ASSET TRACKING, MONITORING AND RECOVERY SYSTEM BASED ON HYBRID RADIO FREQUENCY IDENTIFICATION AND GLOBAL POSITIONING SYSTEM TECHNOLOGIES

by

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DECLARATION

I, Itumeleng Olebogeng Matshego, hereby declare that the work which is submitted here is the product of my own independent research and that all the sources I have used and quoted have been pointed out and acknowledged by means of a complete reference list. In addition, I declare that the work is submitted for the first time at this university/faculty towards the *Magister Technologiae* (MTech) degree in the Information Technology Department and that it has never been submitted to any other university/faculty for the purpose of obtaining a degree.

ABSTRACT

Tracking involves information gathering, manipulation and proving information on the location of a set item. Many single or hybrid technologies – Global Positioning System (GPS), Radio Frequency (RF), Bluetooth (BLT) or Wireless Fidelity (WiFi) – have been used to provide tracking information of an asset of interest. The use of hybrid technology in tracking assets has proven to be effective if the selection of the technologies used is done correctly. This study used a hybrid of GPS and Radio Frequency technologies to track assets of interest because of their characteristics for use inside and outside a building. In this study GPS geo-fencing was used and time interval was used to receive data from the technology. Heuristic methodology, which enabled us to divide a room into sections, was used, where testing was done in sections in a room with different types of material, such as bricks, wood or metal, and the RF signal degradation, called attenuation, was measured. A straight-line distance and a sum of distances at 30-minute intervals were calculated to determine how far the asset had travelled from the point of origin to the new position. A distance of less than 10 metres was ignored. Geofencing was used to trigger an event since it indicates that the asset has crossed the permitted boundary. An RF reader was placed at the door to identify when the asset left a building and triggered an event. A model was used for searching for a missing item in a room. The results showed that the system was able to produce two distances, one straight-line distance and the other the approximate sum distance travelled by the asset in 30-minute intervals. The RF model was able to find an asset in a room filled with different materials.

Keywords: searcher, global positioning system, radio frequency tracking, signal strength, mobile tracking.

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ABBREVIATIONS

GPS- Global Positioning System

GSM- Global System for Mobile Communication

SMS- Short Message Service

AVL- Automatic Vehicle Location

GUI- Graphical User Interface

RF- Radio Frequency

AGPS- Assisted Global Positioning System

RFID- Radio Frequency identification

API- Application Programming Interface

APN- Access Point Name

SRAM- Static Random Access Memory

EEPROM- Electrically Erasable Programmable Read Only Memory

PWM- Pulse-width Modulation

DC- Direct Current

IDE- Integrated Development Environment

DBMS- Database Management System

RDBMS- Relational Database Management System

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CHAPTER ONE: INTRODUCTION

1.1 Introduction and Background

Tracking involves information gathering, manipulation and proving information on the location of a set item (Deschner et al., 1998). The significance of tracking was first acknowledged in the early 90s by Lee and Billington (1992), when they acknowledged that, without asset tracking, supply chain management presented severe pitfalls for its customers. FedEx had earlier on developed and implemented the world's first tracking system for its shipment on a larger scale, where customers could track the location of their shipment (Janah & Wilder, 1997). Following that, the development of tracking increased exponentially and has now evolved into an industry requirement, where tracking is considered a norm in logistical services (Jakobs et al., 2001; Ciuba, 2004).

The above origin of tracking services has led to companies investing in providing various tracking services to their customers (Coia, 2001; Amrou et al., 2019). The information that is sent to the client includes notifications of delays, exact positioning and delivery issues, also known as events (Loebbecke & Powell, 1998). Apart from logistics and shipment, tracking has a major role in other spheres of business and personal life and provides valuable information (Juma, 2014).

With regard to the importance of tracking, there have been many studies discussing tracking and its role in business. The contributors to this body of knowledge have focused mostly on the client's benefit as opposed to how it benefits business. Our study provides a review of literature pertaining to tracking and contributes to the literature through new knowledge.

The Global Positioning System (GPS) is a technology that is employed to identify location and movement using a constellation of numerous satellites orbiting space that transmit and receive data; the GPS constellation consists of 24 satellites (Kamppi et al., 2009). GPS technology is accurate, offers flexibility and is, in some instances, robust; however. it has limitations in detecting satellite signals inside buildings or built-up areas and this hampers the effectiveness and efficiency of locating assets in congested, built-up areas (Ni et al., 2003). This means that location awareness of an asset is compromised, and considering that location awareness and monitoring are important requirements for people and companies, this limitation is a huge gap in GPS Technology. Pooja (2013) indicates that GPS Technology is suitable for outside environments as opposed to inside. However, Syrjärinne and Wirola (2008) indicate that the Assisted Global Navigation Satellite System (AGNSS) has made significant improvements on GPS positioning in congested areas. On the other hand, Drira (2006) indicates that GPS is much preferred because of its accuracy and its availability to users across the globe. The same sentiments are shared by Kim et al. (2004). On the other hand, GPS receivers can access the GPS satellite signal despite weather conditions throughout the year. A study conducted by Mishra and Shenyblat (2000) indicates that GPS satellites have errors in determining the exact location of the GPS receiver, the errors being due to issues such as satellite clock errors, selective availability, ionosphere delay, multipath, ephemeris error, troposphere delay, etc. The exact location of the receiver is around 156 metres in vertical plane and 100 metres in horizontal plane (Mishra & Shenyblat, 2000). Sandhoo et al. (2000) indicate that even though GPS has been experiencing three decades of development, the integrity, accuracy and availability require further improvement. These improvements should enable users, especially civilians, to receive three signals at once which improve the Standard Positioning Service (SPS) accuracy to a few metres (Bossche et al., 2004). By so doing, jamming capability is hampered (McDonald, 2001; Miller, 2004).

The identification through radio frequencies is termed radio frequency identification, commonly known as RFID (Khast, 2017). The technology consists of an information management system, data carrier technologies and products that carry data amongst these via radio frequency (Khast, 2017). Landt (2005) indicates that radio wave recognition technology was first discovered by Faraday when he found that light and radio waves are forms of energy. At a later stage, Landt (2005) also notes that in 1946 Leon Theremin was instrumental in engineering a tool that could direct a certain radio wave to a desired location. It was also possible to translate these waves into an understandable language through a diaphragm hooked up to a vibrating device, and hence this tool was considered to be the initial RFID device. Stockman (1948) indicates that radio frequency is a technology that dates from 1948. Experts are, however, divided, in that the first RFID was in the form of Identification Friend or Foe (IFF), which was invented by Great Britain in 1933 and was used to distinguish enemy fighter jets from theirs during World War II (See figure 1.1) (Khast, 2017).

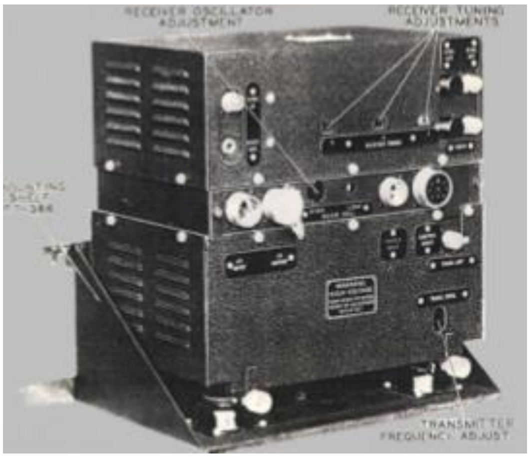

Figure 1.1: Radio Frequency Identification Friend or Foe Machine (Source: Khast, 2017)

However, RFID has been getting more attention from various institutions because of its advantages and simplicity. In the United States of America, numerous companies such as Wal-Mart, Pfizer, Tesco, and Gillette insist that their suppliers should be RFID-compatible; even the Department of Defence (DoD) has this predefined condition in place (Jung, 2007). The technology is also used in the medical industry to avert counterfeit medication. Shipping companies utilise RFID for security purposes, the tracking of animals and tracking hospital equipment and its property (Young, 2005). In modern times, RF technology is used in numerous applications as it consumes fewer human and financial resources (Zimu, 2010).

Benefits of RFID

Both readers and tags can be in different sizes and shapes. Some of the benefits of using RFID technology include:

- Tags can be hidden or embedded in most materials.

These days, however, we use new technologies in conjunction with the old to get great Having

- Owing to the fact that tags are available in different sizes and shapes, users can choose one of them according to their needs.
- To read the code, the tag does not have to be placed under the direct vision of the reader.
- Because of to the nature of tags (no need for direct contact), there is no wear or tear.
- There is no possibility of manipulating the stored serial codes in the tags. Owing to the small size of tags and their freedom to move, their use by organisations and institutions is highly flexible.

Tracking and locating assets and knowing how assets are being used and or abused is of paramount importance for both individuals and businesses. Knowing how assets are being used and or abused. There are various environments whereby location based tracking is critical, from hospitals, warehouses, informal settlements, congested areas such as flats.

Having said this, one fact that we cannot run away from is that we now use new technologies in conjunction with the old to get great interaction between the various technological disciplines. An excellent example would be the use of RFID along with GPS, considering that each of these technologies has its advantages and disadvantages (Bertocco et al., 2009).

In the past, tracking of assets utilised identification cards (IDs) for authentication and tracking, from basic paper ID to advanced cards with electronic units embedded on them, such as Near Field Communication Technology (Agrawal & Bhuraira, 2012).

Table 1.1. Method Comparison of GPS and RF Tracking (Source: Damani et al.,2015)

Technology	**Technology Component**	**Advantage**	**Disadvantage**
GPS	GPS module with microcontroller	• Ease of navigation and localisation. • Search based on area • World Wide availability	• Fast decrease in battery life and hardware • Obstacles deflect the signal • Signal multipath, fading, diffraction occurs
RFID	RFID Transceiver, Antenna, Transponder, RFID Tag	• Does not require line of sight to be clear. • Easily performs data updates. • RFID tags are easily installed and replaced • Size and weight of components are small and easily to install	• Only 8 frequency bands are available. • It does not have any standard. • Difficult for RFID reader to read data from RFID tags that are in liquid and in some metal

1.2 Problem Statement

GPS signals do not permeate solid structures like trees, walls, buildings, rocks, etc. This makes it problematic to track assets inside buildings using GPS, as signals reflect, causing multipath reflections which result in major inaccuracy (Leick, 2004). The utilisation of RFID location-based tracking using triangulation outside in open areas and less densely populated areas is a major issue because of the fact that it utilises beams which require transmitters, towers and receivers (Sweeney, 2006). Therefore, using RF to track assets outside buildings requires extensive aerial coverage and hence most studies focus on using RF inside buildings, plantations and warehouses (Sweeney, 2006; KIM, 2007; Lawrence, 2013). This study aims to find an effective way of combining the two technologies in tracking assets inside and outside buildings.

1.3 Purpose of the Study

The purpose of this study is to investigate how to improve effective asset tracking of movable assets both inside and outside buildings.

1.4 Research Questions

How can we accurately track mobile assets outside and inside buildings?

In order to the answer the main question, the following questions were answered:

- What technologies have been used in mobile asset tracking in the literature?
- What mechanism can be used to track mobile assets inside and outside buildings?
- How can a prototype of a mobile asset tracking system be developed for outside and inside buildings?
- How can the effectiveness of the prototype be evaluated?

In order to answer the research questions, the following objectives were fulfilled:

- To investigate what technologies have been used in mobile asset tracking in the literature
- To propose a mechanism to track mobile assets inside and outside buildings

- To develop a prototype of a mobile asset tracking system for outside and inside buildings
- To evaluate the effectiveness of the prototype.

1.5 RELATED STUDIES

Reddy and Basha (2012) indicate that the Global Positioning System is the most popular technology used to establish the outdoor position information of any item as it covers a wide geographical terrain and area. Because the technology utilises latitudinal and longitudinal positions calculated from at least four satellites, locating an asset can be very simple. However, inside buildings, the use of GPS to locate assets has major limitations, mainly due to line of sight interference with satellites orbiting the earth. The use of both RF and GPS solves these limitations. The use and reliability of RF is superb in that it cannot be easily replicated and is also stable. Hence RF has been used in various industries, such as security, healthcare, retail, transportation, warehousing and distribution. Indoor positioning systems are dependent on the use of various technologies (Fisher & Manahan, 2012). The use of RFID is also advocated in tracking patients inside hospitals as they are being moved from one ward to another. By so doing, the authors argue that one would have eliminated user-initiated activation and the line of sight problem faced by GPS technology while providing one hundred per cent accuracy.

In their research, Sultana et al. (2016) utilise a combination of GPS, Wi-Fi and smart phone to track assets inside and outside buildings. Outside buildings, the GPS works well by utilising trilateration to find the accurate position of the asset, whereas inside buildings, the utilisation of Wi-Fi technology is vital in pinpointing the location of a particular asset. The hardware configuration consists of a Wi-Fi transmitter and receivers situated in various areas of the building. As the transmitter moves from one floor to another, at certain instances a receiver picks up that a particular unit is within its range, thereby helping in locating the asset. A hypothetical test was conducted in a building with a four floors, where the asset in question was represented by a dot on the mobile phone showing its exact location on the floor. The major limitations of this solution are the costs associated with setting up various Wi-Fi receivers at various points of the building. Secondly, the solution gives an approximate location. So in case of recovery in a congested building, the unit can be traced to a floor but its exact location cannot be known and this is not ideal for recovery.

Bisio et al. (2015) have taken a different approach in tracking assets inside congested buildings or areas, especially on construction sites. They use a hybrid model of RFID and Bluetooth. The model is based on registering all asset information on a database, then tagging each asset and each person with an RFID.. The manager is then equipped with a smart phone which notifies him as to which asset has been taken by whom and where the particular asset is in the room, warehouse or construction site. Should the asset leave the designated area for any reason, then the manager is notified via the smart phone. The idea behind this process is to eliminate the limitations that come with GPS inside buildings, where signal cannot penetrate or where signal is disturbed due to congestion.

These limitations of a GPS-based system are further noted by Verma and Bhatia (2013), who discovered that the utilisation of GPS in combination with GSM applications software to track assets is not effective indoors owing to the aforementioned issues. However, their study focused mainly on tracking assets outside as opposed to both inside and outside. Secondly, the solution was based on the premise that all users had utilised a desktop to log in so as to be able to track their assets, and therefore it does not accommodate mobile access for those users who are on the go but are still determined to track and locate their assets.

Geske’s (2000) solution of asset tracking by a wireless system utilisng GPS was based on the premise that a receiver linked to a server with maps integrated provides the location data for to the system. User interface is then used as an application running on machine. The analysis and distribution of data feeds was done by both the client and server application through the Internet. The client and server application communicate via cellular modem connection to the Internet.

In his studies, Lawrence (2013) had the aim of implementing low-cost DGPS to get accurate positioning by using two smartphones, where one phone was used as a receiver and the other as a transmitter. The method entails having the transmitter phone sending signal via cellular network infrastructure using 3G network. The transmitter smartphone is placed at a stationary position or location and then an android application is created as the interface for the receiver smartphone. The co-ordinates are ascertained at four hours’ regular intervals at the same location. The limitation of such a solution is that tracking is not done in real time. The other limitation is that the solution does not work inside buildings because the GPS signal is not able to penetrate buildings and solid structures.

This inability of GPS signal to penetrate walls was overcome by the use of RF in locating assets inside buildings by Kim (2007). He implemented a fixed RF reader inside a building acting as a checkpoint which would measure and analyse information about an asset's location change. The reader would then pick up signal from all RF units embedded into all assets transmitting their location within the building. The reader's signal range worked well in larger areas and signal interference was not an issue. Then he utilised a handheld RF reader that led the search to the exact or terminal asset being traced. When there is a missing item, the purpose of applying RFID is to minimise search time, effort, and investment cost by guiding the detector (handheld reader only, or handheld and fixed RFID reader). The experiment was conducted only in a rectangular-shaped room with no obstacles or unusual layout.

Ahmed et al. (2015), on the other hand, developed a real-time vehicle-tracking system which utilised an Arduino Uno R3 module, a SIM 808 module linked to a GPS and a GSM antenna with a battery source. The system was embedded into a vehicle and allowed for real-time monitoring.

In the above system, the data is received via the GPS receiver; this data would be constituted of the latitudinal and longitudinal positions of the particular vehicle via the satellite constellation, the information being transferred via Short Message Service (SMS) through a GSM modem. The GSM modem is linked to an Arduino Uno R3 microcontroller. At the same time, Hypertext Transfer Protocol is used to transfer information of the vehicle's position to the HTTP server. The specially built web application interface used PHP, Javascript or jQuery, HTML with embedded Google maps. Application Programming Interface (API) is used to display the vehicle's position. The real-time monitoring is achieved by having the geopositional data retrieved every two seconds and the maps synchronising at the same time, thus achieving real-time tracking.

The system allowed for accurate data in real time which enabled the user to track a vehicle and also assisted in terms of recovery of the vehicle in case of loss or theft. The shortcoming of such a system was the amount of time it took for the GPS module to connect to the network due to poor weather conditions as the GPS module requires a clear line of sight with the GPS constellation. This means that in case of indoor tracking and monitoring, such a solution was unable to track the vehicle.

The inability to track is caused by errors to the receiving signal of the GPS receiver owing to the fact that obstacles like tall buildings and solid infrastructure block the view of the sky; the effect of this is multipath error to the receiving signal of the GPS receiver. As a result, on error being initialised, inaccurate results are received as the signal tends to jump from one place to another, sending inaccurate values of latitude and longitude to the server for display on the Google map.

1.6 Research Method and Design

Research is defined as a process where facts are discovered by means of investigation (Olivier, 2004), whereas research design refers to procedures and strategies for research that extend the choices from extensive assumptions to comprehensive methods of data collection and analysis (Creswell, 2009). A comprehensive literature study was carried out to enable the researcher to gain a profound understanding of the study domain.

1.7 Ethical Considerations

Ethics can be thought of as moral values and/or principles that a researcher is expected to abide by or take into account when investigating case studies, such as making sure that other authors are correctly acknowledged by utilising references, and maintaining a high level of objectivity (Zikmund et al., 2010). Creswell (2014) takes it a step further in that he states that, because research cannot be conducted by just anyone, those that engage in this subject matter must adhere to ethical considerations when doing so. No participants were put in any harm's way during this study. Anonymity and confidentiality were also guaranteed verbally and in writing, thereby fostering and establishing a trust relationship with participants. In order to protect their privacy, no business names were disclosed of those businesses that took part in this research.

1.8 Limitations of the Study

The study was subjected to the following limitations that can be improved upon in future studies:

- The study is geographically limited to South Africa.
- The assets on which the hybrid tracking solution was tested are limited to just one asset.
- The findings came from using two specific technologies and therefore findings cannot be generalised across all other technologies.

1.9 Outline of the Dissertation

This study consists of five chapters; a brief description of each is given below:

Chapter 1 Introduction and background: This gives an introduction and the background to the problem statement and is followed by the context of the study, study location, research objectives and research questions.

Chapter 2 Literature review: The chapter comprises a literature review on tracking followed by theories of GPS and RF adoption. This chapter looks at what other researchers have previously argued in relation to this topic.

Chapter 3 Research methodology and design: The methodology and design of the study is described here. It includes discussions on research methods, research strategies and data mathematical techniques, among others.

Chapter 4 Data analysis and Results: The data analysis and results of the study are evaluated.

Chapter 5 Recommendations and Conclusion: The study is evaluated, the conclusion discussed and recommendations made.

CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

Radio frequency and global positioning systems for identifying and pinpointing locations have been used for many years. The complexity and diversity of these technologies have enhanced the ability of humankind to monitor, locate and communicate (Landt. 2005).

In the literature, the Global Positioning System is described as a constellation consisting of 24 satellites orbiting space that transmit and receive data (Kamppi et al., 2009). Radio Frequency Identification, described by Landt (2005) as an engineering tool that could direct a certain radio wave to a desired location, is reviewed in this chapter from previously published papers across numerous countries. The review highlights the benefits of utilising one or both of these technologies to monitor, locate and recover assets, along with a hybrid of other myriad technologies. Also discussed are the shortcomings of the technologies along with their vulnerabilities.

2.2. Need for Tracking

Tracking, as it is known today, is based on the notion of a constellation of satellites orbiting around the earth transmitting data which is then translated by receivers into usable information (Thomas et al., 2017). Millions of humans, goods and assets move across the country from one point to another every day. For many people the safety of their assets and the peace of mind of knowing that their assets and loved ones are safe is a critical issue (Shaaban et al., 2013). Applications where tracking is required and used include, but are not limited to, smart houses, stock monitoring and control in factories and disaster management, child tracking, location, identification and tracking of patients in hospitals, map generation, customers and stock observation in supermarkets, observation of visitors at exhibitions, anomaly detection and outdoor navigation, among other applications (Gani et al., 2013).

In their recent paper, Ashok et al. (2016) highlight the need for tracking in the freight space as it provides security in relation to theft. The tracking of goods between departure and destination aid in improving profitability in the business community as it reduces loss and subsequent insurance payouts. Tracking is not only an outdoor activity; indoor tracking of assets is just as important (Sultana et al., 2016). The need for asset allocation and tracking is not new: in their paper, Bisio et al. (2015) highlight various studies that have looked into indoor asset allocation and tracking using a hybrid technology.

Abdalsalam and Dafallah (2014) indicate that over the years tracking has moved from a requirement to a need, which has the potential not only to save lives but also to keep track of assets. There is an increasing need for tracking devices, which can be lifesaving. During periods of disaster, people can use these systems to keep track of victims. Tracking provides several services, such as locating missing people and stolen assets, keeping track of employees to monitor where they are at all times during the workday, of teenagers to control their movements and of smaller children and elders when they go missing, and for many other purposes (Solé& Loan, 2011).

On the 4th of March 2019, the worst tropical cyclone, Idai, which reached speed of about 205Km/h, hit the Southern Hemisphere in Africa, in particular Mozambique, and this proved to increase the need for human tracking solutions which improve the tracking of victims and can be lifesaving during periods of such disasters (Abdalsalam & Dafallah, 2014). Abdalsalam and Dafallah (2014) go on to say that keeping track of movement of elders, children and employees and locating stolen assets are some of the services that can be provided by tracking, inclusive of various other purposes.

2.3. Global Positioning System (GPS)

The history of GPS is invested in the dealings and work of Dr Ivan Getting and the USA's Department of Defence as their goal was to develop a satellite course-plotting system to assist users to navigate for surveillance in particular in the 1960s (Zhao, 2014). The original idea behind GPS was for military and intelligence use during the Cold War (Ahmed et al., 2015). Since then, GPS technology has developed to a massive constellation of 32 satellites that orbit the Earth, where each of the orbits has six satellites which are 120 degrees apart from each other (Drira, 2006; Solé & Loan, 2011; Boström, 2011 & Kim, 2007). Hershberger (2013) also states that each satellite orbits the earth once every 12 hours. The GPS technology is set in such a way that it allows its users to determine the location of the asset in question in three dimensions (Hershberger, 2013). Adwan (2015) notes that the actual name for GPS is Navigation System with Timing and Ranging Global Positioning System (NAVSTAR), and it is controlled by the government of the United States of America. The Global Positioning

System (GPS) is a technology that is utilised to identify location and movement, using a constellation consisting of 24 satellites orbiting space at an altitude of 20 000 meters at a 55-degree orbital plane; these satellites transmit and receive signals (Kamppi et al., 2009). GPS also allows users to determine their location in three dimensions, with each satellite orbiting the earth twice a day on the same axis; this is because each orbit takes 12 hours (Boström, 2011). Thompson et al. (2012) state that six satellites are always in view of Earth at any given point. Pooja (2013) indicates that GPS Technology is suitable for outside as opposed to inside environments. Solé and Loan (2011) explain, however, that GPS was developed not only for the Department of Defence, but also the National Aeronautics and Space Administration (NASA), and should have the following features:

- Global coverage
- Continuity
- Availability
- Capability for serving high-dynamics platforms

On the 27 April 1995, the GPS reached its full operational status and saw its commercial interest, use and success peak (Hedgecock et al., 2014). Recently, however, a system has evolved where movement of mobile objects can be tracked by embedding GPS technology into those objects (Zhao, 2014).

The ability to track assets in transit on freight using the Global Positioning System (GPS) is a concept that is not widely used (Ashok et al., 2016). Ashok et al. (2016) goes on to highlight that using Google Maps APIs along with GPS play a pivotal role in how tracking of freight can be successfully implemented. The utilisation of GPS enables location of objects using time and information. As explained earlier, GPS is in its basic format known as a Global Navigation Satellite Service (GNSS), which is a constellation of satellites which uses a combination of altitude, latitude and longitude to locate accurately the position of an asset (Chaudhari et al., 2015).

The misplacement of high-value items, also known as assets, is a major financial and production disadvantage to organisations (Kelepouris & McFarlane, 2010). The issue of wanting to track, monitor and recover assets is not new and people have been faced with different scenarios around this matter (Bisio et al., 2015).

According to Abdalsalam and Dafallah (2014), the basic construct of a GPS tracking solution is made up of a portable tracking device attached to whatever it is that one is interested in tracking, be it an asset, vehicle, person or animal They go on to explain that the GPS receivers or modules receive coordinates from a minimum of three satellites and these coordinates are sent via SMS and GSM to the tracking centre. This is the same explanation given by Shruthi et al. (2015), who add that GPS uses satellite and ground stations. Adwan (2015) discussed the three main segments of GPS, which are:

- The Space Segment: This consists of six different orbital planes made up of a constellation of satellites that orbit the earth. At any given point, there are four satellites which transmit in a one-way signal format to the receiver's equipment on earth.

- The Control Segment: This is where the various satellites that orbit the earth are controlled and monitored via a control centre. Aspects controlled include telemetry, space segmentation, orbital plane changes, maintenance, etc.

- The User Segment: Instruments are used to receive the signals from the various satellites and determine their current location, as seen in figure 2.1 below.

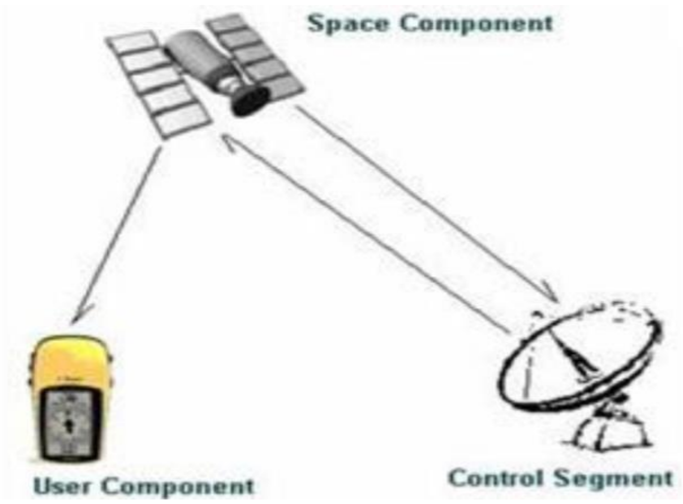

Figure 2.1: Segments of GPS (Source: Adwan, 2015 (adapted))

Adwan (2015) goes on to state that, because of the high accuracy of GPS, it holds true for outdoor tracking, also known as global tracking, whereas technologies such as Bluetooth, WiFi and RFID are mostly suitable for local tracking, also known as close-proximity or indoor tracking. The reason that GPS is used for global tracking is that it can detect longitude and latitude values anywhere on earth in any weather condition (Rakesh, 2014). Lawrence (2013) concurs in this, noting that GPS is the clear choice for location determination because of prices declining over the years. Lately, GPS is being used in our daily lives in ways completely unforeseen when it was discovered, while there has also been exponential growth and broad private and commercial acceptance as the technology is widely used for localisation and navigation outdoors because of its high accuracy (Ren et al., 2011; Pham, 2011).

Up until this point, the benefits of GPS have been discussed. However, as with all technologies, in reality there limitations: there are myriad errors that affect the precision of accuracy and localisation (Hedgecock et al., 2014). According to Hedgecock et al. (2014), these errors include:

- Satellite Clock Bias

  In order for a satellite to ensure that its clock is properly aligned to the actual GPS time, a stable atomic clock is used. In most cases however, these two clocks can be out of synchronisation by up to 1ms before sending synchronisation corrections. So the bias aspect means that actual GPS transmission of its PRN code is done at an incorrect time.

- Receiver Clock Bias

  All GPS receivers are also prone to clock bias, as with GPS Satellites. In this case the biases deviate more and change rapidly owing to the use of low-cost components and oscillation instead of components used in GPS Satellites. This has a massive effect on the bias time because of the receiver clock bias.

- Satellite Orbital Errors

  The GPS Satellite constellation has a specific design where the numerous satellites rotate in a specific orbit around the earth. However, inaccuracies in the pre-defined orbital path are caused by various forces and factors, such as infrared radiation, tidal movements, gravitational forces, solar radiation pressure and deformations of the earth.

Unfortunately, these shifts can neither be predicted nor anticipated and corrected in time.

- Atmospheric Effects
  Ionosphere and tropospheric deformation of the radio waves as they travel through the various layers of the Earth’s atmosphere have a negative impact on the GPS signal as the speed of light delay the propagation of radio waves

- Antenna Phase Centre Offsets
  The type of antenna used to receive GPS signal, the type of antenna used and any small manufacturing anomalies have an impact on the error offsets. These factors have an influence on how GPS signals are received and transferred by the antenna, which is the electrical phase centre. This is also known as the Antenna Reference Point (ARP).

- Relativistic Effects
  The theory of relativity as stated by Albert Einstein is omnipresent and its effect on GPS signal cannot be ignored. In essence, the theory states that, for objects moving slowly, time runs faster. GPS satellites move at a speed of 3,874m/s in relation to the Earth, causing their clocks to run more slowly than the clocks on Earth. This causes clock inaccuracies of about 7.2 microseconds per day.

- Multipath
  Multipath is seen as one of the most difficult errors in GPS signal. This error can be caused by a variety of hard surfaces such as trees, buildings, people, the ground, etc. Multipath error occurs when signals bounce off such surfaces as they are reflected on the aforementioned objects that are next to the receiver.

- Carrier Cycle Slips
  Loss of satellite signal is also a massive issue caused by signal being dropped during transmission. This is also referred to as loss of lock.

2.4. Tracking with GPS

Shruthi et al. (2015) highlight the fact that the most common use of GPS is the Automotive Navigation System (ANS), which is used for tracking vehicles. However, Chaudhari et al. (2015) assert that human tracking can be done using GPS: in their solution, comprised of a GSM model with a SIM card that is GPRS enabled, the GPS, which on its own has a transmitter and a receiver where all the aforementioned technologies come together, can locate the person with the Subscriber Identification Module (SIM) card through Internet access. Sultana et al. (2016) share the same information as Chaudhari et al. (2015) in the use of GNNS systems in location, tracking, monitoring and recovery of various assets, including, but not limited to, vehicles, persons and other assets. In their paper, Sultana et al. (2016) proposed a theoretical design of a GPS tracking system along with its implementation. The proposed solution is based on the use of a GPS module, a Personal Digital Assistant (PDA) with WiFi functionality and a GSM system. The construct of their solution is based on the integration of WiFi and GSM and then using GPS in terms of latitude and longitude positioning, which gives you a higher accuracy when tracking assets indoors.

Verma and Bhatia (2013) utilise GPS to track a vehicle and also to find the shortest route that a vehicle can take, thereby optimising trips. The solution is based on a combination of both hardware and software, where the hardware components used are GPS, GSM module, Atmega microcontroller MAX 232, 16x2 LCD, and the software used for interface is design inclusive of a web application for the client.

The aforementioned studies and methods of asset tracking using GPS with myriad other technologies all define the various functions of asset tracking, monitoring and recovery. The common denominator is that GPS and GSM modules are an important part of the technology (Ashok et al, 2016), in that they can provide the various coordinates to pinpoint an asset with good signal strength. However, cases such as those presented by Bisio et al. (2015) and Sultana et al. (2016), show us that, in congested or built-up areas, GPS GSM alone does not give us the best solution; hence they need to be combined with other technologies in order to improve on accuracy and get the desired results.

Gaikwad and Pawar (2015) implement real time GPS tracking with SMS tracking, which sends real-time latitude, longitude, altitude, speed and location, and all the information is displayed on a graphical interface. Alternatively, in his thesis, Adwan (2015) investigated the tracking of people using GPS and general packed radio service (GPRS), which has the benefit of low costs, rather than GPS and SMS,. The same method of GPS and GSM tracking was used by Ahmed et al. (2054), Bojan et al. (2014), Shruthi et al. (2015) and Thomas et al. (2017) for live tracking of a vehicle. Users can also use the system to get notifications of public transport, as illustrated in figure 2.2.

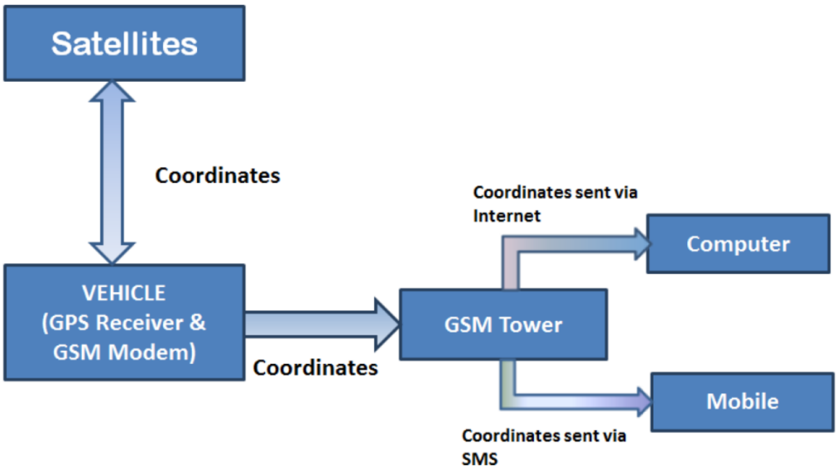

Figure 2.2: Block Diagram of Vehicle Tracking System (Source: Ahmed et al., 2015)

The above diagram shows the flow of how Ahmed et al. (2015) configured their GPS, GSM vehicle tracking system, where the vehicle is installed with a GPS receiver which gets its coordinates from satellites; it then forwards these coordinates via GSM module to a GPS tower. The tower then sends the information to the specified server, using the Internet to display the same coordinates on Google Maps. Wambayi (2016) took it a step further, in that he investigated the tracking of schoolchildren in transit, using GPS and Android mobile smartphone with Internet and Near Field Communication (NFC), whereby parents and school administrators are able to access trip information and event notifications, as seen in figure 2.3 below.

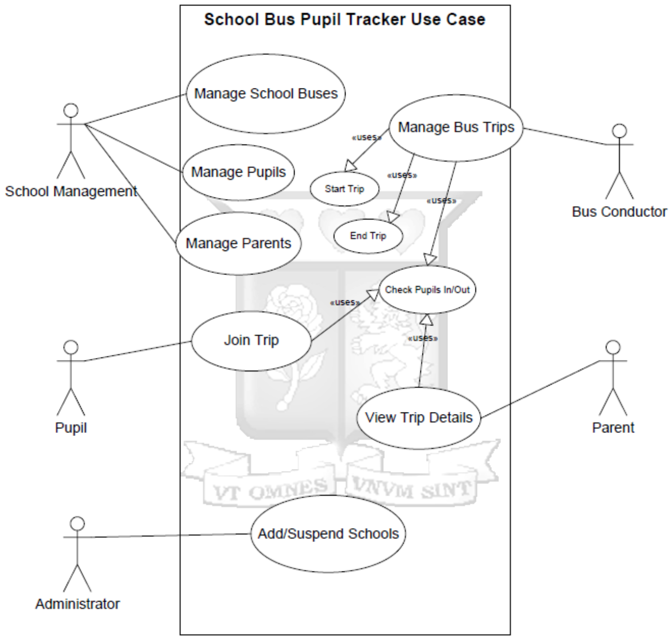

Figure 2.3: Use Case Diagram - School Bus Pupil Tracker System Using GPS (Source: Wambayi, 2016)

In their 2017 paper, Zhou et al. (2017) used GPS data obtained from various smartphone devices to predict user trip ends. Ashok et al. (2016) used GPS, GSM, SMS and biometrics in security goods in transit. The solution comes at a cost, however, owing to hardware requirements. Abdalsalam and Dafallah (2014) designed a model for an accurate real-time GPS tracking system using SMS and GSM transmitting information to a server integrating Google Maps Application Program Interface (APIs).

Sudheera et al. (2015) investigated how GPS and GPRS are used in tracking offshore fishing boats to report on Unregulated, Unreported, Illegal Fishing (UUIF).

All these related studies have a common theme in that they use GPS and other technologies outdoors; hence Sultana et al. (2016) and Gani et al. (2013) both investigated the use of GPS technology for indoor tracking by combining it with WiFi/cellular network.

All these related works prove not only that there are vast areas in which GPS can be used to track assets and goods from different domains but also that combining the GPS technology with other technologies boosts the usability of identification, tracking, monitoring and recovery of various assets.

Faraday's theory in 1864 of energy being formed by both light and radio waves was the first recognition of radio waves via technology (Khast, 2017). Khast (2017) goes on to explain that an invention by Leon Theremin in 1946, where sound formed radio waves that he was able to transfer to the desired destination, was the first form of RFID, in that these sound waves would then be translated into understandable language because the diaphragm would be connected to a vibrating device and it would be mobilised as waves. Meanwhile a decade earlier, in 1939, the British had devised a technological tool referred to as Identification Friend or Foe (IFF), which was used in World War II to identify enemy aircraft, in particular the German fleet (Landt, 2005).

Following the IFF in World War II, the commercialisation of RFIDs for civil applications was seen in the 1960s as electronic commercialisation also took shape in the form of Electronic Article Surveillance (EAS) systems (Bertocco et al., 2009). EAS systems were used mostly in retail, where the construct of the application was based on a 1-bit transponder, which had one of two states: default (1) ON or (2) OFF. All items on the shelves were set to the default state of (1) ON and only after payment did the transponder change to bit (2) OFF. In the case where an item carrying a bit (1) ON transponder was detected as exiting the doors, an alarm would be triggered. EAS systems were adopted for theft detection and prevention and are considered as the first passive RFID applications (Chiara, 2015). In 1973, Rasua (2012) noted that the first patent was awarded to Mario Cardullo for a passive, read-write RFID tag. This was the first RFID tag with memory, and modern tags, which have shrunk to the size of a grain of rice, have capabilities to either read only (ROM), Electrically Erasable Programmable Read-Only Memory (EEPROM), or to use batteries, and much, much more. Recently RFID has been used in the development of the Internet of Things (IoT) (Zhi-yuan et al., 2010). Nikitin and Rao (2006) acknowledge that RFID has a long history and identify it as a technology that is wirelessly used to collect data.

Chiara (2015), in his master's thesis, also describes RFID as wireless telecoms technology has gained popularity and which is used for the sole purpose of automatic identification and whose effects are used in various fields, such as pharmaceutics, retail, aerospace, apparel, automotive, chemical, defence, health care, labelling, logistics, manufacturing, and packaging.

Rasua's (2012) statement that the use of RFID has gained extreme popularity and therefore this has made it hard to say how many RFID systems are deployed internationally, supports Chiara's (2015) description of the numerous fields where RFID has been applied,.

RFID technology has been characterised by its growing popularity. Consequently, a large and diverse number of RFID solutions are being used by more and more business companies including governments, which have implemented RFID technologies to track and control documents and order tasks such as customs and passports (Rasua, 2012). Interventions by law enforcement agencies in curbing transaction-related fraud through the use of RFID have been introduced by the European Central Bank (Knežević et al., 2015)

Nonetheless, RFID technology comes with its faults: Knežević et al. (2015) explain that issues such as privacy and ethics are some of the major issues in introducing RFID technologies into everyday activities. They further point out that it is impossible for RF to read off from liquid and metal parts and also that the RF tags are too expensive. As for the problem with RFID and privacy, Mainetti et al. (2013) state that goods tagged with an RFID which contains an EPC code can lead to customers' private data being readable outside the confines of the intended environment. In terms of technological disadvantage, RF has a higher lag time when compared with wire link (Arimany, 2011)

Another disadvantage is that RF is slower than wire links, as it has to communicate in both directions through the same medium. Having different modulations on the receiver and transmitter can solve this problem, but it is an expensive solution. In this case, half duplex is the common strategy used.

However, in their research, Jones and Chung (2016) state that safety in stock management and the ability to replenish stock is greatly increased when retailers introduce RFID technology. RFID tags enable companies to be more efficient in the automation process of checking goods, shipment and optimising cross-docking (Sweeney II, 2010). Sundaresan et al. (2015) also look at environments where the implementation of object tracking using RFID can be effective, such as vehicle tracking, tracking of materials, children, farming and a person's entry into or exit from offices. In other related work, Khast (2017) describes the implementation of RFID in the transportation sector and Chawla and Ha (2007) discuss the tracking and location transportation systems using passive RFID tags. On the other hand, Tseng et al. (2007) elaborate on the tracking of vehicles in toll plazas as they arrive within a certain range.

Gerdisen et al. (2014) make mention of research conducted into human tracking, where GPS technology was used indoors with an error rate of 4 metres. Hutabarat et al. (2016) improved on this by adding RFID along with GPS to accomplish a similar outcome.

2.5. Tracking with Radio Frequency Identification (RFID)

Kim (2007) indicates that the use of RFID to track items not only reduces time but also has a positive cost implication as it is cheaper. His method involved the use of RF tags, and stationary and handheld readers. Bojan et al. (2014), Ahmed et al. (2015) and Dukare et al. (2015) investigated vehicle tracking using RFID with an accuracy of 4 meters to 6 meters. The solution comprised tag (passive, semi-passive and active), reader (antenna or integrator) and software (middleware). In addition, information about speed, location and mileage could be read from the vehicle and updated every 60 seconds and read to the system from the tags to the reader with an attached antenna using RF waves, controlled by a microprocessor or digital signal processor. Kavulya (2014) looked at implementing the tracking of inventory, specifically books in the library, through the use of RFID, while Doan (2017) used a similar solution to broaden logistical tracking using RFID. Masum et al. (2013) and Kärkkäinen (2005) show that supply chain can be optimised with the implementation of RFID tracking technology for inventory management. The concept was then modified to be able to track inside buildings specifically for lab equipment by both Raman (2012) and Samrand (2016). Chanrasekaram and Oustad (2008) also indicate that pharmaceuticals have successfully implemented RFID tracking technology to track and monitor drugs, in terms of stock levels and for security purposes. They go on to say that tagging of patients' wristbands using RFID to track and monitor patients' whereabouts is also widely used in some hospitals. RFID and Bluetooth combinations have also been successfully employed to track assets, using smartphones (Bisio et al., 2015). Bisio et al. (2015) use RFID tags, Bluetooth low-energy tags and a smartphone's functionality to track and recover assets in a construction site or similar congested area. The smartphone runs an android application and an Asset Proximity Locator (APL), as well as a Wandering Objects Location Finder (WOLF).

2.6. Tracking Using Global Positioning System (GPS) And Radio Frequency Identification (RFID)

Combining the two technologies, RFID and GPS, not only allows us to track assets outside but also inside buildings; it also improves security of data transmission as the medium of communication is air, which is prone to attacks (Bapat & Nimbhorkar, 2016). Their solution comprises hybrid technologies, GPS, GSM and RFID. The same technologies were used by Damani et al. (2015) to track vehicles, whereby the GPS coordinates are sent to the unit and transferred to the server via the GSM technology medium. After locating the vehicle, RFID, via RF receivers, is then switched on to pinpoint its exact location.

2.7. Conclusion

This chapter discussed the background, benefits and challenges associated with various tracking technologies. The chapter also investigated hybrid technologies that have been used in order to maximise the advantages of those technologies and minimise their disadvantages. Hybrid models of GPS and RF were also surveyed.

CHAPTER THREE: RESEARCH METHODOLOGY AND DESIGN

3.1. Introduction

Location recognition applied to asset management by RFID is different from location recognition using GPS, Infrared, and Radar. The purpose of applying RFID is to minimise searching time, effort, and investment cost by guiding the detector when there is a missing item. This chapter is composed of two sections. Section A provides the model setup for GPS technology tracking items outside of buildings. Section B provides the model setup for using RFID technology inside a room.

3.2. Section A: GPS Model Setup

GPS has three main segments; the space segment, the control segment and the user segment (Pawlowski, 2015; Pachica et al., 2017; Artono et al., 2020).

From space, the GPS constellation consists of 31 satellites orbiting in 6 orbits at an altitude of 20 000 kilometres from the earth. Each satellite has an atomic clock which is used when the satellite transmits messages to earth and is also used to determine the accuracy of each satellite. Each GPS satellite's position has coordinates, where the user's position has the following coordinates, and distance between the user and satellite is calculated using formula 3.1 (Zuva, 2012; Li et al., 2020):

$$d_i = \sqrt{(x_i - x_u)^2 + (y_i - y_u)^2 + (z_i - z_u)^2} \tag{3.1}$$

where i is the number of satellites

Equation 3.1 can be written as a system of three equations shown below:

$$\begin{aligned} d_1 &= \sqrt{(x_1 - x_u)^2 + (y_1 - y_u)^2 + (z_1 - z_u)^2} \\ d_2 &= \sqrt{(x_2 - x_u)^2 + (y_2 - y_u)^2 + (z_2 - z_u)^2} \\ d_3 &= \sqrt{(x_3 - x_u)^2 + (y_3 - y_u)^2 + (z_3 - z_u)^2} \end{aligned} \tag{3.2}$$

After knowing the distance to three satellites, it is possible to arrange a set of three equations with three unknowns (x_u, y_u, z_u). This enabled us to calculate the receiver's distance. The distance d_i is determined by the time between the moment t_{is} of transmitting the signal by the satellites and the moment t_{ur} of its reception by the user's receiver:

$$d_i = c(t_{ur} - t_{is}) \tag{3.3}$$

where $= c = 2.99792458 \times 10^8$ m/s is the speed of light.

Wherein t_{is} is determined by the atomic clock that is installed on the satellite and is sent to the receiver. The receiver would then calculate t_{ur} after receiving the signal based on its own internal clock. It should be noted that terrestrial segments of GPS control the clocks on the satellites. They also act in line with the GPS time. However the receiver's clock is not synchronised with the GPS time. This introduces a bias error from equation 3.3:

$$p_i = c(t_{ur} - t_{is} - b_u) \tag{3.4}$$

where p_i is the pseudorange.

Wherein b_u is another unknown quantity. Therefore the receiver's position (x_u, y_u, z_u) and the receiver's clock error b_u can be determined by using information from four satellites using the four equations:

$$p_1 = \sqrt{(x_1 - x_u)^2 + (y_1 - y_u)^2 + (z_1 - z_u)^2} + cb_u$$

$$p_2 = \sqrt{(x_2 - x_u)^2 + (y_2 - y_u)^2 + (z_2 - z_u)^2} + cb_u \tag{3.5}$$

$$p_3 = \sqrt{(x_3 - x_u)^2 + (y_3 - y_u)^2 + (z_3 - z_u)^2} + cb_u$$

$$p_4 = \sqrt{(x_4 - x_u)^2 + (y_4 - y_u)^2 + (z_4 - z_u)^2} + cb_u$$

Following which, the calculations of the latitude φ_u and longitude λ_u in the equation as well as the height h_u above sea level, are calculated as follows:

$$\varphi_u = \arctan\left[\frac{z_u}{\sqrt{{x_u}^2+{y_u}^2}}\right] \tag{3.6}$$

$$\lambda_u = arctan\left(\frac{y_u}{x_u}\right) \tag{3.7}$$

$$r_u = \sqrt{{x_u}^2 + {y_u}^2 + {z_u}^2} \tag{3.8}$$

$$h_u = r_u - r_e \tag{3.9}$$

where r_u is the distance from the centre of the earth to the user's receiver's GPS and r_e is the average radius of the earth and φ_u is the geocentric latitude (Skog & Händel, 2009).

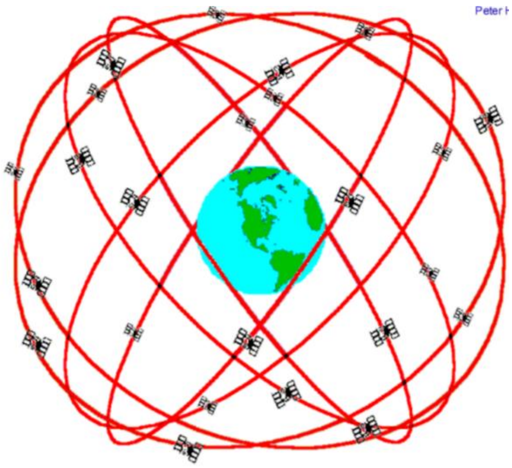

Figure 3.1: GPS Constellation (Source: Lawrence, 2013)

In order to calculate the distance between two receivers with latitude and longitude, equation 3.9 is to be used (Zuva et al., 2012)

$$d_{AL}(\varphi_1\lambda_1\varphi_2\lambda_2) = 2r\,\text{arcsin}\left(\sqrt{sin^2\left(\frac{\varphi_2-\varphi_1}{2}\right) + cos\,(\varphi_1)cos\,(\varphi_2)\,sin^2\left(\frac{\lambda_2-\lambda_1}{2}\right)}\right) \tag{3.10}$$

where $\left(\varphi_1\lambda_1\right)$ and $(\varphi_2\lambda_2)$ are current GPS coordinates for the tracker receiver and the actual asset receiver location respectively.

It is very important to note that “lat” and “lon” stand for latitude and longitude respectively. North latitudes and west longitudes are taken as positive and south latitudes and east longitudes are taken as negative (Zuva et al., 2012; Rose et al., 2014).

3.2. Calculation Of Distance Between GPS Receivers

After locating the asset in question via GPS satellite, the user can see the location exactly via Maps API. However, in the real world, assets move around and therefore we need to trace the path or route that the asset took. This means that the search path should be calculated using the heuristics search method calculation. The main aim of a heuristics search model is to quickly search the path. The heuristic calculation model generates multiple paths that need to be evaluated and, based on the results, it chooses a complete path. This is done as described in the following paragraph.

The asset that was tracked outside in the open used GPS technology through the GPS module that is installed in the asset. We then set up a geofence boundary which triggered an alert event as soon as the boundary was breached by moving the asset outside the boundary without consent. The tagged item continued reporting its live location as it moved outside, where the GPS constellation could receive the signal. The searcher, through the online platform, traced the asset’s location unit it stopped transmitting signal. The searcher then used the GPS longitudinal and latitudinal coordinates to track the unit’s last known location outside of a building or room.

Finding the path taken by the asset to reach the final destination

The location of the asset was denoted as GPS points P_{k-1} at time intervals of 30 minutes, where P_0 is the initial position of the asset (the location where the asset must be), = 0,1,2…k-1, and P_{k-1} represents the last location of the asset. The distance between two points is given as d_i where i = 1,2,3…n. The approximate distance travelled by the asset is given by the equation 3.12. Figure 3.2 illustrates the model of how the asset travelled.

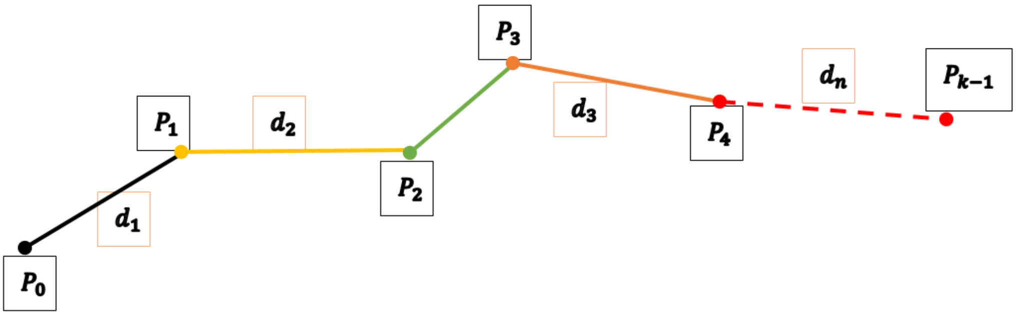

Figure 3.2: GPS asset route calculation

In heuristics search, the link closest to GPS point 1 is calculated, using equation 3.12.

$$d = \sum_{i=1}^{n} d_i \tag{3.12}$$

where $i \in [1, n]$

The equation 3.12 calculates the total distance covered by the asset in 30-minute intervals. The distance d_i is calculated using the Haversine formula in 3.13 (Chopde & Nichat, 2013).

Following this, we would then need to calculate the distance that the asset covered, also known as GPS distance. This enables us to follow the route and distance that the asset would have covered. We consider the distance covered by using the latitude and longitude value determined by the GPS module without any changes to the values received by the GPS module. The distance would therefore be calculated by calculating the distance between two consecutive GPS coordinates and summing these distances. Chopde and Nichat (2013) suggest that using the Haversine formula in 3.13 is best suited to calculate the distance.

$$d_1(\varphi_0\lambda_0\varphi_1\lambda_1) = 2r \arcsin\left(\sqrt{sin^2\left(\frac{\varphi_1-\varphi_0}{2}\right) + cos\,(\varphi_0)cos\,(\varphi_1)sin^2\left(\frac{\lambda_1-\lambda_0}{2}\right)}\right) \tag{3.13}$$

$$d_2(\varphi_1\lambda_1\varphi_2\lambda_2) = 2r \arcsin\left(\sqrt{sin^2\left(\frac{\varphi_2-\varphi_1}{2}\right) + cos\,(\varphi_1)cos\,(\varphi_2)sin^2\left(\frac{\lambda_2-\lambda_1}{2}\right)}\right) \tag{3.14}$$

$$d_3(\varphi_2\lambda_2\varphi_3\lambda_3) = 2r \arcsin\left(\sqrt{sin^2\left(\frac{\varphi_3-\varphi_2}{2}\right) + cos\,(\varphi_2)cos\,(\varphi_3)sin^2\left(\frac{\lambda_3-\lambda_2}{2}\right)}\right) \tag{3.15}$$

……………………………………………………………………………………

$$d_n(\varphi_{n-1}\lambda_{n-1}\varphi_n\lambda_n) = arcsin\left(\sqrt{sin^2\left(\frac{\varphi_n-\varphi_{n-1}}{2}\right) + cos\,(\varphi_{n-1})cos\,(\varphi_n)sin^2\left(\frac{\lambda_n-\lambda_{n-1}}{2}\right)}\right) \tag{3.16}$$

Therefore, the systems of equations can be generalised as in 3.17.

$$\sum_{n=1}^{n} d_i = \sum_{i=1}^{n} 2\, r\, arcsin \arcsin\left(\sqrt{sin^2\left(\frac{\varphi_n - \varphi_{n-1}}{2}\right) + cos\,(\varphi_n) cos\,(\varphi_{n-1}) sin^2\left(\frac{\lambda_n - \lambda_{n-1}}{2}\right)}\right) \quad (3.17)$$

3.3. Interface Model Design for GPS

It has to be noted that the Haversine formula does not take into account error rate.

After the various calculations in terms of determining which methodologies to use, we designed an application that allowed us to track the movement of an asset outside, utilising GPS, and inside, utilising RF. In developing the user application, an Agile development strategy is preferred as it favours the concept of delivering service at a higher frequency, as opposed to the Waterfall development strategy. Also, Waterfall model development testing is done only at a later stage, which also delays the deployment of the system. Table 3.1 indicates the various attributes that should be captured when registering a new asset on the system.

Table 3.1 Asset Attribute Registration Requirements

Field	**Data Type**	**Source**	**Compulsory**
Asset Name Unique Identification (UID)	String, not more than 20 characters	Provided from the tracking unit hardware	Yes
GPS Date	DateTime	Provided from the tracking unit hardware	Yes
Satellites	Number	Provided from the tracking unit hardware	Yes
Address	Variable Character()30)	Provided from the tracking unit hardware	Yes

Altitude	Variable Character()30)	Provided from the tracking unit hardware	No
Username	Variable Character()30)	Provided by the user	No
Password	Variable Character(30)	Provided by the user	No

The platform is to allow the user to select an active asset to monitor and indicate which assets are actively monitored.

3.4. Location Management

The location of the asset should be visible on the map. This is the GPS last known location. The GPS update interval rate should also be updated via the platform at 30-minute intervals. The user should be able to see the various points where the asset has moved, meaning that the route was plotted on the map. An important feature that should be available is for the user to the able to create and set up a geofence, which is a virtual boundary, whereby, should the asset step outside or inside this geofence, an event would be triggered to alert the user of this event. This is used as the known location where the asset is supposed to be.

From the aforementioned requirements, a simple use case diagram can be drafted and implemented, as seen in figure 3.3.

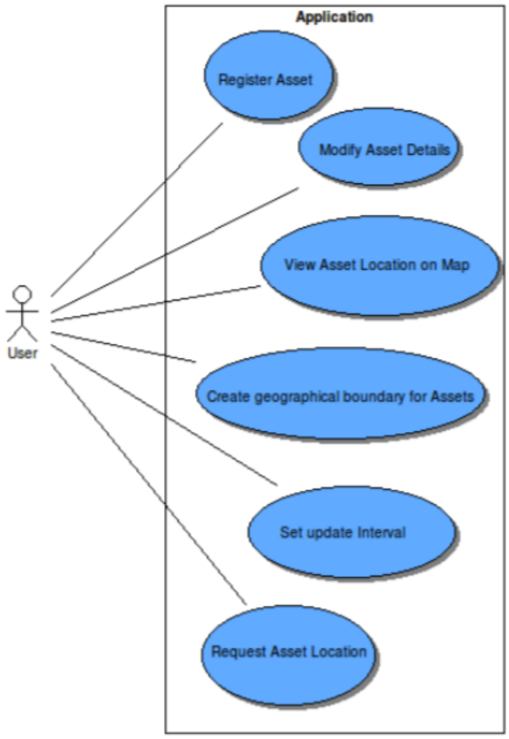

Figure 3.3: Use Case Diagram for GPS Asset Tracking

Various data structures and programming patterns were used in implementing the use case diagram, for instance, Java, which is an object-orientated language, and the writing of classes, which helps in the separation of logic and data structures, and the combination of various data classes that hold logically related data, such as Asset, AssetType, AssetData, SMSlogs, GeofenceData etc.

3.5. Section B: RFID Model Setup

There are various types of RFID readers; however, we used a type of a reader called a fixed reader, for location-based search in a room. It tells whether an item is in a certain area or not. Setting up this reader in a large area may improve performance and cost efficiency. This type of reader is handheld, and leads the searcher to the terminal location of a tagged item.

This reader works on a continuous mode, which scans the tagged item strength level continuously in repeating cycles within a specified range. We considered using data from the handheld reader in continuous mode to find the location of a tagged item inside a room. Although we would be able to know the signal strength level, we would not be guaranteed its correct distance because dynamic interferences affect the range. In addition, the distance is changed by other items in the same area, so it is hard to standardise the criteria. Second, exception mode reports to the reader when a tagged item is detected in the configured range. We use exception mode scanning in our model.

The handheld reader identified the object signal in the minimum distance in order for the exhaustive search to succeed. Furthermore, we assume that a searcher can predict the location where s/he can find the item location, using GPS coordinates. When the searcher does not have any background about the room, even though the searcher holds the RFID handheld reader in the particular area, it is difficult to suggest a certain heuristic policy. In this case, the searcher just does an exhaustive search, which is the search method used when the possible location of a tagged item or the path of search can be predicted. In the next section, we consider how to track the location of a tagged item.

3.5.1. RFID Random Route for Object Search in Room

The object that we are supposed to find is located in a given room. The size of the room is X (width) and Y (length), as given in figure 3.4a. We initially assume that the tagged item is located in any given location inside the room with equal probability. This study used the steps proposed by Kim (2007).

In this study we assume that the room is rectangular. Let the area of the room be . and let the detecting radius of the sensor be , as in figure 3.4b. Let be the searching velocity from the left edge to the right edge when the searcher walks parallel with the bottom line of the room. Then, when an area of has been searched completely by the handheld sensor, the minimum searching time of exhaustively walking around the room is defined as .

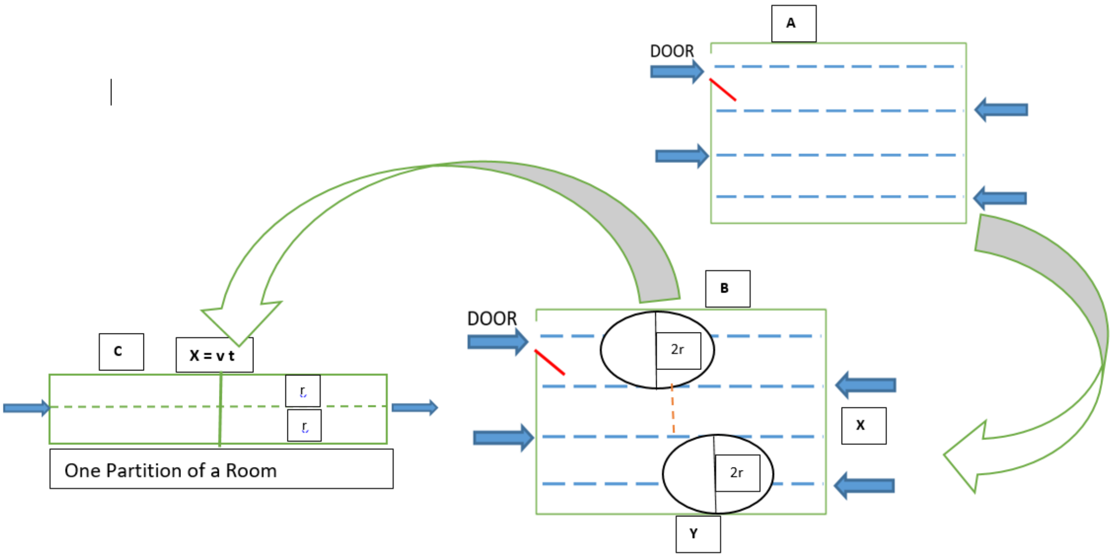

Figure 3.4: Exhaustive Search Routes in a Room (Source: Kim, 2007)

It takes $\mathrm{T_e}$ duration to search the entire room, and under the assumption that the tagged item is in the room, the probability that the tagged item is found within $\mathrm{t_p}$ seconds is uniformly distributed in equation 3.17.

$$\mathrm{t_p} = \frac{1}{\mathrm{T_e}}, 0 \le \mathrm{t_p} \le \mathrm{T_e} \tag{3.17}$$

By the definition of $E[T]$ (expected value of T, the expected time to find an object is as follows : $E[T] = \frac{1}{2} \times \mathrm{T_e}$. Here, there is one more factor to consider. Using a handheld reader to detect the tag within a radius r, we need to look manually for the tag by opening cabinets, looking under tables etc. The manual time to find the tag is dependent on radius r. Define the time to find the tagged item manually by $h(r)$. For the expected time $g(r)$, to find the tag in the room, given that tag is in the room, we use equation 3.18

$$g(r) = \frac{1}{2}\mathrm{T_e} + h(r) \tag{3.18}$$

As r decreases, the time to find the approximate location is increased, but the time to do the fine search increases.

3.5.2. Travelling Route Determination by Heuristic Method

We used a heuristic approach to search from beginning to end. It is the basic approach but this heuristic method was applied because the given information about the whereabouts of the item in the room is unclear.

In this heuristic method, both distance and probability are considered to decide a travelling route. In other words, every single time a searcher travels within the room, the searcher decides the next section based on the distance from current location and the probability of the tagged asset location.

Entering the room, a searcher tours all sections of the room in order, from the left section to the right, and from the upper section location to the lower section. The section that the searcher visits initially is given the lowest index. To avoid detecting the tag in the other section during searching of the current section of a room, we need to restate t_e mentioned before. Thus, with a handheld RF reader, the time to do an exhaustive search of a section, when the searching path is given below.

Let R_c be the repeated number of searches from edge to edge in each section from top to bottom. That is

$$R_c = \frac{y}{2r} \qquad (3.19)$$

The value of R_c is then rounded up to the nearest integer. and t_e is restated in equation 3.23.

$$t_e = \frac{y}{2r} \times R_c \qquad (3.20)$$

Since each section that has the same probability for containing the tagged item is uniformly distributed, let $S_i(i = 1,2 \cdots, N)$ denote the probability that the tagged item is located in subsection i. We can generalise the total expected time to do an exhaustive search of the entire room with the handheld reader.

(1) Amount of time to search for the tag in a section 1, we use equation 3.21.

$$\bar{s}_1 \times \left(\frac{x}{v_1} \times R_c \times \frac{1}{2}\right) = s_1 \times t_e \times \frac{1}{2} \qquad (3.21)$$

(2) Amount of time to search for the tag in a section 2, we use equation 322.

$$\bar{s}_2 \times \left(t_e + t_e \times \frac{1}{2}\right) \quad (3.22)$$

(i) Amount of time to search for the tag in a section of the room I, we use equation 3.23.

$$\bar{s}_{\mathrm{i}} \times \left((i-1) \times t_e \times \frac{1}{2}\right) \quad (3.23)$$

Therefore, the expected time to find the item when doing an exhaustive search of the entire room uses formula 3.24.

$$|\boldsymbol{E}^{\mathbf{1}}[\boldsymbol{T}] = \sum_{i=1}^{S} \bar{s}_1 \times \left((i-1) \times t_e + t_e \times \frac{1}{2}\right) \quad (3.24)$$

3.6. Conclusion

This chapter outlined the research methodology and design approach for tracking an asset, using a hybrid solution, outside and inside a room in a building

We set up two models in this chapter: a model for tracking the tagged asset using a GPS module outside of a building and a RF module for tracking the asset inside a room where GPS could not be used owing to signal limitations.

In order for a position to be accurately determined by each GPS satellite, a satellite's position with three coordinates, along with the module/user's coordinates and distance between a satellite and user, is used to determine a module's position with reference to a specific satellite. Formula 3.1 was then used to determine the location.

Four satellites were used in order to track, monitor and locate an asset using GPS. After calculating the position of the four satellites we then calculated the latitude φ_u and longitude, λ_u as well as the height above sea level of the tagged asset.

Following that, we calculated the distance between two known points, that is, where the tagged asset was meant to be and where it had been moved to; this is known as the position between two receivers with latitude and longitude equation. We then discussed the basic interface design that was used to monitor the tagged asset with a graphical user interface application, and setting up a geofence and receiving notifications from it.

The second section of this chapter covered the RF model, which was used in tracking the tagged asset inside the room. We used a handheld RF reader in order to communicate with the RF module that is tagged on the asset. The width and length, known as the area of the room, was taken into consideration before trying to locate the asset. As the location of the item in the room was unclear, the searcher moved in in a methodical way from top left to the bottom right in a segmented room to avoid overlapping,, known as a heuristic method, Entering the room, a searcher toured all sections of the room in order, from the left section to the right, and from the upper section location to the lower section. This exhaustive search was done until the asset was located in the room.

CHAPTER FOUR: DATA ANALYSIS AND RESULTS

4.1. Introduction

The purpose of this chapter is to present and discuss the findings of the experiments conducted in the previous chapter. The discussion is based on data obtained from tracking an asset, using hybrid technologies. The findings are presented in both graphical and narrative formats The research and experiment focused on utilisng global positioning system (GPS) and radio frequency (RF) to track a particular asset inside and outside of buildings, along with the potential benefits of each. The chapter further contains the results obtained to answer the research questions of the study. A chosen asset was installed with a particular GPS chip and RF chip in order for us to prove our theory.

The main objective was to develop an understanding of what has been achieved in the tracking of assets inside and outside buildings by first investigating what has been done in the literature to develop an optimal solution in the adoption of the current technologies and to establish whether hybrid technologies can be adopted, and then to recommend the most suitable solution. The findings presented in this chapter demonstrate the potential for using multiple technologies to achieve our objective.

4.2 Observation and Interpretation of Results

After having simulated and built an asset-tracking solution, the performance of the system was intently scrutinised and the results gave a meaningful and significant conclusion. A model was chosen and a number of assets were tested against the model. A fixed asset in the form of a smart TV and a mobile asset in the form of a mobile vehicle were used in our test environemnt. The properties of the chosen assets had an impact on the model that was chosen. It was discovered that some properties of both assets played a role in the outcome of the results.

4.3 Experimental Setup

In light of the required technologies discussed in chapter 3 and the detailed analysis of how GPS and RF technologies communicate, the application built required that the design use the correct methodology, libraries, data structures, design, and design patterns, while not compromising user experience and security; the maintenance and testing processes which enhance and guarantee the solution’s robustness are also paramount. An asset fitted with a GPS and RF module was tracked from one location to another; it was placed inside a room where GPS could not locate it and so RF had to be used to locate it. The RF technology was then tested under different environments in the specified room. The results, outputs and systems used are then discussed.

Firstly, a Samsung LED TV model C21FCS unit was installed with a GPS module and RF module, as seen in the diagrams 4.1 below.

Figure 4.1: GPS AND RF Interior Tagged Samsung LED TV

A tracking application platform was then built that allowed the user to locate and trace the desired asset through the application interface. The interface is used to set up some trigger parameters that allow the user not only to see that it has been triggered but also to be automatically notified.

4.3.1 Design Interface

A user is presented with a login screen which requires him to provide his login credentials in order to access the platform. Controls were primarily designed to allow them to change without altering the source code, which gives us flexibility for different screen orientations to be handled on the fly by the framework. This allows for the application to handle differently on mobile devices as well as desktop devices. The **figures 4.2** and **figure 4.3** below reflect this.

Figure 4.2: Desktop Interface Tracking application login page

Figure 4.3: Mobile Interface Tracking application login page

4.3.2 Unit Setup

The **figures 4.4 and 4.5** below show the main view after the user has successfully logged onto the platform. The user is presented with a variety of options that not only allow the user to monitor the asset but also change reporting settings for the GPS unit. If an area has more than one unit in close proximity to another, the system reflects this with a blue bubble, indicating the total number of assets being tracked within the area. Secondly, for RF, the system displays RF active towers. This is so that a user can select a tower to see if a tagged item is within range of a specified RF tower.

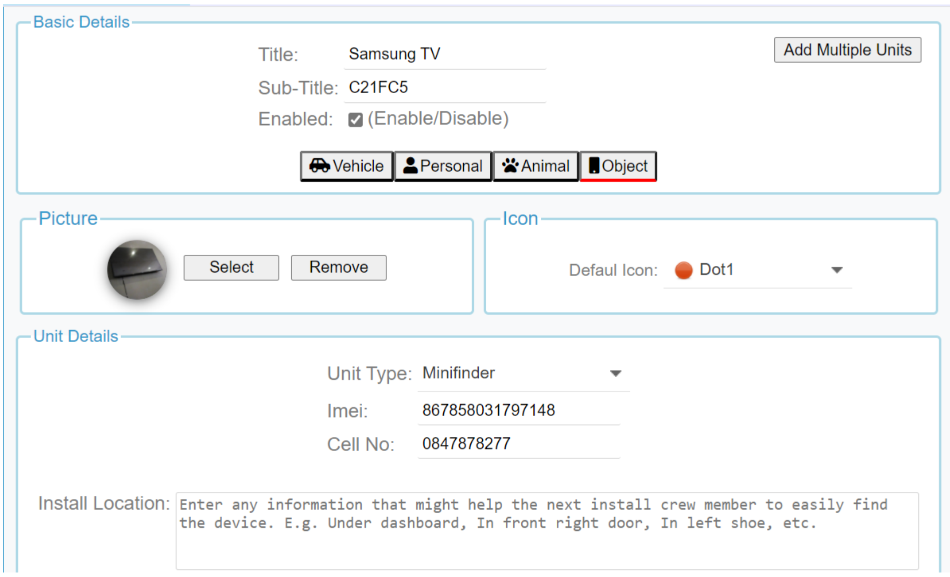

Figure 4.4: GPS unit setup interface

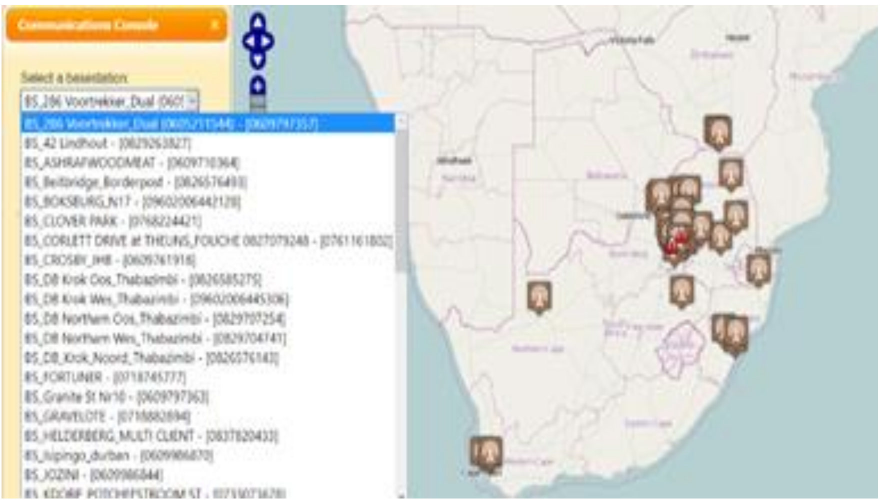

Figure 4.5: RF unit setup interface

Secondly, the GPS reporting interval is set, meaning that the number of times it is to send data packets are controlled, along with the alerts for the RF unit, as seen in **figures 4.6 and 4.7.**

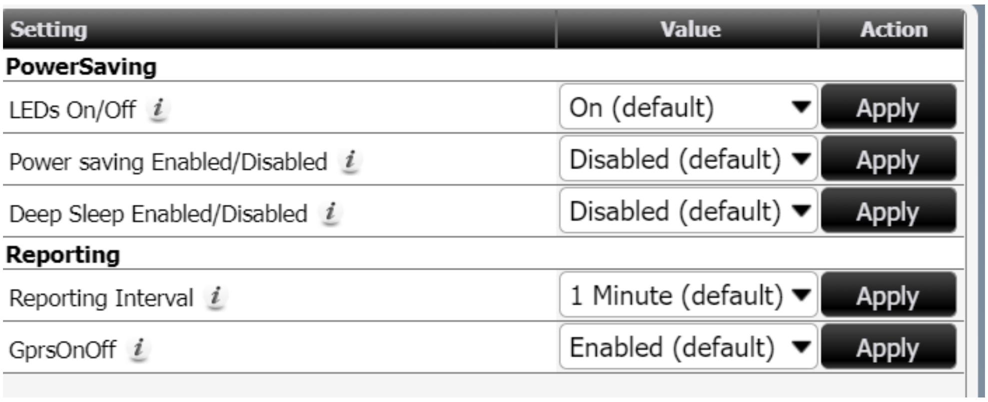

Figure 4.6: GPS unit alert report interval setup interface

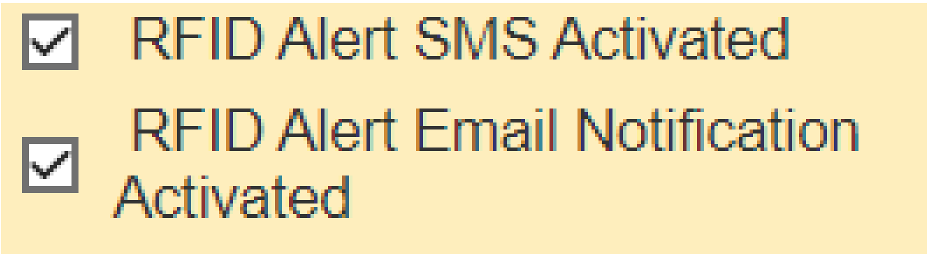

Figure 4.7: RF unit alert notification setup interface

4.3.3 Geofencing

A GPS geofence is a virtual barrier which is used to virtually ringfence an asset. The system is developed to provide the user with four geofence settings from which the user can choose. Forbidden areas are those areas which an asset is not allowed to enter. High-risk areas are those areas which have been identified by the user as having a high posibility of losing an asset. Designated areas are those that the user has identified as a safe area where an asset is allowed to operate. Normal geofence may be used as an area identified as a safe area, as seen in figure 4.8.

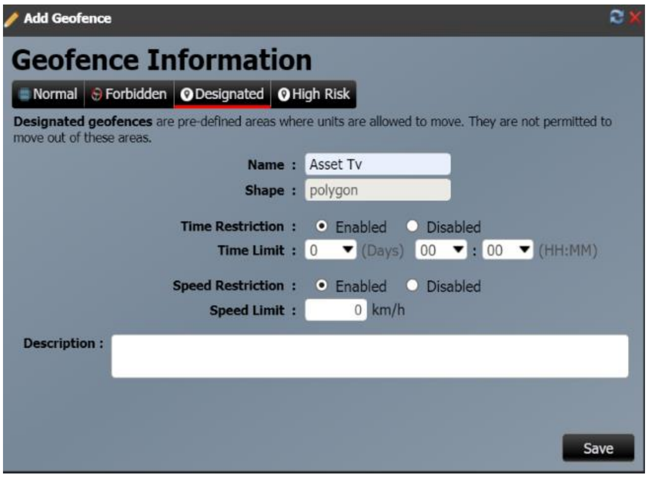

Figure 4.8: Geofence notification setup interface

To distinguish one area from the other, the system uses a colour identification scheme, as can be seen in **figure 4.9 and figure 4.10**. This allows the user to know which geofence has been violated. When a violation is triggered, an event notification is sent to the user, either via SMS, email or instant messaging application, as seen in **figure 4.11**.

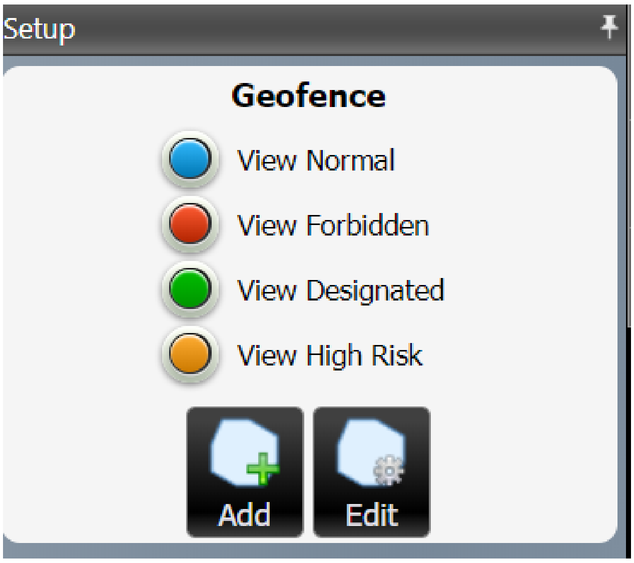

Figure 4.9: Geofence colour setup interface

Figure 4.10: VUT Geofence Setup

Figure 4.10 shows the GPS border setup at a University of Technology in Gauteng, South Africa. This fences the tagged asset within the geofence parameter. Once the asset leaves the University's premises, it violates the area in which the asset should be located at all times. A notification event, as in **figure 4.11,** is triggered through the GPS chipset, and received on the tracking monitoring system and Telegram Application. The tagged asset is then moved from the university's geofenced area, which triggers a geofence violation event. The asset is then tracked live outside of the building, using GPS as it moves, as seen in **figure 4.12**

Figures 4.13 shows a notification that is triggered when the asset violates the geofence areas. This is when the asset is moved beyond its designated area. **Figure 4.12** shows live tracking of the particular asset, using GPS.

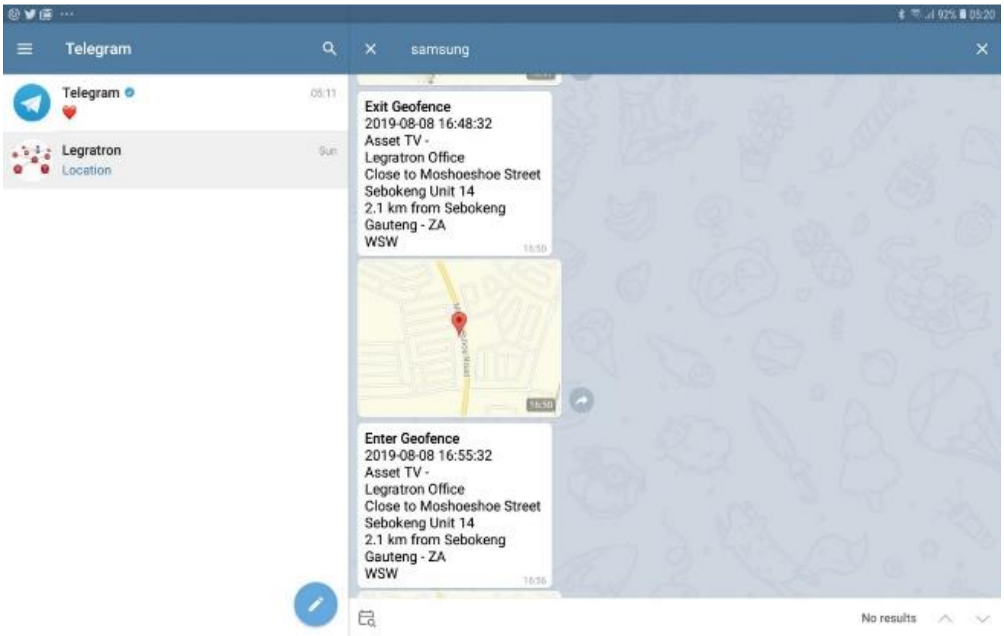

Figure 4.11: Geofence violation notification

4.4. Analysis and Discussion of Results

Results for GPS unit tracking and RF unit tracking are discussed in these sections.

4.4.1. GPS Unit Tracking

As the tagged item is *en route* after violating the geofence barrier, the GPS signal of the tagged asset is constantly reporting its live GPS position outside the building, as seen in **figure 4.12**

Figure 4.12: GPS live asset tracking

As the tagged asset moved from a set location where it was supposed to be and geofenced, the starting point was indicated by the green flag **(figure 4.13)** and the point where the asset has ended is indicated as point two in figure 4.13. This is where the unit was placed having travelled an approximate sum distance of 60.3 km, which is different from the straight line distance of 45.82 km. Upon reaching the set destination, this being a block of buildings, the longitude and latitude positions of the GPS module were recorded as 26.31867 and 28.003214, respectively, as the tagged asset entered a room at the set location, as seen in **figure 4.13 below**.

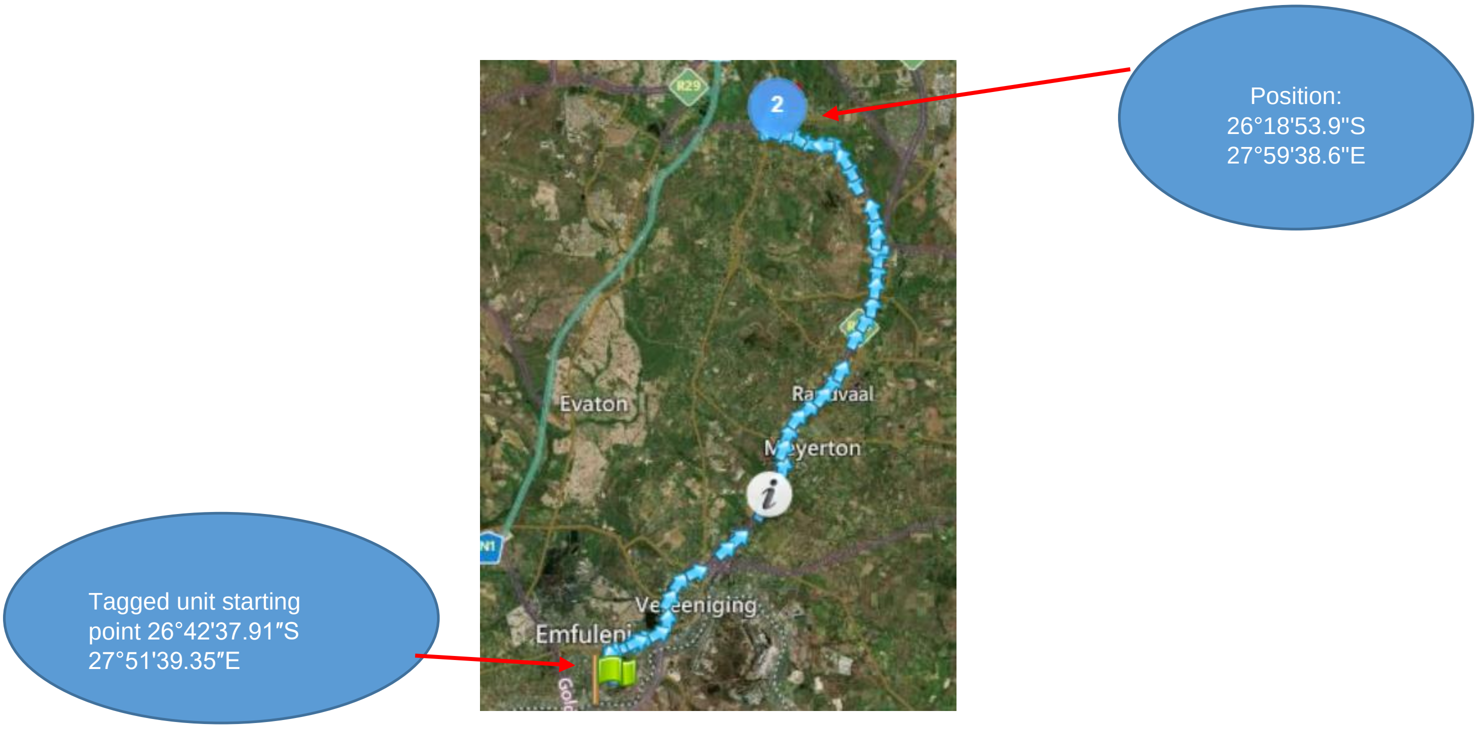

Figure 4.13: Unit Travel Route with Destination Coordinates

The asset was then moved from outside the building into a room inside the building, where GPS signal is lost. The last GPS position coordinates give an indication of the last place the asset was. Then, using a handheld RF reader with the assistance of the last position of the unit, GPS is used to get to the place. Considering that GPS does not transmit inside buildings or rooms, the unit's exact position inside the room at the set building could not be located.

4.4.2. Radio Frequency Unit Location

Upon reaching the building, the standard RF tag is woken up via a signal from the RF receiver. The receiver signal strength indicator (RSSI) measured in decibel-milliwatts dBm represents the measure of power received from a radio signal. The RF module is then activated using a RF handheld reader, depicted in **figure 4.14** and **figure 4.15.**

Figure 4.14: RF handheld receiver version

Figure 4.15: RF handheld receiver apparatus

To find an RF-tagged item indoors, a handheld RF reader was used, based on the following experiment. In this case, a tagged item was searched for using a handheld reader. The radius that we used for the RF reader to start searching for the tagged item was from 1 metre to 4 metres. The tagged item was in an enclosed room, which gave us a certain probability of detecting the asset in a subsection of the area, as in the table of probability below.

This means that the time it took to locate the tagged item and the area in which the tagged item was to be found would be divided into parts to make sure that the searched area was not repeated. Searching the room with a handheld RF reader is advantageous in that detection and location are conducted without unnecessary repeated calculations, In some instances, such as when a fixed reader is used, heuristics are used in order to locate tagged items,.

Three tests were then run inside the building in a room. The first test was conducted by placing the tagged asset in an empty room; the r was measured to determine the proximity of the tagged asset. The main aim was to get the RF handheld reader to illuminate a minimum of four bars for each search measuring. The RF reader was placed close to the tagged item and then moved further away. This was done in order to measure the change in attenuation as the distance increased between the RF transmitter and receiver.

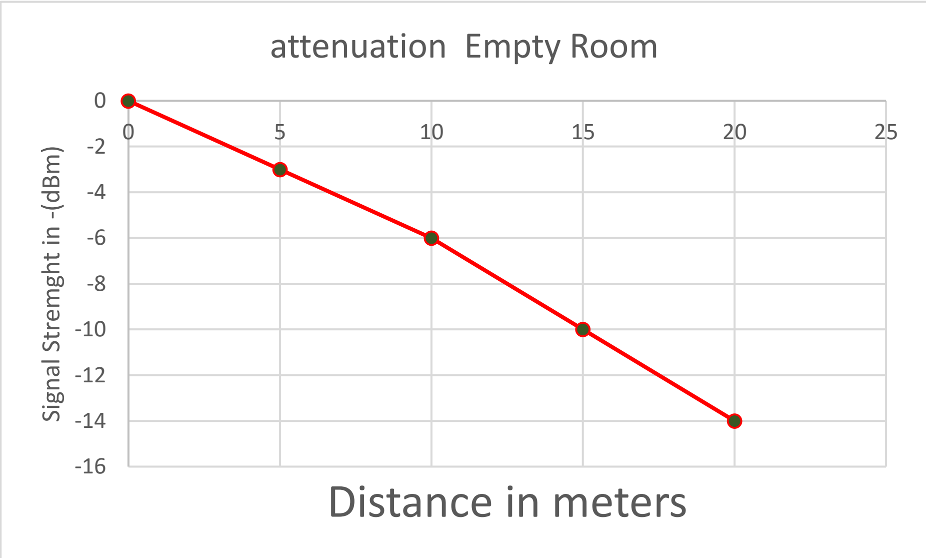

Figure 4.16: RF signal Attenuation in an empty room

As can be seen in **figure 4.16,** a tagged asset is located using radio frequency. As this decreases, the signal strength increases, which is measured in negative decibel-milliwatts. The was measured at various distance points in an empty room, measuring the power ratio of the signal strength. The closer the –dBm number is to zero, the stronger the signal. The handheld reader, on the other hand, indicates the signal strength by illuminating the eight led lights under the display screen, as seen in **figure 4.17** and **figure 4.18.** The minimal strength of -10dbm was the strength that we worked on.

Figure 4.17: RF at -10 dbm signal strength

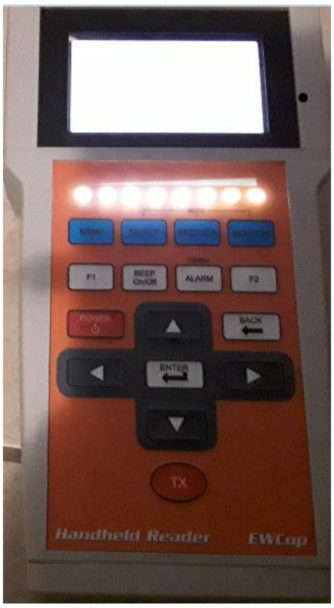

Figure 4.18: RF at -0.5 dbm signal strength

The experimental environment was then adjusted to see if and how different conditions affected the location of the tagged asset. This was done by moving the asset to different areas of the room, and also behind certain inhibitors such as a wooden cupboard, a brick wall and under a metal table. The activation of the RF transmitter and signal strength and attenuation, which is the measure of reduction of signal strength, were measured and recorded. The results were then tabulated, plotted on a graph and compared.

Table 4.1 Attenuation Signal Strength Results

Distance	Empty Room	Wooden Cupboard	Brick Wall	Under Metal Table
0m	0dbm	0dbm	0dbm	0dbm
5m	-3dbm	-3,45dbm	-3,66dbm	-4,4dbm
10m	-6dbm	-6,9dbm	-7,32dbm	-8,7dbm
15m	-10dbm	-11,5dbm	-12,2dbm	-14,5dbm
20m	-14dbm	-16,1dbm	-17,8dbm	-20,3dbm

Table 4.1 above shows the experimental results of the tagged asset. Searching for the asset in a room, we needed a reading of a minimum of -10dbm, which in turn confirmed the existence of the tagged item within the room. To visualise the data in table 4.1, the following figures 4.21 to 4.23 show how attenuation affects the reading of the RF reader.

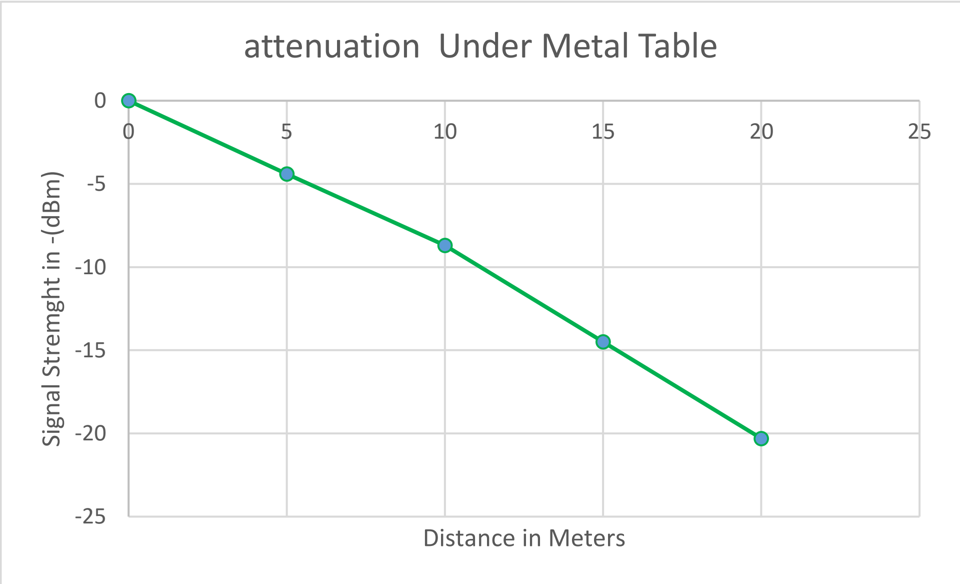

Figure 4.19: RF signal attenuation under a metal table

In **figure 4.19**, the graph shows that the radio frequency signal increases to the negative as the distance between the radio frequency-tagged item transmitter and the radio frequency received increases. The tagged item was placed under a metal table and searched for, compared with the same asset in an empty room. For us to get the required minimum -10dbm, the r value decreased from 15 metres to 11.25 metres. A percentage decrease of 45% was measured when the reader was at 15 metres for an empty room and after placing the RF-tagged item under a metal table, which increases attenuation.

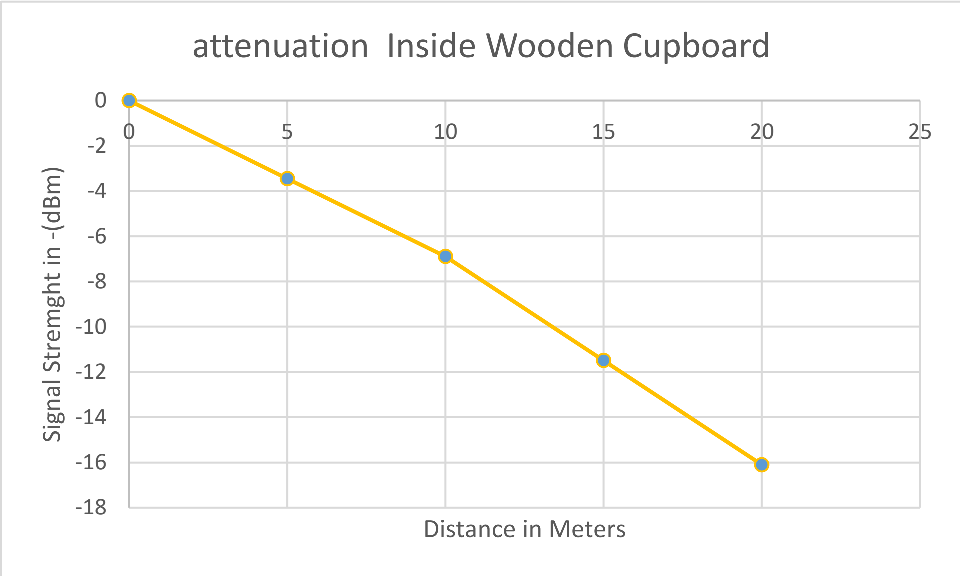

Figure 4.20: RF signal attenuation inside wooden cupboard

Figure 4.20, above, shows the results after placing the tagged item inside a wooden cupboard. The results measured showed that, compared with the same item in an empty room where the r value is 15 metres, there is a 15% drop in signal strength. The –dbm where r was 15 dropped from r = -10dbm to -11.5dbm.

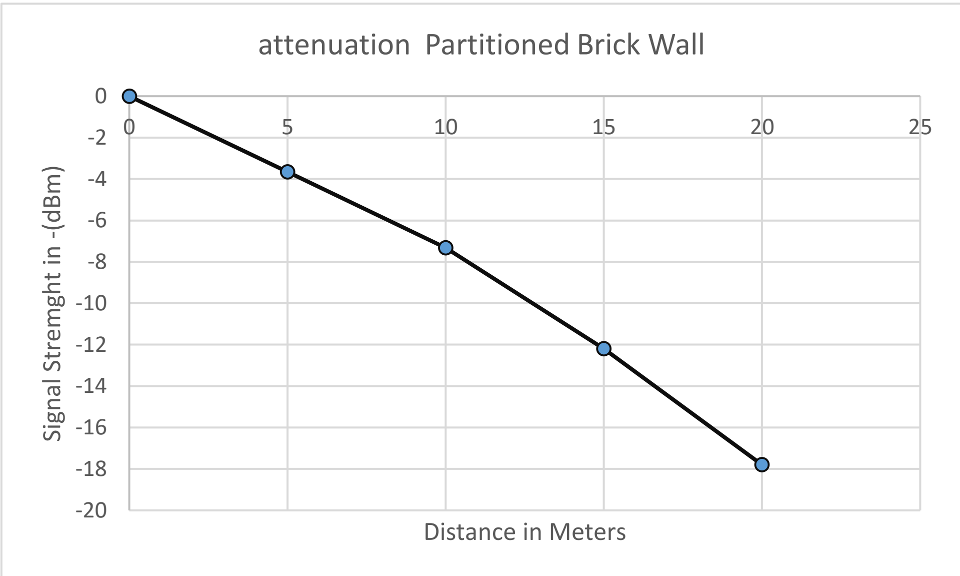

Figure 4.21: RF signal attenuation behind a brick partitioning wall

Figure 4.21 is a graph of the tagged asset that was placed in a partitioned room. The rooms are partitioned by a brick wall. At r =15 the signal strength dropped by 22% compared with when the tagged item was in an unpartitioned empty room.

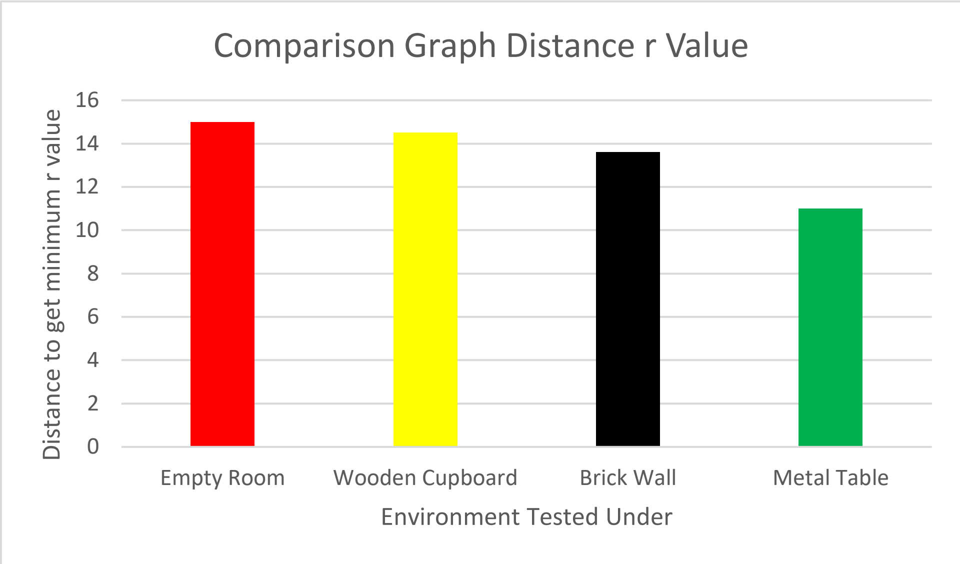

Figure 4.22: RF signal attenuation graph bar comparison

Figure 4.22, above, shows how the signal strength decreases affected by various obstacles and environments that could be found in a typical room. The results are tabulated in table 4.1. The bar graph is a comparison of a radio frequency transmitter-tagged asset being located inside a room. Four test conditions were tested inside the specific room. Firstly, the room was empty, except for the tagged asset. A mobile handheld signal receiver was used to locate the asset. The proximity of the receiver was then altered and signal strength recorded as the distance between the transmitter and receiver increased.

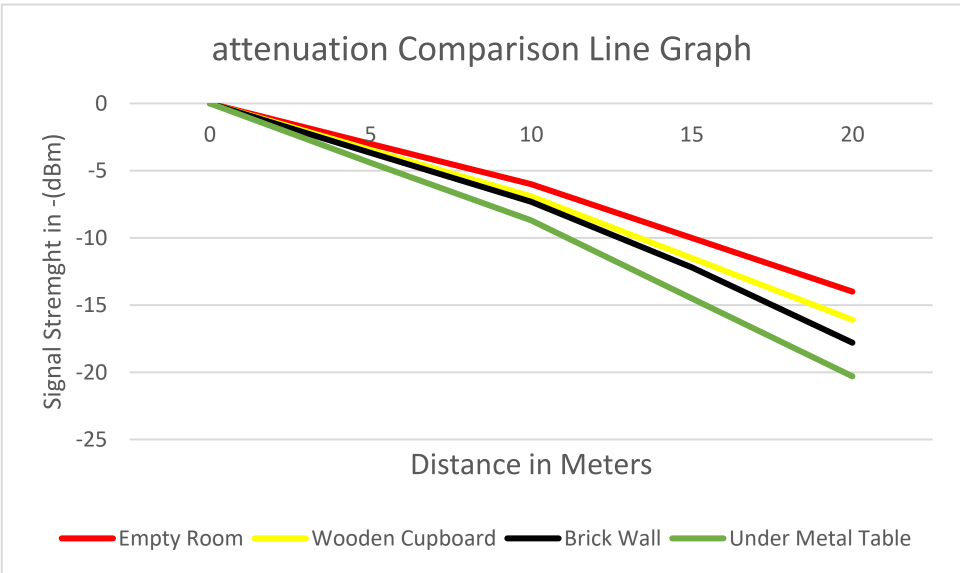

Figure 4.23: RF signal attenuation graph line comparison

Figure 4.23 shows how signal strength degradation at various r points is affected by the various items. As discussed, the optimal minimum strength required for the handheld reader is -10dbm, which illuminates four LED lights on the handheld receiver to indicate the presence of the tagged item in the room. **Figure 4.2.3** shows that this required reading was attained at different r values in a room that had various items.

In an empty room, the r value required is 15 metres; however, in a room that has metal the r value was roughly 13 metres, and in a room that has wood, the r value is 9.6 metres, etc.

This means that if a room has both metal and wood, the r value is the average of the two, which is 11.3 meters.

The demarcation of a room using heuristic search shown in chapter 3 figure 3 was influenced by the type of material in the room, that is, depending on what types of obstacles are found in a room, a searcher is able to determine how to search the particular room for a tagged asset.

4.5. Chapter Summary

In this chapter we presented, analysed, compared and discussed a hybrid solution of tracking, monitoring and locating an asset using GPS and RF technologies inside and outside of buildings. A technological tracking platform was then described, explaining how a user would activate and set up the various modules that are used to achieve our objective. It is evident that the solution can be used to locate tagged assets for security and other solutions.

Graphical comparisons were used based on the various attenuation tests that were done. Furthermore, the tagged asset was placed in different environments and areas so that the signal strength and GPS accuracy were tested, inside and outside buildings.

CHAPTER FIVE: DISCUSSION AND RECOMMENDATIONS

5.1. Introduction

The monitoring, tracking and location of assets inside and outside of buildings is paramount, not only to protect the safety of assets but also to assist with asset management, be it for personal or business use. Knowing where your assets are and being able to locate them is not only a want but a need.

In this study we looked at a hybrid model in the tracking of an asset and we also built a model and designed and implemented it to achieve our objectives. An asset was tagged with a GPS and RF module, which was then moved from its actual position to an unknown place.

Results showed that the model works in both environments and where one technology lags, the other has the capability and robustness to locate the asset.

5.2. Objectives

The objectives of this research were fulfilled as follows:

5.2.1. Objective One

Objective one was to investigate the literature for technologies used in mobile asset tracking.

This objective was thoroughly covered in chapter two in the literature review to find what technology had been used to track items. Various technology models were explored in the literature review, where distinct technologies such as Bluetooth and Radio Frequency were used by Bisio et al. (2015) and Sultana et al. (2016), who utilised the Global Positioning System (GPS) and Wi-Fi. The technologies had their limitations, however. as per the literature review. Advancements in the technology space have allowed a hybrid of technologies to be linked and used to achieve the aforementioned objective. In addition, a low-cost DGPS was developed by Lawrence (2013), using two smartphones with 3G to try to achieve the same objective.

5.2.1. Objective Two

The second objective was to investigate what mechanism can be used to track mobile assets inside and outside buildings.

The mechanisms of GPS and RF were proposed in the thesis, allowing us to use the advantages of both technologies but also overcoming the disadvantages of each technology, as discussed by Sweeney (2006). We also tested their robustness. GPS was tested outside of buildings along with geofencing events. The GPS mechanism was also tested to find the route and distance that the object had travelled while the asset was in being moved from its original location. RF was tested inside a room in a building using different materials as obstacles which affect attenuation in the room through the use of a handheld RF receiver which picked up the RF transmitter signal.

The findings showed that that the hybrid solution of integrating GPS and RF provided the mechanism that we required to be able to track an asset inside and outside of buildings.

5.2.3. Objective Three

The third objective was how to develop a prototype of a mobile asset for tracking outside and inside buildings.

We developed a prototype application based on the principles of Agile development, which allowed us to deliver the prototype service at a higher frequency, as opposed to the Waterfall development strategy. The development of the prototype was based on the advantages and disadvantages of each technology. Compatibility and security of the technologies were also major factors in the development of the prototype. Factors such as cost, ease of use and integration, reliability and uptime of the technologies were considered when implementing the prototype. Combining Global Positioning Systems and Radio Frequency, along with developing Graphical User Interface (GUI) monitoring and reporting, we were able to locate the tagged asset. The prototype was tested and it proved to be effective.

5.2.4. Objective Four

The fourth objective was to evaluate the effectiveness of the prototype.

The results in chapter 4 detail the effectiveness of the prototype through graphical images showing how the tagged asset was able to monitored, tracked and located, using proposed hybrid technologies. Signal strength and latitudinal and longitudinal accuracy were also measured. The tagged item was also placed In different environments in the room, where the attenuation effect was also measured and discussed. The distance between the GPS points was an approximation because GPS drift is a factor. The RF gave the area where the device could be found. Adoption of the proposed prototype not only reaps the benefits of the solution but can also be expanded to accommodate other environments such as logistics.

5.3. Suggestions

Tracking of assets is an on-going project, especially in densely populated areas. To ensure its success, a lot of investment in terms of the infrastructure has to be made. Issues such as GPS drift may still present issues in terms of accuracy and attenuation of signal still has its shortcomings. The technological readiness of individuals and businesses must be taken into account before the implementation of such a technology. Bluetooth Near Field Communication technologies can be looked at as cheaper technology options for tracking inside buildings as they consume less power.

5.4. Conclusion

The main aim of this study was to propose and develop a hybrid solution for tracking assets both inside and outside of buildings by combining raw satellite GPS coordinates for outside tracking with radio frequency. Taking attenuation into account, we were able to achieve accurate localisation. This study also investigated how to improve asset tracking of moveable assets inside and outside of buildings. We managed to show that the hybrid use of GPS and RF can be considered an improvement in tracking of movable assets inside and outside of buildings. Our work is comparable with that of Pawlowski (2015), Pachica (2017) Masum (2013), Fisher (2012) and Knežević (2015). While most of these studies employ only simple-point positioning, our study improved on this in that we used events such as geofencing, and asset route travel calculations for GPS took into account how obstacles impaired RF signal, which in essence affects the attenuation.

5.5. Future Work

The tracking of assets can be expanded not only to the physical location of the asset but also to tracking and learning the asset's behaviour by incorporating artificial intelligence models that can pick up trends and track and learn the behaviour of such an asset.

No complex computer security issues were addressed. Further, the web server provides no way of restricting access to the location data. Authentication and encryption procedures could be implemented to solve these problems. Lastly, by building more client devices and expanding the server program, the system could be converted into a fully functional multi-client tracking system.

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