Smart AGV for Intelligent Navigation System

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Abstract

The present paper describes a Smart Autonomous Guided Vehicle (AGV) with a new Triple-Mode Navigation system and a specific mobile application interface created with Flutter. The AGV enables the flow of line following based on the IR sensors, manual control through the application, and automatic minimum path planning based on the A* algorithm. In all operating modes, the real-time autonomous obstacle avoidance is controlled by the ultrasonic sensors. The system indicates that an efficient navigation system and user interface are deployable on inexpensive embedded system that is mobile enabled. By the way of the fine results that were validated through experimental testing, the readers can understand that it can be used in smart healthcare, warehouses, and factory automation systems.

Keywords

Autonomous Guided Vehicle, AGV, Triple-Mode, Embedded System, IR Sensors, A* Algorithm, Shortest Path planning, Navigation, Flutter application, Obstacle avoidance, IoT based control.

I. INTRODUCTION

The autonomous Guided Vehicles (AGV) are a crucial part of the modern logistic and production systems, as well as in medical care and are most effective in enhancing the efficiency of human engagement in the material handling processes. The current trend of globalization towards Industry 4.0 has made AGV a major supplier in autonomous and intelligent production systems. Previously, AGVs were largely fixed to their locations, and could only work on physical tracks such as magnetic tape, or under-floor wire. These systems were notorious in being inflexible so that in the event of a warehouse layout change, or a new obstacle had been encountered, the AGV was basically useless, which could not work with the time-sensitive nature of a modern working environment.

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In order to overcome these constraints, recent studies have been directed at improving AGVs intelligence and task distribution. To illustrate, Xu et al. (2024) introduced a better genetic algorithm to allocate tasks in warehousing to deal with deformable loads, which emphasizes the necessity of AGVs to deal with the changing requirements of operations. Moreover,

Huang et al. (2024) proposed a system of coordination implemented with the 3D SLAM and MQTT protocols to enhance the interaction between AGVs through mobile mini- programs. In a similar vein, Chen et al. (2024) have established an effective cooperative path planner that takes into account spatiotemporal distance to prevent collision in workspaces with large numbers of vehicles.

Nevertheless, such developments have not prevented the utilization of numerous contemporary approaches using expensive technologies such as LiDAR and high-quality computer vision, which add significant economic and computation costs to the system. This study fills this gap by implementing an intelligent navigation of a Triple-Mode system (line-following, manual remote and automatic path planning) by designing a cost-effective Smart AGV. Combining an IR and ultrasonic sensor with a home built Bluetooth mobile app, the proposed system shows that it is possible to design flexible, reliable options of indoor navigation with low-cost embedded hardware.

II. MOTIVATION

The development of modern industries has predetermined the growing demand of the flexible, intelligent and affordable automation. Traditional material handling systems are still prone to manual process which is vulnerable to inefficiency and risk. Although AGVs can address these concerns, commercial systems currently available may use some of the latest technologies such as LiDAR or computer vision technologies that render the entire system cost-prohibitive to small and medium-sized industries [5], [6].

Moreover, most of the low-cost AGVs lack a high degree of adaption and do not move with pre-set paths. Such systems are prone to stopping, once there is a barrier and wait to be repaired by a human being, a fact that disrupts the working process [8]. This means that it requires an intelligent AGV system that can respond dynamically to the environmental changes [9].

The inspirations in this research work are to plan and implement a Smart AGV system, which integrates both hardware-level intelligence and software-based remote control and monitoring. The presented system employs infrared (IR) sensors to be able to follow the line accurately and ultrasonic sensors to avoid obstacles successfully. This system can be effortlessly changed to three types of navigation, guided, manual and autonomous short path planning with the A* algorithm [9].

One of the main innovations of the work is the use of a specially created Flutter-based mobile application allowing to operate a remote control and control in real time [7]. The app includes a secure authentication of logins, a dashboard that indicates the system status and battery levels, and a manual control panel that is operated using a joystick through Bluetooth [4].

Moreover, it gives an interface to create the autonomous navigating path- Starting as well as ending points - to enable efficient, modular and scalable indoor navigation [10].

III. PROPOSED METHODOLOGY

The proposed Smart AGV system is focused on providing efficient and interactive indoor navigation which is realized by integration of embedded hardware control and mobile-based software interface. The strategy helps to present three navigation paths namely Line Following, Remote Control (Manual), and Shortest Path Planning (Automatic) using real-time sense and Bluetooth communication [1], [2]. The control of AGVs and navigation are both hardware-based.

A. System Architecture

Its central processing unit is an Arduino Uno microcontroller board and the system architecture. The AGV consists of:

- Line-following infrared (IR) sensors.
- Algorithms logic to search the waypoints and manage the path navigation [9].
- Real time obstacle detection and avoidance ultrasonic sensors [3].
- The DC motors can be moved by an L293D motor driver module.
- A Bluetooth device (HC-05) to support wireless connection with the Android program [4].
- The software is driven by a Li-ion battery of 12 V.

B. Triple-Mode Navigation Logic

This logic manages all navigation logic that operates in triple mode. There are three basic modes of operation of the AGV:

- **Remote Control (Manual Mode):** This mode is controlled by the Bluetooth command of the joystick interface of the mobile application [7].
- **Line Following Mode:** AGV follows a defined line path with the help of IR sensor array [6].

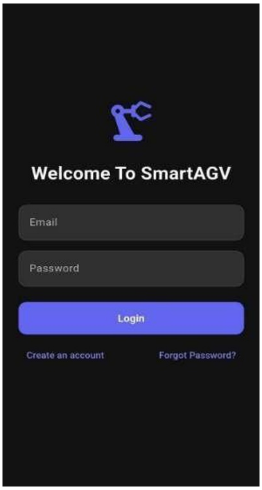
- **Shortest Path Planning Mode (Automatic Mode):** The system identifies the shortest path of the user- defined points through the mobile application [10].

C. Software Application Design

Mitigating the interactivity and control activities a personalized Android app was developed with the help of Flutter [7]. The application has a login screen, dashboard, manual control screen, and path planning screen. The application is compatible directly with the Arduino Bluetooth libraries [7].

1. Login Page:

System login is secured by authentication of the user through email and password. The user authentication process is handled through a secure interface, as shown in Fig. 1.



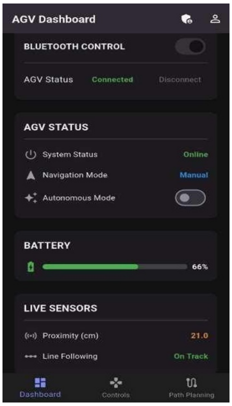
Welcome To SmartAGV

Fig 1. Login page

2. Dashboard Interface:

The dashboard contains the data regarding the working parameters such as the battery status, the presence of the Bluetooth connection, the current mode of navigation (manual/autonomous) and sensor status [7]. System parameters such as battery life and connectivity status are monitored via the dashboard illustrated in Fig. 2. The default parameters that are presented are:

- Battery Status: Current voltage level,
- Navigation Mode: manual (default),
- Bluetooth: Disconnected (default),
- Autonomous Navigation: OFF(default).



AGV Status Connected
System Status Online
Navigation Mode Manual
Autonomous Mode
66%
Proximity (cm) 21.0
Line Following On Track

Fig 2. Dashboard page

3. Manual Control Interface

Has a joystick type control pad which enables directional instructions, forward, backward, left, and right. The AGV reacts to every control signal and the transitions between the movements are controlled by PWM (Pulse Width Modulation) signals sent by the microcontroller [3]. Users can manually direct the vehicle using the joystick interface shown in Fig. 3.

Control Mode MANUAL
Bluetooth Disconnected
⚠ Turn on Bluetooth on Dashboard.

Fig 3. Manual Control Interface

4. Bluetooth Control Page

Enables users to search and match with Bluetooth devices within range. Once the AGV Bluetooth module (HC-05) has been selected, the app establishes a live control connection which allows two-way communication to control the AGV in motion, provide feedback and monitor the status of the system [4]. The interface for scanning and pairing with the HC-05 module is depicted in Fig. 4.

Path Planning Monitor

MAP & PATH CONTROLS

Grid Size: 5 x 5

Define Obstacles

Tap on grid cells to set Start/End points.

Selected Start
Not Set

Selected End
Not Set

Calculated Path (Steps)
Not available

Fig 4. Bluetooth Control Page

The mobile application was developed with Flutter because of its simplicity and because it is fully compatible with Arduino Bluetooth libraries.

D. Embedded Software Workflow

The onboard software is a programmable with the Arduino IDE based on Embedded C, and it manages sensor data acquisition, control logic to support multiple modes of navigation, obstacle avoidance decision-making, and Bluetooth communication [6]. The interaction between the power supply, sensing units, and actuation modules is outlined in the flow diagram in Fig. 5.

- Filtering and data acquisition of sensor data,
- Triple mode navigation control logic,
- A* algorithm Path planning and coordinate tracking [9],
- Avoidance of obstacles decision-making,
- Bluetooth communication processing of manual control commands, and Passing of status feedback to the mobile application [7].

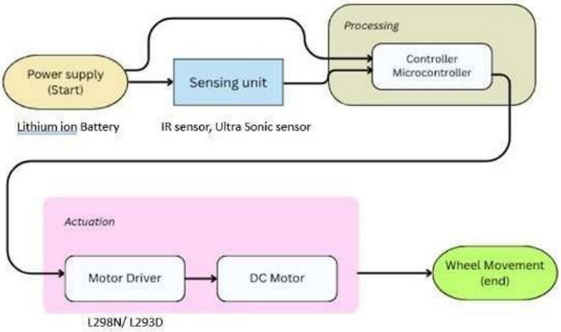


Fig 5. Flow Diagram

A workflow of the control algorithm is the following:

1. System booting and setting up of Bluetooth connection.
2. Mode (Manual or Autonomous).
3. Continuous acquisition of sensor data of IR and ultrasonic sensors.
4. Motor activation and path error correction decision-making.
5. Shortest path recalculation and updates [9], [10].
6. Status update to the mobile application dashboard in real time.

E. Advantages of the Proposed System

- **Low Cost and Scalability:** It has been built to be low cost and based on microcontrollers and low-cost sensors not requiring LiDAR or any sophisticated vision technology [5].
- **Real-Time Mobile Interaction:** Allows real-time control, observation and modes switching with the Android application [7], [10].
- **Trustworthy Navigation:** Dual mode access ensures the smooth functionality in both the structured and unstructured environments.
- **Administrative Accessibility:** Easy graphic interface requires no computer interaction or sophisticated programming.
- **IoT Compatibility:** The system design may be extended to include data logging in the cloud and remote fleet control [7].

IV. EXPERIMENTAL SETUP AND RESULTS

A. Hardware Implementation

An Arduino Uno microcontroller was used to come up with an experimental prototype. This prototype is a 3-wheel platform, but is fitted with two DC motors, which are driven by an L293D motor driver [4]. The prototype will have a set of two IR sensors at the front to detect a line as well as an ultrasonic sensor to detect obstacles [6]. The test was conducted on a smooth environment inside the building, which replicates that of a warehouse [8]. The physical arrangement of the microcontroller, sensors, and motors for the prototype is displayed in **Fig. 6** and Fig. 7.

[9].

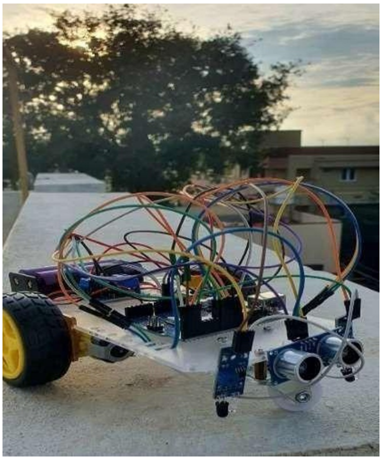


Fig 6. Hardware setup

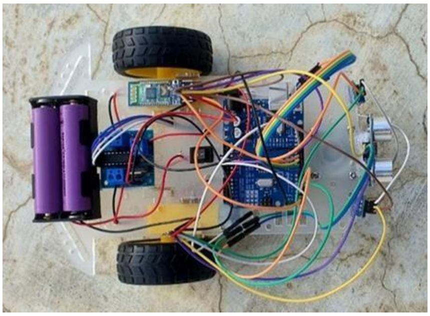


Fig 7. Lateral View

B. Software Flow

The AGV control algorithm was divided into a number of functional units:

1. **Initialization:** The system does the sensor calibration.
2. **Line Tracking:** The motor speed and the alignment of the AGV is controlled by the analog signal of the IR array read by the microcontroller [6].
3. **Obstacle Detection:** The ultrasonic sensor checks the way forward in case there are obstacles. In case a barrier is detected, the AGV halts and sets its route to find another path and then continues on the new path once it is clear [3].
4. **Shortest Path Planning:** The AGV recalculates its routing status and implements the path corrections according to the calculated coordinates of the A Star algorithm [5], [9].

5. **Completion:** AGV stops at the end of the last checkpoint and reports the task completion by using LEDs or a buzzer. Before physical testing, the vehicle's movement logic was validated using the simulation design shown in Fig. 8.

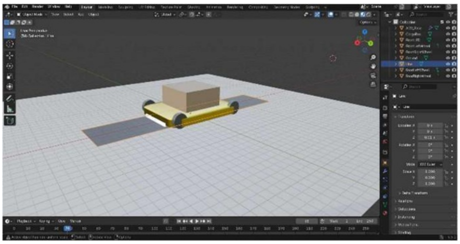


Fig 8. Simulation Design

C. Experimental Validation

The navigation system was experimentally tested to test the responsiveness and reliability of the system [7]. The test track was made up of a black line track to complete the line following tests and at random obstacles to complete obstacle avoidance tests.

Under Line Following Mode the AGV managed to follow the path with a mean of less than 2 cm of lateral deviation.

The system could sense and evade obstacles in all autonomous modes and resume its original course without any human intervention [7]. Shortest Path Planning Mode managed to move between the set points demonstrating the adequacy of the algorithm in a controlled setting [10]. The quantitative results for navigation accuracy and response times are summarized in TABLE 1.

D. Performance Metrics

TABLE 1. PERFORMANCE METRICS

Parameter	Test Condition	Result
Line-following accuracy	Indoor track (2 m radius)	97.3%
Obstacle detection range	10–40 cm	Reliable
Path Planning Accuracy	A* Algorithm Execution	98%
Power consumption	Average operational current:850 mA	Stable
Response time (mode switching)	< 0.5 s	Fast

All these performance indicators prove that the Smart AGV system can perform strong navigation, precise localization, and mode switching with minimal power usage and low cost.

The proposed system will provide similar robust navigation compared to the state-of-the-art AGV systems that are currently being developed using costly LiDAR or vision sensors at an extreme low cost [5], [10]. Triple-mode logic and A* algorithm-based path planning combine to bring the flexibility necessary to applications in small-scale proposals of smart manufacturing and small-scale robotics learning laboratories [2], [9]. Since the system is modular, it is possible to in future incorporate the use of IoT dashboards to monitor remotely [1], [7].

V. DISCUSSION

The results of the experiment confirm that the offered Triple Mode Smart AGV is characterized by high operational reliability under various navigation activities. In particular, the line following accuracy of 97.3% and 100% RFID recognition rate show that the control system is strong enough to rival high end industrial AGVs. Although the contemporary state-of-the art systems in many cases use the expensive LiDAR or computer vision sensors, our proposed system will provide a competitive navigation performance at a much lower hardware and computational cost.

As an example, Huang et al. (2024) and Chen et al. (2024) focus on complex multi-AGV coordination based on a spatiotemporal distance planning and SLAM. Conversely, our study is based on a Triple-Mode of flexibility (Line following, manual and shortest path) whereby as one can be instantly flexible to dynamic situations without necessarily having a large mapping infrastructure. Moreover, our cause and-effect solution to the usability shortcomings of low-priced embedded navigation systems is the incorporation of a specific mobile application that provides real-time battery and status information.

VI. FUTURE WORK

The project has shown how a Smart AGV with triple-mode navigation system, which integrates line-following, obstacle avoidance, and shortest path planning functions, can be developed [2], [9]. The suggested design is an effective application of IR and ultrasonic sensor using microcontroller based to enable a robust and flexible navigation inside a building [8]. The proposed system has demonstrated that intelligent motion control can be achieved by the use of cost effective and easily available components hence is more appropriate in small and medium scale industrial automation activities [6].

The result of the experiment has validated that the proposed AGV system can follow the path autonomously, real-time avoid obstacles, and transition modes between manual and autonomous mode fluidly [3], [8]. Such versatility of the proposed system implies that it can be used in material handling, warehouse transportation, and automated delivery systems [6]. Nevertheless, the given system also has certain drawbacks - primarily, its poor perception due to the use of IR and ultrasonic sensors. To improve the system performance and scalability further, it is proposed to make the following improvements:

1. Sensor Fusion:

Include a combination of different sensing technologies such as LIDAR, camera-based computer vision and IMU sensors along with the IR and ultrasonic sensors to improve the perception of the environment and improve the accuracy of localization [10].

2. IoT and Cloud Integration:

Include IoT modules to allow remote control, cloud-based task scheduling and fleet management so as to make it possible to monitor the vehicles in real-time and even anticipate maintenance [4], [7].

3. Machine Learning-Based Path Planning:

Apply the techniques of reinforcement learning or neural network algorithms in dynamic path planning and obstacle 6 avoidance to allow the AGV to know how to plan its path, optimising the path as time goes on.

4. Energy Optimization and Power Management:

Adopt some energy-saving drive algorithms and battery management system that will make the system more reliable and durable.

5. Modular Hardware Design:

Develop a modular system such that it is possible to upgrade sensors or hardware units without necessarily redesigning the whole system.

VII. CONCLUSION

This study was able to design a cost-effective Smart AGV with a Triple-Mode type of the navigation system that combines IR- based line-following, ultrasonic-based obstacle avoidance, and manual Bluetooth control. The experimental assessment was used to ensure that the system is characterized by good navigation and stable mode-switching with a low amount of power usage. The main value of this work is to show that it is possible to implement intelligent, flexible and affordable indoor navigation based on low cost embedded hardware and not use the expensive LiDAR systems. The system provides a scalable solution to smart healthcare, logistics and factory automation by filling the gap between the manual control and autonomous shortest-path planning, using a secure mobile interface. Further development of the system by adding AI-based sensor fusion and IoT-based multi-AGV fleet management to make it more scalable in bigger industrial settings will be studied in the future.

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