usability of the application prototype is very positive. This positive assessment is a significant improvement over the pre-test carried out in section 3.4.10, where 80% of respondents were indecisive.

The summary of the responses in the post-test is shown in Table 4.5 below. The table reveals the outcome of the post-test.

Table 4.10: Summary of responses from the post-test

	Q1 (%)	Q2 (%)	Q3 (%)	Q4 (%)	Q5 (%)	Q6 (%)	Q7 (%)	Q8 (%)	Q9 (%)	Q10 (%)	AVG (%)
Strongly Agree (SA)	20	100	20	100	0	80	0	40	0	60	42
Agree (A)	80	0	80	0	60	20	100	60	100	40	54
Neutral (N)	0	0	0	0	40	0	0	0	0	0	4
Disagree (D)	0	0	0	0	0	0	0	0	0	0	0
Strongly Disagree (SD)	0	0	0	0	0	0	0	0	0	0	0

From Table 4.5, the average of the 'strongly agree' responses is 42%, while the average of the 'agree' responses is 54%. Also from the table, the average of the 'neutral' responses is 4%, while the 'disagree' and the 'strongly disagree' responses are 0%. This data is pictorially represented in Figure 4.23 below.

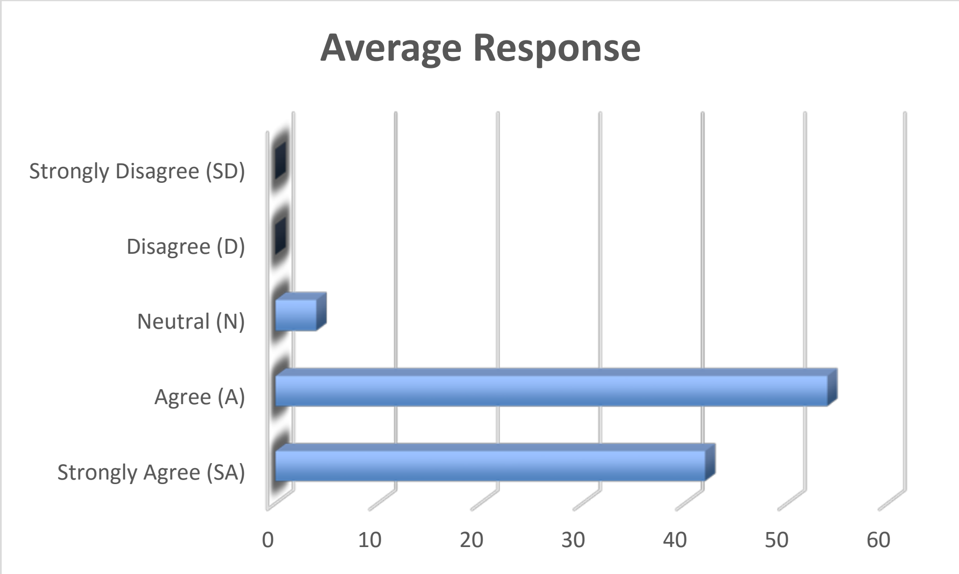


Figure 4.23: Representation of summary of responses from the post-test

From Figure 4.23 above, the percentage of the respondents who chose the 'strongly agree' and the 'agree' responses are 42% and 54% respectively, while the percentage of the 'neutral' responses is 4%. This 4% response is because of irregular presentation of alerts, as well as the application's inability to navigate in real-time. Thus, alerts do not show up frequently. The respondents assumed it is a flaw. Furthermore, the sum of the percentages of the 'strongly agree' and the 'agree' responses is 96%. This shows a substantial improvement over the pre-test.

The pre-test had a 44% success rate. The application was optimised, refined and improved. On the other hand, the post-test had a success rate of 96%, which is an increase of 118%. The post-test clearly shows an impressive improvement from the pre-test to the post-test. Table 4.6 and Figure 4.24 below illustrates this.

Table 4.24: Evaluation of pre-test and post-test

	Pre-test Average (%)	Post-test Average (%)	Difference in Iterations (%)
Strongly Agree (SA)	2	42	40
Agree (A)	42	54	12
Neutral (N)	42	4	-38
Disagree (D)	10	0	-10
Strongly Disagree (SD)	4	0	-4

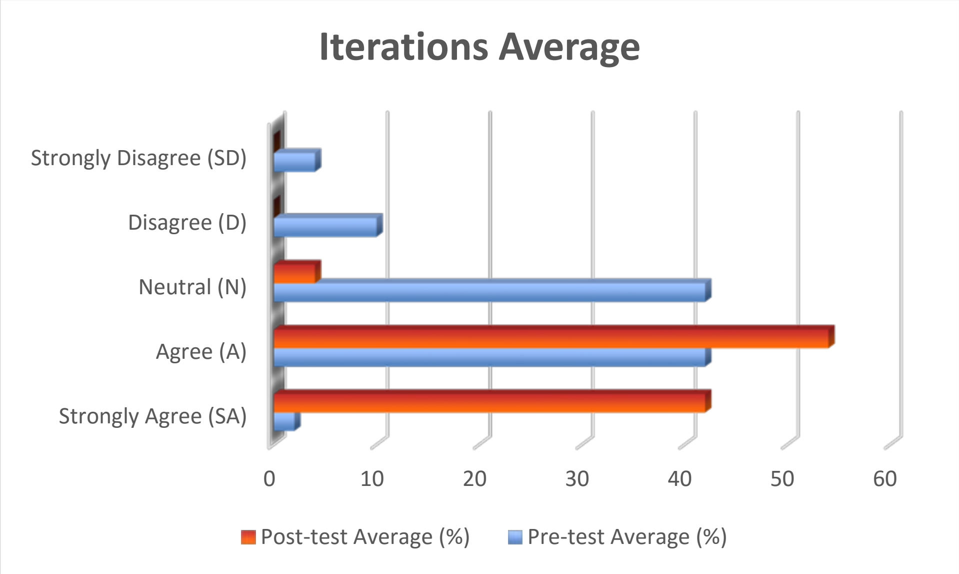


Figure 4.25: Representation of the evaluation of first and second iterations

From Figure 4.24, the comparison between the pre-test and the post-test is visualised. When the 'strongly agree' data and the 'agree' data for post-test is higher than the pre-test data, the application is considered to be effective, efficient and usable. The 'neutral', 'disagree' and the 'strongly disagree' data for the post-test are either nil or lesser than the pre-test data. For the 'strongly agree' data, post-test leads by a convincingly wide margin. For the 'agree' data, post-test also leads. However, for the 'neutral' data, the margin has reduced drastically after the post-test result. Moreover, the 'neutral' data of the post-test has no significant effect on the app, which is caused by the app's inability to navigate real-time. This is the app's major limitation.

4.5 Chapter Conclusion

This chapter presented the experiment and the implementation of the navigation service. The various applications and components used were clearly outlined in the preliminary experiment carried out, while taking note of the benefit of the process. In addition, the various manipulations implemented in the experiment were set out. Furthermore, a final test of the navigation application, known as the post-test, was carried out and the result was presented. Overall, the implementation of the navigation application at the preliminary experimental stage up to the final test stage constitutes the central direction of this chapter.

The chapter began with the preliminary experiment of this study in order to establish the direction of the implementation when it comes to the main experiment. An experiment was conducted with an RFID reader, RFID tags and Arduino, in order to determine the range, accuracy and performance of the devices and the navigation system. Similarly, a setup of NFC Shield, NFC tags and Arduino was also used to determine the range, the accuracy and the performance of the devices and the navigation system. Consequently, the NFC setup was implemented in the navigation service and the outcome was observed. Based on the result or outcome observed, the experimental stimulus, which involves manipulating the code of the navigation application, was applied to the main experiment to improve the navigation service. Hence, participants did the final post-test and the implication on accuracy, functionality and usability were observed. The discussion and the evaluation of these metrics, along with other performance metrics, are presented in the following chapter, chapter five.

CHAPTER FIVE: EVALUATION AND DISCUSSION

5.1 Introduction

The objective of this study was to explore innovative ways of improving the transmission of mobile wireless signals in indoor and closed spaces, in order to contribute towards a more effective and productive use of mobile navigation applications. To aid this investigation, tests and experiments were conducted to probe the research questions for this study. The test began with the pre-test, which sought to investigate a control and an experiment apparatus for design inconsistencies. There were limitations discovered after the test and this necessitated the need for further experiment in order to address these limitations. The experiment, in which a stimulus was introduced, as well as the post-test, which investigated the control and experiment apparatus, was presented. These tests and experiment validate the objective of this study. Having presented the pre-test in chapter three, the experiments, post-test and the findings were presented in chapter four. Consequently, this chapter evaluates and discusses the said findings.

This chapter discusses and links the final formal test results of the implementation to the insights gained from existing literature and the benefit of providing a simple and user-friendly interface. Section 5.2 contextualises the findings by evaluating and comparing the findings with the existing knowledge. This is followed by a review of the research sub-questions in section 5.3. Finally, the chapter ends with a summary and conclusion in section 5.4.

5.2 Contextualising the Findings

With an array of the available positioning and navigation technologies, a user has the ability to choose any for a particular purpose, and be able to put up with inhibitions that may exist in such technologies at the same time. It is worth noting that no single technology can solve all the problems inherent in a positioning and navigation system. For this reason, various technologies address specific limitations in a system. Although some systems perform better than others do, there are still limitations in the various existing technologies. This has necessitated the need to carry out further research into this field, including the study in this thesis.

The research problem in this study was that current technologies and methods of indoor positioning and navigation are complex, costly, inaccurate and difficult to implement in challenged spaces of less developed countries, despite the unique benefits. This therefore limits the usability of these technologies. As a result, the main research question for this study is, "***How should the use of NFC improve support and effectiveness of an indoor navigation system in less developed countries, with***

regard to cost, accuracy and usability?" Of note in the main research question is the absence of complexity as a metric in evaluating the navigation system. This is because, as discussed in section 1.11.6, the complexity of a system is directly related to the cost. In other words, when the complexity of a system increases, the cost also increases. Hence, cost as used in the research question indirectly refers to complexity as well. In Table 5.1 below, the evaluation metrics identified and used include complexity, cost, accuracy, privacy, real-time and usability. However, accuracy, privacy and real-time are metrics that determine the usability of a system. Hence, only usability was introduced in the research question as its evaluation encompasses accuracy, privacy and real-time.

Furthermore, the pre-test was carried out with some questionnaires that were answered by five respondents. The navigation application that was tested involved a combination and improvement of two applications, taglocate (Bolz, 2011) and smartcampus (Hansen *et al.*, 2013). However, inconsistencies were observed at the end of the pre-test by the respondents, which suggest that an improvement was necessary. Thereafter, an experiment was conducted on the application by introducing what was referred to as an experimental stimulus. This experimental stimulus is simply the manipulation or the tweaking of the navigation application's code. The manipulation resulted in an improvement in the navigation application and the researcher tested it as a confirmation. However, a formal testing was needed to validate this improvement. This testing was done at the post-test stage, which was carried out with the improved navigation application using the same respondents of the pre-test. The outcome of the post-test clearly suggests that the application has improved.

Having conducted the pre-test, experiment and the post-test, the outcome showed an improvement in the post-test compared to the pre-test. This outcome is compared with the result of some existing positioning systems such as taglocate (Bolz, 2011), NFC Internal (Ozdenizci *et al.*, 2011), IMG (Hammadi *et al.*, 2012) and SmartCampus (Hansen *et al.*, 2013). The comparison is based on evaluation metrics such as complexity, cost, accuracy, privacy, real-time and ultimately usability. Taglocate and IMG are QR code and NFC-based positioning frameworks that use QR code and NFC architecture and tools. Similarly, NFC Internal is an NFC-based positioning and navigation system. On the other hand, SmartCampus is a WLAN-based positioning system. Table 5.1 below gives a summary and comparison of findings with the existing indoor positioning technologies.

Table 5.11: Evaluation and comparison of findings with existing technologies

		Evaluation Metrics					
Technology	**Author(s)**	**Complexity**	**Cost**	**Accuracy**	**Privacy**	**Real-Time**	**Usability**
Taglocate	Bolz (2011)	With the inclusion of QR code in the system and multiple information on the application screen, the complexity rises.	Since the system is NFC-based and uses free open-source software and hardware, the cost is low.	Accuracy is high, as a mobile device is tapped to a fixed NFC tag.	Privacy is preserved, as data is stored on the mobile device.	Not real-time	Usability is medium, as the use of two technologies is embedded in the application.
NFC Internal	Ozdeniizci *et al.* (2011)	Complexity is low, as it does not involve installing devices and equipment, only NFC tags.	Cost is low, as it does not involve installing devices and equipment, only NFC tags.	Accuracy is high, as a mobile device is tapped to a fixed NFC tag.	Privacy is preserved, as data is stored on the mobile device.	Not real-time	Usability is medium, as the system is more solution-based than user-based.
IMG	Hammadi *et al.* (2012)	Based on NFC and QR code, with the inclusion of multiple services, the system complexity rises.	Since the system uses free open-source software and hardware in addition, the system cost is generally low.	Accuracy is high, as a mobile device is tapped to a fixed NFC tag.	Privacy is not guaranteed, as personal and position information is stored in a server.	Not real-time	Usability is medium, as multiple uses and technologies are embedded in the application.
Smart-Campus	Hansen *et al.* (2013)	Based on WLAN, with the installation of high computational usage systems, complexity is high.	Cost is medium.	Accuracy is generally low, but medium at room level.	Privacy varies depending on whether data is stored on mobile device or server.	Supports real-time and non-real-time	Usability is high.
NFCPUT InPoint (Subject of Investigation)		Complexity is low, as it does not involve installing devices and equipment, only NFC tags.	Cost is low, as configuration and maintenance is minimal.	Accuracy is high, as a mobile device is tapped to a fixed NFC tag.	Privacy is preserved, as data is stored on the mobile device.	Not real-time	Usability is high, based on users' feedback.

From Table 5.1 above, it is observed that NFCPUT InPoint performs better than the other NFC-based technologies. Similarly, the comparison with WLAN-based positioning systems and the RF systems in general, show that NFCPUT InPoint also performs better except with real-time navigation. This is because there is no regular update of user position with the NFC technology. In addition, since NFC is the technology used, it is inherently simple and secured. Since position determination is done in the mobile device and not in the server, privacy is guaranteed. Furthermore, with respect to cost, open-source software and hardware generally reduce implementation cost. Therefore, the usability of the navigation application has improved based on users' feedback. These findings are now explained with respect to the research questions under investigation in the following section.

5.3 Review of the Research Sub-Questions

Having examined the main research question in the preceding section, the research sub-questions derived, which this study is based on, are discussed in this section. They are:

1. Why are the existing positioning and navigation technologies still experiencing challenges?
2. How can the NFC technology influence cost in an indoor navigation system?
3. How should the NFC technology improve accuracy in an indoor navigation system?
4. How should the NFC technology improve usability in an indoor navigation system?

5.3.1 Research Sub-Question 1

Why are the existing positioning and navigation technologies still experiencing challenges?

This sub-question was answered through a systematic literature review. Hypothetically, the existing positioning and navigation technologies are still experiencing challenges. Such challenges include poor performance in terms of accuracy, high cost, poor ease-of-use, poor functionality, poor user privacy, poor context-awareness in terms of building solutions that are not 'jack of all trades', and poor usability. Studies and researches have shown that these challenges depend on a number of factors such as complexity, cost, accuracy, scalability, privacy, functionality and usability. The challenges were discussed within the context of these factors. Cost, as well as usability, is a factor that is of particular interest in less developed countries. Scalability is a factor that also influences the cost. The other factors are technically dependent and not limited to any geographical location.

Although, various techniques and technologies have been used to explore and implement indoor positioning and navigation, inhibitions and limitations persist. This is because no single technology is a universal solution to the positioning and navigation challenges. However, some technologies perform better than others do, due to the mode of transmission and the environment in which they perform. Technologies that have been used in the implementation of indoor navigation systems are complex and expensive to implement. As technology matures, however, there is the likelihood of a simple and low-cost implementation. A detailed review of positioning technologies has been given in sections 2.2 and 2.3 in chapter two.

5.3.2 Research Sub-Question 2

How can the NFC technology influence cost in an indoor navigation system?

Generally, the development of the indoor positioning and navigation system is complex. This therefore results in high cost. Some systems that are scaled for commercial use or wide coverage may also result in high cost. In effect, free open-source software and hardware were used in the design and the implementation phase of this study in order to reduce the cost of development. The creation of the indoor map, in section 3.3.2 of chapter three, was demonstrated with available open-source tools. However, in order to achieve a close zoom in mobile phones, the map could either be hosted with a commercial company, or be used in a server with high quality CPU and RAM. This may only be necessary when the application is to be commercialised or made public. The preliminary experiments carried out in section 4.2 of chapter four established ways in which the use of NFC technology and open-source systems reduce complexity and cost.

Indoor positioning was demonstrated by using open-source software and hardware freely. Therefore, a simple navigation application with a clear interface was developed, in section 4.3, with open-source applications using the iterative and prototyping software development methods. Using the iterative and prototyping models will help to reduce cost and the amount of time spent on developing a software. Reducing complexity, and ultimately cost, is the goal of this sub-question. In addition, NFC, as a technology, is inherently simple and easy to implement when compared with other positioning technologies. Therefore, NFC technology can reduce the cost of an indoor navigation system.

5.3.3 Research Sub-Question 3

How should the NFC technology improve accuracy in an indoor navigation system?

The accuracy of the positioning technologies discussed in section 2.3 of chapter two are not all remarkable. As a result, most of the positioning and navigation researches focused on improving accuracy indoors. This is because an improved accuracy is an improved performance. The determination of accuracy in an outdoor scenario is different from that of indoors. While a distance of 10 metres may be acceptable outdoors, in indoor environments accuracy in the range of centimetres is preferred. This is because of the closeness of doors and the positions of interest indoors.

Furthermore, the accuracy of the optical, Bluetooth, WLAN and RFID technologies is low; while the accuracy of infrared, audible sound, active bat, cricket, dolphin and sensor network technologies is medium. Based on the test carried out in sections 4.3 and 4.4, the NFC technology improved the accuracy of the positioning system in this study. Few positioning systems have achieved this level of accuracy. They include the magnetic and UWB technologies, which have high accuracy. However, their complexities are higher than that of NFC. There has to be an increase in the complexity of the system for the accuracy of the magnetic and the UWB technologies to be precise, thus resulting in an increase in cost. This increase in complexity was avoided in this study. However, the NFC's inherent simplicity and accuracy means that the application will not increase cost. The use of proximity algorithm ensures the accuracy of the positioning is high, and that it is within the range of 10 cm and below. Hence, hypothetically, the NFC technology can improve the accuracy and the performance of an indoor navigation system.

5.3.4 Research Sub-Question 4

How should the NFC technology improve usability in an indoor navigation system?

The usability of a system takes into consideration the performance of metrics such as complexity, cost, accuracy, privacy and scalability. In other words, the usability of a system depends on the performance of these metrics. Although the usability test is carried out because of the user, the test or experiment is focused on the application and not the user. Usability testing is an empirical method that requires the design of a formal experiment that is carried out with controlled apparatus. Section 1.11.8 of chapter one discussed the usability and the functionality of a system, with the trade-off that may exist in the development of systems generally. In section 4.3 of chapter four, a prototype of the NFC navigation system was developed. The functionality of the application was simplified as much as possible. This is because an increase in the functionality of a system could result in an increase in complexity. The developed application was evaluated for usability with the feedbacks from users. This can be found in section 3.4 of chapter three and section 4.4 of chapter four. The usability test is meant to determine design inconsistencies and usability problem areas within the user interface and content areas. Figure 5.1 below shows a flow diagram of the usability test.

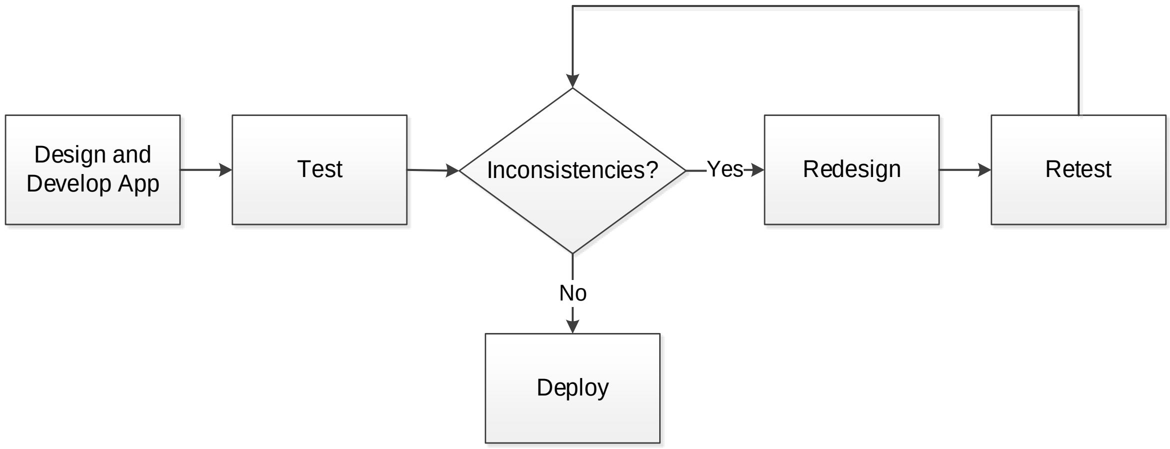


Figure 5.1: The usability test flow diagram

After undergoing two iterations (pre-test and post-test), the usability improved from 44% to 96% based on the feedback received on the subject of investigation, which is the navigation application. Based on this feedback, the functionality of the application was considered usable. Hence, the usability and the functionality of the application was balanced. Therefore, hypothetically, the NFC technology can improve the usability of an indoor navigation system.

5.4 Chapter Conclusion

This chapter discussed the findings of the tests and experiments performed, and their implication on the indoor navigation application, especially in relation to the existing literature and knowledge. The findings were related to the research problem and the main research question. A review of the research sub-questions and their connection with the findings and existing literature was presented.

The findings from the pre-test, experiment and the post-test show that the NFC technology can improve usability support for indoor positioning and navigation in less developed countries. The findings were evaluated by comparing them with the existing NFC-based technologies and solutions. It was discovered that the improvement achieved in this study outweighed that of the existing technologies. The findings were placed in relation to the research sub-questions in order to identify areas where the research questions were answered by the findings. The areas that were addressed with the research sub-questions addressed include cost, accuracy and usability. The conclusion and the recommendation for future work are presented in the following chapter, chapter six.

CHAPTER SIX: CONCLUSION AND FUTURE WORK

6.1 Introduction

The aim of this study was to investigate and evaluate the usability and the full potential of the NFC technology as an enabler of indoor positioning and navigation in challenged spaces of less developed countries. In effect, this thesis undertook a fundamental study in order to develop and test an indoor navigation system using NFC for performance and usability. The NFC navigation system demonstrates that mobile devices embedded with NFC can be used to navigate indoors by tapping NFC tags. The tests and experiment carried out showed that the NFC positioning and navigation system is usable in indoor terrains of less developed countries. Hence, further work may be required to expand and commercialise the use of the NFC technology for indoor navigation.

In this final chapter, section 6.2 summarises each chapter by stating the goals and the outcomes discussed in each chapters. This is followed by the unique and specific contributions made to this research in section 6.3. The areas for future work, that could provide the next steps along the path to a pervasive and ubiquitous system in this research area, concluded this chapter and thesis in section 6.4.

6.2 Summary of Chapters

The proliferation of mobile devices has increased its mobility such that users spend more time working with such devices. Hence, it can be used in a number of ways including its ability to be used as a navigation device in outdoor and indoor terrains. Navigation in outdoor environment is an established activity with the use of the GPS. However, there is still room to carry out more research on optimal, simple and cost-effective means for indoor positioning and navigation. While indoor navigation applications have a great deal of potential to aid users’ interaction and orientation with mobile devices, a user-friendly solution is critical to their success. This can be achieved when the positioning techniques and technologies are taken into consideration. NFC was pointed out as ideally contributing to the development of pervasive and ubiquitous systems. The NFC positioning system has the potential to take care of all the limitations that exist in other positioning technologies except real-time navigation. NFC has the advantage and benefits of cost, accuracy and precision, simplicity and performance, scalability, privacy and usability.

All these constitute the background to the research problem that was presented in chapter one, highlighting limitations and challenges that exist in current technologies of indoor positioning and navigation. This led to the research problem statement, which highlighted the problem, its impact, the hypothesis and the gap that the research intends to investigate. The hypothesis for this study is that indoor navigation systems can be implemented without complexities or high cost and still be able to work effectively as the existing systems. Thereafter, the aim of the research, as well as the objectives, questions, approach and the conceptual model – on which the research is based – were presented. The research approach used in this research is the quantitative and the experiment method of empirical enquiry, as well as software engineering and synthesis research methods. Furthermore, the important terms and concepts prevalent in this thesis were clarified and explained, leading to the elaboration of the layout of this thesis. This introduction in chapter one laid a good foundation for the existing literature to be reviewed.

Chapter two covered a detailed review of the existing literature, providing a comprehensive overview of state-of-the-art positioning techniques and technologies used in indoor positioning and navigation systems. The drastic influence of GPS over orientation and wayfinding in outdoor environment is overwhelming. However, the same cannot be said of navigating in indoor environment. Neither GPS nor current indoor positioning technologies had worked well indoors. Each positioning and navigation technologies provide different benefits to users in their unique and dynamic scenario. This unique benefit is dependent on the positioning technique(s) used. The positioning techniques reviewed from literature were classified into signal metrics and properties, as well as positioning algorithms. The signal metrics are AOA, TOA, TDOA and RSSI, while the positioning algorithms are triangulation, trilateration, proximity and scene analysis/fingerprinting. One or more of these techniques are applied in the positioning technologies so that their benefits will be appreciated in whatever scenario they are used. Furthermore, the positioning technologies were discussed based on six different classifications namely: IR, Ultrasound/Ultrasonic, Audible sound, Magnetic, Optical/Vision-based and RF. These positioning technologies were discussed based on the main medium and techniques used to determine position. The RF-based positioning system was further classified into Bluetooth, UWB, WSN, WLAN and RFID.

The different technologies were compared, and their strengths and limitations discussed based on the positioning technique, infrastructure complexity, system cost, accuracy and precision, simplicity and performance, scalability, privacy and security, and usability. While some of these technologies suffer from line-of-sight or multipath effect, others suffer from inaccurate positioning. Indoor navigation systems have not been widely adopted mainly due to issues pertaining to these factors. The limitations that these positioning technologies face in their usage scenarios tend to affect the functionality and performance of the positioning system. Thus, certain trade-offs exist. For instance, a system that will have a very good accuracy in real-time will tend to increase in complexity and/or in cost in order to achieve this. Therefore, a trade-off between accuracy and complexity or cost exists.

Chapter three discussed the research approach and the methodology employed in this study, highlighting the ontology and epistemology it fits into. Since the nature of the problem under investigation pertained to technical innovations, the experiment method, which is a positivist paradigm, was used to achieve the objectives of this study by testing the control and the experiment apparatus. The experiment design was classified into pre-test, experiment and post-test for ease of data collection and analysis, and are used to test both the control and the experiment apparatus. Furthermore, to be able to carry out experiments, an understanding of the applications, components and service employed in the indoor positioning and navigation system implementation was necessary, and this was presented in this chapter. These applications and components are free open-source software and hardware. Such systems are cost-effective, easy to install and maintain, and provide a great sense of security. For ease of understanding, the components were divided into three parts, namely map generation, positioning component and navigation component.

With various tools available for the creation of maps for indoor usage, MapWarper and JOSM editor were considered appropriate for creating the map in this research. This was achieved by using OpenStreetMap, which is an open-source collaborative map platform. In order to create a good map that would be usable in mobile devices, the floor plan of the test-bed building was rectified using MapWarper. The rectified image was used to map indoor spaces in JOSM editor using nodes and links. The created map was used in the positioning and navigation application. In addition, the navigation path that was used in the navigation service was prepared using JOSM editor. Furthermore, the positioning components that were discussed include Arduino, Parallax RFID reader, NFC Shield and RFID/NFC tags, while the navigation components include PandaBoard, SerialPort-Server, Android SDK, Eclipse IDE and Samsung Galaxy SIII Smartphone. These components were used to develop the control apparatus, which was tested at the pre-test stage. The participants of the test completed a questionnaire to convey their observations on the application. Their thoughts helped to improve the responsiveness and the usability of the application at the experiment stage.

Chapter four presented the implementation of technologies, applications and navigation service, by building on what was done in chapter three. Preliminary experiments were performed to demonstrate the indoor position of a user with Arduino, RFID and NFC readers, and RFID/NFC tags. The experiment was demonstrated with an HTML code in a web application using three NFC tags and the PandaBoard running the Linux OS. The outcome showed that an NFC reader in close proximity to an NFC tag is easy to use within a navigation system. Based on this preliminary experiment and the pre-test, the main experiment was carried out with the experimental stimulus to improve the navigation service. Each question that the respondents answered at the pre-test were analysed and the result was applied to the main experiment. At this point, the prototype navigation application, which was tested at the post-test stage, was developed and extended. The prototype navigation application used the navigation path that was created with JOSM. When a mobile device (mobile phone and PandaBoard) was used to test the application, the outcome confirms a good user interaction during navigation. In addition, the post-test was carried out using the same respondents used for the pre-test. The respondents filled a questionnaire to convey their observations of the application.

Chapter five contextualised and discussed the findings of the experiment and the post-test in terms of complexity, cost, accuracy, privacy, real-time and usability. It also discussed the challenges encountered during the study. The tested navigation application was evaluated and compared with existing applications in order to observe the refinements and the extensions made. The outcome of the evaluation supports the hypotheses of the research questions on which the study is based. The research sub-questions of this study were reviewed. The challenges faced by the navigation system were identified and the areas that were addressed by the findings were provided. Of noteworthy is the usability test, which helped to observe the problems and the inconsistencies with the application when used by the participants. From these tests, it was observed that usability and performance pose concerns that need to be addressed extensively in future work. The evaluation of the various tests further showed that it is possible to navigate effectively in indoor challenged spaces using an NFC-based system. However, the inability to extend support for user testing in a real world scenario was a challenge.

6.3 Specific Contribution

The goal of this thesis was to investigate the feasibility of NFC technology as an innovative, convenient and cost-effective means for improving navigation in indoor challenged spaces. This entailed the design and the development of a prototype indoor navigation application. The design, implementation and evaluation of the NFC system are based on infrastructure complexity, cost, accuracy, privacy, scalability and usability, which are important considerations for a smart environment. Hence, the following contributions are made:

1. Two research articles have already been published from this study, thereby adding to the existing body of knowledge.
2. The development of a symbolic map and path architecture of a floor in the test-bed building that helped to demonstrate users' indoor position and navigation activity. The map was uploaded to OpenStreetMap.
3. The implementation of the RFID and the NFC architectures to demonstrate the use of NFC for positioning in indoor environments produced new insight on how to redress the limitations in challenged spaces.
4. The development of a prototype mobile indoor navigation application, which was implemented on the Android platform, offered new solution to the practical problems inhibiting navigation in indoor challenged spaces – a practical contribution to the community of practice. The application validated the NFC positioning architecture.
5. In Ozdenizci *et al.* (2011: 12-13) and Hammadi *et al.* (2012:340-341), emphasis was placed on searching for a person's name in the position and navigation process. Using a person's name as a search parameter is not efficient because it raises privacy concerns. In this research, point-of-interest as a search parameter was used.
6. In Ozdenizci *et al.* (2011: 12), it was stated that, "The user needs to simply touch to the URL Tag (NFC tag), that contains the URL of indoor map information just before entering the building or area." In a situation where a user forgets to tap the NFC tag at the entrance, or did not notice the tag at the entrance, navigation with the system becomes almost impractical. In this research, it was ensured that every tag had the map information. A user who did not tap the tag at the entrance but taps it within the building will still be able to have access to the map information. Once this is done, tapping other tags will only reveal the user's position and not download the map again.

6.4 Future Work

In recent years, a significant body of knowledge dealing with the complexities and challenges of indoor positioning and navigation has emerged. These works focused on a number of issues related to complexity, cost, accuracy and usability in navigating indoors. Various design complexities, hardware and software level analyses, tests and evaluation have been undertaken to achieve the research objectives. This research has provided a groundwork for the future study of more efficient development of indoor positioning and navigation systems. Hence, this section describes the future research possibilities that will extend and improve the results of this research.

6.4.1 Academic Research Direction

The current application implementation can be improved by implementing the use of text and voice integration in the navigation system. This will aid better performance and usability, which will motivate the elderly, visually impaired and physically challenged persons to adopt the application. The text integration will serve as an option to the path integration that was implemented in this research. The implementation of the voice integration will be useful to the visually impaired. The voice integration is considered for an extension of the study in this thesis.

Another area of consideration for future research is the use of Inertial Measurement Unit (IMU) in a mobile device with NFC. The IMU – which consists of accelerometer, gyroscope and compass, and used in Inertial Navigation Systems (INS) – could aid real-time NFC navigation. This idea would definitely merit further investigation.

Furthermore, this study used a floor of a building as the test-bed. An area of investigation will be on the ability of the application to support navigation across multiple floors via staircase, escalators and lifts. Although there might be some complexities encountered while creating the map and developing the application, it will nonetheless ease navigation across floors in multiple-floor buildings.

6.4.2 Industry Research Direction

From all the positioning technologies discussed, both map data and position data are stored in a server. Although, the Cricket and Optical-based technologies have been extended in other research works to eliminate storage of position data, the base implementation of the technology store users' position data. On the other hand, NFC technology stores only map data in the server (in this case, OSM). It is not impossible that the NFC technology would grow to a point where map data could be stored directly on the NFC tags, thus bypassing the database of map data and server. However, due to the size of the NFC tags at present, the map data cannot be stored in the tags. Eliminating the server and compressing the map significantly into the NFC tag is a consideration for future work. This will aid user privacy. In any case, researching other means of bypassing the server of map data is a noteworthy consideration.

Furthermore, in order to manage the limitations presented in this research, it is necessary to have a thorough understanding of positioning technologies and their strengths and limitations from a localisation and navigation point of view. Then, it will become necessary to implement and improve these technologies. This will result in simplicity, functionality, usability and be of great value to users. Due to the ongoing research work on NFC, it will become very popular in the nearest future because of its simplicity, low cost and ubiquity. As a result, NFC can be used in a hybrid make-up with WLAN, RFID or Bluetooth as a cost-effective solution for real-time indoor positioning because of their coverage and existing infrastructures. The hybrid positioning model, which merges two or more techniques or technologies, is becoming more popular and will improve its accuracy, robustness and usability. In addition, it will balance complexity, compensate for the limitations in the technologies and achieve real-time mobile indoor navigation since NFC cannot work real-time. Although the presence of WLAN, RFID and Bluetooth technologies are likely to result in system complexity and high cost, NFC will reduce the system's complexity and thus balance the trade-off.

Communication equals remembering what it’s like not to know.

- ***Richard Saul Wurman***

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APPENDICES

Appendix A: Navigation Code

```
package test.NFCPUT.ac;

import android.app.Activity;
import android.location.Location;
import android.os.Bundle;
import android.webkit.WebView;

public class WebMap extends Activity {
  private static final String TILES_URL =
"http://www.openstreetmap.org/relation/1914177#map=19/-33.93119/18.42914";
  private WebView webView;

   public void onCreate(Bundle savedInstanceState) {
      super.onCreate(savedInstanceState);
      setContentView(R.layout.web_map);
      webView = (WebView)findViewById(R.id.web_map);

      setupWebView();
   }

  private void setupWebView() {
          webView.getSettings().setJavaScriptEnabled(true);
          //If you want to be able to call Android methods on this class add the following
line
          //webView.addJavascriptInterface(this, "AndroidInterface");

          webView.loadUrl(TILES_URL);
   }

  private void updateNewLocation(Location location) {
          if (location != null) {
                  //Create json location and send it to javascript
                  StringBuilder jsonLoc = new StringBuilder();
                  jsonLoc.append("{");
                  jsonLoc.append("hasAltitude:
").append(location.hasAltitude()).append(", ");
                  jsonLoc.append("hasAccuracy:
").append(location.hasAccuracy()).append(", ");
                  jsonLoc.append("hasBearing:
").append(location.hasBearing()).append(", ");
                  jsonLoc.append("hasSpeed:
").append(location.hasSpeed()).append(", ");
```

```
			jsonLoc.append("accuracy: 
").append(location.getAccuracy()).append(", ");
			jsonLoc.append("bearing: ").append(location.getBearing()).append(", 
");
			jsonLoc.append("speed: ").append(location.getSpeed()).append(", ");
			jsonLoc.append("latitude: ").append(location.getLatitude()).append(", 
");
			jsonLoc.append("longitude: 
").append(location.getLongitude()).append(", ");
			jsonLoc.append("altitude: ").append(location.getAltitude()).append(", 
");
			jsonLoc.append("time: ").append(location.getTime());
			jsonLoc.append("}");

			webView.loadUrl("javascript:updateNewLocation(" + jsonLoc.toString() 
+ ")");
		}
  }

  private void centerAt(double lat, double lon) {
		webView.loadUrl("javascript:centerAt(" + lat + ", " + lon + ")");
  }

  private void changeFloor(int floor) {
		webView.loadUrl("javascript:changeFloor( { level: " + floor + " })");
  }

  private void testUpdateNewLocationAndCenterAt() {
     Location l = new Location("Dummy Location");
     l.setLatitude(-33.93119);
     l.setLongitude(18.42914);
     l.setAltitude(0);
     updateNewLocation(l);
     centerAt(l.getLatitude(), l.getLongitude());
  }
}
```

Appendix B: Localisation Code

```
package test.android.NFCPUT.protocol;
import java.io.IOException;
import java.util.List;
import android.content.Context;
import android.content.Intent;
import android.nfc.FormatException;
import android.nfc.NfcAdapter;
import android.nfc.Tag;
import android.view.Gravity;
import android.widget.Toast;
import de.berlin.magun.nfcmime.core.NdefMimeRecord;
import de.berlin.magun.nfcmime.core.RfidDAO;
import de.berlin.magun.nfcmime.core.ZipFileSystem;
import android.NFCPUT.R;

public class NfcIntentResolver {
    private RfidDAO dao;
    private String id;
    private String scheme;
    private String geoUriStr;
    private String iiiUriStr;
    private ZipFileSystem zfs;
    private Context context;

    protected NfcIntentResolver(Context context, Intent intent) {
        this.context = context;
        parseNfcIntent(intent);
    }

    private void parseNfcIntent(Intent intent) {
        if(intent.getAction().equals(NfcAdapter.ACTION_NDEF_DISCOVERED) ||
           intent.getAction().equals(NfcAdapter.ACTION_TECH_DISCOVERED)) {
          Tag tag = (Tag) intent.getParcelableExtra(NfcAdapter.EXTRA_TAG);
          dao = new RfidDAO();
          id = dao.getTagId(tag);

          if (SettingsSingleton.getInstance().isDownloadFromNfc()) {
             getFilesFromNfc(tag);
          }

          if (intent.getAction().equals(NfcAdapter.ACTION_NDEF_DISCOVERED)) {
             scheme = intent.getScheme();
             if (scheme != null) {

                if (scheme.equals("geo")) {
                   geoUriStr = intent.getDataString();
                }
                if (scheme.equals("iii")) {
                   iiiUriStr = intent.getDataString();
                }
             }
        }
```

```
    }
}
private void getFilesFromNfc(Tag tag) {
   List<NdefMimeRecord> recordList = dao.getCachedMimeRecords(tag);
if (recordList != null) {
   for (int i = 0; i < recordList.size(); i++) {
       if ("application/zip".equalsIgnoreCase(recordList.get(i).getMimeString())) {
           try {
              zfs = new ZipFileSystem(recordList.get(i));
              List<String> filenames = zfs.getFileNames();
              for (int j = 0; j < filenames.size(); j++) {
                  String fname = filenames.get(j);

                  if (fname.endsWith(".iir") || fname.endsWith(".osm")) {
                      zfs.write(SettingsSingleton.getInstance().getDatapath());
                  }

                  if (fname.endsWith("iir")) {
                     SettingsSingleton.getInstance().setDatafile(fname);
                     Toast t = Toast.makeText(context,
             context.getString(R.string.reffile_found), Toast.LENGTH_SHORT);
                     t.setGravity(Gravity.TOP, 0, 0);
                     t.show();
                  }

                  if (fname.endsWith("osm")) {
                     SettingsSingleton.getInstance().setGeometryfile(fname);
                     Toast t = Toast.makeText(context,
             context.getString(R.string.geomfile_found), Toast.LENGTH_SHORT);
                     t.setGravity(Gravity.TOP, 0, 0);
                     t.show();
                  }
              }
           } catch (IOException e) {
             e.printStackTrace();
           } catch (FormatException e) {
             e.printStackTrace();
           }
         }
       }
    }
  }
  public String getId() {
      return id;
  }
  public String getScheme() {
      return scheme;
  }
  public String getGeoUriStr() {
      return geoUriStr;
  }
  public String getIiiUriStr() {
      return iiiUriStr;
  }
}
```

Appendix C: Questionnaire for Usability Test

Thank you for taking the time to fill out this questionnaire. Your input is an enormous help to creating a mobile application that will be widely usable. All information provided in this survey is confidential and will be used for research purposes only. Your participation is completely voluntary. If at any time you feel uncomfortable with your participation, you are at liberty to opt out. If you have any further questions, input or ideas, do not hesitate to state it at the end of the questionnaire.

		Strongly Disagree	**Disagree**	**Neutral**	**Agree**	**Strongly Agree**
1	The app had a clear, clean and explicit interface.					
2	The app minimized the number of steps it took to complete tasks.					
3	Information presented on screen was easy to comprehend.					
4	Information needed for a specific task was grouped together on a single screen.					
5	Alerts were only presented at appropriate times.					
6	I found the application prototype to be easy to use.					
7	The menu items were well organized and functions were easy to find.					
8	The buttons were well organized and easy to find.					
9	Navigating around the application screen was very easy.					
10	My overall impression of the application prototype is very positive.					

General Comments/Recommendations

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