

**A PROJECT REPORT**

**ON**

AUTONOMOUS SHOPPING CART

By

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**(CPE/17/3102)**



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**ABSTRACT**

Autonomous technologies have become rooted in several areas of our daily lives, and the retail industry is no different. This paper explores the world of self-driving shopping carts, a novel idea enabled by Radio-Frequency Identification (RFID) technology. The aim is to optimise the shopping experience by utilising RFID technology to automate tasks that are conventionally performed by retailers and customers.

The report opens with an overview of the retail industry's changing environment and the demand for creative solutions to boost productivity. The basic function of RFID technology in the autonomous shopping cart paradigm is then examined. Important elements such as RFID tags, readers, microcontrollers, sensors, and motor systems are broken down to show how each one contributes differently to the overall architecture of the system.

An overview of autonomous shopping cart functionality is provided, with a focus on features like inventory management, autonomous navigation, automatic item identification, and self-checkout capabilities. The advantages of this technology—including better customer experiences, more efficient stores, cost savings, and insightful data—are thoroughly examined and presented.

The research does not, however, avoid discussing the difficulties and factors that come with putting RFID-based autonomous shopping carts into practise, such as upfront costs, compatibility problems, and security worries. A phased rollout strategy, staff training, and testing methodologies are the main topics of discussion during the implementation phase.

In order to further optimise the shopping experience, the research suggests future improvements including predictive analytics and integration with mobile apps. The study concludes that RFID-enabled autonomous shopping carts mark a significant change in the retail environment, providing both immediate advantages and opening the door for ongoing innovation and advancement in the field of contemporary retail experiences.

**BACKGROUND OF RESEARCH**

A key component of worldwide trade, the retail sector is always looking for new and creative ways to improve customer satisfaction and operational effectiveness. Technological advancements are reshaping traditional paradigms, and one frontier for exploration in the retail sector is the integration of autonomous systems. This research background explores the history of retail, the difficulties encountered, and the pivotal role that Radio-Frequency Identification (RFID) technology played in the advancement of self-driving shopping carts.

Evolution of Retail: With the introduction of digital technologies, the retail environment has experienced significant changes. The way that customers engage with goods and services has been completely transformed by e-commerce platforms, online marketplaces, and smart devices. Still, the physical store is an essential part of the whole shopping experience, so new ways to make it more relevant and effective are needed.

Issues That Traditional Retail Faces:

The challenges faced by traditional retail models include the need for improved customer engagement, lengthy checkout procedures, and manual inventory management. These difficulties have spurred research into cutting-edge technologies that can resolve these issues and bring back the in-store shopping experience.

The rise of autonomous technologies: These technologies, which make use of machine learning and artificial intelligence, are now essential to many different industries. Recognising the potential of automation, the retail industry has worked to implement these technologies in order to improve customer convenience and efficiency during their shopping experiences.

RFID Technology's Function:

RFID technology has become more and more popular in the retail industry. It is well-known for its capacity to track and uniquely identify objects using radio waves. RFID is being used for more than just conventional inventory management; it is also being used to create autonomous and intelligent systems. Accompanying the deployment of RFID readers in shopping carts and integrating RFID tags with products opens up possibilities for autonomous navigation, real-time inventory updates, and easy item identification.

Autonomous Shopping Carts: The idea of autonomous shopping carts combines autonomous systems with RFID technology. These smart carts, which come with sensors, RFID readers, and microcontrollers, automate tasks that were previously completed by customers and retail employees, revolutionising the way people shop. The goal of the study is to examine the complexities involved in setting up and refining these kinds of autonomous systems in a retail setting.

To put it briefly, the background of research establishes the context for comprehending the development of retail, the difficulties encountered by conventional models, the emergence of autonomous technologies, and the critical role that RFID technology plays. It highlights the need for creative solutions and lays the groundwork for investigating self-driving shopping carts as a game-changing innovation in the retail industry.

**PROBLEM STATEMENT**

Manually pushing and navigating a shopping cart is a common part of traditional shopping experiences, which can be tiresome, especially in crowded stores or for customers with physical limitations. Additionally, despite the fact that technology has changed many facets of retail, little innovation has been made to the shopping cart itself.

The following issues arise as a result of the lack of automated and user-friendly shopping cart solutions:

1. Manual Effort: Carrying shopping carts around the store requires customers to exert physical effort, which can be taxing, particularly when making multiple stops.
2. Accessibility: Physically challenged or elderly customers may have trouble navigating through crowded aisles or pushing heavy carts, which limits their ability to shop.
3. Lost Shopping Time: Customers waste time navigating and managing their carts when they could be choosing products and making decisions about purchases.
4. Limited Multitasking: The need to manage the cart limits customers' ability to browse and choose products, decreasing their overall shopping effectiveness.
5. Ineffective Store Layout: Due to the traditional cart-dependent shopping model, stores may find it difficult to optimise their layouts, which could have an impact on customer flow and store revenue.

These problems are attempted to be solved by the proposed autonomous shopping cart with RFID/NFC communication and gyroscope integration. By relieving customers of the manual task of cart management and navigation, the cart's ability to autonomously follow a designated user, assisted by RFID/NFC communication for tracking and a gyroscope for stability, aims to improve the shopping experience. In a field where traditional shopping carts haven't changed much in decades; this project aims to innovate.

**AIM AND OJECTIVES**

1. Integrate RFID/NFC technology into the shopping cart, allowing users to communicate with the cart through RFID/NFC cards or tags
2. Integrate a gyroscope sensor to provide orientation data, ensuring stability and balance during cart movement
3. Implement ultrasonic and infrared sensors for obstacle detection and avoidance, enabling the cart to navigate safely through the store environment.
4. Utilize wheel encoders to measure wheel rotation and estimate the cart’s distance travelled for accurate localization
5. Develop a navigation algorithm that combines sensor data to control cart’s movement, ensuring smooth turns and precise manoeuvrability.

The main aim of this robotics project is to Develop a robust and reliable navigation system for the shopping cart to manoeuvre autonomously within a store environment, avoiding obstacles.

**SCOPE OF THE RPOJECT**

The scope of the hardware system includes:

1. RFID/NFC Integration: Identify and procure the necessary RFID/NFC components for the shopping cart, including readers, tags, and cards. Develop a system to read RFID/NFC cards/tags carried by users and associate them with the profiles stored in the database.
2. Hardware Selection: Identify and procure the necessary sensors, including a gyroscope, ultrasonic sensor, infrared sensor, wheel encoder, along with a microcontroller unit to process sensor data and control cart movement.
3. Sensor Integration: Connect and calibrate the sensors with the MCU, ensuring reliable and accurate data acquisition.
4. Navigation System: Develop an algorithm that incorporates sensor data to control the cart’s movement, allowing it to avoid obstacles, maintain stability and make smooth movements.
5. Safety measures: Implement safety features that will utilize the sensor data to trigger approximate responses, such as stopping or changing direction when collisions are detected.
6. Manual Override: In case of emergency or if the user wants to manually control the cart, a manual override option will be included.
7. Testing and optimization: Conduct rigorous testing to verify the accuracy and reliability of the sensor integration and navigation system. Optimize the algorithm to ensure efficient cart movement

**CHAPTER TWO**

**LITERATURE REVIEW**

**HISTORICAL BACKGROUND**

The historical trajectory of autonomous robots traces a compelling narrative marked by transformative technological breakthroughs. Commencing from antiquity to the 20th century, the concept of autonomous machines has roots in ancient myths, gaining substantial traction during the Industrial Revolution with the inception of programmable machinery ().

The 1950s and 1960s ushered in the era of robotics, epitomized by the creation of the first industrial robots like the Unimate by George Devol and Joseph Engelberger. This period set the stage for subsequent advancements, notably the exploration of mobile robots capable of autonomous navigation. Stanford University's Cart in 1979 emerged as a pioneering computer-controlled autonomous vehicle, foreshadowing a paradigm shift (*History of Robots - Adelaide Robotics and Computer Science Academy*, n.d.).

The 1990s and 2000s witnessed remarkable progress, propelled by the integration of sophisticated sensors such as lidar and the refinement of software algorithms. This era laid the foundation for the diversification of autonomous robots across industries, from healthcare and agriculture to logistics ().

The subsequent decade marked a significant surge in autonomous vehicles, exemplified by the endeavours of companies like Google's Waymo and Tesla. The 2010s also witnessed the widespread utilization of drones in various applications ().

In the current landscape, autonomous robots are integral to diverse sectors, showcasing advancements in AI and machine learning. Notably, collaborative robots (cobots) are reshaping human-robot interactions. This historical evolution underscores the continuous innovation driving the integration of autonomous robots into everyday life ().

**OVERVIEW OF AUTONOMOUS SHOPPING CARTS**

**Autonomous robots**

An autonomous robot is a robot that is designed and engineered to deal with its environment on its own, and work for extended periods of time without human intervention. Autonomous robots often have sophisticated features that can help them to understand their physical environment and automate parts of their maintenance and direction that used to be done by human hands(Wahde, 2012).

Applications span various fields, including manufacturing, agriculture, healthcare, logistics, and space exploration. Examples include self-driving cars, drones, robotic vacuum cleaners, and industrial robots.

**Traditional Shopping carts**

A shopping cart, a ubiquitous feature in retail establishments, especially supermarkets, serves as a convenient tool for customers to transport merchandise within the store premises before heading to the checkout counter or tills(“Definition of SHOPPING CART,” n.d.). The shopping experience posed significant challenges for customers who, in the absence of dedicated shopping tools, had to navigate stores with goods in baskets or in their hands. This lack of a specialized shopping apparatus transformed grocery shopping into a time-consuming and laborious process, as shoppers were compelled to transport items manually from the shelves to the cashier desks. Recognizing the need for a fundamental change, there arose a necessity to revolutionize and enhance the efficiency of the shopping experience (Raghavan, 2023). The inaugural shopping cart, conceived by Sylvan Goldman in 1937, featured a frame resembling a folding chair equipped with wheels and two baskets, marking a transformative moment in the evolution of retail convenience (*Large Capacity Shopping Cart*, n.d.).

While the original design was relatively simple, modern shopping carts are predominantly crafted from metal or a combination of metal and plastic. These contemporary iterations are thoughtfully engineered to nest within each other, allowing for efficient collection and movement of multiple carts simultaneously, thereby optimizing storage space(Wilson, 1978). Shopping carts come in various sizes, ranging from standard options to larger models capable of accommodating a child. Specialized designs cater to specific needs, including carts for two children and electric mobility scooters with integrated baskets designed for individuals with disabilities(*3 Features Your Shopping Cart For A Service-Based Business Should Have - PaySimple*, n.d.).

The evolution of shopping carts, as chronicled by historical references, illustrates not only their functional adaptation to consumer needs but also their impact on the efficiency of shopping experiences within retail environments.

**Reason for automation**

The goal of improving the shopping experience is what drives the automation of the conventional shopping cart into an autonomous system that follows its user on its own(Alves et al., 2018). The goal of switching from a manual, user-driven cart to an autonomous one is to make shopping more convenient, to expedite the process, and to give customers a more effective and convenient way to go through stores while carrying the things they have chosen. The objective of this change is to incorporate technological improvements in order to streamline the entire shopping experience and enhance user satisfaction and ease of use (Sales et al., 2016).

**Brief existing use cases**

Caper AI: Caper AI developed an autonomous shopping cart that utilizes computer vision and sensor fusion to identify items as they are placed in the cart. It allows customers to skip the traditional checkout lines, making the shopping process more efficient.

Cadenas Intelligent Cart: Cadenas' Intelligent Cart is designed to follow customers autonomously as they move around the store. It uses sensors and cameras to navigate and avoid obstacles, providing a hands-free shopping experience.

5G Self-Driving Shopping Cart (SK Telecom): SK Telecom showcased a 5G-powered self-driving shopping cart that can autonomously follow customers. It uses advanced connectivity and sensor technologies to navigate through the store.

Kiwibot: While not a traditional shopping cart, Kiwibot has developed small autonomous robots designed for delivering food and groceries. Users can interact with these robots via a mobile app, and the robots navigate sidewalks autonomously.

Amazon Go: Amazon Go stores implement a different concept where customers can grab items and leave without going through a traditional checkout process. The store uses a combination of sensors, cameras, and machine learning to track items taken by customers and automatically charges their Amazon accounts.

Eli Mobile Robot: The mobile robot ELI serves as a smart shopping cart, able to take the customer to the location of the products, follow them throughout the store while they choose, and accept automatic payments, among other things.

**What is RFID?**

RFID stands for radio frequency identification, which is a wireless system made up of readers and tags. The RFID tag sends out radio waves through one or more antennas, which are then picked up by the reader. Passive tags draw power from readers, while active tags have batteries. RFID finds applications in tracking and monitoring, offering advantages over traditional bar-code technology such as non-line-of-sight identification and support for additional data points. RFID tags have the capacity to store many pages of data in addition to a single serial number. Readers can be fixed on a post or suspended from above, or they can be mobile enough to be held in one's hand.

**RELATED WORKS**

**Autonomous Wheeled Mobile Robots**

In the realm of autonomous robotics, Wheeled Mobile Robots (WMRs) have gained widespread popularity due to their suitability for applications characterized by modest mechanical complexity and energy consumption. Their versatile usage extends across various military and civilian domains, encompassing tasks such as surveillance, transportation, inspection, exploration, and numerous other applications. These deployments span diverse environments, whether structured or unstructured in nature, showcasing the adaptability and efficiency of WMRs in addressing a range of practical scenarios(Kamel & Zhang, 2014).  
Mobile robots find applications in both military and civilian contexts, playing pivotal roles in tasks such as search and exploration, surveillance, and transportation, among various other applications. Ground mobile robots are typically classified into two main types: wheeled mobile robots (WMRs) and legged mobile robots (LMRs). Furthermore, the scope of mobile robots extends beyond terrestrial domains, encompassing unmanned aerial vehicles (UAVs) and autonomous underwater vehicles (AUVs). This diverse categorization highlights the versatility of mobile robots, showcasing their significance in a wide array of domains and applications (Kamel & Zhang, 2014).

The exploration of robot kinematics involves analysing the arrangement of robots within their operational space, understanding the interconnections among their geometric characteristics, and examining the limitations imposed on their trajectories. Kinematic equations are intricately linked to the geometric composition of the robot. For instance, a stationary robot can exhibit a Cartesian, cylindrical, spherical, or articulated structure, while a mobile robot may be equipped with one, two, three, or more wheels, with or without motion constraints. A comprehensive understanding of kinematics serves as a foundational requirement for delving into the realms of dynamics, stability attributes, and the control mechanisms governing the behaviour of the robot. (Tzafestas, n.d.).

The primary techniques employed an autonomous involved the application of trigonometry and Pythagoras's theorem. To guide the robot along a predefined pathway, a control system utilizing PD (Proportional-Derivative) control was implemented. This control mechanism aided in ensuring the robot's precise navigation and alignment with the specified route, enhancing its efficiency in performing inspection tasks (Saat et al., 2018).

The incorporation of an Inertial Measurement Unit (IMU) for measuring angular rate and acceleration along three axes plays a crucial role in the navigation control system of land vehicles. Notably, land vehicle motion exhibits a broader range of acceleration in the x-axis and angular rate in the z-axis compared to other axes. The sensitivity of a sensor is inversely proportional to its measurement range. To achieve optimal sensitivities across all sensors, a multi-sensor system is essential to cover a wide range of motions. The fundamental components of the IMU encompass a microcontroller, gyroscope, and accelerometer. The microcontroller receives dual sets of acceleration data in the x-axis and two sets of angular rate data in the z-axis. Algorithms for selecting sensor data are employed to derive the six Degrees of Freedom (6-DOF) of the land vehicle. The IMU exhibits commendable linearity in the measurement of acceleration and angular rate, making it applicable for monitoring driver behaviour during sudden accelerations or braking manoeuvres (Wahyudi, 2015).

The project aims to create an autonomous robot capable of independent movement without continual human intervention. The autonomous robot is divided into two main components: electronic and mechanical parts. The electronic components include the controller board, infrared sensors, and ISD 2560 ChipCoder. The controller board comprises the microcontroller PIC 16F877A, power supply unit, and motor driver ST L293D. On the other hand, the mechanical components consist of the gear-box with DC motors and the robot's casing (Kee et al., 2008).

Utilizing sensors embedded in a robot’s bumper, binary data is generated to indicate obstacle detection, subsequently processed through specific control algorithms. These algorithms play a pivotal role in path planning and navigation. The robot's bumper acts as a preventive measure against collisions with walls and furniture, prompting the robot to reverse or alter its path based on the processed information (Hasan et al., 2014).

An algorithm was proposed to establish a potential field employing an artificial pheromone system consisting of data carriers and autonomous robots. The approach incorporated a cost-effective and straightforward data carrier, serving as a non-contact memory rewritable by the mobile robot. Autonomous operations of the mobile robots involved the simultaneous reading and writing to the data carriers for the renewal process. A methodology was devised for constructing the pheromone potential field within data carrier systems, allowing the derivation of a nominal model through parameter optimization to minimize errors. The selection of appropriate parameters, crucial for both simulation and implementation, is integral to achieving optimal results. This pheromone potential field model holds promise for application in a transportation network system, contributing valuable insights to the development of autonomous navigation in the context of shopping cart robotics (Herianto et al., 2007).

**Development of Human Following Robots**

One popular robotics application that has attracted a lot of attention is human-following robots, which have the potential to improve human-robot interactions and enable a number of useful scenarios (Gockley et al., 2007). The main goal of human-following robots is to follow and track a human user in a variety of environments on their own. The intention is to enable accurate movement tracking of the user by the robot through a smooth and natural human-robot interaction(Gupta et al., 2017). They are can be seen in applications such as healthcare, public spaces, industrial settings, etc.

**Human detection systems used in robots**

Human detection is a crucial aspect of autonomous robotic systems, enabling them to navigate and interact with users in various environments. Human-robot interaction is one of the core problems with service robots. These robots must be able to recognise and track humans in their environment in order to carry out such a duty and offer the required services(Bellotto & Hu, 2009).

Such systems include:

1. laser-based leg detection using the onboard laser range finder (LRF).
2. Computer Vision-Based Human Detection: One prevalent approach utilizes computer vision algorithms for human detection. Viola and Jones (2001) introduced a rapid object detection method employing a boosted cascade of simple features, providing real-time performance in identifying and tracking humans within visual data1.
3. Lidar-Based Human Detection: Lidar sensors, leveraging laser technology, create detailed 3D maps of environments. Campbell et al. (2009) demonstrated the effectiveness of Lidar for human detection in RGB-D indoor scenes, contributing to spatial awareness in robotic systems2.
4. Infrared (IR) Sensors: In low-light conditions, Infrared (IR) sensors play a vital role in human detection by identifying heat signatures. Vasanth and Pugalenthi (2015) incorporated IR sensors in an autonomous robot, enabling effective human detection and following capabilities3.
5. RFID-Based Human Detection: Radio Frequency Identification (RFID) technology offers proximity-based human detection capabilities. Jadhav and Mohanraj (2018) proposed a human detection robot utilizing RFID technology, showcasing its applicability in various scenarios
6. Ultrasonic Sensors: Ultrasonic sensors emit sound waves and analyse their reflections to detect objects, including humans. Liu and Chang (2015) introduced an intelligent ultrasonic sensor for blind human detection and navigation, emphasizing its role in enhancing robotic spatial awareness5.

These diverse technologies showcase the evolution of human detection systems in robotics. The choice of a specific detection system depends on project requirements, environmental constraints, and the desired level of precision. Integrating these technologies into autonomous robots enhances their ability to perceive and interact with the surrounding human environment.

**Integration of RFID Technology**

Radio frequency identification (RFID) emerges as a wireless communication technology, facilitating the remote reading of identity information from low-cost electronic tags by computers, all accomplished without the need for a battery within the tags. As RFID technology advances in maturity, it is poised to usher in a new era of applications that leverage the affordability and widespread availability of automatic identification (Nath et al., 2006).

In the recent years, radio frequency identification (RFID) technology has transitioned from a relatively obscure realm to widespread implementation, particularly in applications geared towards expediting the processing of manufactured goods and materials. Distinguishing itself from the traditional bar-code technology, RFID facilitates non-line-of-sight identification, allowing for efficient tracking and monitoring from a distance. Notably, RFID tags surpass the capabilities of bar codes by supporting a more extensive range of unique identifiers and accommodating additional data points, such as details about the manufacturer, product type, and even the ability to measure environmental factors like temperature (Kaur et al., 2011).

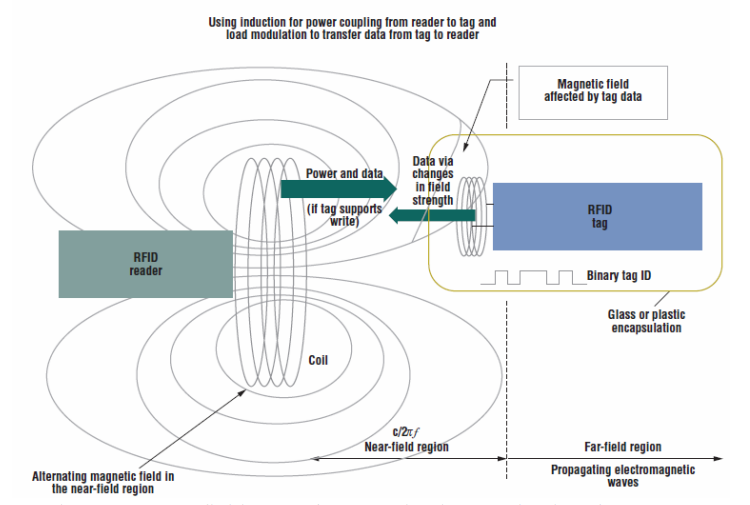
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Figure 1. Near-field power/communication mechanism for RFID tags operating at less than 100 MHz

**Summary of Literature Review:**

1. Autonomous Robot for Inspection (Saat et al., 2018):

Objective: Creation of an autonomous robot for inspection using trigonometry and Pythagoras's theorem.

Methodology: Employed PD control for precise navigation, with the incorporation of an IMU for measuring angular rate and acceleration.

Results: Achieved precise navigation and alignment with the specified route for efficient inspection tasks.

Limitations: Specific challenges or limitations are not explicitly mentioned.

2. Electronic and Mechanical Components (Kee et al., 2008):

Objective: Development of an autonomous robot capable of independent movement without continual human intervention.

Components:

- Electronic: Controller board with microcontroller, infrared sensors, and ISD 2560 ChipCoder.

- Mechanical: Gear-box with DC motors and the robot's casing.

Results: Creation of a robot with electronic and mechanical integration for autonomous movement.

Limitations: Detailed limitations or challenges are not specified.

3. Obstacle Detection and Path Planning (Hasan et al., 2014):

Objective: Utilizing sensors embedded in the robot’s bumper for obstacle detection and implementing specific control algorithms for path planning.

Methodology: Binary data generated by bumper sensors used to indicate obstacle detection and guide path planning.

Results: Effective obstacle detection and path alteration to prevent collisions.

Limitations: The specific limitations or challenges are not explicitly stated.

4. Pheromone Potential Field Model (Herianto et al., 2007):

Objective: Proposing an algorithm to establish a potential field using an artificial pheromone system for autonomous navigation in shopping cart robotics.

Methodology: Cost-effective data carriers with a rewritable pheromone potential field, involving reading and writing by autonomous robots.

Results: Holds promise for application in a transportation network system, contributing insights to autonomous navigation.

Limitations: The study lacks specific details on practical implementation and real-world testing.

Autonomous Robots Overview:

Definition: Robots designed to operate in their environment without constant human intervention.

Features: Possess sophisticated features for understanding and interacting with the environment.

Applications: Extensive applications in manufacturing, agriculture, healthcare, logistics, and space exploration.

RFID Technology Overview:

Definition: Radio Frequency Identification – a wireless system with readers and tags for remote reading of identity information.

Features: Offers advantages like non-line-of-sight identification and support for additional data points.

Applications: Tracking and monitoring with capabilities surpassing traditional bar-code technology.

Related Works:

Wheeled Mobile Robots: WMRs gain popularity for applications in surveillance, transportation, inspection, and exploration.

Robot Kinematics: Analysing robot arrangement and geometric characteristics for understanding trajectories.

Development of Human Following Robots: Integration of RFID technology for wireless communication and remote identity reading.

The development of the autonomous shopping cart involves a multi-faceted approach, combining sensor technologies, control algorithms, and navigation strategies to achieve autonomous movement, obstacle avoidance, and potential field-based navigation. Specific challenges and detailed real-world implementation aspects are not extensively discussed in the provided information.

In the pursuit of designing and developing an autonomous shopping cart using RFID/NFC communication and gyroscope integration, it is essential to understand the existing body of knowledge and research in related fields. The literature review below provides an overview of relevant technologies and concepts that contribute to the feasibility and advancement of this project.

1. RFID/NFC Communication: RFID (Radio-Frequency Identification) and NFC (Near Field Communication) are wireless communication technologies that enable the identification and tracking of objects through electromagnetic fields. In retail environments, RFID/NFC tags are commonly used to label products for inventory management and tracking. These tags store unique identifiers that can be read by RFID/NFC readers, allowing for real-time identification and monitoring of items. The application of RFID/NFC technology to an autonomous shopping cart provides a means for item tracking and user identification, forming the foundation for the cart's autonomous behaviour.
2. Gyroscope Integration: Gyroscopes are sensors that measure angular velocity and provide information about the orientation and rotation of an object. In robotics, gyroscopes are crucial for maintaining stability and accurate navigation. Integrating a gyroscope into the autonomous shopping cart aids in controlling its movement, especially when following a user or navigating around obstacles. By analysing angular changes, the cart can adjust its path and orientation, ensuring smooth and stable navigation.
3. Autonomous Navigation: Autonomous navigation involves algorithms and sensors that allow a robot to move in an environment without human intervention. In the field of robotics, autonomous navigation has gained significant attention due to its applications in various domains, including logistics and service robotics. Algorithms such as simultaneous localization and mapping (SLAM) contribute to the creation of maps and the localization of the cart within its environment. Path planning algorithms guide the cart's movements, considering obstacles and desired destinations.
4. Obstacle Avoidance: Obstacle avoidance is a critical aspect of autonomous navigation. Research in this area has yielded various techniques, including reactive approaches based on sensor feedback and proactive path planning strategies. These techniques aim to ensure safe navigation by detecting obstacles and determining optimal paths to avoid collisions.
5. User Following: User following is a concept commonly seen in service robotics, where a robot tracks and follows a user while maintaining a safe distance. This behaviour involves sensor feedback, control algorithms, and user tracking methods. Research has explored different methods, including vision-based tracking and sensor-based tracking, to achieve accurate and responsive user following behaviour.

**CHAPTER THREE**

**METHODOLOGY**

**Chapter 3: Methodology**

In this chapter, we outline the methodology employed in the development and implementation of the autonomous shopping cart system. The methodology encompasses the key steps and processes undertaken to achieve the objectives of creating a robust and efficient autonomous shopping cart with the simplest possible path planning and a human-following algorithm.

3.1 System Architecture

To guarantee effective communication and integration amongst its components, the autonomous shopping cart system is built with a modular architecture. The main parts include an infrared sensor for user tracking, two ultrasonic sensors for obstacle avoidance, RFID technology for user identification, an ESP32 microcontroller unit (MCU) that acts as the system's brain, and DC motors for cart movement. Real-time data sharing between sensors and the MCU is emphasised in the architecture to enable smooth decision-making for the best possible navigation.

3.2 Hardware Setup

This section details the hardware components utilized in the construction of the autonomous shopping cart. It includes a comprehensive overview of the selected sensors, actuators, and microcontroller units. Special attention is given to the selection criteria for each component, ensuring they meet the specific requirements of the project.

3.2.1 ESP32 Microcontroller

The ESP32 MCU is selected for its versatility and computational capabilities. This section details the specific model chosen, its key features, and how it interfaces with other hardware components.

3.2.2 Ultrasonic Sensors

Two ultrasonic sensors are integrated into the system for obstacle avoidance. This subsection outlines the selection criteria, placement, and wiring of these sensors to ensure comprehensive coverage for detecting obstacles in the cart's path.

3.2.3 RFID Technology

RFID technology is employed for user identification. The methodology explains the type of RFID tags used, their placement on the user or items, and the mechanism for RFID tag reading by the ESP32 MCU.

3.2.4 Infrared Sensor

An infrared sensor is utilized for uniquely following the user. This part describes the infrared sensor's specifications, positioning, and the logic behind its use in tracking the user's movements.

3.2.5 DC Motors

DC motors are responsible for the cart's movement. This section provides details on the type of DC motors chosen, their power requirements, and the mechanical setup for translating electrical signals into cart motion.

3.2.6 Arduino IDE

The Arduino IDE is the chosen development environment for programming the ESP32 MCU. Here, we discuss the rationale behind choosing Arduino IDE, its compatibility with ESP32, and the benefits it offers for the development process.

## 3.3 Software Development

The software development process involves the creation and implementation of algorithms for path planning and human following. This section discusses the programming languages, development environments, and libraries used in the software development. Additionally, it outlines the logic and flow of the implemented algorithms.

### 3.3.1 Path Planning Algorithm

We detail the path planning algorithm chosen for the autonomous shopping cart. This may involve a straightforward algorithm suitable for the project's scope, considering factors such as simplicity and efficiency.

### 3.3.2 Human Following Algorithm

The human-following algorithm is crucial for ensuring the cart moves in tandem with the user. This section elaborates on the logic behind the chosen human-following algorithm, taking into account user detection, tracking, and cart movement coordination.

## 3.4 Integration

Integration involves combining the hardware and software components into a functional system. This section discusses the challenges encountered during integration and the strategies employed to address them. It also explores the testing procedures implemented to verify the seamless operation of the entire system.

## 3.5 Testing and Validation

To ensure the reliability and performance of the autonomous shopping cart, rigorous testing procedures are undertaken. This section outlines the testing scenarios, methodologies, and criteria used to validate both the path planning and human-following functionalities.

## 3.6 Ethical Considerations

The development of autonomous systems raises ethical considerations. This section addresses potential ethical implications related to user safety, privacy, and the responsible use of technology. Strategies to mitigate ethical concerns are also discussed.

## 3.7 Data Collection

In the process of testing and validation, relevant data are collected to evaluate the performance of the system. This section outlines the types of data collected, the methods employed, and the significance of the collected data in assessing the autonomous shopping cart's functionality.

## 3.8 Limitations

Every project has its limitations. This section provides a candid discussion of the constraints faced during the development of the autonomous shopping cart, including technical limitations, environmental constraints, and other factors that may impact the system's performance.

## 3.9 Summary

This chapter concludes with a summary of the methodology, highlighting key steps, challenges, and considerations throughout the development of the autonomous shopping cart system. The methodology provides a foundation for the subsequent chapters, where the results and findings of the project will be discussed. - Conduct thorough testing in various store environments to evaluate the performance of the path planning and human-following algorithms. Iterate on the design based on real-world testing and user feedback.

11. \*\*Regulatory Compliance:\*\*

- Ensure compliance with relevant regulations and safety standards for autonomous systems operating in public spaces, addressing any legal or safety considerations associated with the project.

12. \*\*Cost-Effectiveness:\*\*

- Consider the cost implications of the system components, sensors, and algorithms to ensure the project remains economically viable for potential deployment in retail environments.

By addressing these key aspects, the development of an autonomous shopping cart using RFID with path planning and human-following capabilities can be well-rounded and effective. Each aspect contributes to the overall functionality, safety, and user experience of the autonomous shopping cart system.