Dissertation

Master in Computer Engineering – Mobile Computing

Autonomous Wheelchair with a Smart Driving Mode and a Wi-Fi Positioning System

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Abstract

Wheelchairs are an important aid that enhances the mobility of people with several types of disabilities. Therefore, there has been considerable research and development on wheelchairs to meet the needs of the disabled. Since the early manual wheelchairs to their more recent electric powered counterparts, advancements have focused on improving autonomy in mobility. Other developments, such as Internet advancements, have developed the concept of the Internet of Things (IoT). This is a promising area that has been studied to enhance the independent operation of the electrical wheelchairs by enabling autonomous navigation and obstacle avoidance. This dissertation describes shortly the design of an autonomous wheelchair of the IPL/IT (Instituto Politécnico de Leiria/Instituto de Telecomunicações) with smart driving features for persons with visual impairments. The objective is to improve the prototype of an intelligent wheelchair. The first prototype of the wheelchair was built to control it by voice, ocular movements, and GPS (Global Positioning System). Furthermore, the IPL/IT wheelchair acquired a remote control feature which could prove useful for persons with low levels of visual impairment. This tele-assistance mode will be helpful to the family of the wheelchair user or, simply, to a health care assistant. Indoor and outdoor positioning systems, with printed directional Wi-Fi antennas, have been deployed to enable a precise location of our wheelchair. The underlying framework for the wheelchair system is the IPL/IT low cost autonomous wheelchair prototype that is based on IoT technology for improved affordability.

Keywords:

Indoor positioning system, autonomous wheelchair, Internet of Things (IoT), Raspberry PI.

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ListofAcronyms

ARIA→Active media Robotics Interface for Applications Software

AOA→Angle-of-Arrival

API→Application Programming Interface

AI→Artificial Intelligence

CDC→Centers for Disease Control and Prevention

CCD→Charge-Coupled Device

DPDT→ Double Pole Double Throw

DSR→Design Science Research

DS→Design Science

DSRM→DS Research Methodology

EOG→Electro Oculo Graphic

GIS→geographic information systems

GPS→Global Positioning System

IR→Infra-Red

IPL→InstitutoPolitécnico De Leiria

IoT→Internet of Things

LRF→Laser range finders

Maid→Mobility Aid for Elderly and Disabled People

MIT→Massachusetts Institute of Technology

MEMS→Micro-Electro-Mechanical Systems

Mavs→Mobility Assisting Vehicles

MPI→Multi-Path Interference

NLPR→National Laboratory of Pattern Recognition

OMNI→Office wheelchair with high Maneuverability and Navigational Intelligence

POMDP→Partially Observable Markov Decision Process

RFID→Radio-Frequency Identification

RSSI→Received Signal Strength Indication

RSS→Received Signal Strength

US→Ultrasonic Sensors

UWB→Ultra-Wideband

UAV→Unmanned Aerial Vehicle

VAHM→Vehicle Autonome pour Handicapé Moteur

WSN→Wireless Sensor Network

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1. Introduction

This dissertation builds upon previous research in the IPL/IT (Instituto Politécnico de Leiria/Instituto de Telecomunicações) Low Cost Autonomous Wheelchair. This project is based on a low-cost prototype of a wheelchair which can be both voice- and eye-controlled by a user. Nevertheless, the previous prototype is able to avoid collisions by analyzing images of the area surrounding by the wheelchair. Moreover, the IPL/IT wheelchair prototype has the ability to transform a non-motorized wheelchair in a low cost electrical wheelchair.

The first prototype was constructed using a low cost laptop, a National Instrument data acquisition board, two 24 Volts motors with gears, two wheels, one headset, two webcams and one helmet. Furthermore, for the second version of the prototype, a GPS driving mode was implemented. The current project attempts to refine this last prototype to further reduce its cost and implement new useful technologies. Technologies utilized in this new endeavor will include enhanced indoor and outdoor positioning systems and the usage of wireless sensors in the context of Internet of Things (IoT).

1.1. Background

The independent mobility of humans will be one of the crucial issues of the coming century as the number of individuals who suffers mobility impairment is on the rise across the globe. A study by Centers for Disease Control and Prevention (CDC) estimated that around two million people in America depend on wheelchairs for day-to-day tasks and mobility (Alsibai&Manap, 2015). Hence, wheelchairs are one of the important devices in the contemporary world since it plays a vital role in determining the quality of life for individuals with mobility impairments such as wheelchair users (Thaper et al., 2004). Manual or electrical wheelchairs serve the purpose for most cases. However, the majority of the individuals who use these wheelchairs may encounter an array of barriers during their activities of daily living. The barriers comprised of bad weather, narrow aisles, door handles or door pressure, no ramps or steep ramps, travel surfaces, no curb cuts or blocked cuts,obstructed travel, etc. (Meyers et al.,2002). Another difficulty they face is the complexity in the usage. Majority find it difficult to learn and use the features, which in turn put a hindrance on their path to integrate more into the community (Mclain et al., 1993). The lack of information regarding the favorable and safest path to the destination makes many individuals hesitant to visit unfamiliar places because they have no information about the new environment and its accessibility conditions (Thaper et al., 2004). They are left with no option other than to rely on repetitive and regular routes with least obstructions for their daily movement. Even these routes are not expected to be free from hindrances, such as icy walkway, road blockades, etc. This problem can be overcome by providing accurate and reliable prior information about access and mobility options, which would help to facilitate safe and effective wheelchair navigation around unfamiliar environments.

Research related to proper navigation started in the early 1980s at Stanford University, which explored the application of Ultrasonic Sensors (US) to an adapted wheelchair. Later, in the 1990s, other researchers across the world began their work in developing innovative Mobility Assisting vehicles (MAVs) which were similar to standard mobile robot with a set of motors, wheels, sensors and controllers (Levine et al., 1999). Those activities were spreading out throughout the world in the pursuit of the so-called Intelligent Wheelchair (IW). Some of the recent advances in modern wireless communication technology, remote sensing technology, geographic information systems (GIS), navigation technology (GPS) and intelligent information systems pave the way to develop navigation aids for the blind and visually impaired. However, the use of such systems for the navigation in wheelchairs is still under explored. Existing car navigation systems are also inappropriate for wheelchair navigation mainly because of the lack of relevant information to wheelchair accessibility like sidewalks, sidewalk conditions including grade, steps, smoothness and building conditions.

Majority of the research until now has been focused on developing ‘smart’ wheelchairs for navigation assistance in indoor environments only (Simpson et al., 2004). They use sensors to detect obstacles and make use of computer vision or environmental markers for the purpose of localization and navigation. Even though some works targeted outdoor navigation by using GPS and other sensors (Imamura et al., 2004), they largely focused on obstacle detection and autonomous navigation and failed to explore the identification of infrastructure of the environment and accessible route planning. Numerous studies pointed out the application of GPS and GIS in developing navigation maps for individuals with disabilities. The study by Beale et al., (2000) developed a GIS based navigation system for wheelchair users in urban areas. Kurihara et al.,(2004) proposed a general architecture of GIS, aimed to assist the users in building barrier free street maps by using the Internet and the highly accurate GPS. The authors Sobek and Miller (2006) introduced a web-based system which helps the differently abled pedestrians in routing. This system was also capable of performing analytical evaluation of existing infrastructure. However, all of these systems failed in providing real-time navigation assistance to wheelchair users.

1.2. Autonomous Wheelchairs

An autonomous wheelchair or smart wheelchair is “a uniquely modified powered wheelchair which is equipped with a control system and variant sensors” (Alsibai&Manap, 2015). It is also called as a mobile robot base to which a seat has been attached (Simpson, 2005). Smart wheelchairs are designed to provide assistance to users who are suffering with severe mobility impairment, visual impairments, etc. The primary purpose of the autonomous wheelchair is to reduce or eliminate the user's full responsibility on moving the wheelchair. They are also specifically designed with respect to the user’s situations and disabilities. A smart wheelchair comes in two different forms, one is a standard power wheelchair to which a computer and a collection of sensors have been added and the second one is a mobile robot base to which a seat has been attached. Early smart wheelchairs were mobile robots to which seats were added. The majority of smart wheelchairs designed and available in the markets are the heavily modified versions of commercially available power wheelchairs and Office wheelchair with high Maneuverability and Navigational Intelligence (Simpson, 2005).

1.2.1. General requirements

The designing of the autonomous wheelchairs invites the attention in two major areas; *adaptability to the individual* and fulfillment of *safety requirements*.

1.2.1.1. Adaptability to the Individual

Adaptability to the individual is the prime requirement that a smart wheelchair should have to gain the acceptance among the potential users. Especially the design of smart wheelchair to support persons with disabilities should consider the manner in which the remaining skills of the human operator could adequately be complemented by the design. Hence, the control systems in the chairs are able to carry out tasks with the help of the human operator and his or her skills. Thus, a smart wheelchair is a highly interactive system which is together controlled by the human operator and the software of the device.

1.2.1.2. Safety requirements

The functional area of smart wheelchairs is directly in touch with the people who have some sort of impairment. Hence, their malfunction could cause severe harm to people. For example, if the handicapped operator of the wheelchair instructs the vehicle to go to the medicine cabinet, the dependable execution of the command might be critical to life. Therefore, these devices have to be considered as *safety-critical systems.* Taking this into account the manufacturers used formal methods like hazard analysis techniques and model checking to define the safety requirements of the system (Lankenau et al., 1998).

1.2.2. Functionality

The functionality of the wheelchairs varies with respect to the targeted group. Adaptability and easy to use are the two prime areas that should be targeted in the design of an autonomous wheelchair. A smart wheelchair should perform with high reliability and robust in the natural environment of its user. Configuration and the maintenance of the functional blocks have to be as intuitive as possible so that a company technical staff can handle it without the help of any robotic expert. The major functions and the respective functional blocks in the wheelchair are described in the upcoming section.

1.2.2.1. Human-machine interface

Joysticks are the widely used standard input devices to give instructions and commands. The Voice recognition system which involves the recognition of the human voice to move the wheelchair is also popular among the users. Wheelesley project used the human operator to control the wheelchair with the help of high-level commands via a graphical user interface on a notebook (Yanco, 1998). The SIAMO (Spanish acronym for Integral system for assisted mobility) project adopted a Charged coupled device (CCD) micro camera, mounted in front of the user in order to track his or her face (Lankenau&Rofer, 2000). Another interesting input method that has been implemented involve detection of the wheelchair user's sight path through electro oculo graphic (EOG) activity (Yanco, 1998). Again,some also make use of machine vision to calculate the position and orientation of the wheelchair user's head (Simpson, 2005). The projects, such as INRO and the RobChair made use of radio link from the wheelchair to remote station for different tele-operation purposes (Lankenau&Rofer, 2000).

1.2.2.2. Obstacle detection

Sensors

Various types of sensors are used to detect and avoid obstacles that come in the path of the movement of wheelchairs. The most popular and frequently used sensors are the ultrasonic sensors (sonar).Their accuracy in detecting the object and low cost makes them popular. The accuracy depends on the sound wave emitted by the sensors strikes the object at right angles. However, as the angle of incidence increases, the possibility of negating the reflection of sound wave toward the sensor also increases. The effect is more evident if the object is smooth or sound absorbent. One major drawback is that sonar sensors are vulnerable to "cross talk," the phenomenon which is characterized as the production of unwanted echo by the signal generated by one sensor, and is received by a different sensor. Another sensor which is frequently used is the infrared (IR) sensors. IR sensors detect the obstacle by emitting IR light and analyzing the interruptions. The main drawback of this sensor is that they can be misled by dark or light absorbent material and also suffers difficulty with translucent or refractive surfaces. Even though the limitations exist, both sonar and IR sensors are commonly used because they are compact, inexpensive, and easy to use.

Still, they are not particularly suited to identifying drop-offs, like curbs, stairs or potholes. For detecting such obstacles both sonar and IR sensors should face almost straight down toward the ground in order to receive an echo. In such case, the smart wheelchair would not have warning in enough time to stop. Such defects can overcome with the use of laser range finders (LRFs), which deliver a 180°, 2D scan within the plane of the hindrances in the surroundings. However, the main drawback of LRFs is their high expense. The consumption of large amount of power makes it difficult to provide complete coverage in moderate cost. "Laser striper," which consists of a laser emitter and a charge-coupled device (CCD) camera is another available sensor device used to detect the obstacles. This device relies on the discontinuities in the image of the laser stripe returned by the camera to calculate distances to obstacles and drop-offs. It is less expensive compared to LRF; however, the accuracy can be compromised when the stripe falls on glass or a dark surface. Again, there exists another sensor called machine sensor which by some researchers were considered as the most promising sensor technology.. This involves much smaller cameras which made it capable of mounting in multiple locations on a wheelchair with much ease. Cameras can also provide much greater sensor coverage. The lower cost is another advantage of these sensors.

Apart from all these available independent sensors, numerous smart wheelchairs, such as Véhicle Autonome pour Handicapé Moteur (VAHM), TAO (Japanese acronym), Office wheelchair with high Maneuverability and Navigational Intelligence(OMNI) & Rolland (Gomi& Griffith, 1998) use the combination of information from multiple sensors to locate obstacles. In this manner, the limitations of one sensor can be compensated by other sensors. If all other sensors are failed, the final line of defense is the bump sensor that is activated when a smart wheelchair comes in contact with an object.

1.2.2.3. Navigation

Smart wheelchairs use internal map to navigate autonomously to the destination. The use of this map ranges from specifying the connections between locations without any information regarding the distance (eg. topological map) to providing adequate information about the distance of the destination(eg. Metricmap).However, a major problem with internal map is the fact that it unambiguously pointed out the location of the wheelchair on the map. Apart from the wheelchairs which uses internal map, there also exists some other technologies, such as automated guided wheelchairs which follows the track laid on the floor to provide autonomous navigation... Some of the smart wheelchairs, such as TAO (Japanese acronym), National Laboratory of Pattern Recognition (NLPR) and Robotized Wheelchair (Simpson, 2005) use machine vision to identify naturally occurring landmarks in the environment, however, the majority create "artificial" landmarks that can be easily identified and linked with a unique location (Simpson, 2005). Furthermore, some other smart wheelchairs have used radio beacons (e.g., MAid, TetraNauta (Simpson, 2005)) or a “local” map which stores the location of obstacles in the wheelchair’s immediate vicinity and moves with the wheelchair (e.g., NavChair, Rolland, SENARIO, for the navigation purpose (Simpson, 2005). These local maps are referred as occupancy grids.

1.2.3. Benefits

In general, people with varying requirements can benefit from the different forms of assistance provided by a smart wheelchair (Simpson, LoPresti, & Cooper, 2008).Being independently mobile is of substantial benefit to both adults and children (Trefler, Fitzgerald, Hobson, Bursick, & Joseph, 2004). Overall, independent mobility enhances opportunities for occupation and education, decreases reliance on family members and caregivers, and stimulates mindsets of self-reliance. Declines in functional mobility are associated with decreased participation and reduced or impaired social connections (Simpson et al., 2008). The psychological effects of decreased mobility include beliefs of emotional loss, diminished self-confidence, loneliness, anxiety, and dread of rejection (Finlayson & van Denend, 2003).

Autonomous wheelchairs can navigate independently without user intervention. Hence, they can benefit persons:

- Who have cognitive disabilities and cannot recollect their destination, the route to get there, or have challenges with analytical functioning.
- Who become tired quickly, and hence find it difficult to traverse long distances.
- Who are visually impaired and hence cannot recognize (or have difficulty in recognizing) prompts in the environment that can aid in navigation (Simpson et al., 2008).

1.3. Internet of Things (IoT)

The Internet of Things (IoT) is the term used to describe the objects that are capable of communicating via the Internet. These objects which range from sensor inputs to actuators that control physical objects with new interactions, requires advances in machine and human interfaces. According to Haller et al.(2008) "A world where physical objects are seamlessly integrated into the information network, and where they, the physical objects, can become active participants in business processes. Services are available to interact with these 'smart objects' over the Internet, query their state and any information associated with them, taking into account security and privacy issues."

1.4. Definition of the problem

There has been significant research effort with regard to the building of autonomous wheelchairs (will be discussed in Chapter 2 for details of earlier research on autonomous wheelchairs). These investigations have been centered on different aspects of autonomous wheelchairs, such as the target users, safety requirements, navigation, obstacle detection, etc. Also, different researchers have placed emphasis on different means of localization and positioning systems. Localization systems help pinpoints the location of a person or an object by means of various techniques and complex positioning methods. These systems are connected in turn to intelligent objects which offer crucial information to facilitate route computation.

The current project proposes to improve the IPL/IT wheelchair prototype to include the implementation of a small ESP8266 Wi-Fi network positioned around the user of the wheelchair. Thus, different wireless devices will be able to communicate with the autonomous wheelchair through a Raspberry Pi (Prasad, Kumar &Parades, 2017) and an ESP8266 Wi-Fi access point device located inside the wheelchair. The wheelchair location and orientation will be estimated by a triangulation process, based on the angle of different Wi-Fi emitters with directional Yagi antennas.

In addition, this project will serve to implement two pending patents of the Polytechnic Institute of Leiria (IPL) and the Telecommunication Institute (IT).

IoT technologies can be used to implement a positioning system for the IPL autonomous wheelchair which will aid in controlling its movement and orientation.

1.5. Justification and Importance

Autonomous wheelchairs can be of considerable benefit to different target users, such as senior citizens and persons with different cognitive and physical impairments. However, most present day wheelchairs are prohibitively priced which limit their access to the users who can derive the most benefit from them. Consequently, the endeavor of this project to improve the existing IPL/IT autonomous wheelchair prototype with the objective of reducing its costs and refining its location and positioning functionality and features will be beneficial to such persons.

1.6. Scope

This project will improve the previous IPL/IT prototype by using IoT technologies and will implement a positioning system for the existing prototype. The wheelchair location will be obtained using a network of ESP8266 Wi-Fi emitters. All ESP8266 devices will be spread in a real indoor scenario and they will communicate with a receiver using a wireless network. The receivers will be NodeMCU (equipped with motorized Yagi Antennas) that will control the movements of the wheelchair after applying a triangulation process for the location.

1.7. Objectives

In general, the objective of the present project is to refine the IPL/IT wheelchair prototype with the intent of reducing its cost and expanding its functionality by incorporating location and positioning features.

Specifically, the purpose of the project is to improve the IPL/IT wheelchair prototype to include the implementation of a small ESP8266 Wi-Fi network. A Wi-Fi access point NodeMCU device located inside the wheelchair will be utilized to permit different wireless devices (clients) to communicate with the autonomous wheelchair. The wheelchair location and orientation will be estimated by a triangulation process, based on the angles of all Wi-Fi Yagi antennas.

In addition, this project will serve to implement two pending patents of the IPL and the IT, namely: *Standing Wave Cancellation and Shadow Zone Reducing Wireless Transmitter, System and Respective Method and Uses* (#109332, April, 2016) and *Standing Wave Cancellation – Wireless Transmitter, Receiver, System and Respective Method* (#109137, February, 2016).

1.8. Methodology

The Design Science (DS) in information systems research (IS) methodology (Hevner, March, Park, & Ram, 2004) was chosen as the research strategy for the project. This methodology is concerned with the creation of optimal artifacts and endeavors to satisfy three objectives: "S: it is consistent with prior literature, it provides a nominal process model for doing DS research, and it provides a mental model for presenting and evaluating DS research in IS"(Peffers, Tuunanen, Rothenberger, & Chatterjee, 2007, p. 46). The DS process comprises six steps: "problem identification and motivation, definition of the objectives for a solution, design and development, demonstration, evaluation, and communication" (Peffers et al., 2007, p. 46).

Table 1.1 summarizes the details of the phases of the DS process as applicable for the current project.

Table 1.1:Phases of the DS Process

Phase	Phase Name	Description
1.	Problem Identification	Search of the different positioning systems, which allowed to analyze the accuracy of different applications in both internal and external environments, through a methodical study of the techniques and devices to be located, which gives rise to the identification of the problem;
2.	Problem Motivation	The location of certain vehicles in critical places that have restricted access of the GPS signal, which causes the increase of positioning error and even the absolute loss of information;
3.	Definition of Objectives	According to the definition of problems, it was possible to establish which guidelines were taken into account, for the development and investigation of the device that managed to position with a minimum error of location in internal and external environments, for vehicles that have autonomous mobility;
4.	Designing	It is defined by the scope and functional and non-functional

Phase	Phase Name	Description
		requirements, which allowed to establish an optimum design that meets the needs of users, for the intelligent antenna location system and the optimization of a localization technique, that manage to position an autonomous vehicle in motion. This gives rise to the architecture that defines the actions of the system, which facilitated the development of use case diagrams that managed to specify the different operations that the system would perform;
5.	Developing	The implementation of the system was divided into three parts: (i) location system, (ii) Autonomous wheelchair system, (iii) and a patent validator. Each one of them has specific operations that managed to optimize the total application;
6.	Demonstration	The route that the autonomous wheelchair manages to perform is detected by the intelligent antennas and presented in the graphical interface, compared to the original path imposed by the user shows the positioning error reduced by the solution of the patent;
7.	Evaluation	To test the quality of the software, three detection nodes are used in different positions with the data collected, the analysis of the data was performed, comparing the data from the internal and external environment, and observing which one presents a better precision;
8.	Communication	It addresses two publications for the location precision error of the autonomous wheelchair.

1.9. Dissertation Structure

This chapter introduces the dissertation structure and provided an overview of the work proposed in this project. The rest of this dissertation is organized as follows:

Chapter 2 provides a review of state of the art related to the matter under consideration, that is, various aspects of different autonomous wheelchairs, different positioning systems, and so on.

Chapter 3 provides details of the terminology and technologies utilized of the proposed solution.

Chapter 4 describes the testing and results of the proposed solution.

Chapter 5summarizes conclusions of this project and areas for future research will be provided.

2. State of the Art

2.1. Introduction

The objective of this chapter is to provide an overview of the existing research and literature associated with autonomous wheelchairs in the context of the present project. Areas to be covered in the chapter include various aspects of autonomous wheelchairs, Internet of Things, positioning systems. An overview will also be provided of the relevant internal and external location systems in the context of the present project.

A brief discussion of the different types of smart wheelchairs is presented in the following section.

2.2. Types of Smart Wheelchairs

Different kinds of smart wheelchairs have been developed by researchers including autonomous and semi-autonomous wheelchairs. Some wheelchairs operate like autonomous robots. These autonomous wheelchairs, accept commands, such as 'go to goal,' and then design and implement a route to the destination without further human intervention while evading risks and obstacles on the way. This category of smart wheelchairs is best suited for users who do not have the capacity to design or implement a route to a destination (Zeng, 2008). Autonomous or supervisory control has been implemented in several wheelchair projects, such as the Autonomous wheelchair (Nagasaki University and Ube Technical College, Wang, Ishimatsu, &Mian, 1997), the CCPWNS (University of Notre Dame, Yoder, Baumgartner, &Skaar, 1996), the intelligent wheelchair (Osaka University, Kuno, Nakanishi, Murashima, Shimada, &Shirai, 1999a), the SmartChair (University of Pennsylvania, Parikh, Grassi, Kumar, & Okamoto, 2004), and the TAO wheelchair (Applied Artificial intelligence, Inc., Gomi& Griffith, 1998).

Other wheelchairs, such as the OMNI system (University at Hagen, Borgolte et al., 1995), the Tin Man II (KISS Institute for Practical Robotics, Miller & Slack, 1995), the smart wheelchair (Call Centre at University of Edinburgh, Nisbet, Craig, Odor, & Aitken, 1996), the NavChair (University of Michigan, Simpson, Levine, Bell, Jaros, Koren, &Borenstein, 1998), the Wheelesley (MIT, Yanco, 1998), the Rolland

(University of Bremen, Röfer&Lankenau, 2000), and the robotic wheelchair (FORTH, Argyros, Georgiadis, Trahanias, &Tsakiris, 2002), are examples of semi-autonomous or shared-control wheelchairs. Significant proportions of planning and navigation responsibilities are left to the user in such wheelchairs. Therefore, greater planning and continual effort are necessitated in these systems and are only suitable for users who can successfully design and implement a route to a destination (Zeng, 2008).

A third group of smart wheelchairs combine facets of both autonomous and semi-autonomous navigation. Examples of such wheelchairs include the Orpheus wheelchair, (National Technical University of Athens, Sgouros, Tsanakas, Papakonstantinou, &Katevas, 1996), the Senario wheelchair (TIDE, Katevas et al., 1997), and the VAHM wheelchair (University of Metz, Pruski, Ennaji, &Morere, 2002). Varying degrees of control from the wheelchair user are necessitated by a hierarchy of operating levels in these wheelchairs.

As this dissertation places emphasis on autonomous wheelchairs, the next section will provide a detailed examination of their different aspects.

2.3. Autonomous Wheelchairs

As described in the Introduction to this dissertation, autonomous wheelchairs are smart wheelchairs which are developed with the objective of lessening the mobility challenges encountered by persons with diminished mobility (Karim et al., 2017). The following sub-sections describe the essential components of autonomous wheelchairs, facets by which they can vary, principles of navigation, path planning and obstacle avoidance, and so on.

The next sub-section describes the essential components of autonomous wheelchairs.

2.3.1. Essential Components of Autonomous Wheelchairs

Autonomous wheelchairs are comprised of various components. In general, they are powered wheelchairs that have been fitted with an on-board computer and sensors (Simpson, LoPresti, Hayashi, Nourbakhsh, & Miller, 2004). Additionally, autonomous wheelchairs are designed to offer assistance with navigation in various ways, such as: escaping collision (Levine, Bell, Jaros, Simpson, Koren, &Borenstein, 1999; Yanco, 1998); facilitating certain actions (e.g., traversing doorways) (Bourhis&Sahnoun, 2007; Levine et al., 1999); and conveying the users across locations independently (Diaz, Rodriguez, Del Rio, Balcells, & Muniz, 2002; Seki, Kobayashi, Kamiya, Hikizu, & Nomura, 2000). The essential components of an autonomous wheelchair system are described in the following paragraphs.

2.3.1.1. Electronics and Sensors

A key feature that distinguishes autonomous wheelchairs from conventional manual or powered wheelchairs is their capacity to intervene. This is achieved by the installation of sensors which help the wheelchair understand its environment. The sensors are required to be small, light, accurate, low-priced, use less power, and be sufficiently tough to withstand the condition of the surroundings (Simpson, 2005). Typically, multiple sensors are utilised in a single wheelchair and include cameras, ultrasonic and infra-red (IR) range-finders, etc. (Tang, 2012).

The on-board computer is another significant element in any autonomous wheelchair. Its role is to deal with the inputs from the sensors and user and accordingly regulate the wheelchair (Simpson, 2005). The sensors usually include their own particular systems for data acquisition (DAQ), such as signal conditioning circuitry, analogue to digital converters, sensor electronics, and so on, and serial bus interfaces to the computer (e.g., CAN, I2C, RS232/RS422/RS485, USB) thus reducing the requirement for a high-priced and dedicated embedded controller board. Consequently, a PC or laptop has been frequently utilised as the chief source of processing power in research-based smart wheelchair projects (Levine et al., 1999; Matsumoto, Ino, &Ogsawara, 2001; Simpson et al., 2004; Yanco, 1998).

2.3.2. Methods for User Input

Joysticks have been the typical mode of control for powered wheelchairs (Simpson, 2005). While other options exist, the challenges associated with their configuration limit their use with powered wheelchairs. As a result, smart wheelchairs offer researchers the opportunity to experiment with varied and novel methods of user input. The following paragraphs describe a few methods utilised in smart and/or powered wheelchairs.

2.3.2.1. Joysticks

Fehr, Langbein, &Skaar (2000) reported that the most common mode used by users of power wheelchairs were a joystick, chin control, head control, or sip-and-puff. Since several persons find it difficult to manoeuvre the wheelchair in restricted spaces, to traverse doorways, to turn around in halls, or even simply going straight (Fehr et al., 2000), a mode used for user input is force-feedback joysticks which are a significant advancement over the piloting operation of conventional joysticks (Bourhis&Sahnoun, 2007; Brienza& Angelo, 1996). This feature indicates an active joystick which can offer feedback to the user. Force-feedback facilitated control joysticks can be implemented through the use of range-finding sensors and a control algorithm which regulates the degree of force feedback offered to the user depending on the closeness of the obstacle (Bourhis&Sahnoun, 2007; Brienza& Angelo, 1996).

Sip-and-puff devices, on the other hand, may be the answer for users who cannot utilise any part of their body to manipulate a device on a wheelchair. Such devices are triggered by the user's breath and are programmed to mimic the movements of a joystick by means of awareness of whether the user is sucking or blowing, and the power or length of a puff or a sip (Li, Kutbi, Li, Cai, Mordohai, & Hua, 2016). Other forms of devices reported include chin control and finger touchpads (Felzer&Nordman, 2007).

2.3.2.2. Voice recognition

Voice recognition can also be utilized as a manner of user input to wheelchairs and has been implemented successfully on several smart wheelchairs, such as NavChair, SENARIO, and The MIT Intelligent Wheelchair Project (Katevas et al., 1997; Levine et al., 1999; Massachusetts Institute of Technology (MIT), (2007-2017). This form of control is most advantageous for users who are afflicted with grave motor impairments (Levine et al., 1999).

In general, voice recognition control only applies to wheelchairs fitted with systems to detect and avoid obstacles since adequate control is not provided by low bandwidth devices (e.g., voice control) without the safeguard offered by obstacle evasion (Simpson, 2005). As a result, systems (e.g., NavChair) utilizing voice recognition employ its system for obstacle avoidance to fill in trivial, but suitable, commands for navigation (Tang, 2012).

Voice recognition systems have progressed from requiring the user to utter certain pre-defined keywords to allowing the use of natural speech (MIT, 2007-2017Simpson & Levine, 2002). The latter is accomplished by employing the Partially Observable Markov Decision Process (POMDP) since these models have the capacity to determine the intention of the user even when ambient noise, or unclear or indistinct language, for instance, are in existence (Doshi& Roy, 2007).

2.3.2.3. User expressions

User expressions have also been used to control wheelchairs by means of detecting the sight path of the user (i.e., where the user is looking). An approach used is electrooculography activity, i.e., where eye movements are recorded and interpreted, such as in the Wheelesley wheelchair (Yanco, 1998). Another approach is the use of computer vision to determine the position of a user’s head as utilised in the wheelchairs developed by Osaka University (Kuno, Shimada, &Shirai, 2003) and Watson (Matsumoto et al., 2001). Further, Kuno and colleagues (2003) submitted that systems utilising the user expression approach require to be integrated with information obtained from environment sensing as the control inputs originating from merely user expressions are typically accompanied by noise.

2.3.3. Navigation assistance

The forms of navigation assistance provided by smart wheelchairs to their users can range from simple collision avoidance, which leaves the users to perform planning and navigation tasks (e.g., the NavChair, Levine et al., 1999), to following targets (e.g., the MIT wheelchair,Hemachandra, Kollar, Roy, & Teller, 2011; MIT, 2007-2017), a function that does not require any alteration of the environment or the provision of prior information about the area to the system.

Another method of navigation assistance is to instruct the wheelchair to stay on set routes, such as through the use of neural networks. Instances of this method can be seen in the wheelchairs from The Chinese University of Hong Kong (Chow, Xu, & Tso, 2002) and The University of Plymouth (Bugmann, Robinson, &Koay, 2006). This method is appropriate for situations where preliminary training can be provided and settings are not likely to change, such as in homes for the elderly and wards in hospitals.

At the extreme end of the scale are smart wheelchairs which function in a manner similar to autonomous robots. In these cases, the user is required only to indicate the final destination and the wheelchair executes a path to the required location without any further user involvement. A complete map of the region to be navigated is frequently required by such systems (Tang, 2012).Instances of such wheelchairs are Kanazawa University (Seki et al., 2000) and TetraNauta (Diaz et al., 2002). Wheelchairs which implement such methods of navigation assistance are most appropriate for users who do not possess the capacity to design or execute a route to a destination and whose operation is primarily limited to the same setting (Simpson, 2005).

The next section describes the different areas in which autonomous wheelchairs can differ.

2.3.4. Areas of variance

Several groups have planned or built smart wheelchairs. Thus, a variety of techniques and concepts have been discussed or implemented. However, each group has progressed based on their points of interest or focus and thus, there is considerable variance in these. This section provides a summary of the principal areas of variance between different implementations of smart wheelchairs.

2.3.4.1. Mechanics

Most smart wheelchairs have been implemented by transforming already existing powered wheelchairs, such as the Maid (Mobility Aid for Elderly and Disabled people) robotic vehicle (Prassler, Scholz, Strobel, &Fiorini, 1999) and the Bremen Autonomous Wheelchair (Röfer&Lankenau, 2000). This method extends the existing wheelchair infrastructure by adding sensors and computing hardware. Thus, they are able to make the most of the control and motor systems which are hand. For example, servomotors are used in the Tin Man wheelchair to control the host wheelchair by means of an unmodified joystick (Miller & Slack, 1994).

Other wheelchairs have been created from scratch. Such wheelchairs improve conventional designs to enhance the opportunities to travel in difficult settings. They offer complex issues with regard to control but can generate remarkable outcomes. For example, four hydraulic, wheeled, robotic limbs were proposed in the wheelchair project by Lawn and Takeda (1998). The objective of this project was to create a wheelchair with the capacity to climb several stairs and to lift itself into vehicles. Another wheelchair model developed commercially can raise and balance itself solely on its rear wheels by means of complex gyroscopes and numerous Pentium processors (Bourke, 2001).

2.3.4.2. Sensor systems

Sensor systems utilised in autonomous wheelchairs can range from specialised systems, such as laser range finders and optical fibre gyroscopes (Prassler et al., 1999), to ultrasonic sensors and drive or wheel-based position encoders. Present day sensors include global positioning system (GPS) receivers, cameras for image processing, laser range finders, ultrasonic sensors, and infrared sensors which can be utilised for navigation and avoidance of obstacles (Hsieh, 2008).

Systems for collision avoidance frequently use ultrasonic range sensors. The number of sensors can vary. For example, some wheelchairs have used more than twenty sensors (e.g., Fioretti, Leo, &Longhi, 2000; Prassler et al., 1999; Röfer&Lankenau, 1999; Trahanias, Lourakis, Argyros, &Orphanoudakis, 1997) while others have utilised lower numbers (e.g., Tin Man, Miller & Stack, 1994).

Several wheelchair systems have also utilised position encoders (Katevas et al., 1997; Miller & Stack, 1994; Pires, Araujo, Nunes, & De Almeida, 1998; Prassler et al., 1999). These devices can be utilised for fairly accurate localisation ('dead reckoning'). Kinematic constraints are however, presented by wheelchair designs (Miller & Stack, 1994) since their form is the outcome of issues in design apart from robotic motion. Moreover, standard drive mechanisms and pneumatic tyres are utilised by most implementations, both of which additionally decrease the accuracy of such odometry (Borenstein, Feng, & Everett, 1996).

In general, robotic wheelchairs do not widely utilize vision sensing techniques as the wheelchair must have the concurrent capacity to sense and move, that is, not stop to process information. However, some projects, such as Trahanias and colleagues (1997) have used a camera to select and track goals. Another project (Nakanishi, Kuno, Shimada, &Shirai, 1999) utilises two cameras for vision. One camera points inwards and scrutinises the head movements of the user, which are then utilised to steer the wheelchair. The other points outwards and serves to ensure that the device moves in a straight line using techniques to recognise and track the target and also as a remote control feature.

2.3.4.3. Human-robot interaction

This aspect relates to the user's specialised interface with the wheelchair. Most projects have not considered this as a separate requirement and have utilised joysticks to facilitate user input (e.g., Lawn & Takeda, 1998; Prassler et al., 1999; Röfer&Lankenau, 1999). Other wheelchairs, however, have taken this into account. For example, a visual display showing a sequential scanning of commands is used in the wheelchair developed by Fioretti et al. (2000). Selecting a highlighted command is accomplished by the push of a button. Natural language commands by means of a headset microphone are the mode of interaction in another wheelchair (Pires et al., 1998). Another mode of interaction is voice recognition based on a vocabulary defined by the user and techniques of voice printing (Katevas et al., 1997).

2.3.4.4. Implementation of autonomy

Implementation of autonomy in an autonomous wheelchair requires specialised techniques. For example, internal occupancy grids can be utilised for decision-making (Prassler et al., 1999; Röfer&Lankenau, 1999). Sensor information is organised by these data structures into a coarse map which is subsequently utilised to make informed decisions regarding speed and direction. Other techniques utilised include fuzzy logic and specialised rule bases. Intelligence may also be deconstructed into a specific order, such as differences between local and global planning (Fioretti et al., 2000; Katevas et al., 1997; Pires et al., 1998; Trahanias et al., 1997).

It must be noted that extensive processing power is required by most sophisticated implementations and the requirement impacts the dimensions, weight, battery range, reliability, and maintainability of the wheelchair system (Bourke, 2001; Miller & Stack, 1994).

2.3.4.5. Indoor and outdoor navigation

Another area of variance in autonomous wheelchairs is if they are designed for use in indoor and/or outdoor environments. Earlier wheelchairs predominantly focused on indoor navigation. However, others, such as the TAO project, the Intelligent Wheelchair Project, and the Carnegie Mellon University wheelchair provided limited capabilities for outdoor navigation (Yanco, 2000).

The next section describes the principles of navigation in autonomous wheelchairs.

2.4. Principles of Navigation in Autonomous Wheelchairs

The objective of an autonomous wheelchair is to take its user to a chosen destination, securely and successfully. Leonard and Durrant-Whyte (1991) suggested that the problem of navigation for conventional mobile robots could be encapsulated into three questions:“Where am I?”,“Where am I going?”, and “How should I get there?”(p. 376). Zeng (2008) posited that these three questions could be applied to autonomous wheelchairs as well. However, a wheelchair which has the task of transporting a human being requires different answers to these questions in contrast to a traditional mobile robot system. In other words, it should take the specific impairments, aspects, and desires of its user into consideration.

Knowledge of the wheelchair’s location at all times is required by the first question and is typically called localisation. The user who determines his/her required destination can answer the second question while the third question encompasses motion planning (i.e., planning the route and execution of motion). While the route is generally insignificant for an autonomous robotic system, it is extremely significant for a wheelchair as its movement has to take the security, comfort, and specific desires of its user into consideration failing which the user may be injured or experience frustration and finally lose trust in the wheelchair (Zeng, 2008).

The question of motion planning is answered by many robotic wheelchairs, such as the OMNI system(University at Hagen, Borgolte et al., 1995), the Senario wheelchair (TIDE, Katevas et al. 1997),the TAO wheelchair (Applied Artificial intelligence, Inc., Gomi& Griffith, 1998), the Navchair (University of Michigan, Simpson et al., 1998), the VAHM wheelchair (University of Metz, Pruski et al., 2002), the Shariotowheelchair (K.U. Leuven, Vanhooydonck, Demeester, Nuttin, & Van Brussel, 2003), and the SmartChair (University of Pennsylvania, Parikh et al., 2004), through the usage of an intelligent sensor-based system. Control behaviours for these systems can be changed in response to diverse situations in the course of the navigation, such as avoiding obstacles, following walls, passing through doorways, etc. However, although such systems can free the user from the trouble of driving, algorithms and sensor technology, which are frequently the elements which are the most computationally expensive and prone to error, essentially determine the effectiveness of navigation. Moreover, artificial intelligence (AI) may not be adequate to sense and meet the needs of a user. For instance, an awkward direction may be selected for the user by an AI system (Pruski et al., 2002), such as a restricted passage or one with obstacles above the head; or may inhibit movement in the direction of a table or an entrance way if the route to it is not at right angles (Simpson et al., 1998). Some systems for avoidance endeavour to preserve a larger distance to the impediment than required, which could frustrate a user who is devising a short cut. Other obstacles which may be avoided include bright lights, loud noises, or foul smells. However, designing a sensing system for these (and perhaps other) factors is not possible (Zeng, 2008).

Zeng (2008) posits that users, in general, have the best knowledge of their needs and most wheelchair users have some capacity to sense and infer and are typically keen to utilise them. Consequently, to gain acceptance from prospective users, an assistive device should not attempt to replace these capacities but should instead supplement and utilise the skills that are available. He further highlights that the need for complex sensor processing and artificially intelligent systems can be minimised or eliminated if the sensory and planning skills of humans are utilised, leading to systems that are secure, low-priced, and simple. However, it is evident that this may not be the situation when a user requires a fully autonomous wheelchair.

A simple method to navigate a wheelchair is to install physical tracks on the floor of the real-time environment (e.g., the automated wheelchair of NEC Corporation,Wakaumi, Nakamura, & Matsumura, 1992; the CALL Centre smart wheelchair at the University of Edinburgh, Nisbet et al., 1996). The only requirement of this method is sensors for track detection. As a result, the user, who can control the speed and direction of movement on the track, does not need to plan the order of motion. However, since the movement of the wheelchair is restricted to the tracks, such wheelchair systems cannot deal with obstacles or the desire of the user to turn away from the guide path to evade an obstacle. Moreover, the tracks are cumbersome to set up, modify, and support, as they are made of reflective tapes or magnetic ferrite markers (Zeng, 2008)

The next section describes research related to path planning and obstacle avoidance.

2.5. Path Planning and Obstacle Avoidance

In an unfamiliar environment, smart wheelchairs require the generation of a map of the surroundings and path planning for navigation that takes obstacle avoidance into account. Developments over the past decades have resulted in the development of several algorithms and applications for guiding smart wheelchairs in a two-dimensional (2-d) environment (Hsieh, 2008).

Argyros and colleagues (2002) described a robotic wheelchair with the capacity to avoid obstacles while traversing in an open area and trailing a particular moving target. The wheelchair could establish the target's orientation as pertaining to it by processing the colour sequence of the image taken by a panoramic camera. The wheelchair's distance from the target could be assessed by numerous sonars. The wheelchair's motion planning system utilised the principles of motion control to process the sensory data and also considered the non-holonomic kinematic limitations of the wheelchair to implement certain required facets of the control system (Hsieh, 2008).

Kuo, Huang, and Lee (2003) developed an agent-based robotic wheelchair. The controller of this wheelchair included functions associated with planning of paths, avoidance of obstacles, and navigation. Moreover, a fuzzy logic was utilised for avoidance of obstacles and easy motion control of the wheelchair. Shim, Chung, and Sastry (2006) described autonomous exploration for an Unmanned Aerial Vehicle (UAV). They submitted an algorithm appropriate for navigation in urban areas by incorporating model predictive control. The basis of this algorithm was obstacle avoidance through means of a local obstacle map created by a laser scanner on-board the UAV. The model-predictive control was permitted to solve for a collision-avoidance path by means of an optimisation based on a real-time gradient-search. Completing the given path was the responsibility of the tracking control.

Cruz, McClintock, Perteet, Orqueda, Cao, and Fierro (2007) developed, for the purposes of exploration and testing, a cooperative multi-vehicle testbed (COMET). This testbed is based on potential-field control and was implemented using a combination of low-level robotics to produce high-level controllers. Motion-coordination algorithms were added by Cruz and colleagues (2007) to the collection of team controllers, such as deployment, rendezvous (Ganguli, Susca, Martínez, Bullo, & Cortes, 2005), perimeter estimation and pattern formation (Mong-ying& Kumar, 2006), and dynamic target tracking (Chung, Burdick, & Murray, 2006). The use of optimal formation shapes to enhance the performance of prevailing algorithms for motion-coordination was also explored by Cruz and colleagues (2007).

Ren, Beard, and Atkins (2007) discussed information consensus in multi-vehicle cooperative control and described conceptual outcomes concerning consensus seeking in the context of dynamically changing communication topologies.

The next section describes commercial implementations of smart wheelchairs.

2.6. Commercialization of smart wheelchairs

Despite the continued research on smart wheelchairs, few are actually on the market. This limited availability on the market indicates that smart wheelchairs do not have widespread acceptance or use (Simpson, 2005). Furthermore, smart wheelchairs are not commercially viable as they are frequently too expensive and intricate (Diaz et al., 2002). Specifically, the sensors, such as laser scanners, utilised in research wheelchairs are extremely expensive (Simpson, 2005). Moreover, several smart wheelchairs are constructed by merely adding components or subsystems to existing powered wheelchairs which causes their warranty to be voided (Tang, 2012).

Smile Rehab Limited (Figure 2.1) is an example of a commercially available smart wheelchair (Simpson, 2005). This wheelchair was originally developed in The University of Edinburgh in 1987. However, in contrast to several of the smart wheelchairs seen in Section 2.3.6, this wheelchair has basic features, such as a sensor system consisting of contact switches and a line follower. Nevertheless, it has a serial port with a specific protocol permitting interface with an external controller (Tang, 2012).

Figure 2.1: Smile Rehab Limited Wheelchair

Source: http://ilcaustralia.org.au/products/17613, 2011

Another instance is Boo-Ki Scientific's Robotic Chariot (Tang, 2012). This wheelchair builds on a popular powered wheelchair, Pride Mobility Jazzy 11203. A laser scanner and other sensors are fitted retroactively to the wheelchair and is controlled by ActivMedia Robotics Interface for Applications software (ARIA) (Simpson, LoPresti, & Cooper, 2008). The ARIA framework offers complex path planning and obstacle avoidance. However, the end user is required to personalise the navigation functionality of the wheelchair.

Recently, there has been coverage in the online media of autonomous wheelchairs that are expected to be available for use in airports and other places. One initiative is the Panasonic robotic electric wheelchair (England, 2017) which uses autonomous mobility technology. That is, the wheelchair will recognise its position and choose the best route to reach the destination after users provide inputs through smartphone (Figure 2.2).

Figure 2.2: Panasonic's robotic electric wheelchair

Source: England, 2017

The other wheelchair is Whill's all-terrain wheelchair (Figure 2.3) which is built for rough surfaces (Lalwani, 2017).

Figure 2.3: Whill’s all-terrain wheelchair

Source: Lalwani, 2017

The next section describes the current challenges in smart wheelchairs.

2.7. Current challenges in smart wheelchairs

Tang (2012) drew attention to the prohibitive costs of smart wheelchairs. Precise and reliable sensors, such as laser range-finders, are crucial in most robotics applications and contribute significantly to the cost of the system. Therefore, a present challenge in smart wheelchairs is balancing the cost while continuing to requiring accurate sensors (Simpson, 2005).

Another significant challenge concerns the algorithms to be run on smart wheelchairs, such as computer vision algorithms or map generation algorithms. Running these on mobile computing platforms may be difficult as these platforms do not have adequate computing power to support these (Tang, 2012). Moreover, across vendors, there is no physical interface or an accepted protocol for communication between the input devices of a wheelchair and add-on modules (Tang, 2012). Further, due to the limited number of smart wheelchairs on the market, they do not yet have clinical acceptance (Scudellari, 2017;Simpson, 2005).

The next section provides a brief overview of the different driving modes of smart wheelchairs.

2.8. Driving Modes

Drury, Frechette and Shamsuddin (2010 worked on developing a wheelchair with three drive modes (Figure 2.4). These are: Manual Drive Mode, Smart Drive Mode, and Express Drive Mode. Manual Drive Mode signifies that the operation of the wheelchair is similar to a traditional power wheelchair. Smart Drive Mode signifies that the wheelchair is steered by the user but has a feature to avoid collision with obstacles. This is achieved by sensors on the wheelchair which perceive any obstacles and prevents the chair from getting too close by stopping it. Express Drive Mode indicates that the wheelchair has generated a map of an area and can travel to user-defined points on this map. In this mode, the wheelchair plans its own path employing the map and real-time sensor data when it is instructed to move to a specific goal. The shortest possible path is chosen with the lowest number of fixed obstacles currently sensed by the wheelchair. Also, the wheelchair can modify its path to avoid sudden obstacles.

Figure 2.4: Autonomous wheelchair

Source: Drury et al., 2010

Seki, Iijima, Minakata, and Tadakuma (2006) referred to two driving modes in their paper describing a novel step climbing control scheme for powered wheelchairs. The first mode is "front wheel raising mode" signifies the usage of a torque control system with variable assistance ration to forestall hazardous overturning. The second mode "rear wheel climbing mode" uses a position control system with polynomial trajectory as the basis to confidently climb steps and halt at the appropriate place (Figure 2.5).

Figure 2.5: a) Power assisted wheelchair; b) Step climbing motion

Source: Seki et al., 2006, p. 3827

Mahajan, Dicianno, Cooper, and Ding (2013) in a study to assess wheelchair driving performance in a virtual reality simulator, mentioned two driving modes: “Rollers ON” and “Rollers OFF”. In the first mode, subjects utilised their individual joystick to drive theirwheelchairon rollers which also caused the virtual wheelchair to move (Figure 2.6). The simulator used encoder readings from each wheel to regulate the instantaneous linear and rotational speeds of the wheelchair. In the second, the subjects utilised a customised joystick, and a mathematical model was applied by the simulation program to estimate the linear and rotational speeds of the virtual wheelchair.

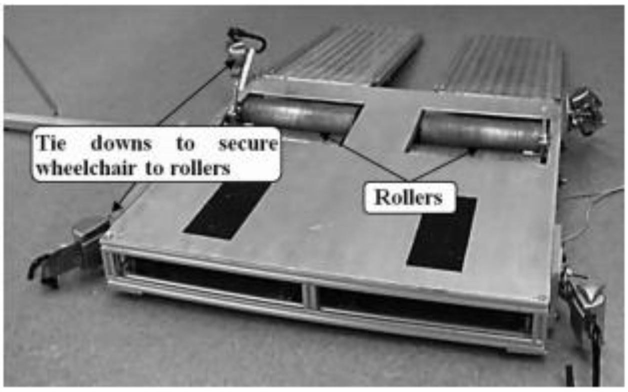


Figure 2.6: Platform with rollers and tie down straps

Source: Mahajan et al., 2013, p. 323

The next section provides an overview of the Internet of Things (IoT).

2.9. Internet of Things (IoT)

As mentioned in the Introduction to this dissertation, the fundamental premise of the IoT is the interaction of everyday objects with and through the Internet. The objects in question can vary from inputs to sensors to actuators (a kind of motor that moves or controls a system or mechanism) (Cooper & James, 2009).

A simple definition of the IoT was provided in the Business Insider (Meola, 2016). This definition indicated that IoT refers to the connection of devices (other than typical fare such as computers and smartphones) to the Internet. Cars, kitchen appliances, and even heart monitors can all be connected through the IoT. And as the Internet of Things grows in the next few years, more devices will join that list.

A paper by Yun and Yuxin (2010) provided a pictorial representation of this vision (Figure 2.7).

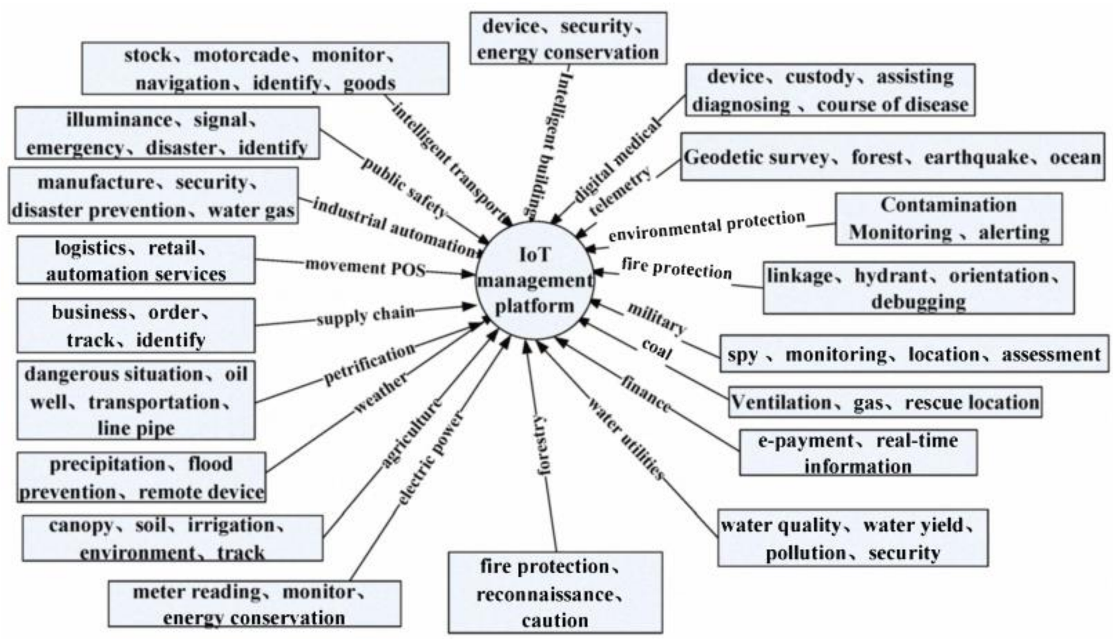


Figure 2.7: Perspective of the application scenarios of IoT

Source: Yun &Yuxin, 2010, p. 71

More formal definitions were provided by the IEEE (2015) in the context of small and large environment scenarios. The rationale for providing multiple definitions was the understanding that the extent of an IoT system could range from a small system which encompasses small sensors and things that are distinctively distinguishable, to larger systems that connect millions of things which have the capability to provide multifaceted services.

2.9.1. IoT in a small environment scenario:

An IoT is a network that connects uniquely identifiable ‘Things’ to the Internet. The “Things” have sensing/actuation and potential programmability capabilities. Through the exploitation of unique identification and sensing, information about the ‘Thing’ can be collected and the state of the ‘Thing’ can be changed from anywhere, anytime, by anything (IEEE, 2015, p. 73).

2.9.2. IoT in a large environment scenario:

Internet of Things envisions a self-configuring, adaptive, complex network that interconnects 'things' to the Internet through the use of standard communication protocols. The interconnected things have physical or virtual representation in the digital world, sensing/actuation capability, a programmability feature and are uniquely identifiable. The representation contains information including the thing's identity, status, location or any other business, social or privately relevant information. The things offer services, with or without human intervention, through the exploitation of unique identification, data capture and communication, and actuation capability. The service is exploited through the use of intelligent interfaces and is made available anywhere, anytime, and for anything taking security into consideration (IEEE, 2015, p. 73).

Coetzee and Eksteen (2011) provided a pictorial representation of the IoT ecosystem (Figure 2.8). In general, things could be tagged, and identified by means of scanners, and the applicable position information could be transmitted. In a similar manner, things on the network with sensors grow smaller, merging into day-to-day existence, while actuator and sensor networks operate on the local surroundings, conveying events and status to higher-level services.

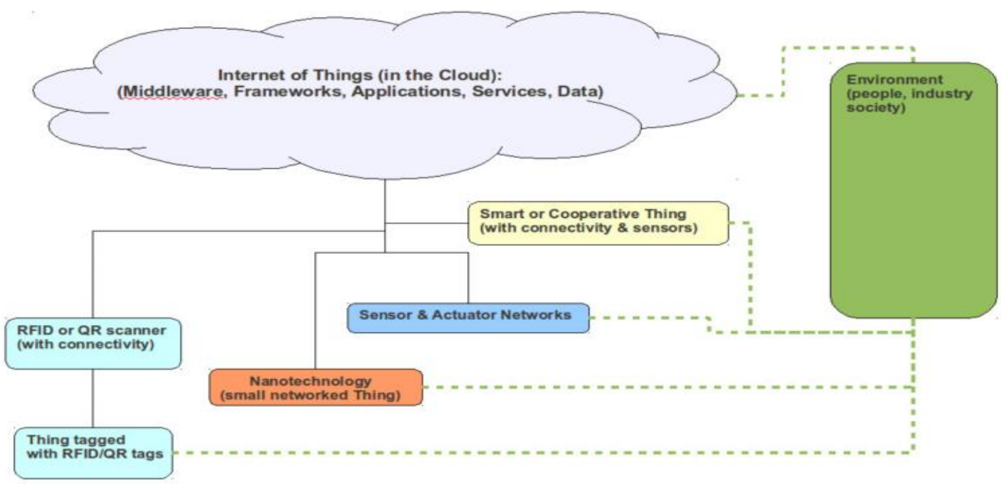


Figure 2.8: IoT ecosystem

Source: Coetzee &Eksteen, 2011, p. 3

The next section describes the features of the IoT.

2.9.3. Features of IoT

Table 2.1 provides a summary of the features of IoT as provided by IEEE (2015).

Table 2.1: IoT Features

Source: IEEE, 2015, p. 72-73

IoT Feature	Description
Interconnection of Things	The IoT is a system that handles the linkage of ‘Things.’ The term ‘Thing’signifies any tangible object that is significant from the viewpoint of a user or application.
Connection of Things to the Internet	The ‘Things’ are connected to the Internet.
Uniquely Identifiable Things	The ‘Things’ in an IoT system are distinctly distinguishable.
Ubiquity	The IoT system is available anywhere and anytime. However, in IoT perspective, the notions of “anywhere” and “anytime” do not inevitably indicate, respectively, “globally” and “always.” Instead, “anywhere” chiefly signifies the notion of where the ‘Thing’ is required. In the same way, “anytime” signifies when the ‘Thing’ is needed.
Sensing/Actuation capability	Sensors/actuators are associated with the “Things” and implement the sensing/actuation required to generate the smartness of the “Things.”
Embedded intelligence	Intelligence and knowledge functions are embedded as tools in intelligent and active objects which help them develop into a peripheral augmentation to the human mind and body.
Interoperable Communication Capability	The IoT system possesses a capacity to communicate using standard and interoperable protocols for communication as its basis.
Self-configurability	The IoT signifies the connection of a large number of diverse devices (e.g., actuators, sensors, network elements, computers, storage devices, mobile phones, etc.). This

IoT Feature	Description
	scenario precludes the use of cloud-based or remote control as they may not be able to adequately scale up to manage the sheer volume of devices. Consequently, self-management is a requirement of IoT devices, both from the perspective of hardware/software configuration and utilisation of resources (e.g., energy, bandwidth, etc.). The chief elements of self-configuration encompass the activities of neighbours and discovery of services, network organisation, and provisioning of resources.
Programmability	A programmability feature exists in the 'Things' of an IoT system.

The next section briefly describes the typical characteristics of the IoT.

2.9.4. Typical characteristics of IoT

Dohr, Modre-Opsrian, Drobics, Hayn, and Schreier (2010) submitted that the IoT has three distinct characteristics. First, it generates new autonomous networks that function with their specific infrastructure. Second, it will be put into operation with new services. Third, it will use new and varying approaches to communication between things and individuals, and things themselves, as well as Machine-to-Machine (M2M) interaction (Commission of the European Communities, 2009; Ley, 2007). Yun and Yuxin (2010) offered the IoT characteristics from different perspectives: comprehensive sense, reliable transmission, and intelligent processing. Comprehensive sense indicates the usage of sensors, Radio-frequency identification(RFID), and two-dimensional code to gather data on things, anytime and anywhere. On the other hand, reliable transmission signifies precise real-time delivery of information associated with things by means of interconnecting the Internet and different communications networks. Intelligent processing indicates the usage of intelligent computing (e.g., fuzzy identification, cloud computing) to scrutinise and deal with huge quantities of information and data, with the objective of implementing intelligent control in things.

The next section reviews the architecture of the IoT.

2.9.5. Architecture of IoT

The architecture of the Internet of Things can be regarded as being composed of three layers: perception layer, network layer, and application layer (Jammes& Smit, 2005). The perception layer comprises an RFID tag and reader, two-dimensional code tag and code reader, GPS, camera, sensors, sensor gateway, sensor network, M2M terminal, etc. The principal function of this layer is perception and recognition of objects, and data collection and storage (Yun &Yuxin, 2010).

The components of the network layer include a converged network established by all types of communication networks and the Internet. This component has been widely accepted to be the most mature. In addition, the network layer contains the IoT management and information centres. In other words, while the network layer has the capability for network operation it is also required to enhance the capacity of the information function. The network layer is the basis of IoT growing into a comprehensive service (Yun &Yuxin, 2010).

The application layer is the combination of IoT technology along with industry expertise to accomplish an extensive set of smart application solutions. IoT can accomplish a degree of integration of IT with the industry by means of the application layer, thus, having a great impact on societal and economic development. However, the primary challenge of the application layer is sharing of information and its security (Yun &Yuxin, 2010).

The next section provides a brief overview of the principal technologies of the IoT.

2.9.6. Principal technologies of IoT

Yun and Yuxin (2010) submitted that there are four principal technologies in IoT, namely, sensor networks, RFID, nanotechnology, and smart technologies.

2.9.6.1. Sensor networks

A new platform become aware of the universe and administer data is offered by wireless sensor networks. These find broad application in several areas, such as defence, agriculture regulation, industry regulation, city administration, manufacture, biomedicine, emergency services, rescue, remote regulation of danger zones, etc.

Wireless sensor networks are composed of numerous nodes with the capacity to communicate, compute, and cooperate in an ad hoc model (Yun &Yuxin, 2010).

2.9.6.2. RFID and Nanotechnology

RFID signifies the use of electromagnetic induction or propagation to achieve non-contact programmed recognition of humans or objects (Yun &Yuxin, 2010).By using RFID tags, things can be distinctly distinguished, to ascertain the position, to recognise alterations in physical data, and to link and interact with a related transponder (Dohr et al., 2010).

The usage of nanotechnology indicates that even very small things can link and communicate with each other (Yun &Yuxin, 2010).

2.9.6.3. Smart technologies

Smart technologies use theoretical knowledge to accomplish specific objectives. Things which become intelligent after embedding smart technologies can interact passively or actively with users. Associated areas in this regard include artificial intelligence, intelligent control systems and technologies, advanced human-machine interaction systems and technologies, intelligent signal processing (Yun &Yuxin, 2010).

The next section draws attention to some general applications of IoT.

2.9.7. General applications of IoT

Table 2.2 provides a summary of the general applications of IoT (Yun &Yuxin, 2010).

Table 2.2: General applications of IoT

Source: Yun &Yuxin, 2010

Application category	**Examples**
Networking	Identification of goods, positioning and communication
Information	Collection of information, storage and query
Operation	Remote configuration, operations,monitoring, and control

Application category	Examples
Security	Management of users, access control, intrusion detection, event alarm, attack prevention
Management	Fault diagnosis, system upgrades, performance optimization, billing management services

2.9.8. Challenges of IoT

A paper by Coetzee and Eksteen (2011) drew attention to some challenges of IoT:

Privacy, Identity Management, Security and Access control:A significant challenge is presented in IoT with regard to "who can see what with which credentials" (keeping in mind that the entities are not restricted to individuals but might be any form of IoT thing) (Coetzee &Eksteen, 2011, p. 6).

Standardisation and Interoperability: Another challenge for IoT is ensuring that it behaves like a platform. That is, there should be no need to keep modifying the underlying infrastructure every time new applications or sensors need to integrate with the IoT (Coetzee &Eksteen, 2011).

Data deluge: Since the number of 'things' participating in the IoT is limitless, dealing with the data stream of innumerable things is a challenge. Another related challenge is ensuring the usability of the data across different generations of users. (Coetzee &Eksteen, 2011).

The next section discusses positioning systems.

2.10. Positioning Systems

Positioning systems or technologies aid in determining the location of individuals or mobile objects. Different positioning systems have different degrees of accuracy. A commonly used positioning system is the GPS which provides both high (cm level) and low (metre level) accuracy positioning capacities based on the manner in which the system is utilised (i.e., types of receivers and methods of positioning) (Hu, 2013).

There is however, a requirement for both indoor and outdoor positioning. While positioning in an outdoor environment can be satisfactorily achieved by GPS, its suitability in indoor settings is limited as GPS signals are hindered most of the time. This led to the need for alternate positioning systems, for example, assisted GPS (A-GPS), Wi-Fi based positioning, and inertial navigation system (INS) (Hu, 2013). The common positioning or location techniques and/or systems are briefly described in the following sections.

2.10.1. GPS

GPS is a US Department of Defense funded and controlled Satellite Navigation System. It offers specifically coded satellite signals that can a GPS receiver can process, permitting the receiver to calculate location, time, and speed. The calculation of location in three dimensions and the time offset in the receiver clock are achieved by means of four GPS satellite signals (Dana, 1995). A simple mathematical principle called trilateration, that is, the method of using measured distances from three satellites to a receiver to locate the receiver, is used as the basis of the operation (Dana, 1995).

2.10.2. Wi-Fi based Systems

Wi-Fi is presently a broadly accepted and utilised positioning technology. In an indoor setting, positions can be ascertained with good precision with the availability of Wi-Fi infrastructure. Most approaches to positioning utilising a Wi-Fi system resemble the Cell ID method. Most advanced Wi-Fi positioning systems utilise methods of signal strength fingerprinting (Shin, Lee, Choi, Kim, Lee, & Kim, 2010) wherein Wi-Fi signal strengths are detected from several access (or reference) points in the area under consideration. Subsequently, the recorded data are archived in a database before smartphone Wi-Fi sensors are utilised by the user to execute real positioning activities in the area. This phase is termed a calibration phase. The real implementation of a positioning activity is achieved by the user ascertaining his/her location by coordinating the observed strength of his/her Wi-Fi signal with the database’s RSS values. The most coordinated signal is chosen as the location estimate (Hu, 2013).

2.10.3. Inertial Navigation System (INS)

INS are self-contained techniques of navigation wherein measurements made available by accelerometers, compasses, and/or gyroscopes are utilised to compute the location and orientation of an object in comparison with an established starting point, speed, and orientation (Woodman, 2007). Potential supplemental tools for indoor navigation include low-cost Micro-Electro-Mechanical Systems (MEMS)gyroscopes and accelerometers. Nevertheless, INS can typically merely offer a precise solution for a short period since the measurement errors (e.g., drifting and bias) of the sensors change rapidly over time and consequently it is challenging to mitigate or separate them from navigation signals (Hide, 2003).Typically, inertial measurement units are composed of three orthogonal accelerometers and three orthogonal gyroscopes, respectively assessing linear acceleration and angular velocity (Hu, 2013).

2.10.4. Magnetic Positioning

Compass chips can be utilised to ascertain magnetic positioning and thus compute position. A compass (e.g., inside a typical smartphone) can be utilised to sense and record the local magnetic variations produced by iron in buildings. These variations can be used to map the indoor position with a precision of 1-2 metres (Bagaric, 2016).

Indoor positioning systems can also use geomagnetic anomalies. S.E. Kim, Y. Kim, J. Yoon, &E. S. Kim (2012) submitted a technique that utilizes the disturbances in the geomagnetic field due to the steel components in a building's structure. Such systems do not need any manner of physical infrastructure and are hence cost-effective. The position of a target can be approximated by contrasting a device's (e.g., smartphone) sensor measurement to the measurements on a building's magnetic footprint after a map of the building has been developed and its magnetic footprint has been recorded. The outcomes of S.E. Kim and colleagues' (2012) study demonstrated that the system's precision was within metres.

2.10.5. Ultra-wideband (UWB)

UWB (Porcino &Hirt, 2003) provides position precision up to 10 cm and so can also be utilised for positioning. UWB utilises short bursts of radio energy, similar to some radars, and then computes the time taken for the other receivers to receive the signal.

This circumvents the multipath challenges owing to the shortness of the radio wave. Accurate outcomes are obtained in this approach. Nevertheless, the challenge is that UWB waves get obstructed very easily about two-fifths of the time.

2.10.6. Visible Light Communication (VLC)

The Visible Light Communication (VLC) concept utilises the intensity modulation and direct detection (IM/DD) in a setting with an unobstructed path (Saab &Nakad, 2011; Yasir, Ho, &Vellambi, 2014).Yasir and colleagues (2014) investigated this notion using simulations and experiments and determined that while it was imprecise when approximating distance using the impact of radiation directivity and the angle of incidence as basis, the error in positioning would be lessened when the normalising method was utilised as the adjustment process. The outcomes of this study demonstrated that the typical error of approximated positions could be decreased to 2.4 cm using the adjustment process in contrast to 141.1 cm without adjustment. Conversely, Saab &Nakad (2011) used approached VLC differently by means of supplementing the positioning system with the outcomes of the accelerometer of the smartphone. The system utilised the accelerometer to sense the device's orientation and the light sensor to sense the light intensity received. The low complexity algorithm of Saab &Nakad (2011) did not necessitate awareness of the physical parameters of the LED transmitters and their tests demonstrated that achieving an average position error greater than 2.5 cm was possible.

2.10.7. Hybrid systems

Some systems of indoor positioning use multiple complementing technologies to enhance the accuracy of the system. For example, Baniukevic, Jensen, and (2013) created a hybrid indoor positioning system using Wi-Fi and Bluetooth. They used a Wi-Fi based method for position estimation and enhanced this system by utilising Bluetooth hotspot devices to assist the Wi-Fi positioning system by using the divide-and-conquer method to partition the indoor space.

2.10.8. Fingerprinting

Fingerprinting is a technique that utilises pattern recognition to assess the location of an object. There are two stages of fingerprinting: learning (or offline) and online. The learning stage comprises archiving the information of each point situated in the study setting. These points have elemental features that require to be collected (e.g., height, angle, distance) before the system is activated. The online stage is when the system is used. In this stage, the parameters that permit comparison with the previously acquired information are collected. These parameters are utilised to determine a set of coordinates that are in proximity to the point under consideration (Li, Quader, &Dempster, 2008).

This method is contingent on the technology to be utilised, for example, in Wi-Fi systems where the location accuracy is connected to the unpredictability of the strength of the signal. This permits the differentiation of the points of reference located in a setting, with the opportunity to reconstruct the test setting.

2.10.9. Other Systems

Several other systems, for example, RFID, Bluetooth, ultrasonic, and infrared, have also been scrutinised for their probable use and capacity for positioning. RFID is the broad term utilised to describe systems that employ radio waves to wirelessly convey the identity (as a unique serial number) of a thing or individual (Hu, 2013). Bluetooth is a technology normally utilised for wireless communications over a short-range with low consumption of power (Zandbergen, 2009). Ultrasonic indicates oscillating sound waves with a frequency higher than the upper limit of the hearing range of humans. Ultrasonic devices can be utilised to sense objects and calculate distances. Infrared refers to the electromagnetic radiation having long wavelengths, which are frequently utilised in short-range communication among devices with embedded infrared. Infrared communications are suitable for indoor settings; however, they cannot penetrate walls, a factor which limits its usability between rooms. All these systems can work only in short-range dimensions (Hu, 2013).

2.10.10. Indoor Positioning Systems (IPS)

Several methods are utilised to compute the indoor position of a receiver. These include Wi-Fi, magnetic positioning, Bluetooth, RFID, UWB, ultrasound, Visible Light Communication, Geomagnetism, or hybrid methods.

2.10.10.1. Commercial Indoor Positioning Systems

A few commercial IPS systems are summarised in Table 2.3.

Table 2.3: Commercial IPS Systems

Source: Bagaric (2016)

IPS System	Principal Positioning Method(s) utilised	System requirement	Accuracy/Error margin
Wifarer (www.wifarer.com)	Wi-Fi, Bluetooth	Any smartphone that has a magnetometer /compass	0.5 metre
IndoorAtlas (www.indooratlas.com)	Uses the magnetic footprint of buildings to map the indoor space.	Any smartphone that has a magnetometer /compass	< 3 metres
Pozyx (www.pozyx.io)	Ultra-wideband	Compatible with different devices	cm
ByteLight (www.acuitybrands.com)	Visible Light Communication	-	-
Phillips	Visible Light Communication	Smartphone	<1 metre
Nextome (www.nextome.net)	Bluetooth Low Energy (BLE)	BLE 4.0 enabled smartphone (Android or iOS)	-

2.11. Internal and External Location Systems

As mentioned in the Introduction to this dissertation, the objective of the present project "Autonomous Wheelchair with a Smart Driving Mode and a Wi-Fi Positioning System", is to improve the IPL wheelchair prototype to include the implementation of a small ESP8266 Wi-Fi network positioned around the user of the wheelchair.

Moreover, Raspberry Pi (Prasad, Kumar &Paradesi, 2017) and an ESP8266 Wi-Fi access point device located inside the wheelchair will make it possible for different wireless devices to communicate with the autonomous wheelchair. Moreover, the location and orientation of the wheelchair will be estimated by a process of triangulation, based on the angle of different Wi-Fi emitters with directional Yagi antennas. Hence, this section describes the various devices utilised for the construction sensor nodes that will constitute the wireless sensor network namely, Raspberry Pi 3, ESP8266, and Yagi antennas.

2.11.1. Raspberry Pi

Raspberry Pi (Figure 2.9)is a low-priced computer, the size of a credit card, which was developed with the objective of supporting the instruction of fundamental computer science in schools. Due to its size it is a competent device that permits persons of all age groups to discover computing and programming. Additionally, it helps persons to commence different types of electronics projects. The Raspberry Pi has the same capabilities of a desktop computer, such as Internet browsing, playing games and high-definition video, creating spread sheets, word processing, and so on (Bagaric, 2016).

Raspberry Pi was developed by the Raspberry Pi Foundation (a charitable association) and is produced by means of licensed manufacturing deals with RS Components, Newark element14, and Egoman which sell the Raspberry Pi online. The Raspberry Pi 3 is the third generation Raspberry Pi (Åsrud, 2017).

Figure 2.9: The Raspberry Pi

Source: Bagaric (2016)

The specifications of the Raspberry Pi Model B can be seen in Figure 2.10

Product Name	**Raspberry Pi Model B+**
Product Description	The Raspberry Pi Model B+ incorporates a number of enhancements and new features. Improved power consumption, increased connectivity and greater IO are among the improvements to this powerful, small and lightweight ARM based computer.
Specifications	
Chip	Broadcom BCM2835 SoC
Core architecture	ARM11
CPU	700 MHz Low Power ARM1176JZFS Applications Processor
GPU	Dual Core VideoCore IV® Multimedia Co-Processor
	Provides Open GL ES 2.0, hardware-accelerated OpenVG, and 1080p30 H.264 high-profile decode
	Capable of 1Gpixel/s, 1.5Gtexel/s or 24GFLOPs with texture filtering and DMA infrastructure
Memory	512MB SDRAM
Operating System	Boots from Micro SD card, running a version of the Linux operating system
Dimensions	85 x 56 x 17mm
Power	Micro USB socket 5V, 2A
Connectors:	
Ethernet	10/100 BaseT Ethernet socket
Video Output	HDMI (rev 1.3 & 1.4)
	Composite RCA (PAL and NTSC)
Audio Output	3.5mm jack, HDMI
USB	4 x USB 2.0 Connector
GPIO Connector	40-pin 2.54 mm (100 mil) expansion header: 2x20 strip
	Providing 27 GPIO pins as well as +3.3 V, +5 V and GND supply lines
Camera Connector	15-pin MIPI Camera Serial Interface (CSI-2)
JTAG	Not populated
Display Connector	Display Serial Interface (DSI) 15 way flat flex cable connector with two data lanes and a clock lane
Memory Card Slot	SDIO

Figure 2.10: Raspberry Pi Model B specifications

Source: Åsrud, 2017

2.11.2. Module ESP-8266

The ESP8266 Wi-Fi module (Figures 2.11, 2.12) permits the connection of a “thing” to the Internet, that is, IoT. Different versions exist with various configurations to suit diverse applications. The configurations vary in size, cost, memory, number of GPIOs (General Purpose Input/Output), etc. (Jalamkar&Selvakumar, 2016).

This module was chosen for this project due to its capacity to send and receive wireless data and also for its ability to sense the strength of a signal given out by another device. In other words, it was chosen as this module can act autonomously as it contains a microprocessor.

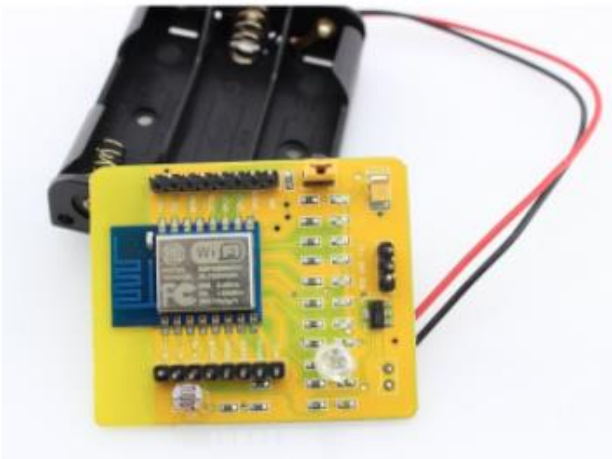


Figure2.11: ESP8266-12E

Source: RLX Components, 2017

Figure2.12: ESP8266-01

Source: Jalamkar&Selvakumar, 2016

2.11.3. Yagi Antenna

Gu, Zhao, Cai, and Zhang (2017) observed that "Yagi antennas have been widely used in modern communication systems due to their features of simple structures, moderate gain and stable unidirectional radiation" (p. 33).A Yagi antenna is defined by the online Oxford Dictionary (2017) as "a highly directional radio aerial made of several short rods mounted across an insulating support and transmitting or receiving a narrow band of frequencies." A Yagi antenna (Figure 2.13) is recognised to possess a driver dipole, a reflector dipole, and several parasitic dipoles (Leong& Itoh, 2008, p. 70).

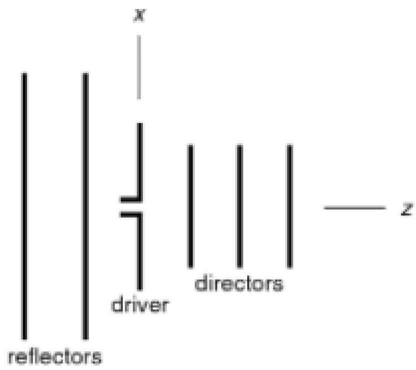


Figure2.13:Schematic of a Classic Yagi Antenna

Source: Leong & Itoh, 2008, p. 70

2.12. Summary

This chapter provides an overview of the existing research and literature associated with autonomous wheelchairs, Internet of Things, and positioning systems. An overview was also provided of the relevant internal and external location systems in the context of the present project.

3. Terminology and Technologies Utilised

3.1. Introduction

This chapter describes the technologies utilised in the proposed autonomous wheelchair system as well as the methodology utilised to derive the desired outcomes. As mentioned in the Introduction to this thesis, the methodology utilised for the project is the Design Science (DS) methodology. Accordingly, this chapter also serves as the Knowledge Base segment of the methodology and describes the various technologies, approaches, and systems that support the development of the autonomous wheelchair system with a smart driving mode and a Wi-Fi positioning system.

A brief overview of the DS Methodology is first provided for the reader's benefit.

3.2. DS Methodology

The origins of the DS methodology can be traced back to the mid-1970s when researchers at the Carnegie Mellon University resolved to pursue this methodology. Subsequently, several scholars focused attention on developing this methodology. One such scholar was Simon (1996) who observed that "The paradigm of design science has its roots in engineering and the sciences of the artificial" (Simon, 1996).

Afterwards, while several perspectives were presented, it was not until almost ten years later that Hevner and colleagues (Hevner, March, Park, & Ram, 2004) offered a complete investigation that expressed the progress of DS in Information Systems, by means of a group of guidelines that result in the implementation of an artefact.

3.2.1. Definition

The description of various methodologies is permitted by the design and research of effective artefacts for the systematic examination of software engineering and design. Artefacts are devised to interrelate with a matter and enhance something in the situation (Figure 3.1)

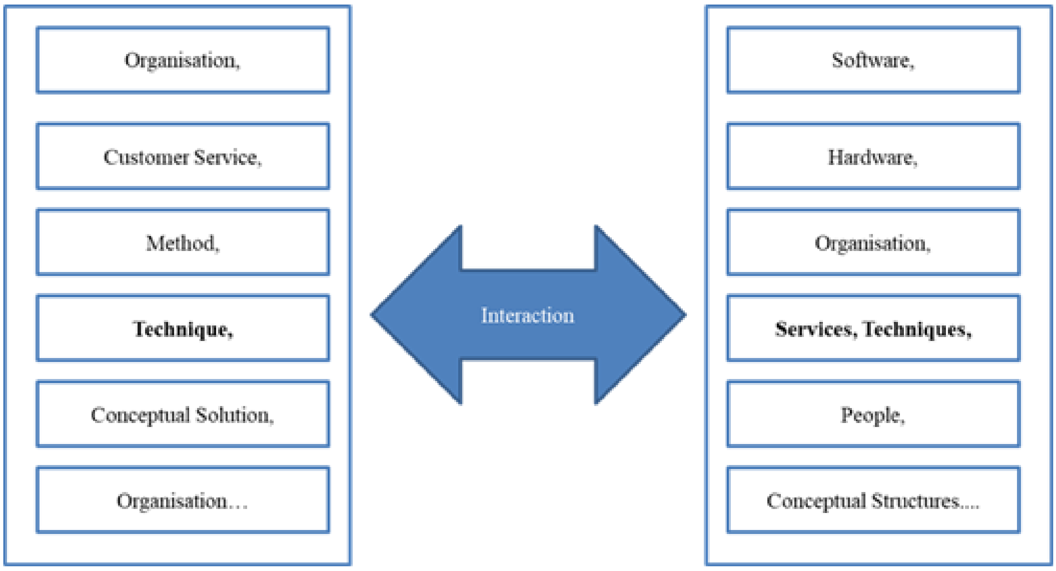


Figure 3.1: DS: Artefact-Environment Interaction

Figure 3.1 indicates that no issue is solved by the artefact. Instead, the inter relation between the artefact and the situation permits the resolution of the problem. Nevertheless, the artefact may interrelate in a different manner in other situations; this can resolve or generate obstructions in objectives from another environment (Wieringa, 2014).

In design science research (DSR), the principal emphasis of research problems are design and research. However, there are two kinds of shortcomings in this regard:

- Design problems: one or more resolutions to the problem of the situation is necessitated, by means of an examination of actual and theoretical objectives,
- Issues of knowledge: an alteration to the universe is not forced, only a response regarding the artefact in the situation.

In summary, the theory of pragmatic research is supported by DSR that permits the explanation of an artefact that resolves issues in a situation (Shrestha, Cater-Steel, &Toleman, 2014). Principles, procedures, and processes are included in the DS research methodology (DSRM) to undertake research. Moreover, DSRM accomplishes three purposes, namely “First, it should be consistent with prior DS research theory and practice, as it has been represented in the IS literature, and with design and design science research, as it has been conveyed in representative literature in reference disciplines. Secondly, it should provide a nominal process for conducting DS research in Information Systems (IS). Thirdly, it should provide a mental model for the characteristics of research outputs" (Peffers, Tuunanen, Rothenberger, & Chatterjee, 2007, p. 31).

3.2.2. DSRM Principles

Hevner and colleagues (2004) submitted that DS research methodology(DSRM) has various principles or guidelines that generate a framework utilised to assess the design process. These prerequisites necessitate detailed research with regard to the production of an artefact. Table 3.1 summarises the different DSRM guidelines (Hevner et al., 2004; Wieringa, 2014).

Table 3.1: Guidelines for Design Science Research

Source: Hevner et al., 2004; Wieringa, 2014

Guideline	Definition
Design as an artifact	Creation of an artifact through a model, method or construction.
Relevance of the problem	Develop different solutions that are based with technology.
Design Evaluation	Demonstrate through evaluation the quality, efficiency and utility of an appliance.
Contribution	Provide significant contributions that are clear and viable in the design of the artefact.
Rigour in research	Implementation of methods and techniques in creation and evaluation of the artefact.
Design as a research process	Find an artefact that meets the objectives solutions to the problems of the environment.
Communication of the Research	Presentation of the artefact to different public that this is oriented to the technology and also to the management.

3.2.3. DSR Framework and Cycles

Figure 3.2 depicts the conceptual framework provided by Hevner and colleagues (2004) for comprehending, performing, and assessing IS research.

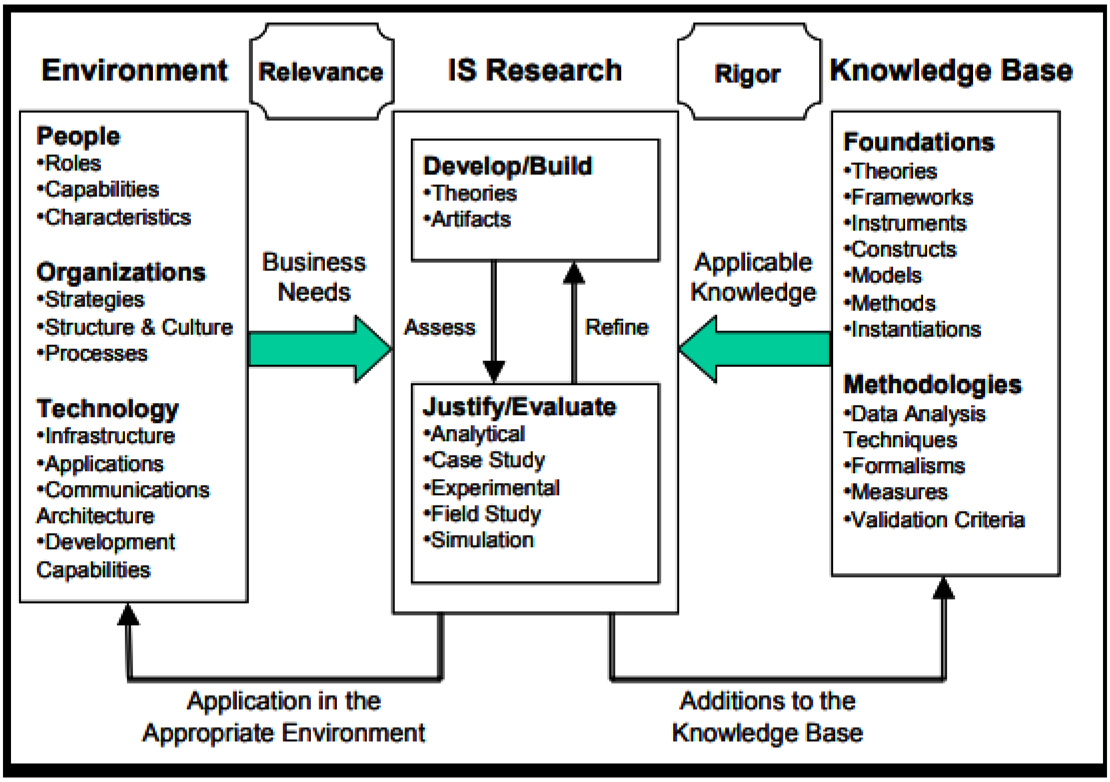


Figure 3.2: Information Systems Research Framework

Source: Hevner et al., 2004, 80

Hevner (2007) used the framework provided by Hevner and colleagues (2004) and placed an emphasis on three essential research cycles on top. The background setting of the research projected is bridged with the activities of design science by the *Relevance Cycle*. On the other hand, design science activities are connected with the knowledge base of scientific foundations, experience, and expertise that informs the research project by the *Rigor Cycle*. Iterations of the fundamental activities of developing and appraising the design artefacts and research processes are performed by the crucial Design Cycle. Hevner (2007) further submitted that the presence of these three cycles was essential in a DSR project. Moreover, they should be definitely distinguishable. Figure 3.3 depicts the three phases of DSR as provided by Hevner (2007).

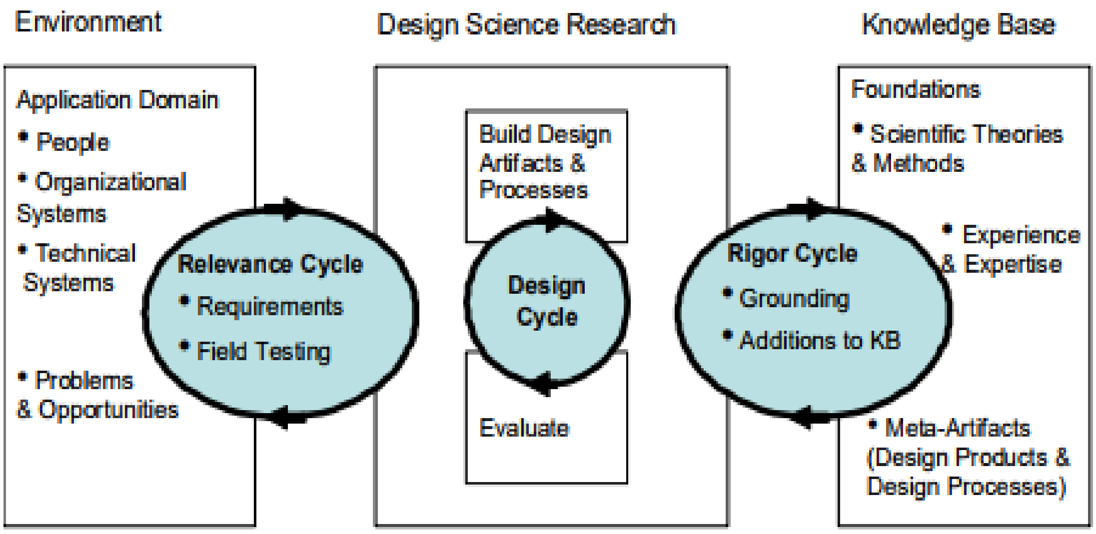


Figure 3.3: Design Science Research Cycles

Source: Hevner, 2007, p. 88

3.2.4. DS Methodology in the context of the current project

The DS methodology is particularly focused on artefact design and development with the objective of enhancing the environment and providing the ability to contribute to other artefacts.

In this project, the DS methodology was utilised to confirm the project effectiveness as it is composed of guidelines that permit the discovery and construction of present theories and artefacts. Moreover, it gives rise to a system's design and developing through usage of various tools and techniques, assessed by numerous evaluations in different settings. Lastly, this project will be communicated for further knowledge by means of a document and a publication for the location precision error of the autonomous wheelchair.

The next sections describe the various tools and techniques utilised in the project.

3.3. Wireless sensors

Wireless Sensors or wireless nodes are electronic circuits (Villaseñor, Galindo, & Jiménez, 2007) which are composed of 3 elements:

- Microcontroller. This is the most crucial element of the circuit as their programmability gives them the capacity to control the other modules.
- Radiofrequency transceiver. This element uses a modulation technique to receive and transmit data.
- Integrated sensor. This device permits the cataloguing of a physical variable and conversion of the same into data which then delivered to the transmitter by the microcontroller.

Different advantages of use are associated with these sensors (Omega, 2017). The primary ones are:

- Security. Wireless modules can be utilised in location that are difficult to reach. Thus, they can be utilised to monitor processes in dangerous settings and transmit data to users who are at a safe distance.
- Convenience. Wireless sensors create a network that permits the regulation and scrutiny, both real-time and remote (e.g., from a base station), of an environment.
- Cost reduction. Wireless nodes reduce the materials (including accessories and conduits) required for data transmission.

When utilised in different settings, wireless sensors have elemental features which are taken into account in various wireless assessment projects (Figure 3.4).

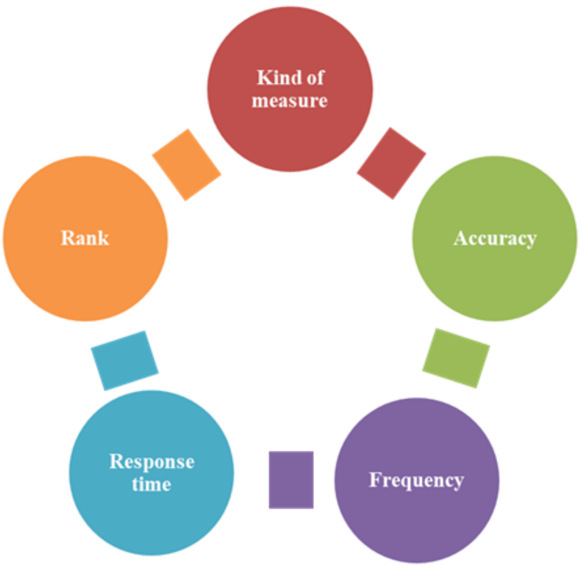


Figure 3.4: Features of Wireless Sensors

3.4. Wireless Sensor Networks

Wireless sensor networks (WSNs) are scattered groups of small nodes connected through wireless means with restricted capacity. Cinefra (2014) observed that a WSN was a “spatially distributed network of communicating sensors, designed in order to monitor and keep under control some environmental conditions (e.g. temperature, sound, pressure, position, etc.) and to cooperatively pass their data through the network to a main location being able to reason and react to the world that surrounds them” (p. 17).

Sensors with various capacities for monitoring, tracking, search, surveillance, and rescue are used to represent the nodes (Kuo, Chen, Cheng, & Lu, 2016). Moreover, the regulation of various conditions including temperature, movement, sound, pressure, etc., is permitted by these sensors. The frequent problem with this kind of technology is the inadequacy of the battery, interference, and superfluous quantities of data.

The main architecture of a WSN comprises a central node and a sensor node array spread in space. The nodes have varying functionalities. For instance, a central node has greater memory and processing capability in comparison to other nodes. Each node is required to be aware of its location and must even provide its position and accumulated information and execute network functions. This is because it does not possess a particular number of sensors and the ability to locate each one of this is not possessed by the base station. Overall, multiple jumps are utilised by the nodes to interact with the central node, under imperfect channel conditions that offer the exact position of the user (Garg &Jhamb, 2013).

3.4.1. Characteristics of WSNs

It can be seen from the preceding discussion that WSNs provide the opportunity to develop numerous applications that permit the monitoring of various phenomena. WSNs take on a group of individual characteristics which are essential for the associated design of algorithms and protocols (VillalbaMacías, 2015) and consequently warrant their quality. The most significant requirements are as follows:

- Resource limitations: Micro-electronic developments have been accomplished in WSNs over the years. Nevertheless, they have some shortcomings that are exactly associated with energy and size, such as, processing, bandwidth, and storage. The key is the usage of straightforward hardware that adapts to power utilisation, which be obtained from the present surroundings (VillalbaMacías, 2015).

- Cost of production: WSNs are typically composed of a large quantity of nodes which permit the obtaining of high precision data. However, the cost of the network can be determined by the cost of the node as the cost of nodes varies based on their complexity (Alwadi, 2015; Pérez, Urdaneta, &Custodio, 2014).

- Network environment and Topology: A WSN can be configured into various topologies, for example, star, tree, mesh, or a combination of these. Table 3.2 summarises the popular WSN topologies.

Table 3.2: WSN Topologies

Topology	Features
Star	It is a system with a single jump, that is to say that all the nodes have a direct communication towards the Gateway, denominated central node. The latter can send data to an external source, however, it has a great disadvantage if one of the nodes suffers a failure, it is considered a lost resource because it does not have an alternate path.
Tree	It is a system where routers communicate with both the end nodes as the Gateway, i.e., it is the data router between the members and the network coordinator.
Mesh	It is a multi-hop system, where each node has the ability to receive and transmit information from node to node and even to gateway. It has a high tolerance to errors, since it presents different communication paths to the central node, due to the implementation of the routing protocols .

Figure 3.5 depicts the WSN network topologies.

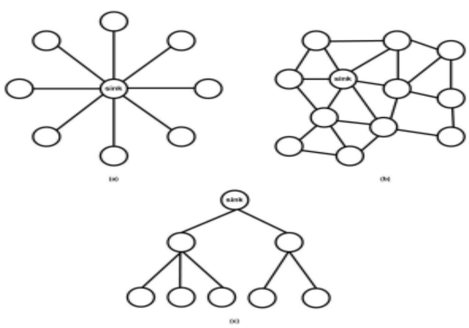


Figure 3.5:WSN Topologies (a) Star topology; (b) Mesh topology; (c) Tree topology

Source: Reina, Toral, Barrero, Bessis, & Asimakopoulou, 2013p. 99

WSN topologies can encounter several modifications since a fixed network infrastructure is not required. Instead, they must be designed in such a manner that they can work and adapt to various situations and special settings (Hernández, 2010).

- Error tolerance. Lack of energy and physical issues can cause the sensor nodes of a network to fail. When a sensor is damaged, the network should continue to function normally without any interruptions. The design and use of the WSN influence the degree of error tolerance (VillalbaMacías, 2015).

- Transmission medium. WSNs use various wireless connections, such as, Radio Frequency (RF), ultrasound, or infrared radio, to communicate. Each of these has its own features that can be susceptible to signal weakness, loss, or delay, particularly in the case of ultrasound and infrared. On the other hand, the most common wireless connection in use globally is RF communications as these have waves with the capacity to pass through buildings, objects, and even persons (Pérez, Urdaneta, &Custodio, 2014).
- Power consumption. Limited-load batteries are a feature of WSN nodes. This gives rise to a form a network design that is contingent on the source of power. A node has the capacity to greatly expand energy in its communication, in particular in receiving data rather than in transmitting it. Lower amounts of energy are consumed in processing of data. The most common type of batteries utilised are primary batteries (as used in typical household appliances) or secondary batteries (i.e., batteries that can be recharged) (VillalbaMacías, 2015).
- Scalability. The design of WSNs must take into account the need to function with hundreds or even thousands of nodes, thus providing support for varying and developing new schemas, applications, and environments.

3.4.2. Architecture of a WSN

This section describes the manner in which a WSN is constituted by diverse devices including, sensor nodes, a base station, and a gateway (Figure 3.6). These devices are described in the following subsections.

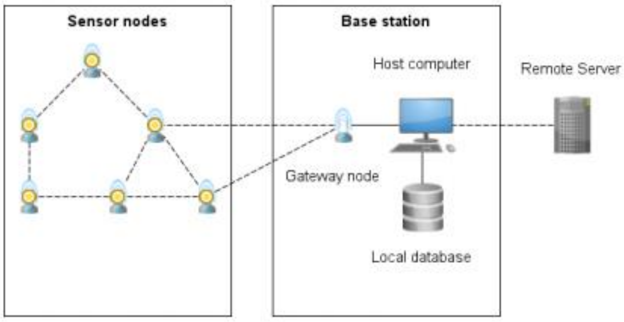


Figure 3.6: WSN Architecture

Source: Michalík, 2013, p. 6

Figure 3.6 depicts an instance of a WSN composed of sensor nodes, a gateway node, a base station and a remote server (Michalík, 2013). Different WSN architectures can be utilised for different applications. The measurements taken must correspond to the digital information acquired. These data must then be transmitted to an element with higher capacity to be analysed (Martínez, Meré, PisónAscacíbar, Marcos, &Elías, 2009).

3.4.3. Sensor Nodes

The most significant component of a WSN is the sensor node. It is the task of this node to detect data, transform them into a digital format and recognize the communication protocol to have the capacity to send and receive frames of data (Michalík, 2013). Sensor nodes are composed of different elements including the following:

- Transceiver. This circuit produces a RF signal from a digital baseband and vice versa.
- Processor. Also called a microcontroller unit (MCU), this element decodes and treats the collected information to transfer it to another device. The components of the processor are a process unit, input/output interfaces, and memory.
- Sensors. These are devices that produce quantifiable physical data in the motorised area. Sensor features include their small size, less consumption of energy, autonomous operation, acclimatisation to any setting, and ability to

function with high volume densities (Martínez et al., 2009). Sensors can be classified into the following three categories:

1. *Omnidirectional passive sensors*. These sensors do not need to manipulate the environment to capture data. They are self-powered and the use of energy is only to boost the acquired analogue signal. In these measurements, there is no notion of the involvement of 'direction'.

2. *Unidirectional passive sensors*. These passive sensors have a well-defined direction from which they must acquire the information. A camera is a typical example.

3. *Active sensors*. These sensors explore the environment. For instance, sonar, radar or some form of seismic sensor that produces shock waves by means of small explosions.

- Memory. Several classes of memory exist, such as, flash memory or integrated into an MCU. The nature of application determines memory, that is, whether the objective of storage is to (i) Save acquired data or (ii) to store the program.

- Energy unit. This is the device to store energy. The lifetime of the stored energy depends on the application. Thus, it is necessary to have alternatives to obtain energy from the setting. Nevertheless, the energy required for data transmission is higher in comparison to the energy required for data processing.

- Mobiliser: This element is responsible for repositioning the nodes for the various activities.

- Other elements: Other elements, depending on the application, include antennas, location systems, power generators, etc. Antennas may be chip of monopole antennas (incorporated into a printed circuit board). In most cases, however, chip antennas are utilised due to their small size and the avoidance of the usage of a connector.

3.4.4. Gateway

The gateway is a special node which supports multiple (two or more) physical interfaces. Furthermore, it permits the connection between the sensor and data networks. This device is fundamental because it permits monitoring and access to the nodes' information.

3.4.5. Base Station

The base station is a device based on an embedded system or computer. It acquires information from the nodes which is then integrated in a database for the users to remotely access.

3.5. Location

The term location, in the context of the current project, signifies the procedure of data collection to ascertain the position of an object as regards a group of points within a definite setting (Farid, Nordin, & Ismail, 2013). Different parameters are required for this purpose that are utilised by the technologies, algorithms, and techniques of localisation. These parameters are then synchronised among them to calculate the position, which create positioning systems by means of ubiquitous computing applications.

Location systems are a supplementary component of the sensor nodes of a WSN. These nodes gather various items of quantifiable information, such as angles, distances, ranges, velocities, etc., which are subjected to a computation of 2- or 3-dimensional coordinates, which are acquired in accordance to the association of fixed coordinates in reality (Axel, 2005).

The configurations, algorithms, techniques, and technologies that constitute a localisation system are described in the following sections. Features utilised for the implementation of the current project are emphasised.

3.5.1. Location: representation

The position of an object in any setting is its location. This can be displayed in one of three ways, namely, absolute, relative or symbolic (Varshavsky& Patel, 2009).

- Absolute. This form of location signifies geographic coordinates which parallels the degrees of latitude and longitude of a point on the surface of the earth (Figure 3.7).

- Relative. This form is so-called since a geographical coordinate can be converted to a symbolic place or a direction.

- Symbolic. This form is utilised in most systems of internal positioning, where it is necessary to specify a starting point of a Cartesian plane, where both the horizontal axis X and the vertical axis Y are specified.

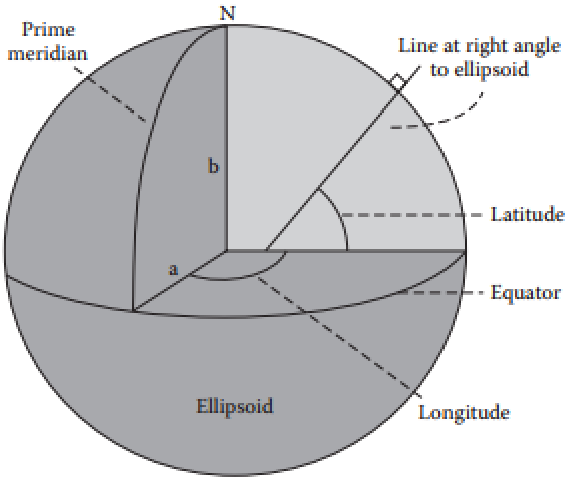


Figure 3.7: Location: Earth's surface

Source: Varshavsky& Patel, 2009, p. 289

Typically, an exact absolute location is specified using the degrees of latitude and longitude of the point on the Earth’s surface as outlined by the system of geographic coordinates. The latitude would quantify the angle between the point and the equatorial plane from the Earth’s centre, if the earth were an exact ellipsoid. However, in reality, the latitude computes the angle between a line that is normal to the reference ellipsoid that estimates the Earth’s shape and the equator. The angle along the Equator to the point is measured by the longitude. The point of zero longitude, or prime meridian, is considered to be a line that passes adjacent to the Royal Observatory in Greenwich, England. Geographically, the term parallels indicate lines of constant latitude, whereas the term meridians signify lines of constant longitude. Meridians are not parallel and all intersect at the Earth’s poles. This manner of depiction is frequently utilised in outdoor location systems such as the Global Positioning System (GPS)(Varshavsky& Patel, 2009).

Latitude and longitude can be utilised to denote any location on the Earth's surface. However, this is not a convenient form of representation in applications that entail human reasoning of location information. Systems such as geocoders (e.g., Microsoft's Virtual Earth or AT&T's Yellow Pages) can be employed to convert addresses into geographic coordinates. A reverse geocoder can be utilised to convert a geographic coordinate into an address. In the same manner, describing locations within an indoor space is not easy. A system may denote a location by employing a local coordinate system within the space by giving and X and Y distance from a predetermined position in the space (Varshavsky& Patel, 2009).

3.5.2. Techniques and Algorithms for Localization

Several factors need to be considered when developing an internal positioning system. One of these is radio signal and the method of distance measurement utilised inside the system. Various methods have been taken into account to resolve the positioning problem. Some of these (Gholami, 2011) include:

- Received signal strength (RSS) method
    - "Strength of the received signal between two nodes deteriorates with distance between them" (Bagaric, 2016, p. 41).
- Angle-of-arrival (AoA)
    - "Measuring the angle of arrival of a signal, from one node to another" (Bagaric, 2016, p. 41).

Dalce, Val, and Van den Bossche (2011) reported that the most common algorithms for localization include Triangulation which is the "process of determining a location of a point by using the geometry of circles and measurement of angles" (Bagaric, 2016, p. 42).

The determining of the position of an object with accuracy in both external and internal settings is permitted by the grouping of localisation techniques and algorithms. GPS (Global Positioning System) is a technology recognised for outdoor use. However, it has shortcomings with regard to battery issues and also location, in particular in places with inferior visibility or in internal settings where several obstacles may impede its signal. Consequently, the use of techniques that acquire data from objects closest to the location of the object is recommended. The following subsections describe the existing techniques in this regard.

3.5.2.1. Proximity Detection

This approach to localisation is one of the simplest and depicts a relative symbolic location. That is, the location of a device is estimated with respect to a point of reference. Nearness can be detected by one or more points of reference, which can be obtained from coordinates located in the signal range, which have restricted exposure. Point weighting can be utilised for a more accurate result. This technique can be utilised with wireless technologies, such as RFID, Infrared (IR), or Bluetooth.

3.5.2.2. Dead Reckoning

The technique of Dead Reckoning (Figure 3.8) permits the calculation of a position using the last location as reference. An earlier knowledge of its speed, direction passed, and time is added to this. Nevertheless, this approach has an aggregate inexactness, which amplifies its accuracy error with time (Farid, Nordin, & Ismail, 2013; Varshavsky& Patel, 2009).

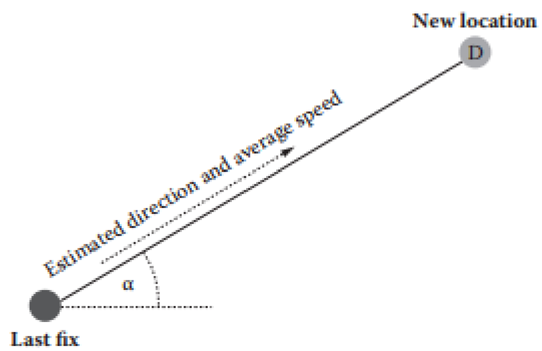


Figure 3.8: Dead Reckoning 2-D

Source: Varshavsky& Patel, 2009, p. 298

3.5.2.3. Triangulation by AoA

The technique of triangulation utilises the AoA of signals traversing from a device to points of reference to assess the location of the device. Figure 3.9 depicts a two-dimensional representation of an instance of triangulation. Determining the angle at which the signal reaches from the device (gray dot) to a point of reference (black dot) limits the device's position adjacent to the line that passes by the point of reference next to the AoA. Two lines result from determining angles from two points of reference. These lines distinctively describe the location of the device at the intersection point. Therefore, it is adequate to have angle magnitudes from only two points of reference to ascertain the device's location in two dimensions. However, in practice, more than two points of reference are utilised to lower errors in angle determination. Either a directional antenna or an array of antennas is required to gauge the AoAof a signal. Most present location systems based on triangulation prefer to gauge the AoAat the points of reference since directional antennas or antenna arrays are usually not available on a mobile device (Varshavksy& Patel, 2009).

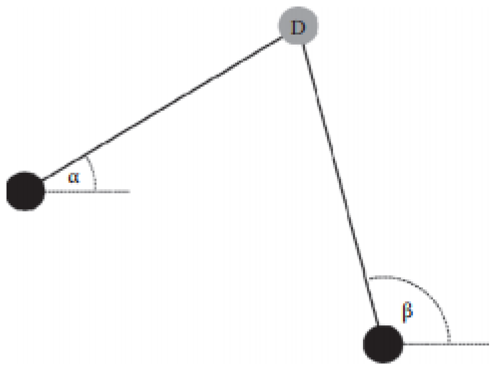


Figure 3.9: 2-D example of triangulation in 2-D

Source: Varshavksy& Patel, 2009, p. 295

3.6. Standing Wave Cancellation

A common occurrence in the field of wireless communication is the standing wave. In environments that contain many obstacles, such as closed spaces, the wave that is being sent from the transmitter to the receiver propagates through space and gets reflected from different kinds of surfaces. These reflections cause the receiving end to receive multiple instances of the same wave, some of them arriving directly, while others arriving after being reflected from a certain object. This occurrence is commonly called multi-path interference (MPI), and represents a common issue in indoor positioning systems that use wireless technology.

The MPI has another side-effect, which is called the standing wave (Figure 3.15). When a wave gets reflected from a surface, it generates another wave that propagates back in the opposite direction. If one puts a receiver somewhere between the transmitter and the reflective surface, detecting the strength of the signal would vary on the position in which the receiver is placed because of the standing wave effect. Certain positions, particularly those that are half wavelength apart, would show no oscillations in the signal strength when measured multiple times. These points along the medium are called nodes (N). Some other points along the medium would yield different results, showing high oscillations in signal strength. The points that contain the highest amount of oscillations are called the antinodes (AN) (IPL, 2016, Patent #109137).

In order to achieve accurate and consistent indoor positioning estimation using signal strength, inside closed spaces, mitigating the effect of the standing wave is one of the problems that needs to be addressed. Currently, a technical solution to this problem does not exist, and as a part of this thesis, a way to solve the problem of the standing wave will be introduced, in cases where wireless communication is used in indoor positioning systems.

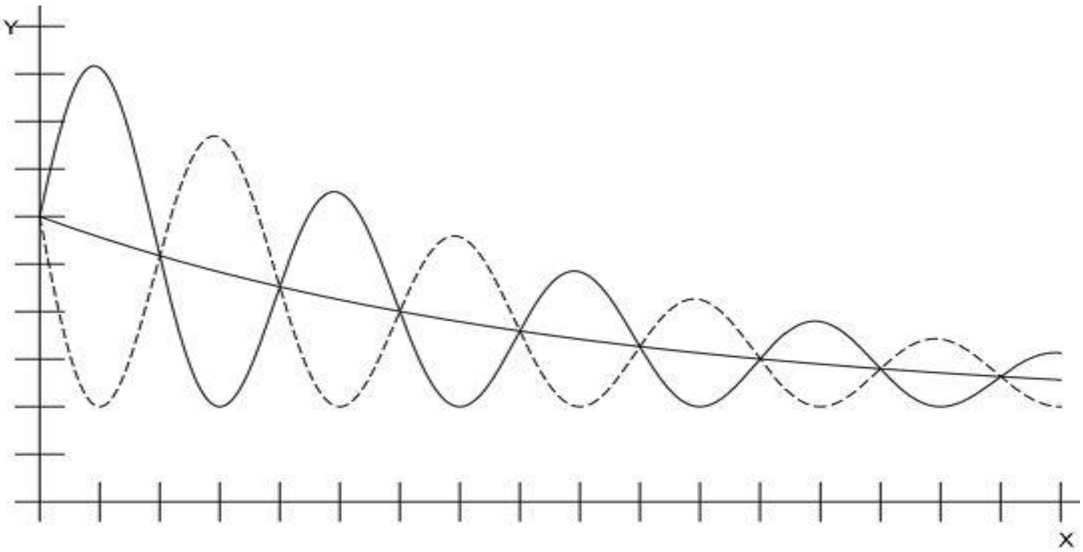


Figure 3.10: Standing wave cancellation

Source: IPL, 2016, Patent #109332

The standing wave cancellation wireless transmitter consists of a signal generator suitable for creating a signal with wavelength λ, an output and a relay switch, connected so that a relay switch alternatively connects the signal generator through a first path generating a first wave and through a second path to the output to generate the second wave. These two paths deliver two different signals. The first wave is created with a wavelength of λ, whereas the second wave is created with half the wavelength λ, by guiding the signal through a different path towards the output, as seen in Figure 3.16.

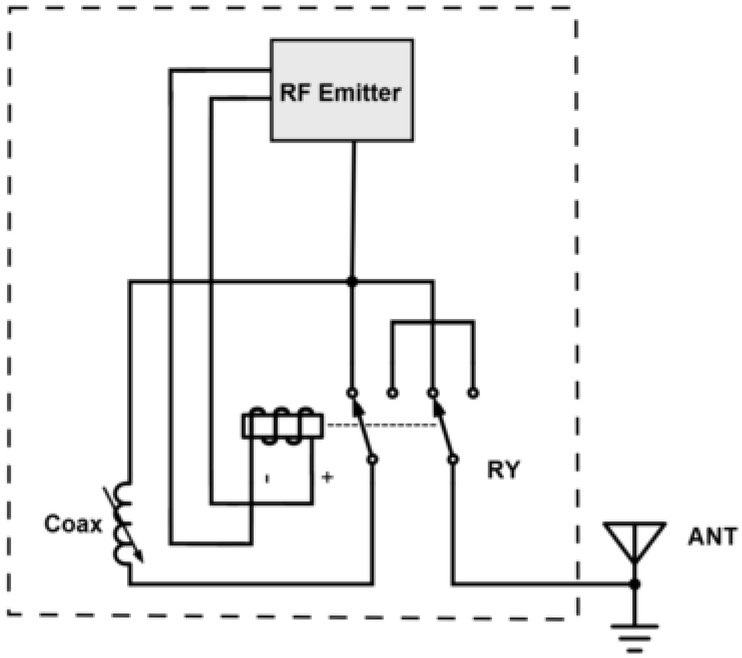


Figure 3.11: Standing Wave Cancellation – Mechanism

Source: IPL, 2016, Patent #109137

To generate the signal, a radio signal generator is used. The signal that the generator generates is then either sent directly to the antenna, or a relay switch (Double Pole Double Throw - DPDT) redirects the signal through a coaxial cable which has a length such as to generate a wave shifted in half the wavelength λ, again to the same antenna. The relay switch is then used in such a way to emit these two radio waves in time-division multiplexing, thus enabling the receiver to mitigate the effect of the standing wave by summing up the two waves before processing them.

A patent (#109332) has been submitted for this mechanism (Reference 65). More information is available in the appendix.

3.7. Design of the New Autonomous Wheelchair

[1]The classification of wheelchairs, in general, is based on the power utilised for movement. Thus, two general categories exist: manually and electric powered wheelchairs. Manual power is used to drive manually powered wheelchairs and these are further classified on the basis of commode design (with or without) and collapsibility (collapsible and non-collapsible). As suggested by their name, electric powered wheelchairs are powered by electricity. Nevertheless, manual intervention is needed to control the user interface (typically a joystick) for the navigation of the wheelchair. Other elements may be affixed to improve the ease of use of the wheelchair (Kumar, Mishra, &Ahamed, 2012).

The proposed joystick-based electric autonomous wheelchair system with additional user-friendly elements is depicted in Figure 3.17.

The main control in the proposed wheelchair system resides with a low cost minicomputer. In the present instance, a Raspberry Pi was selected due to its low price, interaction with other electronic devices, and flexibility and performance in numerical computation. The left and right movements of the wheelchair are accomplished through the use of two DC motors with speed reducers. The wheelchair user is helped by the joystick module to issue commands to the movement control. As the IPL/IT intelligent wheelchair system is the underlying framework of the proposed wheelchair system, further components are added for motor control, voice and eye movement commands, obstacle detection, autopilot (with GPS, with a coloured line, and via web). A specific software is utilised to activate all the components. Other elements of the IPL/IT wheelchair system (Portuguese utility model n.º 11027) are integrated in the prototype. These elements are webcams, joystick, microphone, helmet, electronics for data collection, and DC motors with reducers.

[1] This section was part of a previously published paper related to the current work.

The next section describes the voice and eye control components that are used to command the wheelchair system, followed by a brief overview of the Raspberry PI and ESP8266 connection which serves as the receiving end of the input commands.

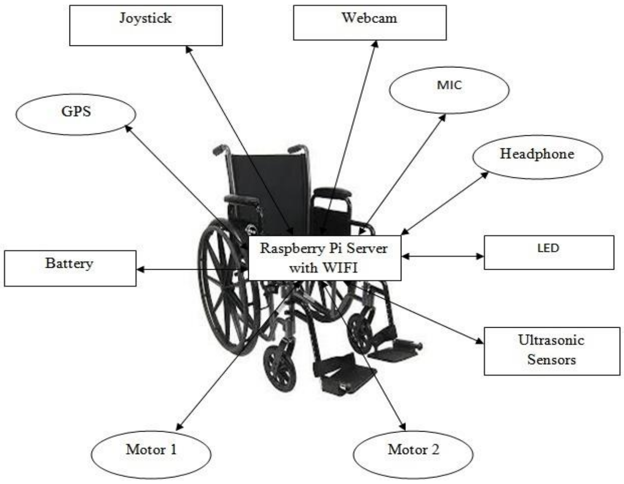


Figure 3.12: Block diagram of Joystick-based electric wheelchair system

3.7.1. Voice Control Component

A wheelchair that is controlled by voice helps a person with disabilities to be independently mobile. This can be achieved by interfacing a voice recognition application with the motors. As the wheelchair prototype uses a Raspberry Pi microcontroller, the DC motors can be controlled using such a voice recognition module to move in accordance to the voice commands. Five commands are utilised to manipulate the direction of the motor, namely, Right, Left, Forward, Backward, and Stop.

3.7.2. Eye Control Component

A wheelchair controlled by eye movements is basically a wheelchair system that is vision-based. User images are obtained using a webcam. The webcam additionally evaluates user intent by monitoring the movements of his/her eyes (Figure 3.18).

Two kinds of commands are provided for eye control in the IPL/IT wheelchair system: manual and smart. The manual commands are Front, Reverse Left, Right, and

Stop. The smart commands are Reading eye movements; validation by Voice commands; Autopilot via Internet; and Autopilot (GPS or coloured line).

Figure 3.13: Graphic interface of the eye-controlled system

3.7.3. Connection of ESP8266 with Raspberry Pi

The positioning system of the wheelchair system is composed of a Raspberry Pi and some ESP8266 modules that include motors to drive the directional antennas. The Wi-Fi antennas aid in obtaining the coordinates (longitude and latitude) by means of a triangulation process.

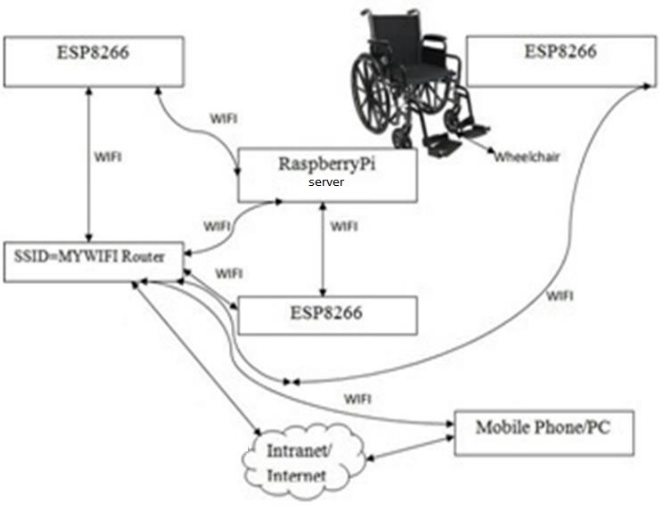


Figure 3.14: Architecture of the location System

These coordinates are then gathered utilizing the Raspberry Pi module. Flores, Marcillo, and Pereira (2017) recently utilised a comparable system to assess the position of a drone. The same positioning system is used with the IPL/IT autonomous wheelchair. The wheelchair can be manipulated by sending commands to the main server from a mobile app. The server then passes these commands to the hardware actually connected to the Internet via the Wi-Fi network which then generates suitable signals to guide the wheelchair. The architecture of the location system is depicted in Figure 3.19. Figure 3.15 depicts the triangulation process.

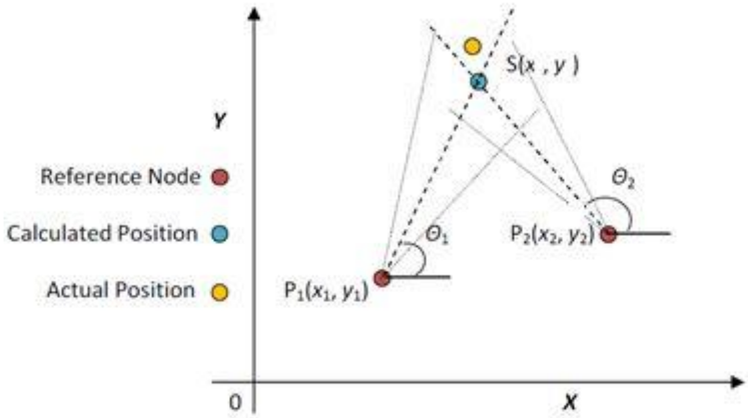


Figure 3.15: Triangulation Process

The antenna direction can be utilised to compute the location of a station (i.e., the wheelchair) by utilizing the AoA technique (Flores et al., 2017) to accomplish smart antenna localisation. The AoA or Angulation technique is comparable to lateration but differs in its usage of angles to position a target (Farid, Nordin, & Ismail, 2013). The Received Signal Strength Indication (RSSI) and the angle at which the maximum value is obtained help to determine the location of the wheelchair. In a wireless environment, the RSSI is the relative received signal strength. It indicates the concentration of power that a receiver receives after possible losses attributable to the cables and antenna. Thus, the robustness of a signal is indicated by the RSSI value (Eko&Pastima, 2017). This information is utilised to establish a line between the wheelchair and the antenna. By clustering no less than one more antenna, the intersection of two of those lines can be determined, which should denote the location of the wheelchair. Assuming the existence of two antennas (A and B) with coordinates a_x, a_y and b_x, b_y, and angles θ_A, θ_B, respectively, and P, the calculated intersection point with coordinates (p_x, p_y), the following system of equations can be utilised to determine the position of the station:

$$P_x = a_x \times \tan\theta_A - b_x \times \tan\theta_B + b_y - a_y \tag{1}$$

$$P_y = \frac{(a_x - b_x) \times \tan\theta_A \times \tan\theta_B + b_y \times \tan\theta_A - a_y \times \tan\theta_B}{\tan\theta_A - \tan\theta_B} \tag{2}$$

Multiple intersections can be determined and an average aggregation method was utilised in this project. That is, assuming that there are a set of N intersection points denoted by a pair of coordinates (x_i, y_i), where i=1, 2,….,N, the average point (x, y) of all intersections can be determined using the following equations:

$$x = \sum_{i=1}^{N} x_i / N \tag{3}$$

$$y = \sum_{i=1}^{N} y_i / N \tag{4}$$

The average point indicated by equations (3) and (4) will provide the approximate position (Shan&Yum, 2007). The calculated position will be used to update a map and this will identify the position of the wheelchair. The Wi-Fi signal angles, of each Yagi antenna, are measured with the equipment pictured in Figure 3.16.

The ESP8266 directional antennas are positioned on two servo motors which have a rotation of 180 degrees. In our scenario, the wheelchair is located inside a geographical equilateral triangle of 20 metres. The ESP8266 are placed at the vertices of the triangle. It is possible, in this manner, to discover the location of the wheelchair with an error margin of 7 centimetres.

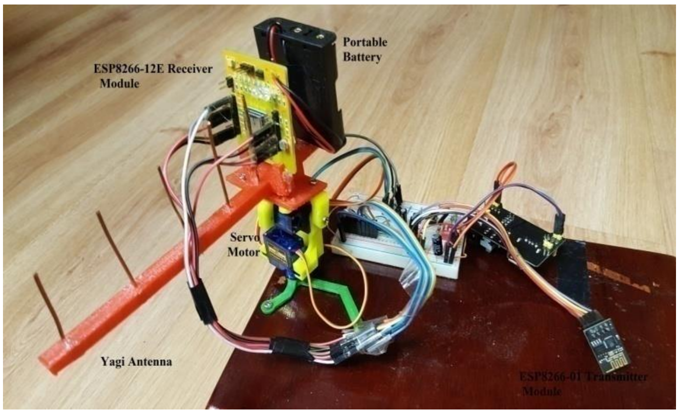


Figure 3.16: Measurement of Wi-Fi signals

As mentioned earlier, the objective of the current initiative is to improve the present facilities of the IPL/IT wheelchair system prototype with the intent of enhancing its user-friendliness, robustness, and accountability to enable both users and wheelchair providers to more successfully locate the wheelchair by means of a mobile application. This initiative uses IoT technologies to enhance the earlier IPL/IT wheelchair prototype. The primary elements of the extended system are: a centralized server with a Raspberry PI minicomputer for control and a set of servo motors for each ESP8266 antenna. A network of ESP8266 modules will be used to obtain the wheelchair location. All the modules are distributed in an indoors scenario and they use Wi-Fi to communicate with the wheelchair server.

The Raspberry Pi unit serves as the heart of the system and offers an interface between the units, namely the GPS, sensors, and the output units (e.g., the servo motors, etc.). The system thus determines its location by computing its position every time it obtains each ESP8266's Wi-Fi signal angles. The positioning system also has the capability to regulate the wheelchair's movement and its direction/orientation. This is moreover a process to improve the safety of the user as all the data is registered and documented in a defined format.

Therefore, the proposed wheelchair system includes:

1. A web server running on Raspberry Pi;
2. A mobile phone which utilises a browser to view the images from the webcams of the wheelchair;
3. A web page which

i. permits dynamic commands for real-time control of the two motors of the wheelchair;

ii. offers supplementary information regarding the different sensors utilised to avert issues, such as collisions;

3.7.4. Hardware requirements

This section summarises the hardware requirements of the autonomous wheelchair system (Table 3.3).

Table 3.3: Hardware requirements for the autonomous wheelchair system

Hardware	**No. of units**
Raspberry Pi with Charger	1
Servo motor	4
Memory Card with Adapter	2
Wi-Fi Antenna	3
USB to TTL Converter	1
Ultrasonic distance sensor	2
USB to UART Module	1
Relay Board – 2	5
Resistors	3
Breadboard	4
Tweezer	1
Wi-Fi pod	1
ESP 8266 Module	4
Rechargeable batteries with shells	2,5
USB Charger	1
Screwdriver	1
Transistors, Capacitors	2

3.8. Summary

This chapter described the technologies utilised in the proposed autonomous wheelchair system as well as the methodology utilised to derive the desired outcomes. The methodology utilised for the project is the DS methodology. Accordingly, this chapter served as the Knowledge Base segment of the methodology and described the various technologies, approaches, and systems that support the development of the autonomous wheelchair system with a smart driving mode and a Wi-Fi positioning system.

4. System Design, Implementation, Testing and Analysis

4.1. Introduction

This chapter comprises the Research Science of Design phase of the Design Science methodology. It describes the requirements specification of the localization system and the wheelchair system. It also presents the system's development, implementation, testing, and analysis. The tools utilized and tests carried out to ensure the prototype's quality are also described.

4.2. Designing

In unusual settings, localization of static and dynamic objects may offer a greater level of positioning error. Nevertheless, the constant requirement to recognize the location of both people and objects has led to the use of previously available techniques and methods to develop and implement a system. The objective of this Wi-Fi location system is the utilization of sensors or modules with particular characteristics, such as, price, dimensions, serviceable life and processing. Also, specific approaches and practices that permit the real-time receiving, handling, and distribution of data to the central node will be utilized. The current work is split into two parts to achieve this task. The first part envisions the modularity of both hardware and software, which results in the production of a sensor node with Wi-Fi elements and receivers, and the carrying out of practices and approaches that ensure an object's position in both dynamic and static states in internal and external settings.

The second part of the work is positioning a particular object, in this case an autonomous wheelchair.

One of the objectives in the first part of the work is the approach and technology used for localization, in which the goal of the positioning system is to reduce the positioning error and estimate an autonomous device's location. These challenges are crucial to the design and implementation of an autonomous device's external and internal localization system.

4.2.1. Scope Specification and Requirements Analysis

4.2.1.1. Reach

This section signifies the relevance cycle wherein the project has two components, namely, the localization system and the autonomous wheelchair system. As per the analysis undertaken in Chapter 3, an object is positioned in static and dynamic states by the localization system. The object to locate is an autonomous wheelchair system. A generic solution is proposed for each of the systems.

Wheelchair system

- The wheelchair will function as the base station and must maintain communication with the remote terminal which can control the wheelchair system. This sends the coordinates that the vehicle must take in 2D movements, to comply with the direction established by the user.
- Communication between the wheelchair and the software will be maintained for the visualization of the movement through the camera present in the wheelchair system.
- Communication and sending of commands is required for the autonomous operation of the wheelchair.

This solution develops a web page for the wheelchair which can be opened using a simple browser and an application that is a component of the main project.

The first permits interaction with the wheelchair system and injects the code that regulates the wheelchair's mobility. The second phase permits the sending of the coordinates that the wheelchair has to travel through.

Figure 4.1 depicts the proposed architecture of the wheelchair system.

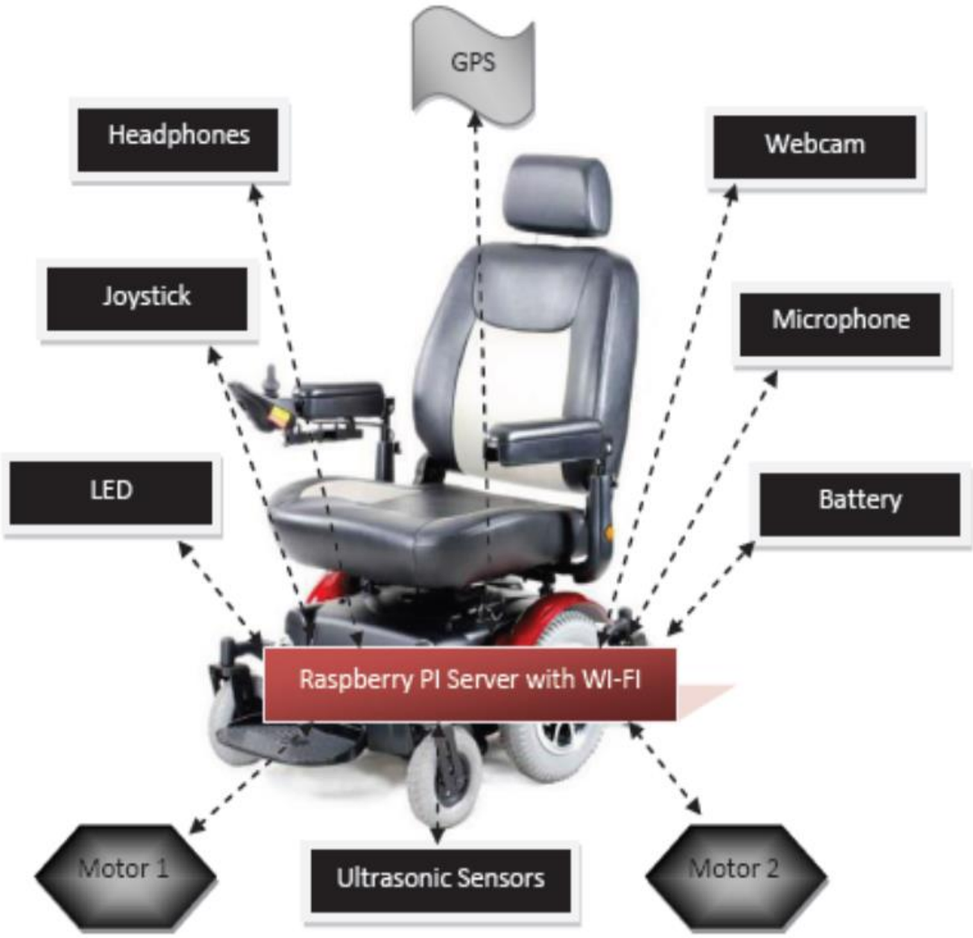


Figure 4.1: General Architecture of the Proposed Wheelchair System

Location System

- Implementation of the transmitter module and the 3 Wi-Fi receivers, for the collection of maximum Wi-Fi power emitted by the wheelchair system in real time.
- Implementation of the AoA localization technique, for the optimization of the positioning (Shan and Yum, 2007).

The location system is a component of the main project that is composed of hardware and software. The hardware details the construction of a prototype which has Wi-Fi devices, antenna, and batteries. The software details the graphical interface of the project in the real-time scenario. Additionally, the software processes the data from the wheelchair system in order to estimate a position.

4.2.1.2. Requirements

The present work comprises multiple systems, each of which fulfils different functions. Accordingly, each has different features that are essential to accomplish its objective. These features are Functional, Non-Functional, and Performance. The following sections define the requirements that are essential to the project's development separated into the wheelchair and localization systems.

Functional Requirements

Table 4.1 and Table 4.2 define the functional requirements respectively of the wheelchair and localization systems.

Wheelchair system

Table 4.1: Functional requirements of the Wheelchair System

Requirement	Functionality	Priority
Autonomous movement	Independent movement of the wheelchair	High
Extend range of capabilities of the IPL/IT prototype wheelchair	To include location and positioning	High
Versatility	Should permit indoor and outdoor use	High
Safety and robustness	System should be able to detect obstacles and potential hazards. Moreover, it should be physically robust.	High

Location System

Table 4.2: Functional Requirements of the Location System

Requirement	Functionality	Priority
Sensor node	Ability of perception of the sensor nodes.	High
Processing of information	Processing of information, for the calculation of coordinates.	High
Sensor node	Detect the angles associated to the maximum emitted Wi-Fi power of the wheelchair system.	High
Estimated initialroute	Estimated initial route sample	High
Sensor node	Horizontal movement of the antenna.	High

Non-Functional Requirements

Table 4.3 and Table 4.4 define the functional requirements respectively of the wheelchair and localization systems.

Wheelchair system

Table 4.3: Non-Functional Requirements of the Wheelchair System

Requirement	Functionality
Low cost	Use of low cost components to keep the wheelchair affordable
Psychological acceptability	Users must feel confident about using the wheelchair

Location System

Table 4.4: Non-Functional Requirements of the Location System

Requirement	Functionality
Sensor node	Use of more than three sensors
Sensor node	The battery must be portable (long life and rechargeable)
Sensor node	Time detection time of the three sensors.
Sensor node	Time detection time, for the start of its mobilization.
Sensor node	Vertical movement of the antenna
Graphic interface	Infinite number of waypoints to trace the initial route

Performance Requirements

Table 4.5 defines the functional requirements respectively of the wheelchair and localization systems.

Wheelchair System

Table 4.5: Wheelchair System Performance Requirements

No.	Description
1	It is necessary that the cellular device has root access to allow the user to have control over the device.
2	Python is the programming language used in the Raspberry PI wheelchair system.

4.3. Conceptual Design

This section describes the Rigour Cycle, where the general architecture of the present project is planned. This supports the development of a different artefact and system by means of various construction approaches and instruments.

4.3.1. System architecture

The architecture of the proposed wheelchair system was presented earlier (Figure 4.1). As mentioned earlier, the main control in the system resides with a low-cost Raspberry Pi minicomputer. The movements (left and right) of the wheelchair are accomplished through the use of two servo (DC) motors with speed reducers. The wheelchair user is helped by the joystick module to issue commands to control the movements of the wheelchair. Provision is also provided for control of movements through eye and voice commands.

The wheelchair system's positioning system is composed of the Raspberry Pi and several ESP8266 modules. Motors are included to drive the directional antennas. A triangulation process is utilized by the Wi-Fi antennas to obtain the position coordinates (longitude and latitude).

4.4. System Implementation

This section corresponds to the Design Cycle and describes the implementation of the system. The wheelchair system is first described followed by the localization system.

4.4.1. Wheelchair system

The implementation of the wheelchair system was performed in the following manner:

1. The preliminary testing was performed using various materials, such as, the servo motors, relay modules, camera module, and ultrasonic sensor.

2. The Raspberry Pi minicomputer was then configured. This included updating and upgrading the kernel.

3. The ESP8266 modules were configured using serial communication.

4. The driving relays were then tested as were the video captures using the camera's on-button click.

5. A network was formed using the ESP8266 modules and the intercommunication between these was established. This is described in the following section.

6. Calculation of distances was accomplished using the ESP8266 modules via the triangulation process. This is described in the following section.

Overall, one end of the system is composed of three sets of NodeMcu and servo motors with antenna assembly as the endpoints. At the other end, there is an ESP8266 chip which serves as the access point. All the ESP8266 and NodeMcu chips are connected to the common Wi-Fi access point thereby forming a closed network for communication and the values will be sent to the Raspberry PI server.

An ESP8266-12E chip equipped with an Antenna module is used to get the RSSI in dBm and the Angle of motor rotation. Presently, servo motor is setup to rotate from 0 to 180 degrees in steps of 1 degree. Hence, the servo motor is rotated at a particular angle and fetches the RSSI of the ESP NodeMcu chip. The NodeMcu chip GpioPin 15 is used to drive the servo motor at a specified angle.

The maximum RSSI obtained by the chip is closely monitored and then sent to the ESP8266 access point. Subsequently, the angleis sent automatically to the server once one complete rotation of the motor is achieved, i.e., 180 degrees.

4.4.2. Location System

This section is associated with the preceding section since it is associated with the target to be found by the location system. Accordingly, two types of modules are described in the following sub-sections: 1) sending and receiving signals, and 2) positioning.

4.4.2.1. Module for Data transmission and reception

This module establishes the implementation and operation of the sensor nodes that comprise the wireless sensor network (WSN).

Each node is composed of three ESP8266-12E modules: one of which acts as an access point whereas the other two act as clients (Fig. 4.2).

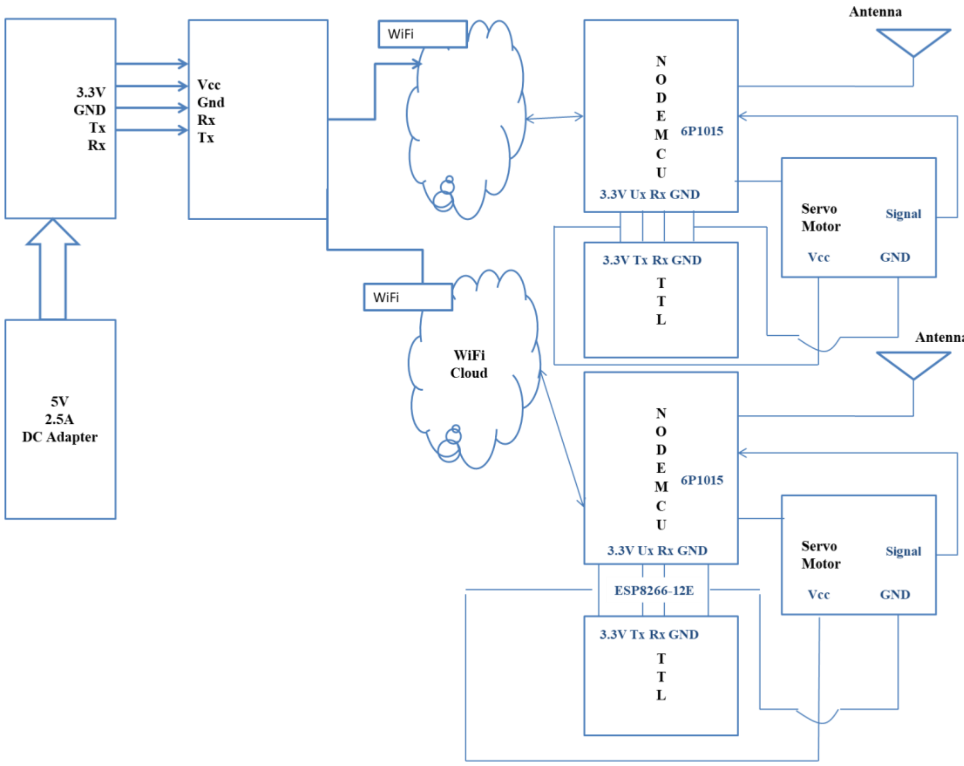


Fig 4.2: Circuit diagram of the sensor node

The two clients provide angle values to the access point which in turn is automatically sent to the Raspberry PI server. As described in Chapter 3 (Section 3.7.3), a small program has been written in the server to obtain the values from the access point using the triangulation method described in the next chapter.

Other devices added to implement this module are (i) a Yagi antenna, and (ii) two servo motors. A set of rechargeable mobile batteries are included for the node's power supply. The devices mentioned in this section have been described in Chapter 2. The tasks performed when the components interact with each other are next defined.

4.4.2.1.1. ESP8266-12E Modules

As mentioned in the preceding section, the ESP8266-12E modules serve both as access point and clients. In the implemented localization system, this component accomplishes the communication between the host computer and the receiving module. Wi-Fi wireless communication is utilized to communicate with the both the sender and the receiver.

The flowchart (Figure 4.3) depicts the process performed by the transmitter module. Opening the receiver's serial connection permits data transmission between the two.

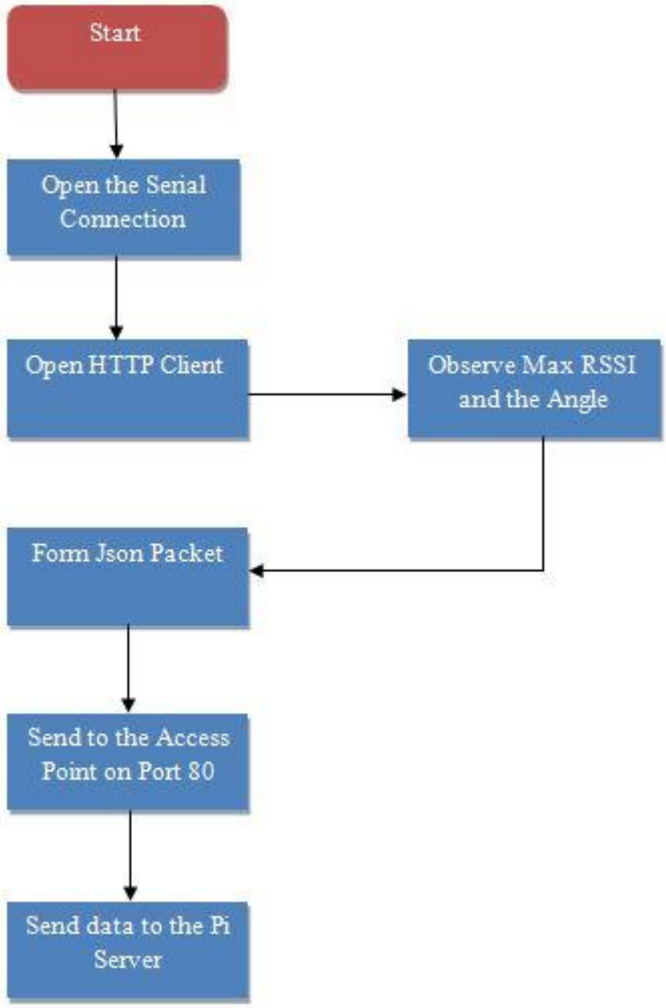


Figure 4.3: Transmitter Module Functionality

The flowchart (Figure 4.4) depicts the process performed by the receiving modules.

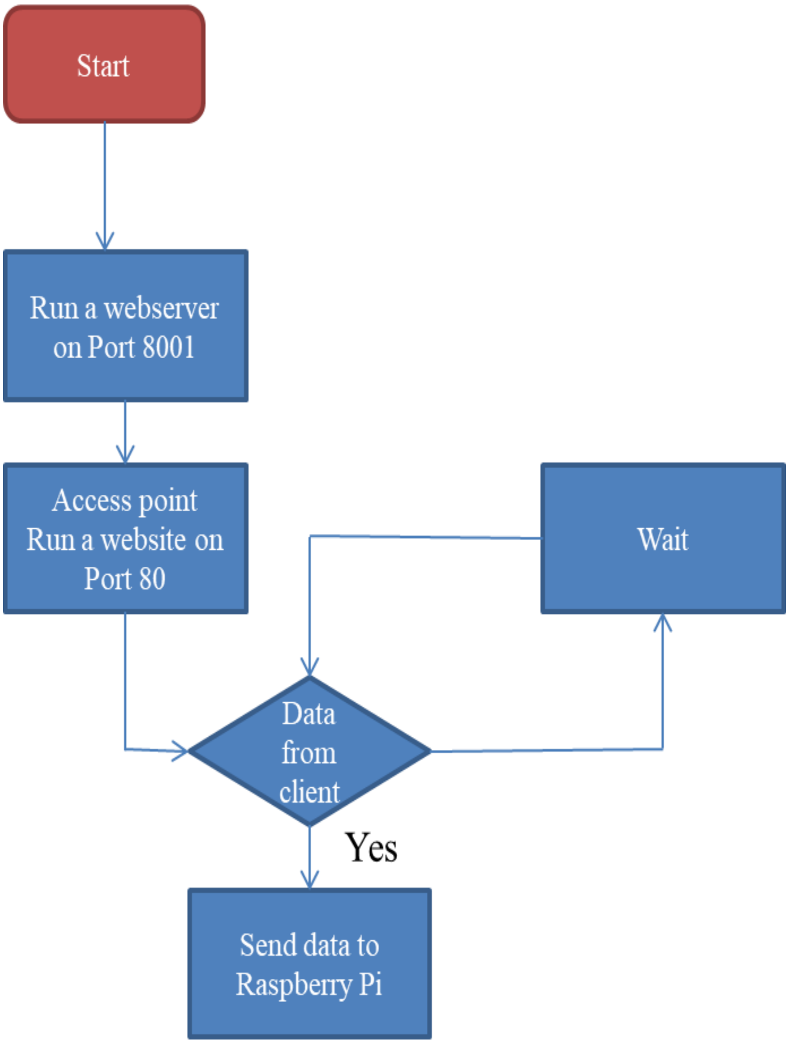


Figure 4.4: Receiver module functionality

4.4.2.1.2. Wi-Fi wireless location module

The Wi-Fi wireless location module comprises three ESP8266-12E modules which serve as transmitter and receiver. Two new electronic devices are added that constitute the sensor node to these components for optimization: (i) 2 Servo motors and (ii) a Yagi antenna. A small rechargeable mobile battery is also added to this unit (see Figure 4.5).

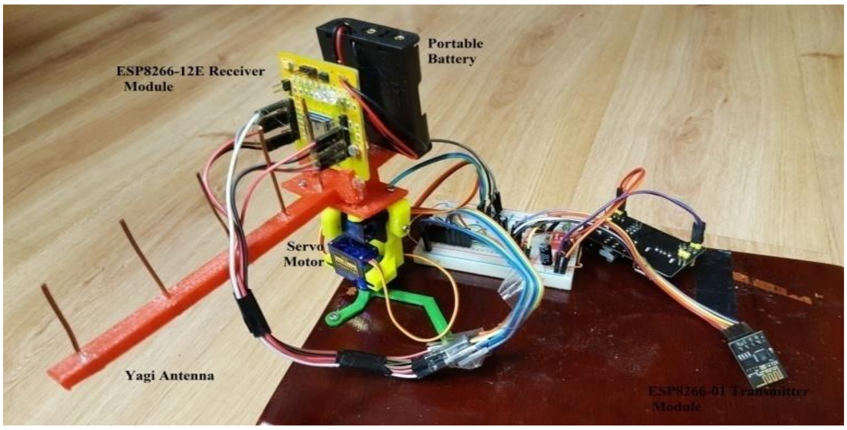


Figure 4.5: Wi-Fi Location Module Prototype

4.4.2.1.3. Modularity of components

Figure 4.5 depicts the circuit diagram of the prototype discussed in the preceding section.

4.4.2.2. Positioning module

As described in Section 3.7.3, the positioning system of the wheelchair system is composed of a Raspberry Pi and some ESP8266 modules that include motors to drive the directional antennas. The Wi-Fi antennas aid in obtaining the coordinates (longitude and latitude) by means of a triangulation process.

4.5. Analysis and Evaluation of Results

This section is also a component of the research phase of Design Science and contains the assessment of the localisation system in internal and external settings while using different states of the wheelchair. The details in this chapter include the testing methodology and assessment of the localisation system and the measured signal.

4.6. Methodology for Testing

4.6.1. Operational System Testing

The wheelchair system, shown in Fig. 4.6, is essentially controlled by a low cost minicomputer, the Raspberry Pi, which easily interacts with other electronic devices, and is flexible and performs well numerically. Two DC motors with speed reducers control left and right movements of the wheelchair. The wheelchair user is aided by the joystick module to issue commands to the movement control. ESP8266 modules were connected with Raspberry Pi. The locating system of the wheelchair comprises of a Raspberry Pi and ESP8266 modules that includes motors to drive the directional antennas. The Wi-Fi antennas aid in obtaining the coordinates (longitude and latitude) by means of a triangulation process. These coordinates are then gathered utilizing the Raspberry Pi module. The wheelchair is manipulated by sending commands to the main server from a mobile app. The server then passes these commands to the hardware actually connected to the Internet via the Wi-Fi network which then generates suitable signals to guide the wheelchair.

Figure 4.6: Proposed wheelchair system

An application was created so that the user of a mobile phone can remotely drive the wheelchair which included:

1. A Web server running on Raspberry PI: Python programs were written for Raspberry PI configuration to enable control of joystick, cameras, relay, starting and stopping and directional commands of motors for video and movement, test videos, ultrasonic sensors (Fig. 4.7), and web server. All the

programs are presented in the Appendix. A screen shot of the relay operation for video camera and wheelchair motion is depicted in Figs. 4.8 and 4.9.

```
import RPi.GPIO as GPIO
import time

GPIO.setmode(GPIO.BCM)
TRIG=23
ECHO=24

print "Distance Measurement"
GPIO.setup(TRIG,GPIO.OUT)
GPIO.setup(ECHO,GPIO.IN)

GPIO.output(TRIG, False)

print "Waiting for Sensor to Settle"
time.sleep(1)

GPIO.output(TRIG,True)
time.sleep(0.00001)
GPIO.output(TRIG,False)

while GPIO.input(ECHO) == 0:
    pulse_start = time.time()
while GPIO.input(ECHO) == 1:
    pulse_end = time.time()
pulse_duration = pulse_end - pulse_start

distance = pulse_duration * 17150
distance = round(distance,2)

print "Distance (cm):", distance
GPIO.cleanup()
```

Figure 4.7: Sample Ultrasonic control back end python program

2. A mobile phone using a browser to view the images for guidance of the wheelchair (Figs 4.8 and 4.9);

3. A Web page provided by the server that provides the following:

   a. dynamic commands to control the two motors in the wheelchair in real time;

   b. additional information on the various sensors used to prevent problems, such as: collisions;

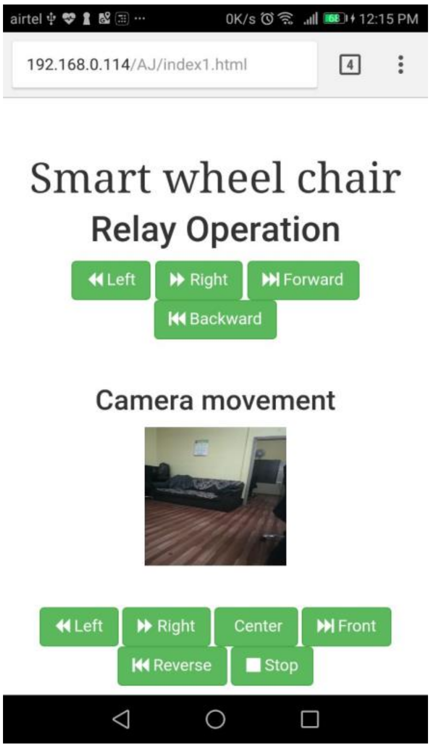


Figure 4.8: Mobile phone screenshot camera and wheelchair reverse end movement control

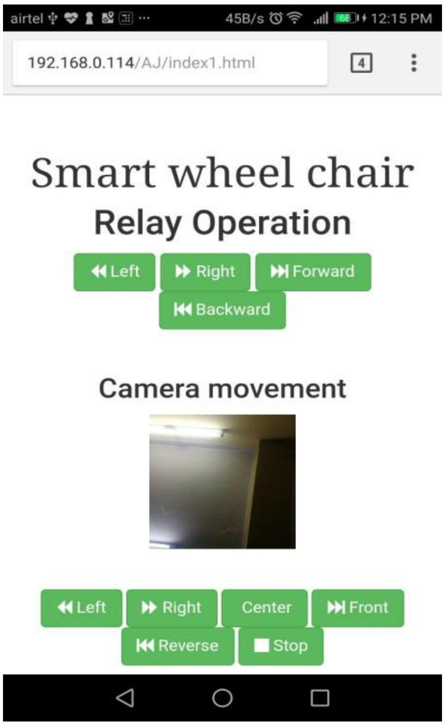


Figure 4.9: Mobile phone Screenshot Camera and wheelchair front end movement control

The operation of the wheelchair system components was observed to be satisfactory.

4.6.2. Positioning System Testing

The assessment of the localization system for the autonomous wheelchair system was partitioned into three distinct components. First, tests in internal and external settings were conducted using a 5x5 m scenario. Second, the accuracy of the system was assessed by computing the relative error. Third, data was collected to relate the power produced by each node. The variables utilized to test the optimization of the localization system are listed in Tables 4.6 and 4.7.

Table 4.6:Conceptual definition of the variables evaluated for the localization system

Variable	Conceptual Definition
Angle	Angle that is formed between the direction corresponding to the maximum RSSI and the reference direction.
Power	Maximum power emitted by the sensor node.
Estimated Error	Difference between calculated and real positions.

Table 4.7: Operational definition of the evaluated variables

Variable	Operational Definition	Indicator	Tool
Power	maxRSSI – Maximum Power	dBm	Raspberry PI, ESP-12E
Angle	hAngle – Angle where the maximum power is found	Grades °	Raspberry PI, ESP-12E
Estimation Error	Euclidian Distance	Metre (m)	Excel

Variable	Operational Definition	Indicator	Tool
Precision Error – GPS	Euclidian Distance	Metre (m)	Excel

Tools such as ESP-12E were utilized to obtain the measures that produce the precision error. Microsoft Excel spread sheets were used to compute the precision error of the system and that gives the coordinates of the wheelchair's position in latitude and longitude. The calculations were again performed using Excel.

4.6.2.1. Triangulation process

The locational coordinates are arrived at using the Angle of Arrival (AoA) method (Fig. 4.10).

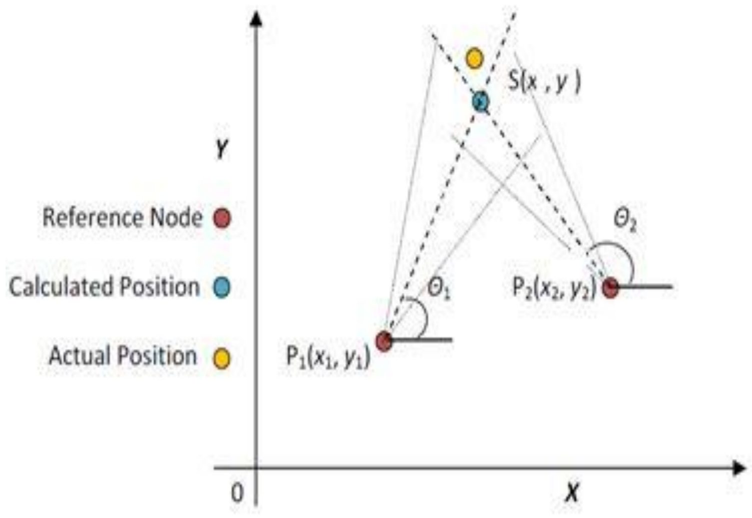


Figure 4.10: Triangulation method using AoA

The localizing method uses Wi-Fi ESP8266 modules and Yagi antennas. Initially, the angles θ_1 and θ_2 are measured for all nodes (here, P_1 and P_2) using the AoA method. Then, the line representing the orientation of highest signal power is calculated at all node references, their coordinates (X_i, Y_i), i=1,2 and angles (θ_1 and θ_2) being known. The intersecting point of the lines S(X,Y) is arrived at as follows:

For line P_1S, slope = $\tan\theta_1 = \frac{Y - Y_1}{X - X_1}$,

we obtain:

$$Y = X \tan\theta_1 + Y_1 - X_1 \tan\theta_1 \quad (1)$$

Again, for line P_2S, slope = $\tan\theta_2 = \frac{Y - Y_2}{X - X_2}$.

Rearranging, we obtain:

$$Y = X \tan\theta_2 + Y_1 - X_1 \tan\theta_2 \quad (2)$$

Solving for X and Y, we get:

$$X = \frac{X_1 \tan\theta_1 - X_2 \tan\theta_2 + Y_2 - Y_1}{\tan\theta_1 - \tan\theta_2} \quad (3)$$

Similarly, we obtain:

$$Y = \frac{(X_1 - X_2)\tan\theta_1 \tan\theta_2 - Y_1 \tan\theta_2 + Y_2 \tan\theta_1}{\tan\theta_1 - \tan\theta_2} \quad (4)$$

Thus, the coordinates of S are:

$$S = \left(\frac{X_1 \tan\theta_1 - X_2 \tan\theta_2 + Y_2 - Y_1}{\tan\theta_1 - \tan\theta_2}, \frac{(X_1 - X_2)\tan\theta_1 \tan\theta_2 - Y_1 \tan\theta_2 + Y_2 \tan\theta_1}{\tan\theta_1 - \tan\theta_2}\right) \quad (5)$$

4.6.3. Multipath interference and standing waves

In wireless communications, multipath is a phenomenon of propagation in which radio signals arrive at the receiving antenna by more than one path.

It results in multipath interference (MPI), which may be constructive and destructive interference, and causes the phase of the signal to get shifted. In this study, two RF emitters (ESP8266 having Yagi antennas) are placed on the tables illustrated in Fig. 4.11. Standing waves can be created when obstacles are placed in the path of a direct wave. The floor, for instance, can generate a standing wave by reflection of the direct wave. Similarly, a wheelchair, as an obstacle, can generate many standing waves by causing a reflection of a direct wave. To overcome these issues, a positioning system which uses a new method for cancelling standing waves has been used in this study. This enhances the locational accuracy of obstacles and minimises the effects of standing waves.

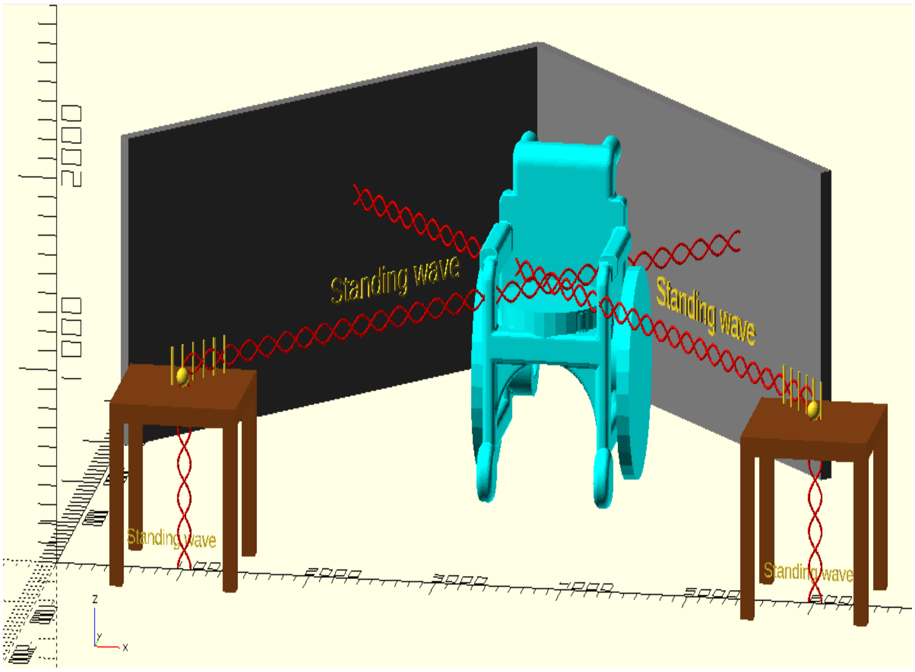


Figure 4.11:Standing waves created by obstacles (scale: mm)

Figure 4.12 shows the standing waves effect on an estimation of indoor positioning system. The system's standing wave effect minimisation is also observed. This phenomenon has a detrimental influence on the estimation accuracy when radio waves are used since wave amplitude varies constantly, thus affecting signal strength, and finally, the positional accuracy.

To overcome the standing-wave effect, a hardware-oriented technique has been carried out to create two standing waves, both having a wavelength λ but differ in phase by λ/2. Figure 5.6 shows that the curve obtained by the summation of the waves is effective for standing wave cancelation when estimating the location.

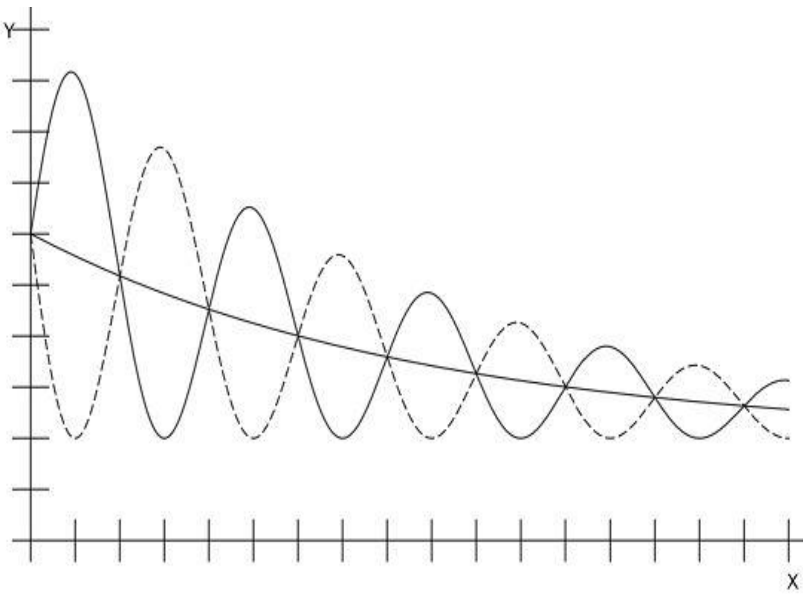


Figure 4.12: Construction of a standing wave with attenuation (X-axis is the distance and the Y-axis is the power of the signal.

Source: IPL, 2016, Patent #109332

4.6.4. Internal Environment Testing

The tests performed in the internal settings were organized with the Wi-Fi nodes being placed at different distances as depicted in Figure 4.13.

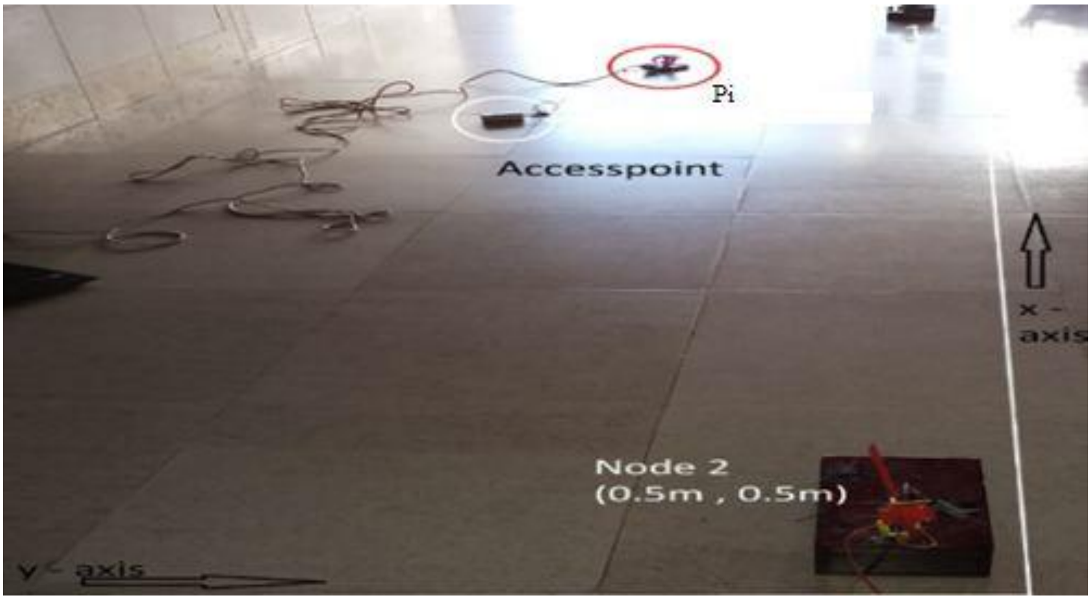


Figure 4.13: Internal Environment Scenario 5 x 5 m

This scenario involves numerous objects such as walls that produce the signal loss and trigger the interference, as a result of the building's structure.

Figure 4.14 shows a method to reduce the standing waves effect and the RF shadow zone that can be useful on an estimation of indoor positioning system. The standing wave phenomenon has a detrimental influence on the estimation accuracy when radio waves are used since wave amplitude varies constantly, thus affecting signal strength, and finally, the positional accuracy.

To overcome the standing-wave effect, a hardware-oriented technique has been carried out to move the RF emitter in order to mitigate the standing wave effect, in a pending patent method. In resume, it is a simple method that consists to move the initial location of an RF emitter around a circle of half wavelength ($\lambda/2$).

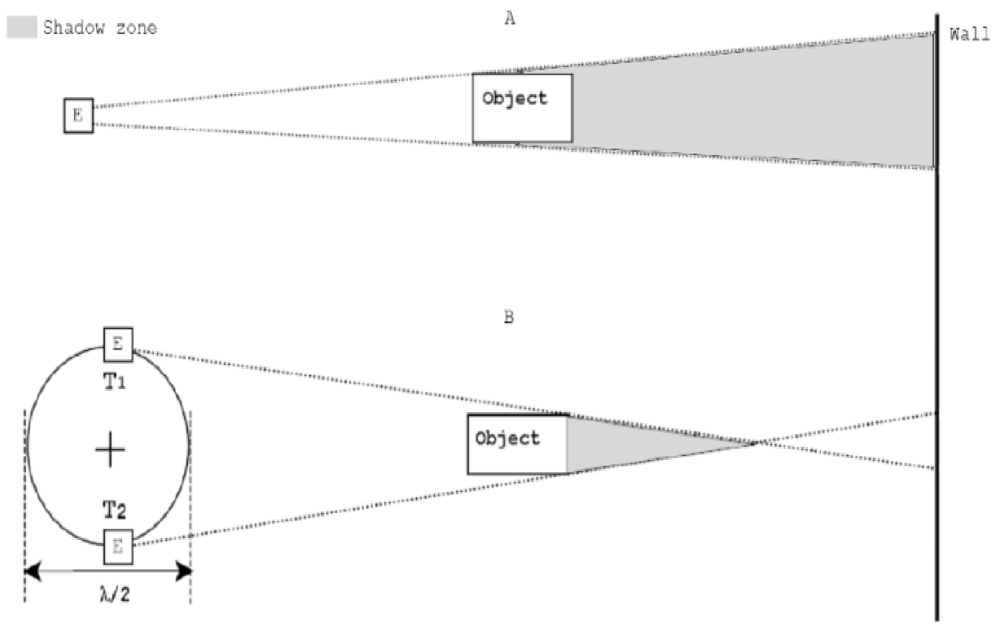


Figure 4.14: Mitigation of a standing wave and reduction of RF shadow zone by moving the initial position of an emitter (E)

Source: IPL, 2016, Patent #109332

A 2D positioning system was set up for optimal transmission and receipt of data to study system accuracy and location error. The device uses an automatic rotation of the Yagi antennas that performs a full scan of our indoor scenario, where the wheelchair is located.

As mentioned in the preceding sections, for each scenario, tests corresponding to the states of the wheelchair were performed. Table 4.8 records initial and final positional readings (both actual and calculated) and the error as computed in the scenario taken in four readings. It can be seen that the error increases with the increase of distance from the nodes to the wheelchair. In the table, the term ‘static’ refers to the state involving manual rotation of the Yagi antennas and ‘dynamic’ refers to the state involving automatic rotation/scan of the Yagi antennas.

Table 4.8: Internal Environnent Scenario: 5 m × 5 m

<table>
<tr><th>State</th><th>Initial Position (m)</th><th>Calculated starting position (m)</th><th>Initial Error E (m)</th><th>Final position (m)</th><th>Calculated final position (m)</th><th>Final error (m)</th><th>%</th><th>Average of error</th><th>% of error location improvement after applying the pending patent method</th></tr>
<tr><td>Static</td><td>(1.3, 1.5)</td><td>(0.7, 0.9)</td><td>0.9</td><td></td><td></td><td>-</td><td></td><td rowspan="4">0.3</td><td rowspan="4">46%</td></tr>
<tr><td>Dynamic</td><td>(2.3, 2.7)</td><td>(2.5, 2.2)</td><td>0.5</td><td>(5.6, 5.8)</td><td>(5.8, 5.4)</td><td>0.4</td><td>14</td></tr>
<tr><td>Dynamic</td><td>(2.6, 2.9)</td><td>(2.8, 3.4)</td><td>0.5</td><td>(2.9, 2.7)</td><td>(3.1, 2.3)</td><td>0.3</td><td>40</td></tr>
<tr><td>Dynamic</td><td>(2.2, 3)</td><td>(1.8, 1.1)</td><td>0.3</td><td>(1.9, 2.7)</td><td>(1.9, 2.7)</td><td>0.05</td><td>84</td></tr>
</table>

4.6.5. External Environment Testing

Evaluations in external settings were conducted outdoors with no obstacles or walls. Figure 4.15 depicts the utilised test settings for the 5x5 m scenarios. Wi-Fi was connected in both scenarios with the same distances employed in the internal settings. This set up permits the comparison of both settings which guided the analysis of the wheelchair system.

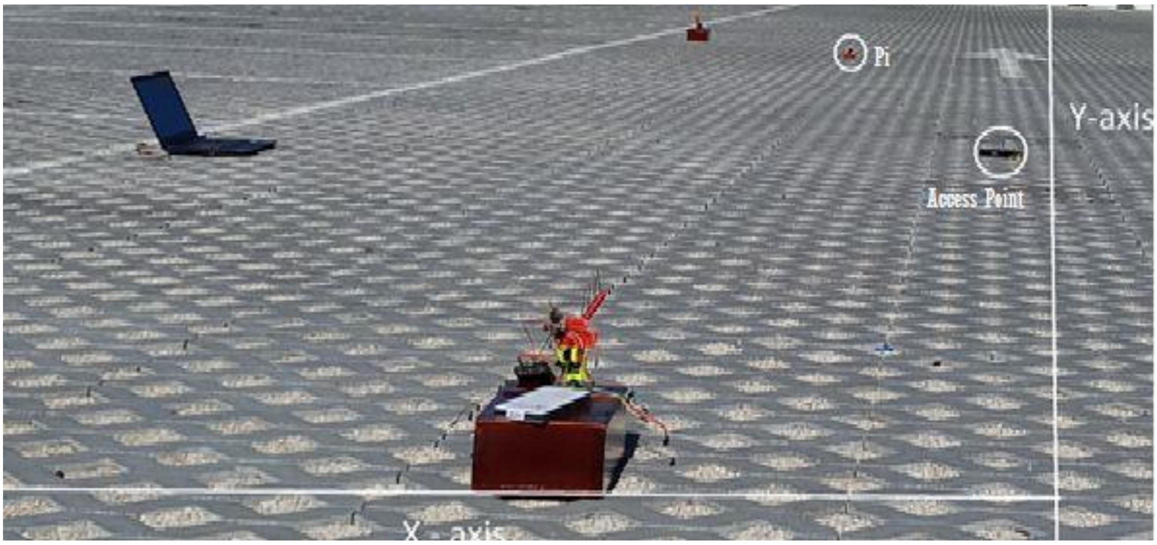


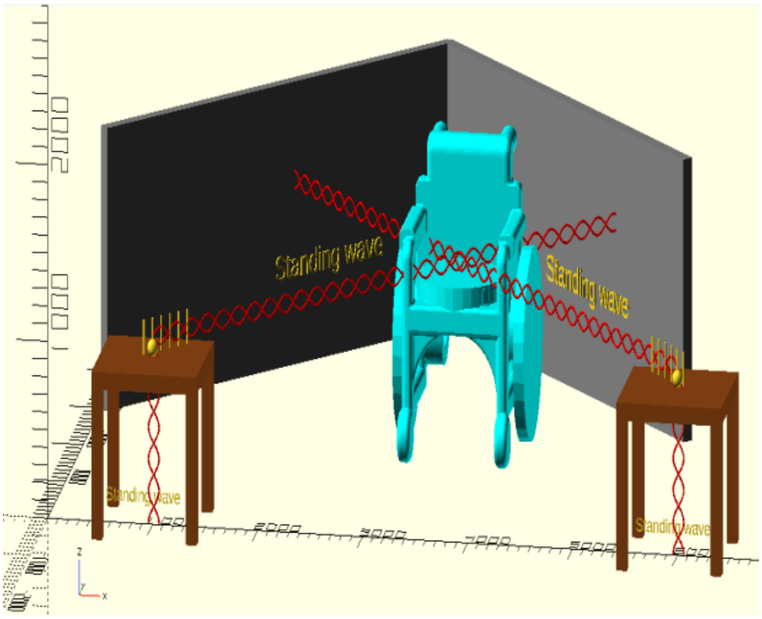
Figure 4.15: Scenario External Environment 5x5 m

The geographic North was used in both scenarios. This permitted the specification of *x*- and *y*-axes which were suitable for the placement of the sensor nodes. The computed outcomes of the two wheelchair states are described are described below.

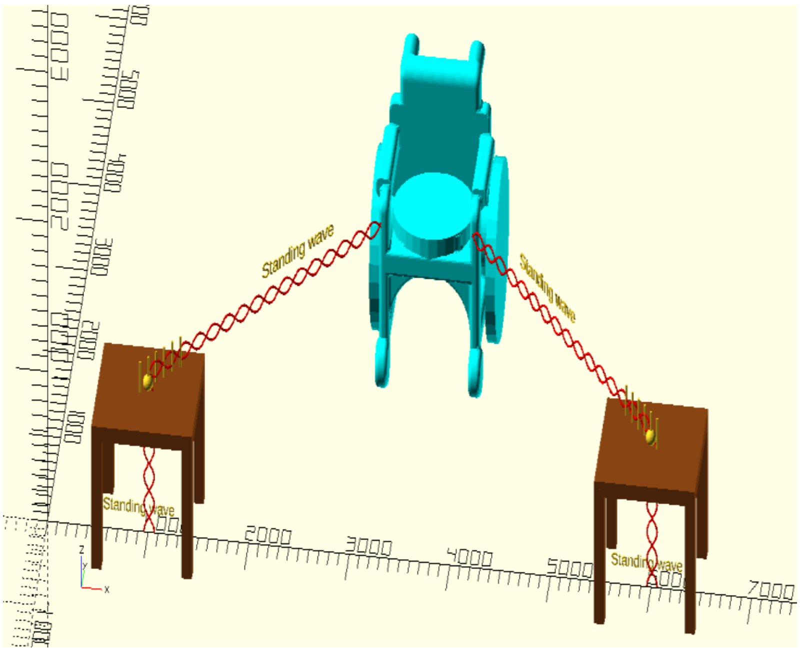
Table 4.9 presents the outcomes of the mean point and the Euclidean distance (position error) of the two wheelchair states. It can be seen that the error, in each outdoor scenarios, is lower in comparison to the internal scenarios. This can be attributed to the absence of obstacles which trigger interference in the signal and also contribute to multipath effect.

Table 4.9: External Environnent scenario – 5m x 5m

State	Initial position (m)	Calculated starting position (m)	Initial E Error (m)	Final position (m)	Calculated final position (m)	Final error (m)	%	Average of error	% of Error location improvement after applying the pending patent method
Static	(1.7, 1.1)	(1.6, 1.1)	0.04					0.14	33%
Dynamic	(1.2, 0.8)	(1.1, 0.8)	0.095	(2.8, 2.1)	(2.8, 2.2)	.07	27.1		
Dynamic	(1.3, 1.1)	(1.2, 1.1)	0.19	(2.1, 2.5)	(2.2, 1.5)	.12	37.1		
Dynamic	(2.3, 3.5)	(2.1, 3.2)	0.38	(5.1, 4.8)	(5.03, 5.04)	.25	35.0		



(a)



(b)

Figure 4.16: Graphical representation of (a) Internal and (b) External scenarios with standing wave generation

4.7. Final Results

Tables 4.8 and 4.9 present the outcome of the above experiment conducted in a 5 m x 5 m environment in a closed room and outdoor settings, respectively. It is seen that the error, in the two different scenarios, increases with growth in antenna distances from the wheelchair. The average error of the experiments was 30 cm and 14 cm. With the application of the pending patent technique, there was a 46% and 33% improvement of error location. By other words, the error is reduced 46% and 33% for indoor and outdoor settings, respectively. The results clearly show that the pending patents technique significantly improves the accuracy of the wheelchair positioning.

4.8. Summary

This chapter described the requirements specification of the localization system and the wheelchair system. It also presented the development and implementation of the system, the tools utilized and the tests carried out to ensure the quality of the prototype.

Also described is the setting up of the low cost modified IPL wheelchair system and initially getting the system operational by programming Raspberry PI for the various video camera and wheelchair movements and configuring the modules.

For estimating the positioning accuracy, a group of evaluations in two different settings, one internal and one external was carried out using a (pending) patent method. It can be inferred from the outcomes obtained in the localisation system and the wheelchair movement that the positioning error is reduced in both internal and external settings on applying the patented method.

The next chapter presents the conclusions of the present work and recommendations for future work.

5. Conclusions and Future Work

5.1. Conclusions

In this dissertation, the creation of an intelligent autonomous wheelchair controlled by voice and eyes movements that utilizes a network of ESP8266 modules to achieve a positioning system was described.

The requirements specification of the localization system and the wheelchair system was described, which was developed and implemented. Tests were carried out to qualitatively assess the prototype.

The low cost modified IPL wheelchair system was made operational by programming Raspberry PI for the various video camera and wheelchair movements and configuring the modules.

The positioning accuracy was studied by a group of evaluations in two different settings by using a (pending) patent method. It was concluded from the localization system and the wheelchair movement test results that the positioning error is reduced in both internal and external settings on applying the patented method.

5.2. Future Work

It is proposed, in the future, to explore the implementation of a more portable solution and to perform diverse tests in different scenarios. The IPL/IT autonomous low cost wheelchair that has a smart driving mode for visually impaired persons will be improved in this manner.

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Appendix A

Back-end Python programs for:

1. **Camera**

```python
import picamera
from time import sleep
import os
from os.path import *

camera = picamera.PiCamera()
camera.capture('/home/pi/programs/html/images/camera.jpg')
```

2. **Joystick**

```python
import spidev
import time
import os
 # Open SPI bus
spi = spidev.SpiDev()
spi.open(0,0)
 # Function to read SPI data from MCP3008 chip
# Channel must be an integer 0-7
def ReadChannel(channel):
  adc = spi.xfer2([1,(8+channel)<<4,0])
  data = ((adc[1]&3) << 8) + adc[2]
  return data
 # Define sensor channels
# (channels 3 to 7 unused)
swt_channel = 16
vrx_channel = 20
vry_channel = 21
 # Define delay between readings (s)
delay = 0.5
 while True:
   # Read the joystick position data
  vrx_pos = ReadChannel(vrx_channel)
  vry_pos = ReadChannel(vry_channel)
   # Read switch state
  swt_val = ReadChannel(swt_channel)
   # Print out results
  print "--------------------------------------------"
  print("X : {}  Y : {}  Switch : {}".format(vrx_pos,vry_pos,swt_val))
   # Wait before repeating loop
  time.sleep(delay)
```

3. **Relay**

```
import RPi.GPIO as GPIO
import time
GPIO.setmode(GPIO.BCM)
GPIO.setup(5, GPIO.OUT)
GPIO.setup(6, GPIO.OUT)
GPIO.setup(13, GPIO.OUT)
GPIO.setup(26, GPIO.OUT)
GPIO.output(5, GPIO.HIGH)
GPIO.output(6, GPIO.HIGH)
GPIO.output(13, GPIO.HIGH)
GPIO.output(26, GPIO.HIGH)
GPIO.cleanup()
time.sleep(0.5)
PIN=str(sys.argv[1])
Mode=str(sys.argv[2])
rspCode=1
if Mode == 'ON':
    if PIN == "5":
      GPIO.output(6, GPIO.HIGH)
       GPIO.output(13, GPIO.HIGH)
       GPIO.output(26, GPIO.HIGH)
    elif PIN == "6":
       GPIO.output(5, GPIO.HIGH)
       GPIO.output(13, GPIO.HIGH)
       GPIO.output(26, GPIO.HIGH)
    elif PIN == "13":
       GPIO.output(6, GPIO.HIGH)
       GPIO.output(5, GPIO.HIGH)
       GPIO.output(26, GPIO.LOW)
    elif PIN == "26":
       GPIO.output(6, GPIO.HIGH)
       GPIO.output(13, GPIO.HIGH)
try:
except:
print '\n',rspCode
```

5. Stepper 2

```
import RPi.GPIO as GPIO
import time

GPIO.setmode(GPIO.BCM)
GPIO.setup(15,GPIO.OUT)

p= GPIO.PWM(15,50)
p.start(7.5)

try:

    while True:
     p.ChangeDutyCycle(7.5)
     time.sleep(1)
     p.ChangeDutyCycle(12.5)
     time.sleep(1)
     p.ChangeDutyCycle(2.5)
     time.sleep(1)

except KeyboardInterrupt:
    print '\n program terminated'
except:
    print '\n Error'
finally:
    p.stop()
    GPIO.cleanup()

```

6. Stop Stepper

```
import RPi.GPIO as GPIO
import time

GPIO.setmode(GPIO.BCM)
GPIO.setup(18,GPIO.OUT)
GPIO.setup(15,GPIO.OUT)
try:
    GPIO.cleanup()
    print "0"
except:
    print "1"

```

7. **Test Video**

```
import sys
import io
import picamera
import logging
import SocketServer
from threading import Condition
from BaseHTTPServer import BaseHTTPRequestHandler, HTTPServer
PAGE="""\
<html>
<head>
<title>Raspberry Pi - Surveillance Camera</title>
</head>
<body>
<center><h1>Raspberry Pi - Surveillance Camera</h1></center>
<center><img src="stream.mjpg" width="640" height="480"></center>
</body>
</html>
"""
class StreamingOutput(object):
    def __init__(self):
        self.frame = None
        self.buffer = io.BytesIO()
        self.condition = Condition()

    def write(self, buf):
        if buf.startswith(b'\xff\xd8'):
            self.buffer.truncate()
            with self.condition:
                self.frame = self.buffer.getvalue()
                self.condition.notify_all()
            self.buffer.seek(0)
        return self.buffer.write(buf)
```

```python
class StreamingHandler(BaseHTTPRequestHandler):
    def do_GET(self):
        if self.path == '/':
            self.send_response(301)
            self.send_header('Location', '/index.html')
            self.end_headers()
        elif self.path == '/index.html':
            content = PAGE.encode('utf-8')
            self.send_response(200)
            self.send_header('Content-Type', 'text/html')
            self.send_header('Content-Length', len(content))
            self.end_headers()
            self.wfile.write(content)
        elif self.path == '/stream.mjpg':
            self.send_response(200)
            self.send_header('Age', 0)
            self.send_header('Cache-Control', 'no-cache, private')
            self.send_header('Pragma', 'no-cache')
            self.send_header('Content-Type', 'multipart/x-mixed-replace; boundary=FRAME')
            self.end_headers()
            try:
                while True:
                    with output.condition:
                        output.condition.wait()
                        frame = output.frame
                    self.wfile.write(b'--FRAME\r\n')
                    self.send_header('Content-Type', 'image/jpeg')
                    self.send_header('Content-Length', len(frame))
                    self.end_headers()
                    self.wfile.write(frame)
                    self.wfile.write(b'\r\n')
            except Exception as e:
                logging.warning('Removed streaming client %s: %s',self.client_address, str(e))
        else:
```

```python
                self.send_error(404)
                self.end_headers()

class StreamingServer(SocketServer.ThreadingMixIn,HTTPServer):
    allow_reuse_address = True
    daemon_threads = True

with picamera.PiCamera(resolution='640x480', framerate=24) as camera:
    output = StreamingOutput()
    camera.start_recording(output, format='mjpeg')
    try:
        address = ('0.0.0.0', 8000)
        server = StreamingServer(address, StreamingHandler)
        server.serve_forever()
    finally:
        camera.stop_recording()
```

8. Ultrasonic

```python
import RPi.GPIO as GPIO
import time
GPIO.setmode(GPIO.BCM)
TRIG=23
ECHO=24
print "Distance Measurement"
GPIO.setup(TRIG,GPIO.OUT)
GPIO.setup(ECHO,GPIO.IN)
GPIO.output(TRIG, False)
print "Waiting for Sensor to Settle"
time.sleep(1)
GPIO.output(TRIG,True)
time.sleep(0.00001)
GPIO.output(TRIG,False)
while GPIO.input(ECHO) == 0:
    pulse_start = time.time()

while GPIO.input(ECHO) == 1:
    pulse_end = time.time()
pulse_duration = pulse_end - pulse_start
distance = pulse_duration * 17150
distance = round(distance,2)
print "Distance (cm):", distance
GPIO.cleanup()
```

9. Web Server

```python
'''
====================================================================================================
File Name : web_server.py
====================================================================================================
'''
import web
import json
import sys
from StringIO import StringIO
from perform import switchRelay, driveMotor
import requests
import sys
import os,signal
import io
import picamera
import logging
import SocketServer
from threading import Condition
from BaseHTTPServer import BaseHTTPRequestHandler, HTTPServer
import threading
import subprocess
from subprocess import Popen,PIPE
import time

cameraRun=False
camThread=None


# Make a temporary database for phonenumbere and otp
urls = (
    '/oprRelay/*.*', 'handleRelay',
    '/oprMotor/*.*', 'handleSteppermotor',
    '/sendData/*.*', 'handleData',
        '/submit/', 'submit'
```

```python
)
app = web.application(urls, globals())

webData = dict()




def execScript(Command):
    proc = subprocess.Popen(Command, stdout=subprocess.PIPE, shell=True)


def check_kill_process(pstring):

    for line in os.popen("ps ax | grep " + pstring + " | grep -v grep"):

            fields = line.split()

        pid = fields[0]

        os.kill(int(pid), signal.SIGKILL)


class handleData:
    def POST(self):
        web.header('Content-Type', 'json')
        web.header('Access-Control-Allow-Origin',      '*')
        web.header('Access-Control-Allow-Credentials', 'true')
        keyUrl = web.ctx
        print "\n Got Incoming Data as : ", keyUrl['path']
        nwebData = []
        data = web.data()
        nwebData = json.loads(data)
        print 'nwebData is :', nwebData
```

```
class handleRelay:

    def GET(self):
        web.header('Content-Type', 'json')
        web.header('Access-Control-Allow-Origin',      '*')
        web.header('Access-Control-Allow-Credentials', 'true')
        keyUrl = web.ctx
        print "\n Got Incoming Data as : ", keyUrl['path']
        nwebData = []
        infoVal = {}
        if "/oprRelay/1" in str(keyUrl['path']) :
            infoVal["status"] = "ON"
            infoVal["relaynum"] = "5"
        elif "/oprRelay/2" in str(keyUrl['path']):
            infoVal["status"] = "ON"
            infoVal["relaynum"] = "6"
        elif "/oprRelay/3" in str(keyUrl['path']) :
            infoVal["status"] = "ON"
            infoVal["relaynum"] = "13"
        elif "/oprRelay/4" in str(keyUrl['path']):
            infoVal["status"] = "ON"
            infoVal["relaynum"] = "19"

                retStr = switchRelay(infoVal)
        return retStr

    def POST(self):
        pass


class handleSteppermotor:

    def GET(self):
        global camera,camThread,cameraRun
```

```
        global camera,camThread,cameraRun
        keyUrl = web.ctx
        print '\n keyUrl:', keyUrl['path']
        web.header('Content-Type', 'json')
        web.header('Access-Control-Allow-Origin',      '*')
        web.header('Access-Control-Allow-Credentials', 'true')
        infoVal = {}
        if "/oprMotor/1" in str(keyUrl['path']) :
            infoVal["status"] = "ON"
            infoVal["motorPos"] = "left"
        elif "/oprMotor/2" in str(keyUrl['path']) :
            infoVal["status"] = "ON"
            infoVal["motorPos"] = "right"
        elif "/oprMotor/4" in str(keyUrl['path']):
            infoVal["status"] = "ON"
            infoVal["motorPos"] = "front"
        elif "/oprMotor/5" in str(keyUrl['path']):
            infoVal["status"] = "ON"
            infoVal["motorPos"] = "reverse"
        elif "/oprMotor/6" in str(keyUrl['path']):
        retVal = driveMotor(infoVal)
        if camThread is None:
        return retVal
    def POST(self):
class submit:
if __name__ == "__main__":
    time.sleep(1)
    headers = {'content-type': 'application/json'}
        print '\n Connecting to the Access Point'
    requests.post('http://192.168.1.129:80/connect', headers=headers)
    app.run()
```

Appendix B

Pending Patent # 109332, April, 2016

ABSTRACT

STANDING WAVE CANCELLATION AND SHADOW ZONE REDUCING WIRELESS TRANSMITTER, SYSTEM AND RESPECTIVE METHOD AND USES

This invention is enclosed in the area of wireless communication systems, generally directed towards the problem of multipath interference, and specifically towards mitigating the effect of the standing wave and shadow zone effect in indoor positioning systems.

It is an object of the present invention a standing wave cancellation wireless transmitter configured to transmit a first wave and a second wave with wavelength λ, with automatic displacement means configured to physically move emitting means at least from a first emission point to a second emission point, wherein (i) the first wave is emitted in the first emission point (ii) the second wave is emitted in the second point.

A system which comprises said wireless transmitter, a method implemented by said system and uses of said wireless transmitter and system are also part of the present invention.

DESCRIPTION

STANDING WAVE CANCELLATION AND SHADOW ZONE REDUCING WIRELESS TRANSMITTER, SYSTEM AND RESPECTIVE METHOD AND USES

FIELD OF THE INVENTION

This invention is enclosed in the area of Wireless communication systems, generally directed towards the problem of multipath interference, and specifically towards mitigating the effect of the standing wave in indoor positioning systems, as well as to the problem of reducing the shadow zone effect in environments with physical obstacles. It relates to the impact of standing waves in wireless communication and proposes a solution to reduce the negative impact of standing waves when wireless communication is used in indoor positioning systems (IPS) while synergistically reducing the shadow zone effect.

Therefore, it consists of an innovative approach suitable for easy to mount and maintain global low cost IPS. This approach enables to solve the issue of standing wave and to diminish the shadow zone effect, providing an IPS with higher precision.

PRIOR ART

A common occurrence in the field of wireless communication is the standing wave. Especially in environments that contain many obstacles, such as closed

Spaces, a wave being sent from the transmitter to the receiver propagates through space and gets reflected in different kinds of surfaces. These reflections cause the receiving end to receive multiple instances of the same wave, some of them arriving directly, while others arriving after being reflected from a certain object. This occurrence is commonly called multipath interference (MPI), and represents a common issue in indoor positioning systems that use wireless technology.

The MPI has another side-effect, which is called the standing wave. When a wave is reflected in a surface, it generates another wave that propagates back in the opposite direction. If one puts a receiver somewhere between the transmitter and the reflective surface, detecting the strength of the signal will vary depending on the position in which the receiver is placed, because of the standing wave effect. Certain positions, particularly those that are half wave length apart, would show no oscillations in the signal strength when measured multiple times. These points along the medium are called nodes (N). Some other points along the medium would yield different results, showing high oscillations in signal strength. The points that contain the highest amount of oscillations are called the antinodes (AN).

In order to achieve accurate and consistent indoor positioning estimation using signal strength, inside closed spaces, mitigating the effect of the standing wave is one of the problems that needs to be addressed. A technical solution to this problem is disclosed in Portuguese patent application PT 109137, and the present application introduces an innovative way to solve the problem of the standing wave when wireless communication is used in indoor positioning systems, providing also an advantageous solution by mitigating the shadow zone effect.

Because of the standing wave effect and having in consideration the position in which a receiver is placed, strength of the signal will vary from point to point, and due to the shadow zone created by possible obstacles the signal will not cover certain parts of a space.

In order to provide a reliable IPS in closed spaces, it is important to achieve accurate estimation of the signal strength and to have signal spreading without interference. Mitigating the problem of both the standing wave and shadow zone greatly increases the precision and accuracy of the IPS.

The solution of Portuguese patent application PT 106755 addresses the cancelling of multipath interference through a CODEC of orthogonal perfect DFT of Golay codes (OPDG). However this CODEC does not address the standing wave issue nor the shadow zone effect. The OPDG autocorrelation peak follows the standing wave fluctuation.

SUMMARY OF THE INVENTION

It is an object of the present invention a standing wave cancellation wireless transmitter configured to transmit a signal with wavelength λ to be transmitted, transmit a first wave and a second wave, being that the wireless transmitter of the present invention comprises emitting means and automatic displacement means, in which the automatic displacement means are configured to physically move the emitting means at least from a first emission point to a second emission point, wherein the wireless transmitter is further configured to:

- emit the first wave through the emitting means in the first emission point and

- emit the second wave through the emitting means in the second emission point,

being that the emitted first wave has wavelength λ and the emitted second wave has wavelength λ and a shift equal to the distance between the first and second emission point.

Referring to Figure 1, a graph displays the effect of the standing wave in an indoor positioning system which includes a wireless transmitter as that previously described. The standing wave effect has a major impact on the accuracy of location estimation in the wireless mechanism, due to the constant change in amplitude of the wave that affects signal strength readings, and thus, location accuracy. To mitigate the effect of the standing waves, hardware-based techniques are implemented to generate two different standing waves.

The first standing wave is a wave with a full wavelength of λ. The second standing wave also has a wavelength of λ, but with a shift of equal to the distance from the second to the first emission point, when the emitting means are positioned in the second emission point. The curve gained from summing up the two waves proves to be better for usage , for example, in location estimation scenarios when considering that an X-axis is the distance and a Y-axis is the power of the signal received. It may be used both in radio waves and ultrasonic waves.

The wireless transmitter of the present invention enables to minimize the average fluctuation of the standing wave effect by forcing the emitting means to move in different directions, as shown in figures 2 to 4 (cancelling standing wave fluctuations over one period movement time). A possible receiver will be reading two values of the received waves, when a complete movement of the emitting means occurs. This movement may be provided in any direction. However, the two values of the received waves should occur when the emitting means make a minimum translation, in any direction, equal to the distance between the first and the second emission point. The two values of the received waves should be used to calculate an average.

This average value is the summed value of the two signals, at the receiver, divided by two. By doing so, the standing wave problem is solved because there are less standing waves fluctuations.

At the same time, the transmitter of the present invention enables to mitigate the problem of the shadow zone.

If the wireless transmitter is in a stationary position, the transmitted waves cannot go through possible obstacles positioned between the transmitter and a possible receiver, such as metal objects (closets, desks) and the signal is reflected by these objects. This may generate a problem, since the transmitted signals might not reach points behind these objects, hindering the receiver to

Correctly receive the transmitted signal and creating a shadow zone.

Therefore, the wireless transmitter of the present invention improves direct visible angles behind these objects and reduces shadow zone, which causes IPS to have a high precision in those areas.

In an advantageous embodiment of the present invention, combinable with any of the previously described, the first and second emission points are at a minimum distance equal to λ /2.

This configuration permits to partially transmit a wireless signal behind certain obstacles. A possible wireless receiver positioned near the external borders of a shadow zone will be able to receive more incoming transmitted waves – corresponding to a signal – than in the case in which the wireless transmitter is static. This effect is represented in Figure 5.

In the present configuration transmission occurs while making symmetric movements originating two opposite waves in one period of the movement.

It is also an object of the present invention a standing wave cancellation wireless system which comprises the previously described wireless transmitter and at least a wireless receiver.

It is yet an object of the present invention a method for the cancellation of standing wave in wireless communications implemented by the previously described system, and which comprises a transmission stage and a receiving stage, wherein the transmission stage precedes the receiving stage and:

- in the transmission stage:
  - i. the wireless transmitter transmits a first wave with wavelength λ through the emitting means in a first emission point;
  - ii. automatic displacement means move the emitting means to a second emission point;
  - iii. the wireless transmitter transmits a second wave with wavelength λ through the emitting means in the second emission point;
- in the receiving stage:
  - i. a wireless receiver, for a received first wave with wavelength λ and a received second wave with wavelength λ and a shift equal to the distance between the first and second emission points, calculates their average on power or amplitude, obtaining a single signal.

This method provides the same advantages and effects of the previously described wireless transmitter and the corresponding system which comprises said wireless transmitter, being the method implemented by such devices.

In a preferred embodiment of the described method, the second emission point is at a distance of $\lambda/2$ from the first emission point.

DESCRIPTION OF DRAWINGS

In all of the following figures, the emitting means are indicated as "emitter" and the automatic displacement means as "motor".

Figure 1 - a graph describing the effect of the standing wave in indoor positioning systems. It displays a standing wave effect reduction obtained through the present invention. The continuous line corresponds to a standing wave with a full wavelength of λ and the dashed line corresponds to a standing wave with a wavelength of λ, but with a shift of $\lambda/2$. The curve gained from the sum of the two waves has better performance for usage in location estimation scenarios. The sum is equal to the trend line, without the undesirable standing wave fluctuations.

Figure 2 - a schematic representation which describes the connection of the automatic displacement means with the emitting means in a linear movement between two positions, with respect to time instants T1 and T2, in order to cancel standing waves (in opposite phases, when the transmitter distance between the two time-positions is half wavelength).

Figure 3 – physical connection of emitting means moving in a pendulum-like way through the action of the automatic displacement means, with respect to time instants T1 and T2 (in opposite phases, when the emitting means distance between the two time-positions is half wavelength).

Figure 4 – representation of the automatic displacement means to which the emitting means are physically connected, moving the emitting means in a circular-like way, and with respect to time instants T1 and T2 (in opposite phases, when the emitting means distance between the two time-positions is half wavelength).

Figure 5 – representation of the difference between stationary wireless transmitter (A) and a circular-like wireless transmitter (B), suitable for reducing a shadow zone.

In the case (A) a stationary wireless transmitter is presented, radiating a signal towards a wall, and in which a metal object does not allow the signal to reach certain points close to a part of the wall. Instead, the metal object sends a signal back to the emitting means/emitter, making a large shadow zone in the area behind it, not allowing to estimate satisfying IPS measurements.

In the case (B), in which the wireless transmitter of the present invention is used, the shadow zone effect is mitigated. The wireless transmitter is circular-like, wherein the emitting means are rotated by the automatic displacement means around the center of a circle (+ sign).

This allows the wireless transmitter to have a greater angle towards the wall and reducing the shadow zone effect, which was being created behind the metal object. With this type of solution, higher precision and satisfying IPS measurements are provided. The same effect is present in pendulum or linear-like solutions.

Figure 6 – representation of the technical solution of the present invention, mitigating standing wave and shadow zone effects. It consists of a closer view of Figure 5B, with the circular-like solution of Figure 4. The shift of the transmitted second wave is equal to the diameter of the circle formed by the movement of the emitting means.

DETAILED DESCRIPTION OF THE INVENTION

The most general configurations of the present invention are defined in the Summary of the invention. These configurations may be further detailed as follows.

In a detailed configuration of the wireless transmitter of the present invention, combinable with any of the previously described, it is further configured to detect the position of a possible receiver and reconfigure the first and second emission points so that the first and second emission points are at the same distance from a possible receiver.

This enables a dynamic reconfiguration of the device, so that the conditions of transmission may remain the same for any possible receiver in any possible point of space.

In several detailed configurations of the wireless transmitter object of the present invention, combinable with any of the previously described, the automatic displacement means are suitable for moving the emitting means between the first and the second emission points in a pendulum, circular or linear-like way.

With reference to figure 2, a linear-like motion is presented. In this figure the emitting means are connected to the automatic displacement means, represented as a motor and a bar. When the motor is working, the emitting means/emitter moves forward and backward with a period equal to the difference between T2 and T1. At the time instant T1, corresponding to the first emission point, a first wave is transmitted with wavelength equal to λ . At the time instant T2, corresponding to the second emission point, a second wave is transmitted with wavelength equal to λ and a shift of λ /2. By calculating the mean of these two values, in a possible receiver, an increase the strength of the signal is provided.

With reference to figure 3, a pendulum-like motion is presented. The natural frequency of oscillation of a compound pendulum is obtained from the ratio of the torque imposed by gravity on the mass of the pendulum to the resistance to acceleration defined by the moment of inertia. In this figure, as in figure 2, the emitting means are connected to the automatic displacement means, represented as a motor and a bar. When the motor is working, the emitting means swing between a first and a second emission point, respectively corresponding to the time instant T1 and the time instant T2. In the time instant T1, emitted first wave has a wavelength λ and at the time instant T2 the emitted second wavehas a wavelength λ with a shift of λ/2. By calculating the mean of these two values, in a possible receiver, an increase the strength of the signal is obtained.

By calculating the average of the two values, a solution for the reduction of standing wave issues is provided. With reference to Figure 4, a circular-like motion is presented. The emitting means are connected to an electrical motor to generate, at least, two values of a certain radio frequency. In this case the emitting means will be moving in circular motion to generate the two values. When the emitting means, at the time instant T1, emit a first wave, its wavelength is λ . When the emitting means, at the time instant T2, emit a second wave, its wavelength is λ with a shift of λ /2.

By calculating the average of these two values, a solution for the reducing of the standing wave issue is provided.

Correspondingly, in a specific configuration of the method of the present invention, the movement between the first and second emission points is pendulum, circular or linear-like.

The wireless transmitter of the present invention, as in any configuration previously or subsequently described, may be used in positioning systems, preferably indoor positioning systems.

The wireless system of the present invention, as in any configuration previously or subsequently described, may be used as a positioning system, preferably an indoor positioning system.

EMBODIMENTS

In a preferred embodiment of the wireless transmitter of the present invention, combinable with any of the previously described, the automatic displacement means comprise a motor and a rigid bar physically connecting the motor to the emitting means.

In an embodiment of the wireless transmitter of the present invention, suitable for ultrasonic communication and combinable with any of the previously described, the emitting means comprise a speaker and the first and second waves are ultrasonic waves.

In another embodiment of the wireless transmitter of the present invention, suitable for electromagnetic communication and alternative to the ultrasonic solution previously described, the emitting means comprise an antenna and the first and second waves are electromagnetic waves.

In specific embodiment of the electromagnetic communication solution, the antenna is suitable for radio communications.

In corresponding specific embodiments of the system of the present invention, said at least one wireless receiver comprises an antenna and electromagnetic wave transducer means or a microphone and ultrasound transducer means.

In corresponding specific embodiments of the method of the present invention, the first and second waves are electromagnetic waves or ultrasound waves.

The several embodiments described are combinable.

Each of the claims of the following set of claims defines specific embodiments.

Lisboa, 12.04.2016

CLAIMS

1. Standing wave cancellation and shadow zone reducing wireless transmitter configured to, for a signal with wavelength λ to be transmitted, transmit a first wave and a second wave with wavelength λ **characterized in that** it comprises emitting means and automatic displacement means, being the automatic displacement means configured to physically move the emitting means at least from a first emission point to a second emission point, wherein the wireless transmitter is further configured to:

– emit the first wave through the emitting means in the first emission point and

– emit the second wave through the emitting means in the second emission point.

2. Wireless transmitter according to the previous claim **characterized in that** the first and second emission points are at the same distance from the automatic displacement means.

3. Wireless transmitter according to any of the preceding claims **characterized in that** the second emission point is at a distance of λ/2 from the first emission point.

4. Wireless transmitter according to any of the preceding claims **characterized in that** it is further configured to detect the position of a possible receiver and reconfigure the first and second emission points so that the first and second emission points are at the same distance from a possible receiver.

5. Wireless transmitter according to any of the preceding claims **characterized in that** the automatic displacement means are suitable for moving the emitting means between the first and the second emission points in a pendulum, circular or linear-like way.

6. Wireless transmitter according to any of the preceding claims **characterized in that** the automatic displacement means comprise a motor and a rigid bar physically connecting the motor to the emitting means.

7. Wireless transmitter according to any of the preceding claims **characterized in that** the emitting means comprise a speaker and the first and second waves are ultrasonic waves.

8. Wireless transmitter according to any of the claims 1-6 **characterized in that** the emitting means comprise an antenna and the first and second waves are electromagnetic waves.

9. Standing wave cancellation wireless transmitter according to the previous claim **characterized in that** the antenna is suitable for radio communications.

10. Standing wave cancellation wireless system **characterized in that** it comprises the wireless transmitter of any of the preceding claims and at least one wireless receiver.

11. Wireless system according to the previous claim **characterized in that** said at least one wireless receiver comprises an antenna and electromagnetic wave transducer means **or** a microphone and ultrasound transducer means.

12. Method for the cancellation of standing wave in wireless communications **characterized in that** it is

implemented by the system of any of the claims 10-11, and which comprises a transmission stage and a receiving stage, wherein the transmission stage precedes the receiving stage and:

- in the transmission stage:
    - i. the wireless transmitter transmits a first wave with wavelength λ through the emitting means in a first emission point;
    - ii. automatic displacement means move the emitting means to a second emission point;
    - iii. the wireless transmitter transmits a second wave with wavelength λ through the emitting means in the second emission point;
- in the receiving stage:
    - i. a wireless receiver, for a received first wave with wavelength λ and a received second wave with wavelength λ and a shift equal to the distance between the first and second emission points, calculates their average on power or amplitude, obtaining a single signal.

13. Method according to the previous claim **characterized in that** the second emission point is at a distance of λ/2 from the first emission point.

14. Method according to any of the claims 12-13 **characterized in that** the movement between the first and second emission points is pendulum, circular or linear-like.

15. Method according to any of the claims 12-14 **characterized in that** the first and second waves are electromagnetic waves or ultrasound waves.

16. Use of the wireless transmitter of any o the claims 1-9 in positioning systems, preferably indoor positioning systems.

17. Use of the wireless system of any of the claims 10-11 as a positioning system, preferably an indoor positioning system.

Lisboa, 12.04.2016

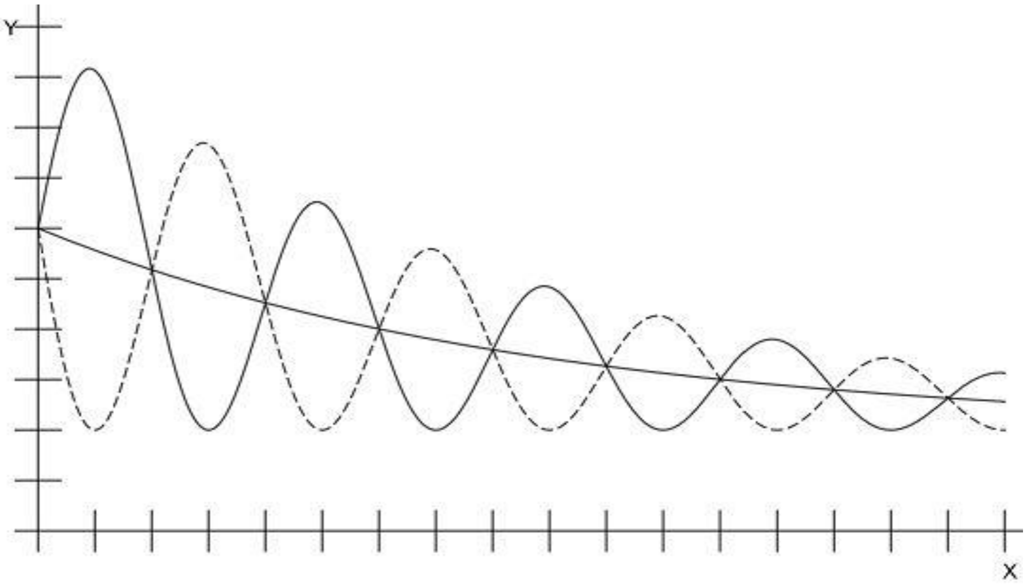


Figure 1

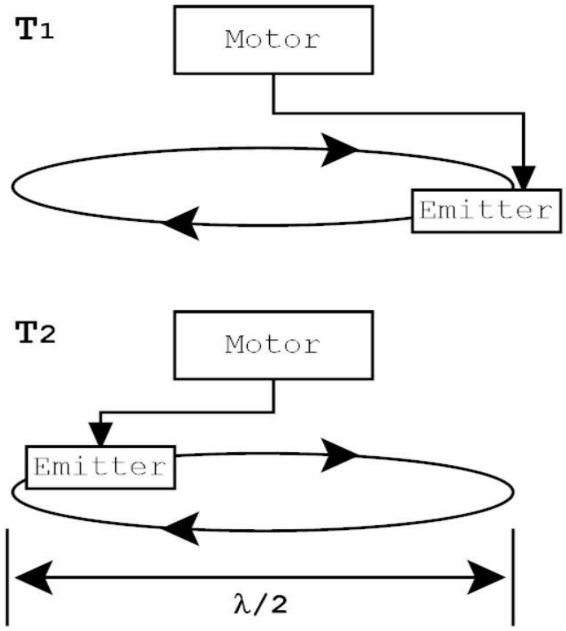


Figure 2

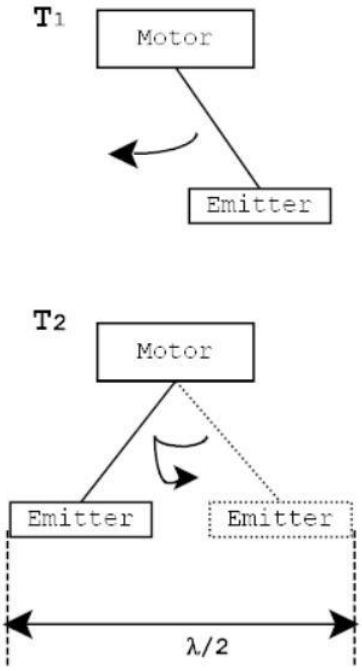


Figure 3

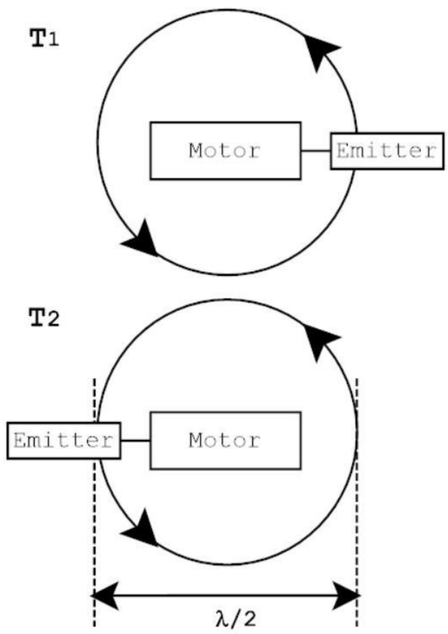
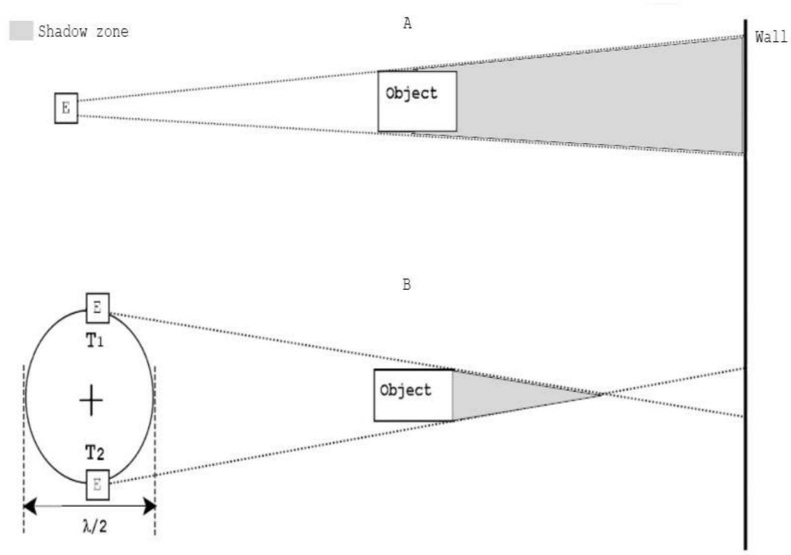


Figure 4



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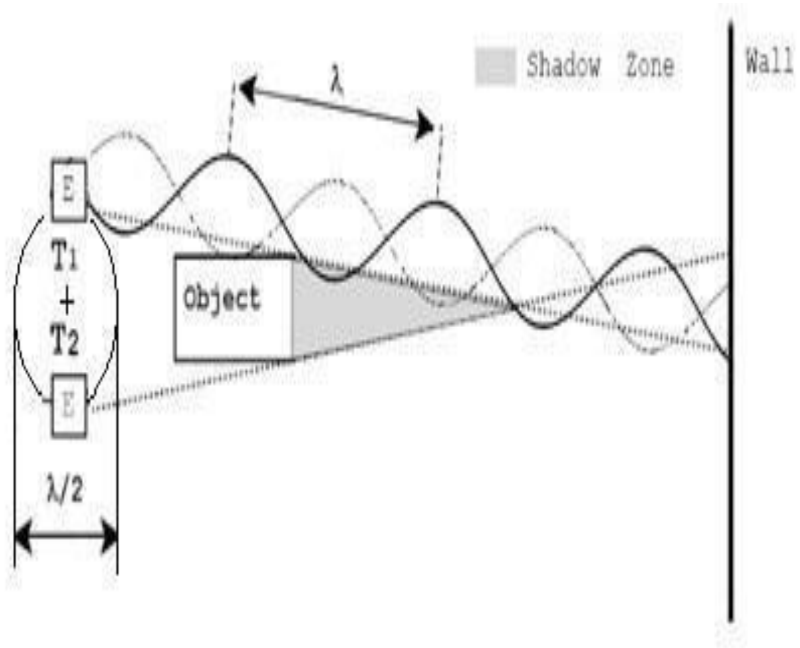

Figure 6

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An Autonomous Wheelchair with Indoor Positioning System and Smart 3D Headphone for the Visually Impaired

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***Abstract*–The Internet of Things (IoT) is an upcoming area that could improve the autonomous operation of EPWs by providing independent maneuvering around obstacles. This study proposes an autonomous EPW having smart driving features for the visually impaired. The initial prototype of the autonomous EPW had voice, eye-movements, and GPS control. This "InstitutoPolitécnico de Leiria/Instituto de Telecomunicações"(IPL/IT)-based wheelchair has remote-control features that could benefit those with low-level visual disability. The tele-assistance features could assist the care-givers of the wheelchair user. Indoor locating systems using 3D printed directional Wi-Fi antennas allow for precise positioning of the wheelchair. The IPL/IT EPW system has been designed with low-cost IoT technology and, for this reason, it will be affordable to all. In addition, the EPW system has been enhanced with a novel smart 3D headphone that can generate acoustic signals in proportion to a 3D object, which would assist the visually impaired in identifying the shape of obstacles, and thus, avoid them.**

Keywords—indoor positioning system, autonomous wheelchair, eye-controlled wheelchair, Internet of Things (IoT), telemedicine, tele-assistance, visually-impaired, seeing with 3D sounds.

I.Introduction

The need for smart products to aid the elderly and disabled is growing constantly. The electric powered wheelchair (EPW) comes as an important mobility device in the lives of disabled people, giving them mobility, independence, and a superior quality of living [1]. In the year 2010, some 540,000 US citizens had benefited from EPWs, and since then, many more have reaped benefits [2]. This vehicle is useful for those with mobility issues of the limbs, especially patients having damages to their spinal cord, muscle dystrophy, cerebral palsy, etc [4, 5]. To assist the disabled, several EPWs are being offered currently in the market [6, 7]. They are of varied types, and can tilt and recline, among other movements [8]. Many methods for controlling EPWs have been suggested, e.g. voice [9], facial direction [10], eye-movements [6], electromyography signals of the neck, arm, and facial muscles [11, 12], electro-oculography (EOG) methods [13, 14], etc.

This study offers an enhanced version of the autonomous EPW for the visually challenged developed by InstitutoPolitécnico de Leiria/Instituto de Telecomunicações (IPL/IT). Internet of Things

The IoT is a network of intelligent mechanisms interconnected to each other having unique digital identities [15, 16]. Items used daily are provided with an intelligent identity capable of detecting, comprehending, and responding to signals as a result of the union of new technologies and the Internet [17]. The IoT architecture comprises of three layers [15]:

- Perception layer: This layer has sensors for sensing and gathering data about the surroundings and locating smart devices in its surroundings.

- Network layer: This layer connects with neighboring network and smart devices and servers, processes sensor data, and transmits it.

- Application layer:This provides application-based utilities to the user.

The IoT system architecture proposed in this study is shown in Fig.1.

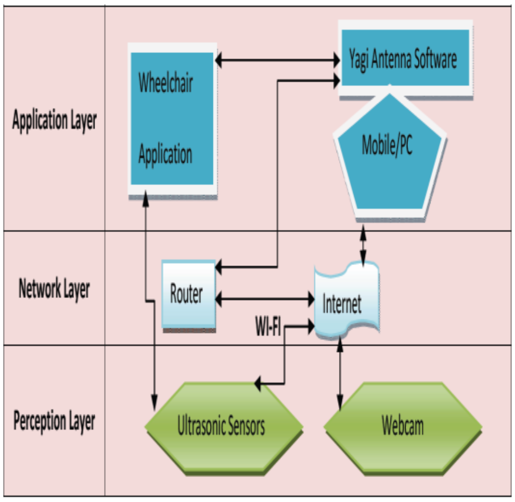

Figure 1.IoT architecture of proposed system.

II. Design and Implementation of Proposed System

A. Wheelchair functionalities

The hardware components of the proposed IPL/IT autonomous EPW with easy to use parts is shown in Fig. 2 and Fig. 3. The primary system control is achieved by an economical Raspberry PI minicomputer. It interacts well with other components, and is flexible and performs numerical calculations well. The movement of the EPW is carried out by two DC motors with speed controllers. A simple joystick module steers the EPW. There are devices for speed, voice and eye motion instructions, barrier detection, and autopilot setting. The custom software, developed by a different IPL/IT group ,manages all the peripheral sensing devices.

The EPW uses control by ocular movements. Instructions for directional motion and halting are managed by a voice command algorithm. A wheelchair that is controlled by voice helps a person with disabilities to be independently mobile. This can be achieved by interfacing a voice recognition application with the motors. As the wheelchair prototype uses a Raspberry Pi minicomputer, the DC motors can be controlled using such a voice recognition module to move in accordance to the voice commands. The voice command algorithm “Correlation of Spectrograms”, applied to our IPL/IT wheelchair, was developed by João S. Pereira, in 2001.

Figure 2. Block diagram of proposed system

Fig. 3. The low cost autonomous IPL/IT wheelchair system, with voice command, eyes movement detection, GPS, colored line follower, and sound reproducer of 3D objects scanned

The IPL/IT wheelchair system contains manual controls for Front, Left, Right, and Reverse movements. Additionally, the wheelchair has smart commands, such as reading eye movements, with a webcam fixed on a helmet; validation by voice commands using a microphone; autopilot using a Global Positioning System (GPS) or a colored line; and autopilot via Internet (Web). Moreover, the IPL/IT wheelchair system is low priced (lower than 400€) and is a modular system that can be modified to suit with any wheelchair. Furthermore, its controls are configurable to any user.

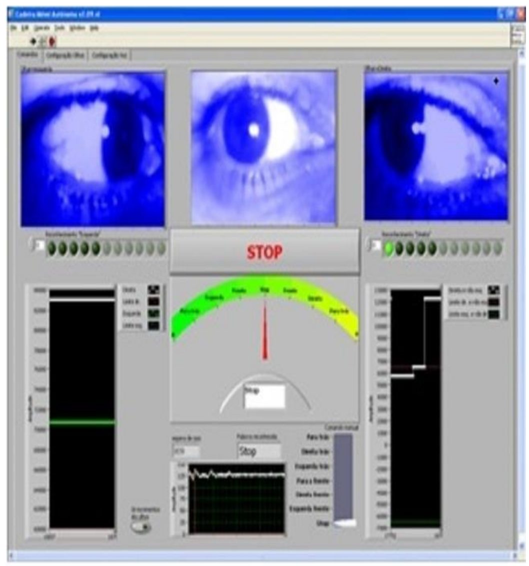

Fig. 4. Graphic interface of the eye-controlled system

The hardware design for the novel3D surround headset system is illustrated in Fig. 5. The system, added to the IPL/IT wheelchair, comprises of(1) three pairs of speakers, (2) an image-based 3D scanner, and (3) an ultrasonic 3D scanner. The ©Microsoft Kinect 3D scanner is used when the object is visible to the user; else the ultrasonic 3D scanner is used. This new model has been incorporated in our IPL/IT autonomous wheelchair.

The Raspberry Pi minicomputer serves as the heart of the system and offers an interface between the units, namely the GPS, the collision avoidance sensors and other sensors. The wheelchair unit receives latitude and longitude information through the GPS system. A mobile app offers both an enriched experience to the user and handy information regarding the location of the wheelchair. The app communicates on a real-time basis with the server. The positioning system also has the capability to regulate the movements of the wheelchair and its direction/orientation. This is moreover a process to improve the safety of the user. The data is registered and documented in a defined format.

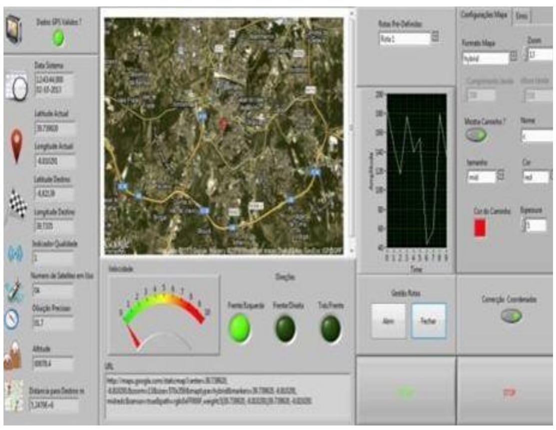

Fig. 6. Locating Wheelchair on Google Map

Therefore, our location wheelchair system include:

1. A web server running on Raspberry Pi;

2. A mobile phone which utilizes a browser to view the images from the webcams of the wheelchair;

3. A server-provided web page which

i. permits dynamic commands for real-time control of the two motors of the wheelchair;

ii. offers supplementary information regarding the different sensors utilized to avert issues, such as collisions (ultrasonic sensors and a Kinect scanner);

iii. Give the GPS location of the wheelchair.

The GPS works well in an outdoor scenario, with an accuracy around 5 meters. This precision is not good enough to drive autonomously a wheelchair. Additionally, it is well-known that the GPS was not designed to work inside building. For this reason, a new indoor positioning system for our wheelchair is presented. Our new system was built with some Wi-Fi ESP8266 modules and a Raspberry Pi to drive directional motorized antennas which gather longitudinal and latitudinal coordinates using a triangulation approach described later. These IoT devices are low cost and provide an affordable solution to any IPL/IT wheelchair user. The coordinates of at least two Wi-Fi Yagi antennas are then gathered utilizing a Raspberry Pi. Flores, Marcillo, and Pereira, in 2017, utilized a comparable system to assess the position of a drone. The same positioning system is reused with the IPL/IT autonomous wheelchair. The wheelchair can be manipulated by sending commands to the main server from a mobile app. The server then passes these commands to the hardware actually connected to the

Internet via the Wi-Fi network which then generates suitable signals to guide the wheelchair.

Figure7 depicts our portable Wi-Fi Yagi antenna system printed in a 3D printer.

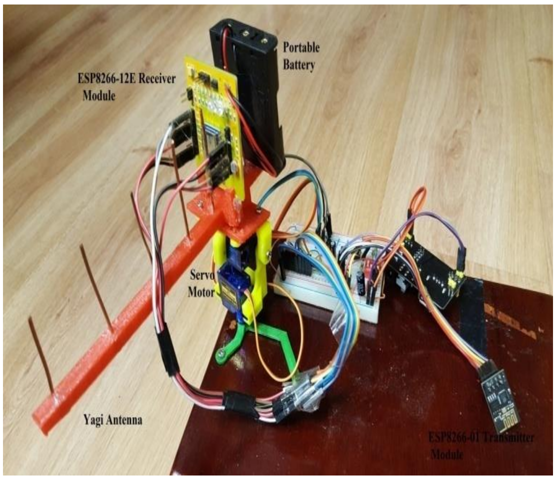

Fig. 7. Portable Wi-Fi Yagi antenna for an accurate indoor positioning system (prototype)

B. Triangulation process

The positional coordinates are arrived at using the Angle of Arrival (AoA) method (Fig. 8).This project suggests a novel localization method using Wi-Fi ESP8266 modules and Yagi motorized antennas. Initially, the angles θ1 and θ2 are measured for all nodes (here,P1 and P2) using the AoA method. Then, the line representing the orientation of highest propagation is calculated at all node references, their coordinates (Xi, Yi), i=1,2 and angles (θ1 and θ2) being known. The intersecting point of the lines S(X,Y) is arrive data's follows [18]:

For line P_1S, slope = $\tan\theta_1 = \frac{Y-Y_1}{X-X_1}$,

we obtain:

$$Y = X\tan\theta_1 + Y_1 - X_1\tan\theta_1 \quad (1)$$

Again, for line P_2S,slope = $\tan\theta_2 = \frac{Y-Y_2}{X-X_2}$.

Rearranging, we obtain:

$$Y = X\tan\theta_2 + Y_1 - X_1\tan\theta_2 \quad (2)$$

Solving for X and Y, we get:

$$X = \frac{X_1\tan\theta_1 - X_2\tan\theta_2 + Y_2 - Y_1}{\tan\theta_1 - \tan\theta_2} \quad (3)$$

Similarly, we obtain:

$$Y = \frac{(X_1 - X_2)\tan\theta_1\tan\theta_2 - Y_1\tan\theta_2 + Y_2\tan\theta_1}{\tan\theta_1 - \tan\theta_2} \quad (4)$$

Thus, the coordinates of S are:

$$S = \left(\frac{X_1\tan\theta_1 - X_2\tan\theta_2 + Y_2 - Y_1}{\tan\theta_1 - \tan\theta_2}, \frac{(X_1 - X_2)\tan\theta_1\tan\theta_2 - Y_1\tan\theta_2 + Y_2\tan\theta_1}{\tan\theta_1 - \tan\theta_2}\right) \quad (5)$$

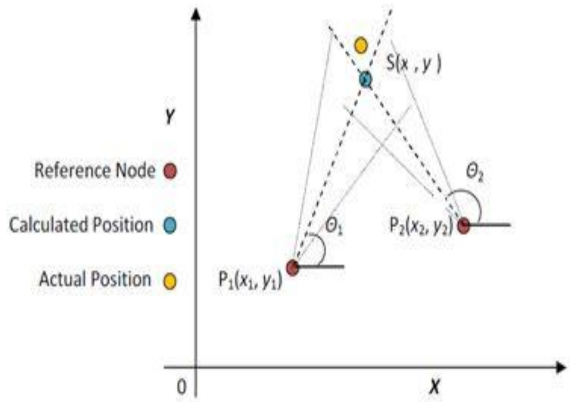

Fig.8. Triangulation method using AoA.

The ESP8266 directional antennas are positioned on two servo motors which have a range of 180 degrees. In our scenario, the wheelchair is located inside a geographical equilateral triangle of 5meters. The IoT technologies with 3ESP8266 modules (Fig. 7) are placed at the vertices of the triangle. It is possible, in this manner, to discover the location of the wheelchair with a minimum error of few centimeters, much lower than the GPS error.

As mentioned earlier, the objective of the current initiative is to improve the present facilities of the IPL/IT wheelchair prototype with the intent of enhancing its user-friendliness, robustness, and accountability to enable both users and wheelchair providers to more successfully locate the wheelchair by means of a mobile application. This initiative uses IoT technologies to enhance the earlier IPL/IT wheelchair system. The primary elements of the extended system are: a centralized server with a Raspberry PI minicomputer for control and a set of servo motors for each ESP8266 antenna. A network of ESP8266 modules was used to obtain the wheelchair location. All the modules are distributed in a real indoors scenario and they use Wi-Fi to communicate with the wheelchair server.

C. Multipath interference and standing waves

In wireless communications, multipath is a phenomenon of propagation in which radio signals arrive at the receiving antenna by more than one path. It results in multipath interference (MPI), which may be constructive and destructive interference, and causes the phase of the signal to get shifted. In this study, two Radio Frequency (RF) emitters (ESP8266 having Yagi antennas) are placed on the tables as illustrated in Fig. 9. Standing waves can be created when obstacles are placed in the path of a direct wave. The floor, for instance, can generate a standing wave by reflection of the direct wave. Similarly, a wheelchair or the walls, as obstacles, can generate many standing waves by causing a reflection of a direct wave. To overcome these issues, a positioning system which uses a new method for cancelling standing waves[19] has been described in this study. This enhances the positional accuracy of obstacles and minimizes the effects of standing waves. In Fig. 9, the system attempts to accurately locate the wheelchair. The wheelchair has a Wi-Fi module that is used to identify the real location, by mean of a triangulation process. Each Wi-Fi directional antenna make a scan, over 180 degrees, until to discover the direction where is the Wi-Fi emitter of the wheelchair.

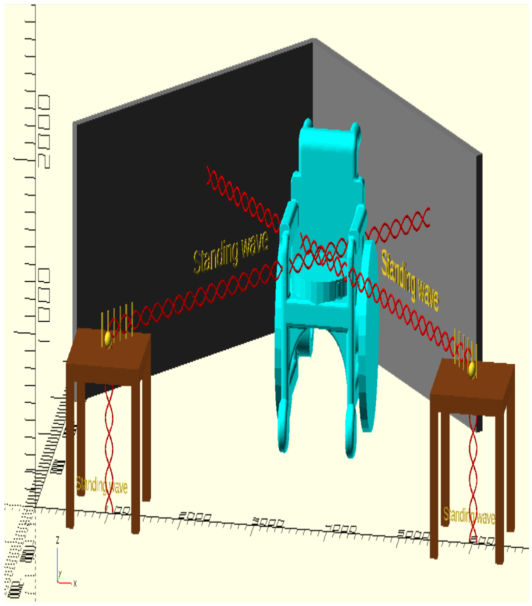

Fig. 9.Standing waves created by obstacles (scale: mm)

Figure 10 depicts a graph displaying the construction of a specific standing wave. The standing wave effect has a major impact on the accuracy of location estimation in a radio wave mechanism, due to the constant change in amplitude of the wave that affects signal strength readings, and thus, location accuracy. The standing wave is a wave with a full wavelength λ, where λ is also the wavelength of the RF carrier. To mitigate the effect of the standing waves, we use hardware-based methods to generate two different waves, in the pending patent [19]. The method generates a second wave with a variable delay that reduces the slow fluctuation of the standing wave.

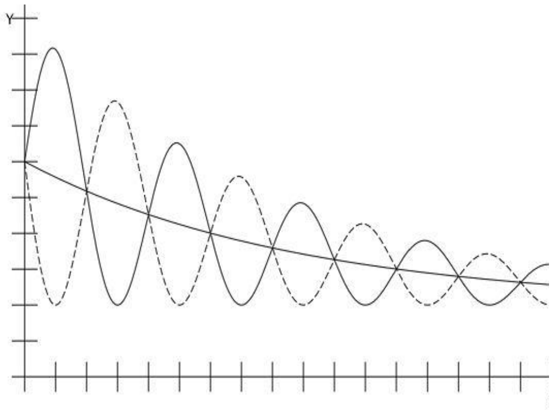

Fig.10. Construction of a specific standing wave (X-axis is the distance and the Y-axis is the power of the signal received)

The standing wave phenomenon has a detrimental influence on the estimation accuracy when radio waves are used since wave amplitude varies constantly, thus affecting signal strength, and finally, the positional accuracy. To overcome the standing-wave effect, a hardware-oriented technique has been carried out to move the RF emitter in order to mitigate the standing wave effect in our 3 pending patents [19], [20], and [21]. In resume, it is a simple method that consists to move the initial location of an RF emitter around a circle of half wavelength (λ /2).

A 2D positioning system was set up for optimal transmission and receipt of data to study system accuracy and location error. Our device uses an automatic rotation of the Yagi antennas that performs a full scan of our indoor scenario, where the wheelchair is located. As it can be seen in Fig. 9, the two RF emitter ESP8266 with Wi-Fi Yagi antennas was located at 5 meters. It is seen from Table 1 that the error, in the 3 different scenarios, increases with growth in antenna distances from the wheelchair. The average error of the three experiments was 30 cm. With the application of the patent pending technique [19] there was a 46% improvement of error location. By other words, the error is reduced 46%. Table 1 presents the outcome of the above experiment conducted in a 5m x 5m environment in a closed room. The results clearly show that the pending patents technique [19] and [20] significantly improves the accuracy of the wheelchair positioning.

TABLE 1. INDOOR LOCATION ERROR RESULTS.

nitial position (X, Y) of the wheelchair [m]	alculated starting position [m]	nitial error [m]	inal position [m]	alculated final position [m]	inal error [m]	verage of the new error [m]	% of error location improvement after applying the pending patents [19] and [20]
2.3, 2.7)	2.59 , 2.20 7)	.57	5.6, 5.85)	5.15 , 5.42)	.4 9		
2.6, 2.9)	2.85 , 3.43)	.58	2.95 ,2.7 1)	3.11 , 2.39)	.3 5	.30	46
2.2, 3)	1.89 , 1.13)	.33	1.99 , 2.7)	1.99 , 2.76)	.0 5		

D.Sound conversion of 3D objects for the IPL/IT EPW

A new surround 3D headphones device is presented in this paper. It uses 3D sounds with a 3D headphone to reproduce 2D image. By using 3D sounds the user will know not only the shape of an object, but also the depth of it. Through the use of a 3D scanner, it is possible to create three-dimensional objects of the environment standing in front of the IPL/IT wheelchair.

With our new method, the surface of the object is virtually covered by multiple virtual sound sources. For each virtual sound source, located on the surface of the object, a distance is calculated between the user and this source. These distances are calculated to simulate the locations of the various sound sources from the three-dimensional space that reach 3 pairs of speakers assembled in a new 3D headphone. Different audible frequencies are used to determine each of the frontal layers. The curves of each layers(cutting the object) are represented by a limited number of points that are used to simulate the origin of the sound sources in a three dimensional space.

The IPL/IT EPW uses a ©Microsoft Kinect scanner to capture 3D objects and convert them to 3D sounds. This converter is designed based on our pending patent [22]. All objects can be scanned and modeled by a decomposition of layers in a 3D Cartesian system (Fig. 11). The points of virtual location of each sound source have equal audible frequencies whenever the R rays are equal, despite the angles B being different in the range 0–360°. The virtual points with high R are represented by low audible frequency range and points with low R are represented by higher audible frequencies. The user can estimate the object shape based on the hearing of an audible frequency proportional to the radius R on each plane.

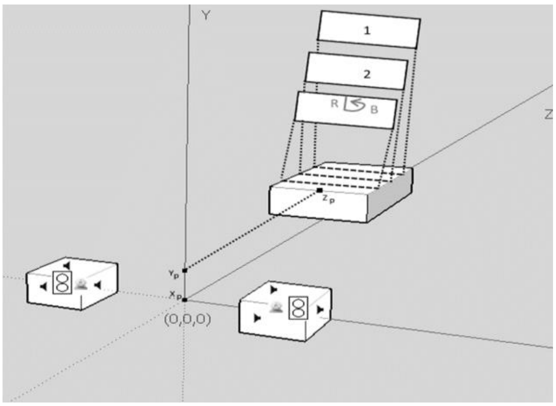

Fig.11. 3D object decomposition, by layer, on a Cartesian system

To generate a particular sound for a particular speaker, the Euclidean separation between each point and each speaker p is calculated as follows:

$$D = \sqrt{(x_P - x_{speaker})^2 + (y_P - y_{speaker})^2 + (z_P - z_{speaker})^2}$$

This distance D is used to generate the sound wave for the corresponding speaker using the formula:

$$y(t) = 256 * e^{-D} * \cos\left(\left(\frac{v}{D} * \frac{2\pi}{10^{-6} * D}\right) + (2\pi/(10^{-6} * D)) * \frac{t}{f}\right)$$

The experiments were carried out using the frequency f = 44.1 kHz. The velocity of sound in air was taken to be v = 340 m/s.

The software responsible for the generation of the sound starts by capturing the scenario or an object using a 3D Kinect scanner. After the 3D object is generated, it is split into various layers and the nearest layer is selected first. After all, the angles and radius are calculated, the sound for each one of the 6 speakers (RB, RU, RD, LB, LU, LD) is generated (Fig. 12). When generation of all 6 sounds is finished, the left group of speakers plays the sounds generated for LB, LU and LD, while the right side plays the sounds for RB, RU and RD and then the software moves to the next layer. If, after all layers have been processed, our software detects any movement, this whole process will be repeated. Figure 12 can be used to better understand the previous method that it is described in the algorithm of Fig. 13.

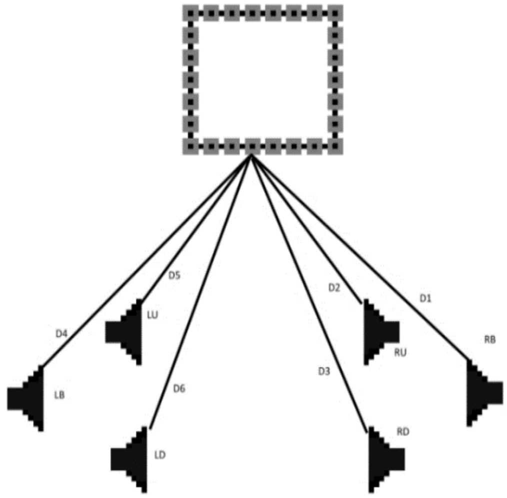

Fig. 12. Distance between speakers and points

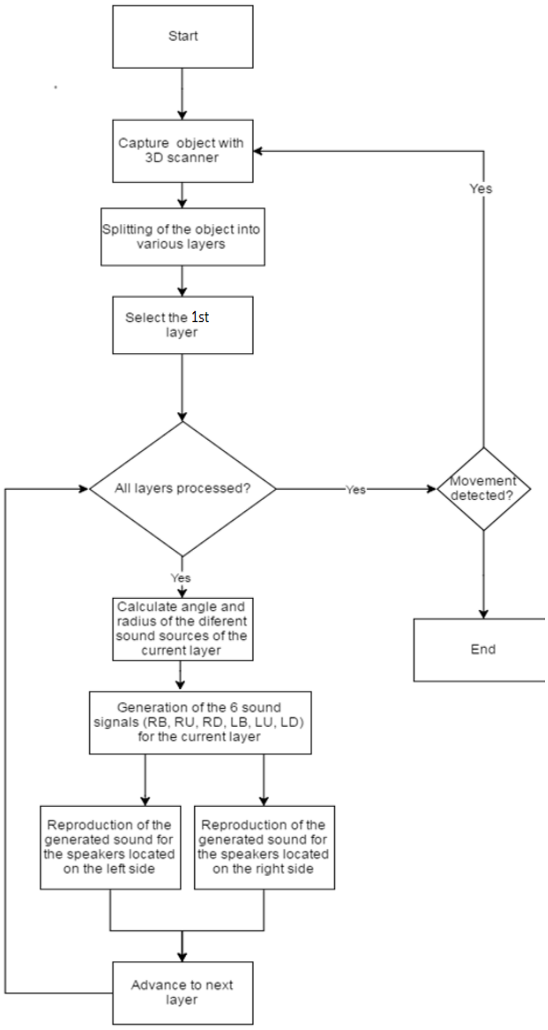

Fig. 13. Algorithm diagram

Figures 14, 15 and 16 illustrate scans of a person making a hand gesture movement, a semi-closed door, and a closed door, respectively. The 3D objects are shown in the left, the scanned images converted into frequency sounds in the right (a different color for each frequency) and the generated sound amplitude below (delivered to 6 different pair of speakers). The colored points of the scanned images represent sounds of different frequencies, for all layers. Comparing the 3 figures 15, 16, and 17, we observe that the more the variation in depth, the longer the duration of sound. After some training, using the 3D headphone of Fig. 5, a blind person was able to recognize easily the 3 different objects. However, it may be possible to recognize other kind of objects if a deep training is used.

In this paper we proposed a solution to convert tridimensional objects into sound in order to give visually impaired people an idea of what an object looks like and how distant it is. Compared to other solutions that use two dimensional images, the use of a tridimensional object gives us a better understanding of that object. Instead of using the intensity of the pixels of an image to generate a sound to describe the image, our method (pending patent [22]) uses separate layers of the object to give visually blind people a better understanding of the object's shape and depth. With the tests performed, it was possible to identify not only the shape of the object, but also to identify its location in a 3D space. In further work, we intend to move the current computer application to a more portable solution. Along with this portable device, we also intend to make more tests with other real obstacles in front of the autonomous IPL/IT wheelchair.

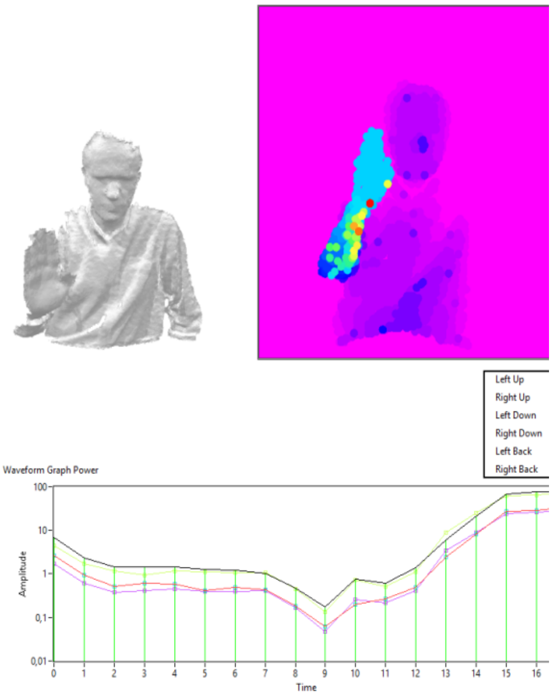

Fig. 14. Audible scan of a person

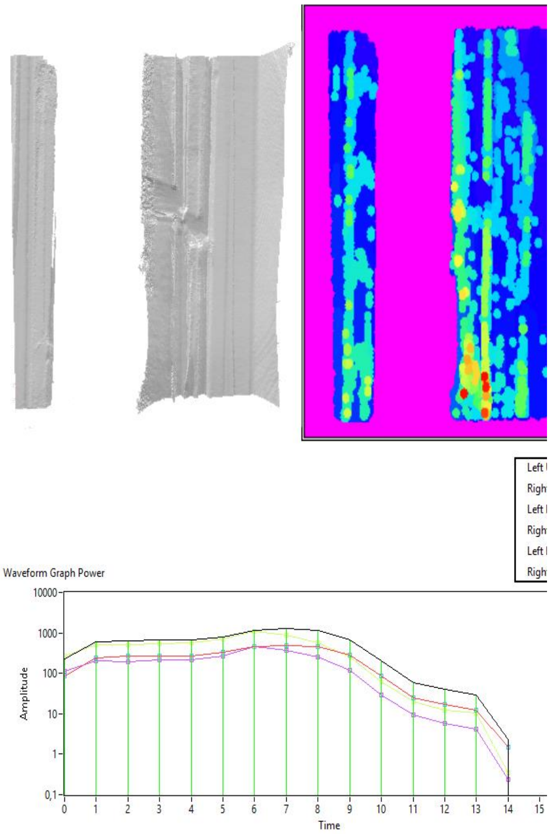

Fig. 15. Audible scan of a semi-closed door

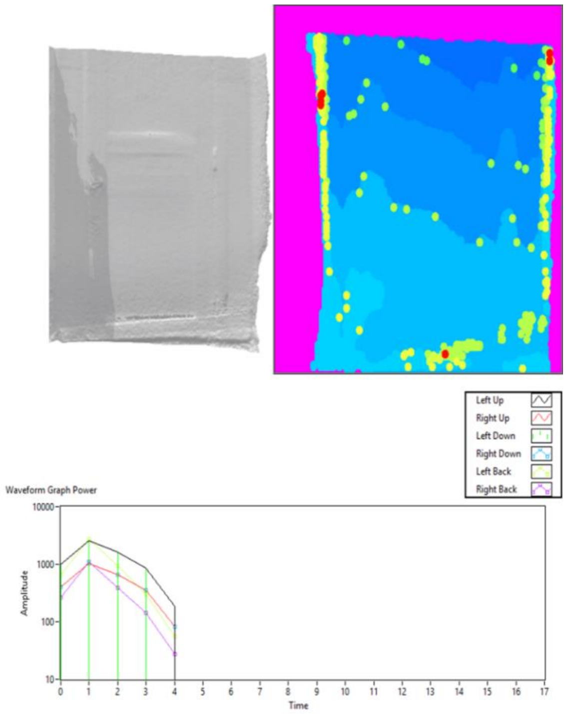

Fig. 16.Audible scan of a closed door

Conclusions

In this study, a smart autonomous wheelchair (IPL/IP EPW) having voice and eye-movement control has been described. The system uses a Wi-Fi network of ESP8266 modules to implement an accurate positioning system. This new system, based on some pending patents, has been tested successfully. The proposed system presents the location of a wheelchair with a positioning accuracy around 30 cm, when the experiment is performed within an indoor scenario. In addition, the IPL/IT EPW has been fitted with a novel 3D scanner that generates 3D sound appropriate to the obstacle sensed. This feature combined with the proposed positioning system will be beneficial to the visually challenged.

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