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# Design and development of guidance algorithm based on optical and QR image system in automated guided vehicle

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## Abstract

This study aims to improve the flexibility and adaptability of Automated Guided Vehicles (AGVs) by developing a guidance algorithm that combines line-following capability with QR code-based navigation. The AGV prototype is equipped with an infrared sensor array for detecting path lines, managed by a Proportional-Derivative (PD) control system to maintain alignment. A GM65 barcode reader is used to scan QR codes placed along the floor, which contain directional and positional data. A Raspberry Pi Zero handles processing and communication tasks, enabling wireless operation. The QR codes serve as auto-identifiers to help the AGV make real-time navigation decisions. Testing showed that the AGV could navigate various routes with an average success rate of 88.4%. The prototype reached an average speed of 0.142 m/s on straight paths, 0.082 m/s on curves with a 10 cm radius, and 1.05 m/s during 90-degree turns. The QR code reader successfully identified codes within an average of 1.62 seconds. Integrating optical sensors and QR code recognition into AGV navigation provides a more flexible and scalable solution compared to conventional methods, particularly in environments that often require changes in layout or routing. The research results are novel and introduce an innovative approach to Automated Guided Vehicle (AGV) navigation by integrating optical sensors and QR codes, offering a more flexible guidance system compared to conventional methods. This approach offers a cost-effective and adaptable alternative for use in industrial automation systems, such as warehouses or production facilities. Further improvements could include route optimization algorithms like Dijkstra's and enhanced control systems for better precision and reliability.

**Keywords:** Automated Guided Vehicle (AGV), guiding algorithm, line-following robot, QR code image.

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## 1. Introduction

Today's industries have integrated with the realms of robotics and automation, resulting in the production of precise and high-quality products that validate the adoption of new technologies [1]. The impact of automation on reducing workforce requirements and physical presence in the logistics sector necessitates proactive measures from stakeholders to enhance workforce skills [2]. As a vital component of this landscape, logistics presents a rich opportunity for the implementation of Industry 4.0 concepts, serving as a catalyst for advancements in both existing and emerging technologies within the industry [3].

Global business logistics play a pivotal role in adapting to evolving consumer demands in the context of globalization and widespread adaptation [4]. The logistics industry oversees the flow of resources, which is inherently complex due to the various modes of transportation and multiple stakeholders involved [5]. The risks of damage, delays, and theft during delivery can significantly affect the reliability of service, a key factor in enhancing customer satisfaction [4]. Critical logistical phases—such as handling, storage, assembly, picking, pallet setup, load model configuration, and transport coordination—are essential to the commercial success of modern logistics services and the profitability of investments made by managers [6]. Integrated Logistics 4.0 aims to create a smart environment by combining innovative technology, human resources, and organizational processes [6] to address inefficiencies and improve effectiveness through seamless, real-time information sharing [7]. Ensuring delivery reliability is vital for enhancing consumer service, as it helps mitigate potential risks, including damage, delays, and theft, all of which can adversely impact revenue and productivity [4]. According to Capua et al., one of the significant challenges in logistics pertains to product storage and picking, which accounts for over 70% of pickers' preparation time in various warehouse picking areas, including both shelved and stacked environments [6]. As a result, Logistics 4.0 provides technological implementations and solutions to address these challenges, leveraging a range of primary technologies such as the Internet of Things (IoT), Automated Vehicles (AV), Automated Guided Vehicles (AGV), Artificial Intelligence (AI), Virtual Reality (VR), Augmented Reality (AR), Big Data, data mining, blockchain, cloud computing, and 3D printing. In particular, Automated Guided Vehicles (AGVs) serve as an integral technology for enabling intelligent logistics within these interventions [8].

Autonomous Guided Vehicles (AGVs) are intelligent devices equipped with onboard processing capabilities that enable decentralized decision-making, including path planning and collision avoidance [9]; they are the future of logistics. The AGV is a robot goods transporting vehicle that transports goods [10]. The adoption of Automated Guided Vehicles (AGVs) within Automated Storage and Retrieval Systems (AS/RS) can automatically access and transport goods, eliminating the need for human labor [11]. However, most AGVs still use optical or magnetic guidance, which results in AGVs being inflexible regarding factory layout modifications, changes in production schedules, or changes in the production process flow [12], [13]. The performance and flexibility of the AGV were determined by the navigation system used [14], [15]. The navigation system points the vehicle towards the destination [16]. To accurately avoid obstacles and reach its target, AGV needs localization for autonomous navigation [17]. Localization, path planning, and reactive AGV scheduling are crucial for the effective and agile integration of AGVs in manufacturing environments [18]. In the development of research related to Autonomous Ground Vehicles (AGVs), QR Codes have been employed to mitigate the risk of collisions and enhance the efficiency of AGV routing [11], [19]. However, QR codes are avoided to avoid confusion in determining the primary localization in the AGV room using monocular KAREMA with ArUco [17]. Meanwhile, the magnetic navigation method is more popular, while QR navigation is less used [1]. This is supported by previous research that demonstrated the efficacy of RFID technology in ensuring 100% readability for container monitoring and identification. This capability comprehensively and accurately represents logistics operations [20]. However, a shortage of RFID guides requires close contact with an AGV and is sensitive to external interference [21]. Despite the challenges, implementing novel technology remains essential to enhance the operational efficiency of AGVs within logistics management. In this regard, the primary objective of this study is to propose an alternative technology solution by optimizing QR Codes with a guidance system for AGVs [22].

Several studies have been conducted to improve the navigation capabilities of the line-following robot method [23] by changing the configuration of infrared sensors [24], wireless sensor networks [25], GPS [26], and the algorithms [27]. In addition, AGV prototype studies utilize auto-ID RFID [28] as a substitute for guides as simulations to increase AGV flexibility [9]. However, a shortage of RFID guides requires close contact with an AGV and is sensitive to external interference [21]. AGV routing is a critical aspect of the logistics industry, and finding solutions to its challenges is urgent. However, most models and techniques from the AGV routing literature are not directly applicable to LGT routing because they usually assume that the AGVs must process a set of tasks with given origins and destinations [29]. AGV routing then consists of finding a suitable route for each AGV from their assigned origin to destination, possibly considering the given marked driving lanes and current traffic situation [30]. To overcome this problem, one Auto-ID can replace information storage with a compact QR code [31]. QR-Code is a matrix-shaped code that can be read using a camera [32]. In addition, the amount of data that can be stored by QR-Code is one potential that can be utilized in databases and inventory tracers and applied to IoT [16] and big data analysis [31]. The use of QR codes for AGV navigation offers several benefits, including compact data storage, easy readability, and potential applications in IoT and big data analysis, making it a promising solution for enhancing AGV flexibility and efficiency.

The quest for enhanced flexibility in Automated Guided Vehicles (AGVs) has spurred the investigation of innovative navigation methodologies. This research introduces a novel approach that harnesses optical guidance systems alongside Quick Response (QR) code technology to achieve this objective. Traditional AGV systems typically depend on fixed infrastructure or magnetic strips for navigation, which can restrict their adaptability to dynamic environments and necessitate significant investment in infrastructure. To address these limitations, this paper presents an algorithm aimed at enhancing AGV flexibility by integrating an infrared sensor array with a Proportional Derivative control system for line-following. Additionally, QR codes serve as auto-identification markers for path determination, with a GM65 module barcode reader interpreting these codes to guide the AGV's directional movement along its predefined route. The scientific contribution of this research lies in its innovative approach to AGV navigation, which combines optical sensors and QR codes to create a more flexible and adaptable guidance system. This modern methodology tackles the shortcomings of traditional AGV systems, offering a cost-effective and easily deployable solution suitable for a broad spectrum of industrial applications. By merging line-following technology with QR code-based path identification, the AGV is capable of navigating complex routes with greater autonomy, adjusting to changes in its environment without needing extensive modifications to existing infrastructure. This research not only advances the field of AGV technology but also lays the groundwork for future innovations in autonomous navigation systems, fostering more efficient and flexible material handling solutions across various industries. The proposed solution has the potential to significantly impact the field of AGV technology, offering a novel and effective approach to enhancing AGV flexibility and efficiency.

## 2. Method

*2.1. Overview*

This guidance system moves the AGV prototype to the desired location. The system architecture of the AGV guidance system is shown in Figure 1. The prototype was equipped with two types of sensors [27], an infrared sensor array and a barcode reader module. Infrared sensor is an array configuration of 11 infrared sensors array This sensor is used to detect line patterns on the floor and is mounted on the front of the AGV chassis [8].

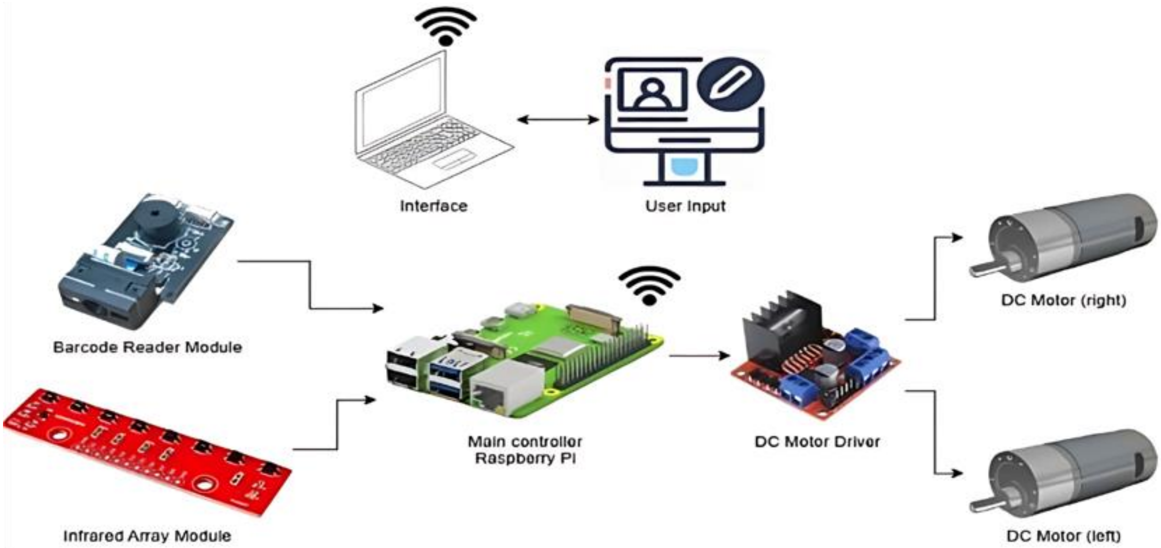


**Figure 1.**
System architecture of AGV prototype.

The barcode reader module is used to read the position and direction of the checkpoint information from a QR-Code image. The sensor is mounted on the right side of the AGV [32] (see Figure ).

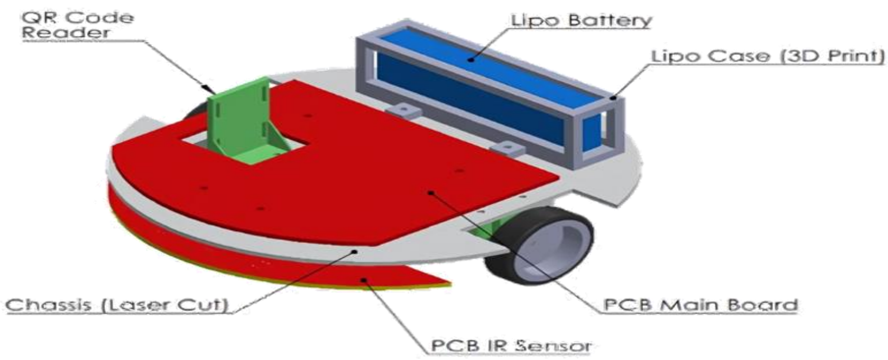


**Figure 2.**
Overview of AGV prototype

Raspberry Pi Zero is used in the prototype, which supports wireless connection and USB communication, and has a 27-pin I/O. To interface with users, Raspberry Pi is used as an access point; therefore, it does not require a cable connection to give commands to the AGV. The AGV prototype driver used a TB6612FNG driver to drive two DC motors [33].

*2.2. System Concept*

This system concept was used to describe the process flow and determine the components involved in the manufacturing process. This guidance system was designed with three main system elements, namely mechanical, electronics, and informatics. The mechanical device in the prototype consists of three parts: the chassis, motherboard, and IR sensor array. Figure  shows the overview of the AGV prototype. It consists of a circular chassis section with a diameter of 190 mm as a place for DC motors mounted with wheels, wheel castors, and LiPo batteries. The electrical devices in the AGV prototype were separated into two parts: the main board PCB and the IR sensor PCB. The components on the PCB Mainboard consist of a series of power regulators, a Raspberry Pi Zero, and a DC motor driver [13]. An IR sensor PCB is an infrared sensor arranged in an array, as shown in Figure 2.

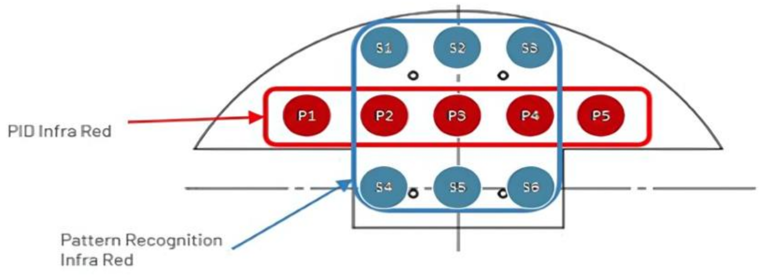


**Figure 2.**
Infrared Sensor Array Design

On the informatics side, the AGV prototype focuses on two aspects: the control of the DC motor motion and the reading of QR images to determine the direction of motion of the AGV prototype. A DC motor motion control was used to maintain the AGV prototype on the desired path. The sensors used to control the AGV remaining in the line are five infrared sensors arranged in parallel and use the Proportional Derivative (PD) control system method by calculating the feedback calculation quantitative error value, as it is shown in Table 1.

**Table 1.**
Quantitative Error Value

| **Infrared Error** | **Value** |
|---|---|
| 00001 | 8 |
| 00011 | 6 |
| 00010 | 4 |
| 00110 | 2 |
| 00100 | 0 |
| 01100 | -2 |
| 01000 | -4 |
| 11000 | -6 |
| 10000 | -8 |
| 00000 | Same as before |

Instructions for the AGV pathway determined by the user were manually sent via an interface application. After the destination data is sent, the AGV finds a path on the line and reads the auto-ID in the form of a QR code installed on the floor. The QR-Code image format consists of the checkpoint position, current AGV position, direction of the checkpoint, and status of the checkpoint. All illustration of the QR image format is shown in Figure 4.

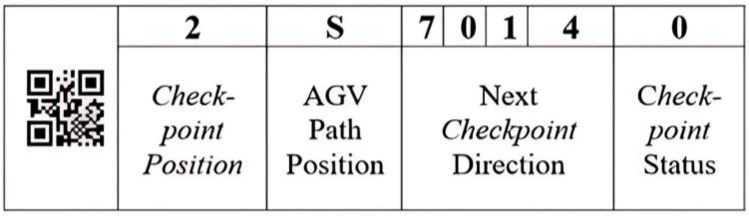


**Figure 4.**
QR Image data format

Figure 4 shows that the AGV is at Checkpoint 2, with node status (0) in path S (south). The checkpoints around checkpoint 2 were as follows: the right direction was checkpoint 7, the front direction was the dead end (0), the left direction was check-point 1, and the back direction was checkpoint 4. The flow diagram in Figure 5 illustrates the position of the AVG at the checkpoint. The QR image data is split into several cell array data, and the 0th array is matched with the AGV destination.

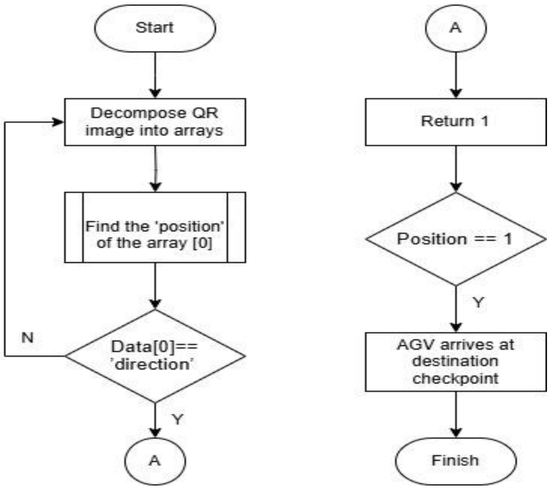


**Figure 5.**
Position checking flowchart.

The determination of the direction to be taken by the AGV is illustrated in the flow chart in Figure 6. The QR image that is read is split into several list arrays and matched using the for-loop function to assign several directions. Directional numbers ranging from 1 to 4 each have the meaning of movement to the right, front, left and back consecutively.

In an automated system designed for the control of autonomous guided vehicles (AGVs), the process commences with the critical step of decomposing a QR code image into arrays. This initial step is essential, as it extracts the information embedded within the QR code, which will subsequently inform decision-making. Following the decomposition of the QR code, the system seeks to identify the position of the first element within the array. This step is pivotal, as it determines the direction the AGV should pursue. The system then evaluates whether the value of this first element is 'direction.' If this condition is met, the process continues; if not, the system may revert to the initial step or undertake an alternative action.

Upon confirming that the value is indeed 'direction,' the system returns a value of 1, signifying that the direction has been accurately identified. The next step involves checking whether the current position equals 1. This verification is crucial to ensure that the AGV has successfully reached its intended destination. If the position is confirmed to be 1, the AGV proceeds on its designated path and ultimately arrives at the destination checkpoint. Once all steps and conditions have been satisfied, the process concludes, indicating that the AGV has effectively and accurately achieved its objective.

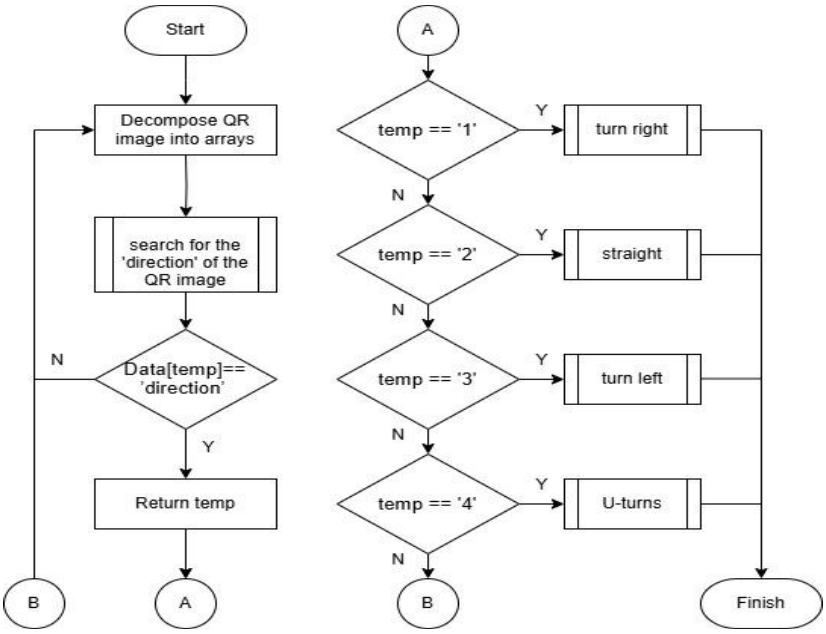


**Figure 6.**
Motion determination flowchart.

In an automated navigation system utilizing QR code technology, the process begins with the essential step of decomposing a QR code image into arrays. This decomposition is crucial as it allows the system to extract relevant information that will guide the vehicle's movements. Once the QR code has been decomposed, the system searches for the 'direction' indicated by the QR image. This involves checking the value of a variable, referred to as `temp`, which will determine the appropriate action for the vehicle.

The first decision point evaluates whether the value of `temp` is equal to '1.' If this condition is met, the vehicle is instructed to turn right. If not, the process continues to the next evaluation. The subsequent check assesses whether `temp` equals '2.' If this condition is satisfied, the vehicle will proceed straight. If not, the system moves on to the next decision point. The next evaluation checks if `temp` is equal to '3.' If this condition holds true, the vehicle is directed to turn left. If not, the system then checks if `temp` equals '4.' If this condition is met, the vehicle will execute a U-turn. If none of these conditions are satisfied, the process may revert to an earlier step. Once the appropriate action has been determined, the system returns the value of `temp`, indicating the direction to be taken. The process concludes when the vehicle has successfully executed the required maneuver, marking the end of the navigation task.

*2.3. Path Scenario*

Autonomous vehicle navigation and material transportation within a facility are made possible by AGV (Automated Guided Vehicle) guidance systems. These systems use a variety of technologies, including as lasers, optical vision, and physical markers like wires or magnetic strips, to either direct the AGV along a predetermined path or enable more flexible, dynamic navigation.

Concerning guidance types, there are several types to guide the Automated Guided Vehicle, i.e., fixed path system and free range or dynamic system. A fixed path system pertains to machinery that operates along a set, predetermined course or track. This system is defined by its restricted mobility and dependence on a fixed framework, guaranteeing reliable movement and accurate control. The dynamic path system is a method for determining the optimal path for a moving object (such as a car or robot) in an uncertain or ever-changing environment. Dynamic path planning continuously recalculates the course as new information, such as moving obstacles or changing conditions, becomes available, in contrast to static path planning, which determines the way in advance using a known map. This enables the item to adjust to unforeseen circumstances and maintain a collision-free path.

The developed system in this research uses fix-path system. If fix-path system there some guidance element is used to guide the Automated Guided Vehicle, i.e. Inductive Guidance or Wire guidance, magnetic tape, line and rails.

Inductive guidance is a method utilized to steer automated vehicles, especially in industrial environments such as warehouses, by employing a wire embedded in the floor that generates a magnetic field for the vehicle to follow. This system provides exact and reliable positioning for vehicles, even in challenging conditions. Inductive Wire Navigation. Is a reliable and precise active navigation technique for both manual and automatic vehicles. Attributes consist of accurate electronics and an antenna that pinpoint the precise location of the signal center, assessing height, side, and angle from the embedded wire transmitting the frequency.

Magnetic tape is among the earliest methods for storing electronic data. Although tape has mostly been replaced as a main and backup storage option, it is still ideal for archiving due to its large capacity, affordability, and long lifespan. The magnetic end facilitates solo measuring and makes this tape the perfect measuring instrument for those dealing with metals. The strong magnetic tip securely keeps the tape measure positioned on iron and steel surfaces.

Lines are essential visual components utilized to form shapes, structures, and express ideas. They can outline boundaries, recommend motion, and even stir feelings. Various line types, such as vertical, horizontal, diagonal, and curved, are linked to different emotions and moods. Essentially, the significance of lines in painting is complex and may be understood in various ways based on the context and the intentions of the artist. By grasping the typical connections and the way lines are employed to craft visual features, observers can enhance their appreciation of the artist's intention and the overall effect of the piece.

Rails refer to a mode of transport that runs on train tracks and is governed by centralized management for its scheduling and safety. The key feature of rail transport is that it necessitates centralized management. In contrast to road vehicles, trains cannot leave at their own discretion; an authority must provide clearance for their passage. Trains need to be meticulously planned and managed in their operations, ensuring both safety and optimal resource utilization. The most unfavorable situation is “lockup,” in which a network becomes congested with trains, no additional movements can occur, and the sole remedy is to reverse certain trains to clear the track.

Infrared array sensors used in AGV prototypes are replicas of line-following or magnetic-following sensors that have industry standards. This sensor requires a black ribbon band with bright base floor color. Paths with multiple intersections were created, as shown in Figure 7.

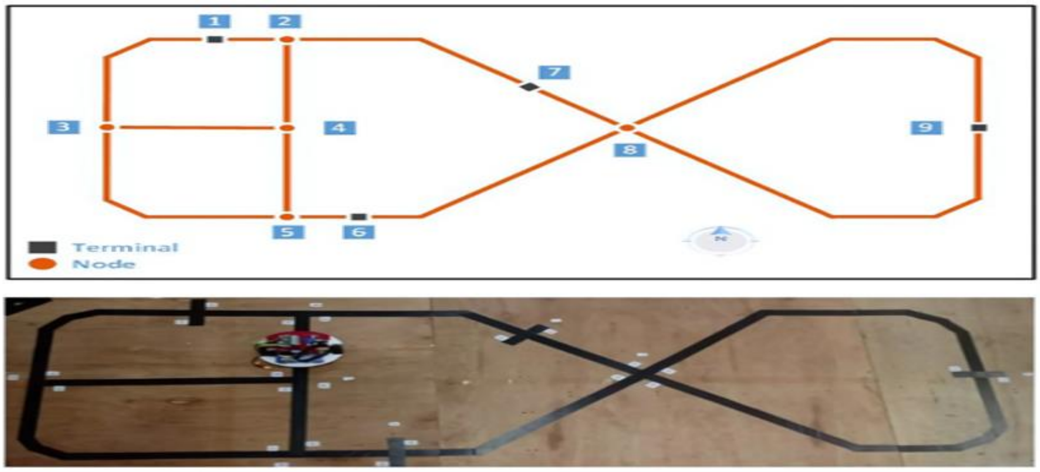


**Figure 7.**
Overview of AGV prototype pathway test.

There are two types of checkpoints in this figure: terminals and nodes. A checkpoint terminal is a representation of a station in an actual factory layout, whereas a checkpoint node is an intersection point. In addition, each direction on the checkpoint is marked with a QR image to the right, and the installation is distinguished according to the position of the checkpoint relative to the compass.

## 3. Results and Discussion

### *3.1. PD Control Response Time Test*

Figure 3 shows that the AGV can maintain the movement in accordance with the path marked by the error at a fixed value of 0.

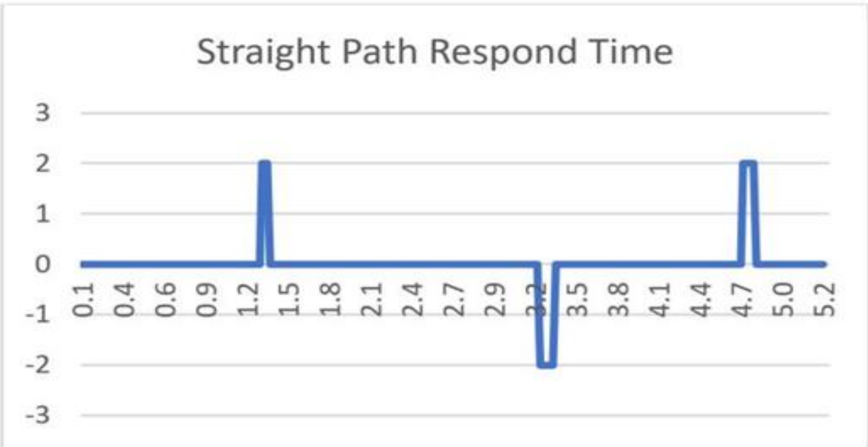


**Figure 3.**
Straight path response time.

In Figure 4, when the AGV turns (2.27 sec), it has difficulty maintaining its position to return to setpoint 0 with a marked value error that persists at value -2 for several seconds, until the second to 3.8 value returns to setpoint.

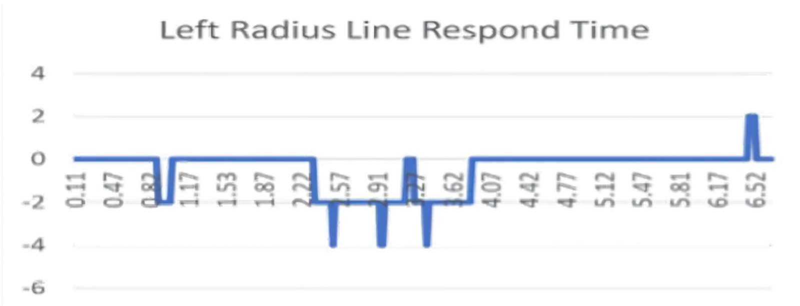


**Figure 4.**
Left radius line response time.

In Figure 5, when the AGV turns (3.7 sec), the AGV also has difficulty maintaining its position to return to setpoint 0 with a marked value error that persists at 2, until 4.2 seconds the value error rises to 4 so that the PD controller can compensate for errors back to the setpoint [34].

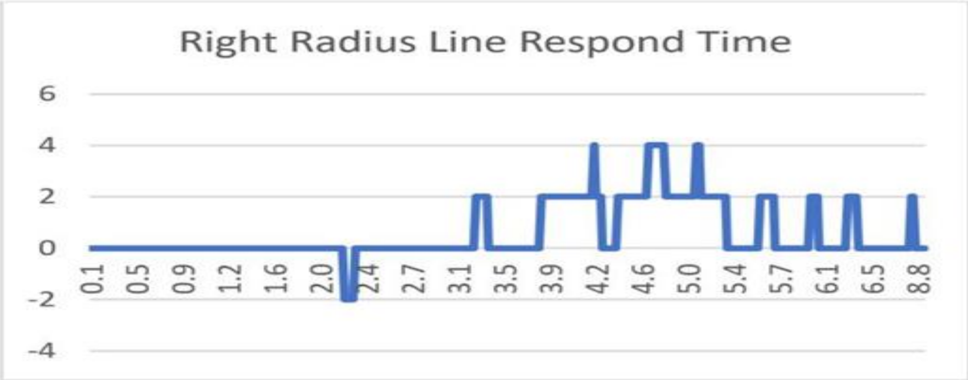


**Figure 5.**
Right radius line response time.

*3.2. AGV Prototype Motion Speed Test*

This test was performed to determine the response of the PD controller using empirical tuning to drive the two DC motors. This test used the test path shown in Figure 7. The speed calculation is based on the average speed from the initial checkpoint to the destination checkpoint and is tested 10 times.

*3.3. Integrated Guidance System Test*

Integrated guidance system testing is a combined testing system that ensures that several linked components, modules, or systems operate seamlessly together as a unit. It guarantees that every component of a system, such as software, hardware, and their interactions, operates as expected. ITS is an essential stage in software development and is also applied in other areas such as construction and data centers to guarantee correct system operation and compatibility.

An Integrated Test System is an essential element of the software testing process, where a complete system is evaluated to confirm alignment among various components. In simple terms, system integration testing (SIT) encompasses the comprehensive evaluation of an entire system that comprises various subsystems, components, or elements.

An Integrated Test System performed on a fully assembled mechanical, electrical, plumbing, and/or fire system to verify that it, its equipment, controls, components, and subcomponents function in accordance with the design specifications under various conditions, including malfunctions.

Integrated Test System encompasses the comprehensive testing of a full system composed of various subsystem components or elements. The system being tested could consist of electromechanical or computer hardware, software, or hardware with integrated software, or hardware/software involving human-in-the-loop evaluations. The Integrated Test System is usually conducted on a more extensive integrated assembly of components and subassemblies that have already been through subsystem testing.

This test was carried out to determine the ability of the AGV prototypes to move in industrial scenarios using all sensors and actuators simultaneously. The test was conducted with five different routes that passed five to six checkpoints, with five attempts each. Assessments are provided every time the AGV successfully reaches the checkpoint without interruption. If the AGV fails to reach the checkpoint, it is positioned at the checkpoint correctly without adding points. All the points were averaged and converted into percentages.

**Table 2.**
Result of AGV prototype motion speed test.

| Path | Turning Speed | Average Speed |
|---|---|---|
| Straight | - | 0.142 |
| Left Radius | 0.086 | 0.06 |
| Right Radius | 0.079 | 0.062 |
| T Left Intersection | 1.194 | 0.063 |
| T Right Intersection | 0.909 | 0.062 |

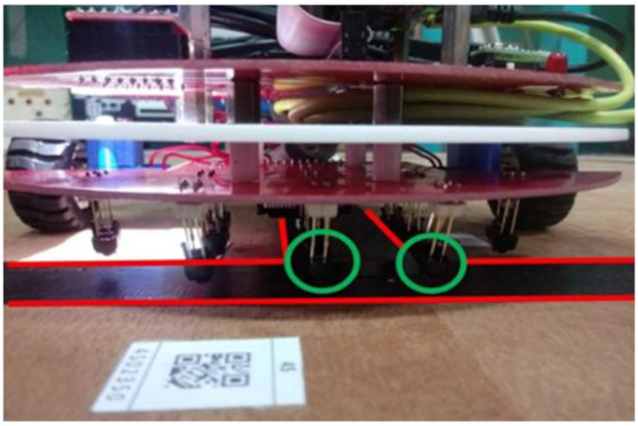

**Figure 6.**
Wrong position of AGV prototype.

Of the five routes tested, the AGV prototype guiding system could move according to the given instructions with an average success rate of 87%. This is due to the influence of the PD controller, which makes it difficult to keep the AGV sensor in the middle, so that the value is a Quantitative Error of 0 and makes the QR. The image is unreadable because the reading position is not right. The incorrect AGV prototype position is exemplified in Figure 6.

*3.4. Discussion*

The proposed method combines an infrared array sensor for line-following with a GM65 barcode reader module to interpret QR codes as directional markers. With this system, AGVs are not only capable of following predefined paths but can also interpret QR code instructions to determine their routes dynamically. Experimental results indicate that this approach achieves a navigation accuracy of 88.4%.

Similar approaches have been explored in prior research on QR-code-based robotic navigation. For instance, Jang et al. [35] discuss the utilization of vision sensors and color codes for AGV drive systems in their study, *Automated Guided Vehicle (AGV) Drive System Using Vision Sensors and Color Codes* [35]. Additionally, Sneha et al. [36] demonstrate the feasibility of QR-code-based indoor navigation for service robots in *Indoor Navigation System Based on QR Code for Service Robots* [36]. Moreover, Zhou et al. [37] present a study on integrating QR codes with WIFI technology for autonomous AGV navigation in *Implementation of QR Code and WIFI Technology in Autonomous Navigation System for AGV* [37]. Furthermore, this study employs a Proportional-Derivative (PD) Controller to ensure AGV movement stability along its trajectory. Experimental results indicate that the AGV moves at an average speed of 0.142 m/s on straight paths and 1.05 m/s when executing 90-degree turns. The GM65 barcode reader module also demonstrates high accuracy, with an average QR code reading time of 1.62 seconds.

## 4. Conclusion

The PD Control System can always keep the AGV on the black band path; however, the PD controller cannot compensate for errors returning to the setpoint if the time span of the error is sufficiently long. The average speed of the AGV was 0.142 m/sec on a straight road, with an average turning speed of 0.082 m/sec, a radius of 10 cm, and a turning speed at an angle of $90^{o}$ with an average AGV speed of 1.05 m/s. In addition, the GM65 module can accurately read QR images with an average time span of 1.62 seconds. The AGV prototype guiding system can move according to instructions given, with an average success rate of 88.4%, owing to the influence of PD controllers, which find it difficult to keep the AGV in the middle, resulting in missed QR readings.

**Table 3.**
Integrated guidance system test result.

| Route | Average Point | Percentage |
|---|---|---|
| 8-7-2-4-3 | 4.4 | 88% |
| 8-6-5-4-3 | 4.2 | 84% |
| 8-7-2-1-3-5 | 5.4 | 90% |
| 4-2-7-8-9 | 4.2 | 84% |
| 4-5-6-8-9 | 4.4 | 89% |
| Average | | 87% |

The following suggestions were made to develop and improve the system proposed in this thesis. 1) In the next study, PD controllers can be added to the integrator control to keep the AGV on track with an error value of 0; 2) In the following studies, it can be applied to larger AGV prototypes to carry large loads; 3) In the next study, Dijkstra’s algorithm can be added to a smarter AGV integration system.

This study introduces an innovative approach to Automated Guided Vehicle (AGV) navigation by integrating optical sensors and QR codes, offering a more flexible guidance system compared to conventional methods. Traditional AGVs predominantly rely on optical or magnetic navigation, which poses challenges when factory layouts or production routes change. To overcome this limitation, this research develops an infrared sensor and QR code-based system that enables AGVs to adaptively recognize pathways.

The primary advantage of this research lies in the adoption of QR codes as an alternative navigation method. Compared to RFID or magnetic track systems, which require specialized and often costly infrastructure, QR-code-based navigation provides enhanced flexibility and cost-effectiveness without compromising accuracy.

For future advancements, this study recommends integrating Dijkstra's algorithm for optimized route planning and refining the PD controller to enhance AGV stability in diverse environmental conditions. In conclusion, this research contributes to the evolution of AGVs toward greater flexibility, efficiency, and adaptability, addressing the challenges of modern industrial automation, particularly in logistics and manufacturing systems.

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