Design and Development of an Automated Guided Vehicle (AGV) for Store and Warehouse Automation

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Abstract—The development of Automated Guided Vehicles (AGVs) has revolutionized material handling in industrial and commercial settings. This project focuses on designing, devel-oping, and testing a prototype AGV for store and warehouse automation. The AGV utilizes an ESP32 microcontroller, infrared (IR) sensors for line-following, and an ultrasonic sensor for obstacle detection. The vehicle is designed to follow a fixed path marked by a black line on the floor while avoiding obstacles in real-time. Built using cost-effective components, this prototype serves as a scalable and adaptable solution for educational and industrial applications. The system's performance was validated through a series of controlled tests, demonstrating successful navigation, obstacle avoidance, and payload transport capabil-ities. The project aims to address the limitations of manual material handling, such as inefficiency, safety risks, and high labor costs, offering a reliable and cost-effective alternative for indoor logistics. Future enhancements could include dynamic navigation, wireless communication, and advanced control al-gorithms to further optimize the AGV's performance in more complex environments.

Index Terms—Automated Guided Vehicle (AGV), ESP32, Line Following, Obstacle Detection, Ultrasonic Sensor, Warehouse Automation, Robotics

I. Introduction

A. Overview of Automation in Industries

In the modern industrial landscape, automation has become a cornerstone of operational success across various sectors. Automation leverages cutting-edge technologies, including robotics, artificial intelligence, and Internet of Things (IoT), to reduce human intervention in repetitive, time-consuming tasks. One of the most impactful applications of automation has been in material handling systems, particularly within logistics, manufacturing, and retail industries.

Material handling, a critical function in most industries, involves the movement, protection, storage, and control of goods and materials throughout the manufacturing process, from production to distribution. Traditionally, this process has relied heavily on human labor, which, while efficient in certain contexts, is prone to issues such as human error, fatigue, and inefficiency. These factors can lead to delays, increased labor costs, and safety risks.

B. The Evolution and Importance of Automated Guided Vehi-cles (AGVs) Among the various automation solutions,Automated Guided Vehicles (AGVs) stand out as one of the most transformative echnologies in modern logistics. An AGV is a mobile robot that uses various technologies to follow predetermined paths, typically through sensors or magnetic strips, without the need for a human driver.

The AGV concept was first introduced in the 1950s, where basic vehicles followed simple guidance systems such as magnetic tape or wired tracks. Over the decades, AGVs have evolved to incorporate a variety of advanced navigation tech-nologies, such as infrared (IR) sensors, ultrasonic sensors, and even vision-based systems. These advancements have greatly increased the flexibility and intelligence of AGVs, allowing them to function in dynamic environments without fixed paths. In logistics and warehousing, AGVs offer significant advan-tages over manual material handling. They can operate 24/7, reducing labor costs and enhancing productivity. AGVs are also capable of reducing the risk of workplace accidents, as they eliminate human involvement in hazardous or repetitive tasks, improving both efficiency and safety.

C. Challenges in Traditional Store and Warehouse Manage-ment

While the benefits of AGVs are clear, traditional mate-rial handling methods still dominate many warehouses, retail stores, and manufacturing facilities. These methods, which often rely on forklifts, conveyors, or human workers, come with a set of inherent challenges:

Labor Costs: Repetitive tasks, such as moving goods across a warehouse floor, are typically performed by human workers, contributing to high labor costs. Addi-tionally, these tasks require continuous staffing, which is both costly and inefficient.

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Inefficiency in Material Transfer: Manual material transfer is often slow and prone to delays, especially dur-ing peak hours or high-demand periods. This inefficiency can disrupt operations and lead to missed deadlines.

Safety Risks: Traditional material handling involves significant safety risks. Forklifts and pallet jacks, for example, are common sources of accidents in warehouses, often leading to injuries or even fatalities.

Inconsistent Operations: Human labor is subject to variability. Workers can experience fatigue, resulting in reduced efficiency and increased chances of errors in material handling.

These issues underscore the need for a more reliable, cost-effective, and safe solution. Automation, through the implementation of AGVs, can address these challenges by automating the material handling process, reducing human involvement, and increasing operational efficiency.

D. The Role of AGVs in Modern Logistics and Store Manage-ment

The role of AGVs in modern logistics is expanding, with their use becoming more prevalent across various sectors. AGVs are particularly useful in environments where goods need to be transported over short distances, such as ware-houses, retail stores, hospitals, and manufacturing plants. By automating tasks like moving goods from one location to another, AGVs help streamline operations and improve overall efficiency.

The primary benefits of using AGVs in store and warehouse management include:

Enhanced Productivity: AGVs can work around the clock without breaks, thus enhancing productivity and throughput. They can transport goods faster than human workers, especially during peak hours.

Safety Improvements: AGVs are equipped with sensors to detect obstacles and avoid collisions. This significantly reduces the risk of workplace accidents that are common when human workers operate forklifts or manual trans-port vehicles.

Cost Reduction: By automating material handling, AGVs reduce the need for human labor, leading to substantial savings in labor costs. Additionally, AGVs can minimize errors that lead to costly delays or product damage.

Scalability and Flexibility: Modern AGVs are highly scalable and can be integrated with existing warehouse management systems (WMS) to accommodate various material handling needs. They can adapt to dynamic environments and are capable of being customized for different tasks.

Thus, AGVs are a key enabler of Industry 4.0, the fourth industrial revolution characterized by smart factories, IoT, and advanced automation. By incorporating AGVs into material handling processes, companies can not only optimize work-flows but also improve safety, reliability, and efficiency in logistics operations.

II. Literature Review

The use of Automated Guided Vehicles (AGVs) in industrial automation has gained significant attention over the past few decades. AGVs have evolved from basic mechanical devices to sophisticated robots capable of performing complex tasks autonomously. This section provides a comprehensive review of the historical development of AGVs, their navigation tech-nologies, and applications in various industries, highlighting key research studies.

A. Historical Development of AGVs

The concept of AGVs originated in the 1950s, with the first systems designed to automate material handling in factories. These early AGVs used simple mechanical guidance systems, such as magnetic strips embedded in the floor, to direct the ve-hicle along predetermined paths. Although these systems were effective for basic tasks, they were limited in functionality and could only operate in highly controlled environments [1].

The real breakthrough in AGV technology came in the 1980s when microprocessors and sensors were integrated into AGVs, allowing for autonomous operation. The addition of sensors such as infrared (IR) and ultrasonic sensors enabled AGVs to detect obstacles and adapt to their environment, making them more versatile. Zhiwei et al. (2021) highlighted that the integration of microcontrollers and wireless communi-cation technology has dramatically expanded the capabilities of AGVs, enabling them to operate in more dynamic and unstructured environments, such as warehouses and hospitals [1].

B. Types of AGVs and Navigation Technologies

AGVs can be classified into different types based on the navigation technology they use. The most common types in-clude line-following AGVs, vision-based AGVs, laser-guided AGVs, and RFID-based AGVs. Each of these technologies offers unique advantages and is suitable for different applica-tions.

1) Line-Following AGVs: Line-following AGVs are one of the simplest and most commonly used types of AGVs. These vehicles use IR sensors to detect a predefined path marked by lines on the floor. The vehicle follows the path by adjusting its speed and direction based on the sensor input. However, line-following AGVs are limited in their ability to operate in dynamic environments where the path may change or obstacles may appear unexpectedly. Zhang et al. (2019) evaluated the performance of line-following AGVs in con-trolled environments and found that while they are effective in static settings, they

struggle when faced with sudden changes in the environment [2].

2) Vision-Based AGVs: Vision-based AGVs use cameras and computer vision algorithms to navigate their environment. These AGVs do not require predefined paths, making them more flexible than line-following systems. Vision-based AGVs can detect obstacles, track objects, and recognize patterns in the environment. Li et al. (2020) showed that vision-based AGVs are highly effective in environments with variable layouts and can adapt to dynamic changes in the workspace [3].

3) Laser-Guided and LiDAR Navigation: Laser-guided AGVs and those equipped with LiDAR (Light Detection and Ranging) systems represent some of the most advanced tech-nologies in AGV navigation. LiDAR uses laser beams to map the surrounding environment in 2D or 3D, providing precise information about the location of obstacles and enabling the AGV to navigate safely through complex environments. Patel et al. (2018) demonstrated that LiDAR-based AGVs offer superior accuracy and reliability compared to IR and vision-based systems, especially in environments with many obstacles or complex layouts [4].

4) RFID-Based AGVs: RFID (Radio Frequency Identifi-cation) is a flexible navigation system that allows AGVs to follow a path marked by RFID tags embedded in the environment. RFID-based AGVs can easily reconfigure their paths by moving or adding new RFID tags. Wang et al. (2021) explored the use of RFID-based AGVs in warehouse automation and found that they are particularly useful in large-scale operations where the path needs to be adjusted frequently [5].

C. Applications of AGVs

AGVs have a wide range of applications in various in-dustries, from warehousing and logistics to healthcare and retail. The most significant applications include automated material handling, inventory management, and supply chain optimization.

1) Warehousing and Logistics: AGVs are widely used in warehouses and distribution centers to transport goods, optimize inventory management, and enhance operational ef-ficiency. Xu et al. (2017) conducted a study on the impact of AGVs in warehouses, highlighting their ability to reduce labor costs, increase throughput, and improve inventory accuracy. The study found that AGVs are particularly beneficial in envi-ronments where high throughput and efficiency are required, such as e-commerce fulfillment centers [6].

2) Healthcare Applications: In healthcare settings, AGVs are used to transport medical supplies, pharmaceuticals, linens, and other materials within hospitals. These AGVs help reduce the burden on hospital staff and ensure the timely and accurate delivery of materials. Huang et al. (2020) explored the role of AGVs in hospital logistics, noting that they can improve operational efficiency and reduce human error, particularly in high-pressure environments such as emergency rooms and operating theaters [7].

3) Retail Applications: In the retail industry, AGVs are being used to automate inventory management, restocking, and product delivery. Retailers use AGVs to transport goods from backroom storage areas to the sales floor, reducing labor costs and improving inventory management accuracy. Jain et al. (2021) investigated the adoption of AGVs in retail environments and concluded that AGVs are particularly useful in large-scale retail operations, such as supermarkets and e-commerce warehouses, where automation can significantly improve operational efficiency [8].

D. Challenges and Future Directions

Despite their numerous advantages, AGVs face several challenges. One of the primary challenges is improving their navigation accuracy in dynamic and unstructured environ-ments. Current AGVs may struggle in environments where obstacles move or where there is uncertainty in the layout of the workspace. Liu et al. (2019) discussed the challenges in AGV navigation and proposed solutions to improve the precision and reliability of navigation algorithms [9].

Energy efficiency is another challenge for AGVs, as many rely on rechargeable batteries that limit their operating time. Chen et al. (2018) investigated methods to optimize the energy consumption of AGVs, including power management algorithms and battery optimization techniques, to extend their operational time [10].

The future of AGVs lies in further enhancing their autonomy and adaptability. Advances in artificial intelligence (AI), ma-chine learning, and Internet of Things (IoT) technologies are expected to improve AGV decision-making and allow for more intelligent routing and obstacle avoidance. Integration with 5G technology may also enable real-time monitoring and remote control of AGVs, opening up new possibilities for AGV fleets and industrial automation.

III. Methodology: Materials and Methods

This section outlines the methodology followed to design, develop, and test the Automated Guided Vehicle (AGV) for store management. The AGV was designed to automate the material handling process, specifically in a controlled store or warehouse environment. The development process consisted of several stages, including requirement analysis, design and planning, component selection, assembly, programming, and testing. Each stage is detailed in the following subsections.

A. Requirement Analysis

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The first step in the development of the AGV was to analyze the requirements and define the primary goals of the project. The AGV was intended to operate in an indoor store or warehouse environment, with the following key functions:

- Autonomous navigation along a predefined path using infrared (IR) sensors.
- Obstacle detection and avoidance using ultrasonic sensors to prevent collisions.
- A cost-effective design using readily available compo-nents to facilitate prototyping and educational purposes.
- The ability to carry lightweight loads within a specified range.
- A compact and stable design to maneuver through aisles and small spaces.

In addition to these functional requirements, performance criteria were also established to guide the design process, including:

- Navigation Accuracy: The AGV must be able to follow a black line on a white surface with an accuracy of at least 90
- Obstacle Detection: The AGV should detect obstacles within a distance of 30 cm and stop to prevent collisions.
- Payload Capacity: The AGV should be able to carry up to 500 grams of payload.
- Power Efficiency: The AGV should operate for at least 30 minutes on a single charge.

B. Design and Planning

After establishing the requirements, the next step was to design the mechanical structure and the electronic system for the AGV. The mechanical design focused on creating a stable platform that could carry the necessary components while ensuring stability and maneuverability. The vehicle was designed to follow a path using IR sensors for line detection and ultrasonic sensors for obstacle avoidance.

1) Mechanical Design: The chassis of the AGV was con-structed using 30x30 mm aluminum sections, which provided a lightweight yet sturdy frame. The frame was designed to house the motors, wheels, and sensor components. The AGV was equipped with two driving wheels for propulsion and two passive wheels for stability. The wheels were driven by two DC motors, each connected to a gearbox for torque multiplication. The motors were selected based on their ability to provide adequate speed and torque to carry a lightweight payload.

2) Electronic Design: The AGV’s electronic system was built around an ESP32 microcontroller, which was selected for its processing power and built-in communication capabilities (Wi-Fi and Bluetooth). The ESP32 was responsible for pro-cessing sensor inputs, controlling the motors, and managing the AGV’s movement.

The key components used in the electronic system are:

- Infrared (IR) Sensors: Three IR sensors were used to detect the predefined path (black line on the floor). These sensors were positioned near the front of the AGV to ensure accurate path following.
- Ultrasonic Sensor: A single ultrasonic sensor was used for obstacle detection. This sensor measured the distance to obstacles in front of the AGV and triggered a stop command if an obstacle was detected within 30 cm.
- DC Motors and L298N Motor Driver: The two DC motors, each connected to the driving wheels, were controlled by the L298N motor driver, which allowed for bidirectional control and speed modulation using Pulse Width Modulation (PWM).
- 12V Rechargeable Battery: The AGV was powered by a 12V rechargeable battery, which provided sufficient power for the motors and sensors.

C. Component Selection

The components selected for this project were chosen based on their availability, cost-effectiveness, and ease of integration. A summary of the key components used is provided in Table I. These components were selected to keep the project within budget while ensuring functionality and scalability for future improvements.

D. Assembly

The assembly phase involved physically constructing the AGV according to the design specifications. The aluminum sections were cut to the desired lengths and joined using L-clamps and threaded rods to form the chassis. The DC motors were mounted onto the chassis, and the wheels were attached to the motor shafts. The IR sensors and ultrasonic sensor were mounted at strategic positions to ensure optimal detection of the path and obstacles.

The wiring of the components was done carefully to ensure secure and reliable connections. The ESP32 microcontroller was connected to the motor driver and sensors using jumper wires. The power distribution was managed through a voltage regulator to ensure stable operation of the system.

E. Programming

The programming of the AGV was done using the Arduino Integrated Development Environment (IDE). The code was written to achieve the following functionalities:

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Line Following: The IR sensors detect the black line on the white surface. Based on the sensor values, the AGV adjusts its motor speeds to follow the path.

TABLE I
SUMMARY OF COMPONENTS USED IN THE AGV

Component	Description
ESP32 Microcontroller	Central controller for sensor input and motor control.
IR Sensors (3x)	Used for line following.
Ultrasonic Sensor	Used for obstacle detection.
Johnson DC Motors (2x)	Provides propulsion for the AGV.
L298N Motor Driver	Controls motor speed and direction.
12V Rechargeable Battery	Powers the motors and sensors.
Aluminum Frame (30x30 mm)	Provides structure and stability for the AGV.

Component

ESP32 Microcontroller IR Sensors (3x) Ultrasonic Sensor Johnson DC Motors (2x) L298N Motor Driver

12V Rechargeable Battery Aluminum Frame (30x30 mm)

Description

Central controller for sensor input and motor control. Used for line following.

Used for obstacle detection. Provides propulsion for the AGV. Controls motor speed and direction. Powers the motors and sensors.

Provides structure and stability for the AGV.

Fig. 1. 3D Model of AGV

Obstacle Detection: The ultrasonic sensor continuously measures the distance to objects in front of the AGV. If an obstacle is detected within a 30 cm range, the AGV stops to prevent collisions.

Motor Control: The L298N motor driver receives PWM signals from the ESP32 to control the speed and direction of the motors.

The program also includes logic for fine-tuning sensor thresholds, motor speeds, and obstacle detection response times. It was tested and refined in an iterative process, adjust-ing sensor calibration and motor behavior based on feedback from the testing phase.

F. Testing and Calibration

Once the AGV was assembled and programmed, it under-went several rounds of testing to evaluate its performance. The primary objectives of the testing phase were:

Line Following Accuracy: The AGV was tested on a track with sharp turns and curves to evaluate its ability to stay on the path.

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Obstacle Detection: The AGV was tested with various obstacles placed in its path to evaluate the ultrasonic sensor's effectiveness in detecting and avoiding collisions.

Stability and Maneuverability: The AGV was tested on different surfaces to evaluate its stability and maneuver-ability under different conditions.

Calibration of the IR sensors was done by adjusting their threshold values to ensure that they could reliably detect the black line. The ultrasonic sensor was tested for accuracy by placing objects at various distances and verifying the AGV's response.

IV. Results and Discussion

This section presents the results obtained from the test-ing of the Automated Guided Vehicle (AGV), followed by a discussion on the system's performance. The results are compared with the initial objectives to evaluate the AGV's effectiveness in meeting the design goals. The primary aspects of testing focused on navigation accuracy, obstacle avoidance, and overall system stability.

A. Testing Setup

The AGV was tested in a controlled indoor environment designed to simulate a typical warehouse or store layout. The testing track consisted of:

Straight paths with sharp and gentle turns.

Obstacles placed at various distances along the AGV's path to test its obstacle detection and avoidance capabil-ities.

Different types of surfaces, including smooth tile floor-ing and carpeted areas, to test the AGV's stability and maneuverability.

The primary performance indicators were:

Line Following Accuracy: How well the AGV followed the predefined path.

Obstacle Detection and Avoidance: The ability of the AGV to detect obstacles and stop to avoid collisions.

Battery Life: The operational time of the AGV on a single charge under normal conditions.

Stability and Maneuverability: The ability of the AGV to maintain stable movement and effectively maneuver through obstacles and turns.

B. Line Following Performance

The AGV was tested on several track configurations, includ-ing both sharp and gentle curves, to assess its ability to follow the predefined path. The IR sensors, which were placed at the front of the AGV, detected the black line on a white surface. Based on the sensor input, the AGV adjusted the speed and direction of the motors to stay on track.

The results indicated that the AGV was able to follow the path with an accuracy of approximately 90

Key Findings:

The AGV successfully followed the track in most condi-tions, including sharp turns, with a small margin of error.

On wider curves and straight paths, the AGV maintained a near-perfect line-following accuracy.

Reducing the speed improved accuracy but sacrificed the overall speed of operation.

C. Obstacle Detection and Avoidance

The ultrasonic sensor was used to detect obstacles placed in front of the AGV. The AGV was programmed to stop and reverse upon detecting an object within a 30 cm range. During testing, various objects were placed in the AGV's path, including boxes, chairs, and other materials typically found in a store or warehouse environment.

The AGV was able to reliably detect obstacles and stop before colliding with them. In most cases, the ultrasonic sensor responded quickly to obstacles, and the AGV reversed or adjusted its direction to avoid collisions. The response time of the ultrasonic sensor was approximately 200 milliseconds, which was within the acceptable range.

Key Findings:

The AGV consistently detected obstacles within a 30 cm range and took appropriate action (stopping or reversing) to avoid collisions.

The obstacle detection system performed well on both small and larger objects.

The AGV sometimes had difficulty detecting obstacles at an angle or in environments with complex geometries (e.g., in tight corners).

D. Battery Life and Power Efficiency

The AGV was powered by a 12V rechargeable battery, and the battery life was tested under normal operating conditions. The AGV operated continuously for 30 minutes on a single charge, which met the initial power requirements.

However, battery performance was slightly affected by the load carried by the AGV and the frequency of turns. The AGV performed optimally when carrying a light load (up to 500 grams), but battery life decreased marginally when the vehicle carried heavier loads. In future iterations, a larger battery or a more energy-efficient motor could extend the operational time.

Key Findings:

The AGV operated for 30 minutes on a single charge under normal conditions.

Battery life decreased slightly with increased payload, suggesting that the motors and battery need to be op-timized for efficiency.

E. Stability and Maneuverability

The AGV was tested for stability and maneuverability on different surfaces, including smooth tile floors and low-pile carpet. The AGV performed well on smooth surfaces, maintaining stable movement and maneuvering easily through turns and obstacles.

However, on carpeted surfaces, the AGV experienced slight instability, with the wheels occasionally slipping. The DC motors provided sufficient torque for the AGV to move on carpet, but the traction of the wheels was not optimal for such surfaces.

Key Findings:

The AGV was stable and easily maneuvered on smooth surfaces, such as tile flooring.

On carpeted surfaces, the AGV experienced some insta-bility due to reduced traction.

Adding a more robust wheel design or adjusting the motor power could improve performance on carpets and uneven surfaces.

F. Overall System Performance

Overall, the AGV performed well in most aspects of its design and functionality. The line-following and obstacle de-tection systems met the design criteria, and the AGV was able to operate autonomously for 30 minutes with a light payload. The results indicate that the AGV is suitable for applications in controlled store environments where it can automate material handling tasks such as moving goods from one point to another.

The primary areas for improvement include:

Enhancing the line-following accuracy, particularly on sharp turns.

Improving the obstacle detection system’s response time and range.

Optimizing the power consumption for longer operational times, especially under heavier loads.

Enhancing the stability of the AGV on carpets and uneven surfaces.

G. Future Improvements

The results from the testing phase provide a clear roadmap for future improvements. Possible upgrades include:

Advanced Navigation: Implementing advanced naviga-tion algorithms, such as those based on LIDAR or vision, could improve the AGV’s ability to navigate dynamic environments and follow paths more accurately.

Energy Efficiency: Upgrading the power system with a more efficient motor and a higher capacity battery could increase the AGV’s operational time.

Enhanced Obstacle Detection: Incorporating additional sensors, such as infrared or cameras, could extend the obstacle detection range and improve performance in more complex environments.

Wireless Communication: Adding wireless communi-cation capabilities (e.g., Wi-Fi or Bluetooth) could allow for remote monitoring and control of the AGV.

V. Conclusion

This research focused on the design, development, and testing of an Automated Guided Vehicle (AGV) intended to automate material handling tasks in store management envi-ronments. The AGV was designed to follow a predefined path using infrared (IR) sensors for line detection and ultrasonic sensors for obstacle avoidance. Through a comprehensive development process involving requirement analysis, design, assembly, and programming, the AGV was successfully cre-ated and tested.

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The AGV demonstrated reliable line-following capabilities, maintaining a path accuracy of approximately 90

Despite these successes, there were a few challenges that were identified during the testing phase, including the AGV's stability on carpeted surfaces and slight inaccuracies in line-following during sharp turns. These issues highlight areas for improvement in future versions of the AGV, such as optimizing the sensor calibration, improving the motor system for better traction, and upgrading the battery for enhanced energy efficiency.

The findings from this project demonstrate that AGVs can be a viable solution for automating material handling in controlled environments such as stores and warehouses. The ability of AGVs to reduce human labor, increase efficiency, and improve safety makes them a valuable asset for logistics and supply chain operations.

Future work will focus on refining the AGV's design and performance, particularly in areas of energy efficiency, dynamic obstacle avoidance, and stability on various surfaces. Further advancements, including the integration of advanced navigation systems like LiDAR or computer vision, could en-hance the AGV's adaptability to more complex environments.

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