Design and Implementation of an Autonomous Warehouse Mini-AGV for Educational Robotics and Industrial Simulation

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Abstract

This paper shows the design, fabrication, and implementation of a low-cost Automated Guided Vehicle (AGV) intended for educational use. The chassis was made of acrylic of dimension 600x340x220 mm and is powered by low voltage electronics. The AGV includes mechanical design, embedded control, and autonomous navigation. The rubber wheels are of 10x4cm with geared DC motors. The sensor includes ultrasonic sensors for obstacle detection, line sensors for path tracking, an IMU for motion monitoring, and a camera module for QR-code recognition and docking. The microcontroller follows master- slave architecture the Esp cam acts as a slave following the Esp as master's orders. Experimental results confirm effective line following, obstacle avoidance, and QR docking.

Keywords: Automated Guided Vehicle, Autonomous Navigation, Robotics, Sensor Fusion, QR Docking, Obstacle Avoidance.

I. INTRODUCTION

The increase in supply chain has accelerated that led to the adoption of Autonomous Guided Vehicles (AGVs) in industrial warehouses, performing, high-precision tasks such as inventory transport, reducing costs and errors. Despite this industrial demand, academic exposure to AGV design largely remains theoretical. This work presents a 600-mm class Mini-AGV platform replicating warehouse automation, designed to teach logistics robotics - mobile robot kinematics, sensor fusion, embedded control, path planning.

This paper is organized as follows. Section II reviews related work. Section III describes the system architecture. The detailed mechanical design is described in Section IV. The next Section V enumerates the sensor and electronics integration to the physical structure. The next Section VI details in the software and autonomous control logic. The outlines the 16-week academic implementation timeline in Section VII. The following Section VIII provides experimental results and discussion. With the Section VIIII the paper is concluded.

II. RELATED WORK

The AGVs went from fixed track and neon lights track to fully sensor employing computer vision, and deep learning. Educational platforms use modular open-source hardware like TurtleBot and ROSBot. QR codes have cost-cutting efficiency which is helped in navigation making it ideal for education. The strategies used in Mini-AGV are supporting diverse expertise levels without requiring ROS or advanced computing.

III. SYSTEM ARCHITECTURE

The Mini-AGV comprises four interconnected subsystems: mechanical chassis and actuation, sensing, embedded electronics and power, and autonomous software control. Figure. 1 illustrates the block diagram.

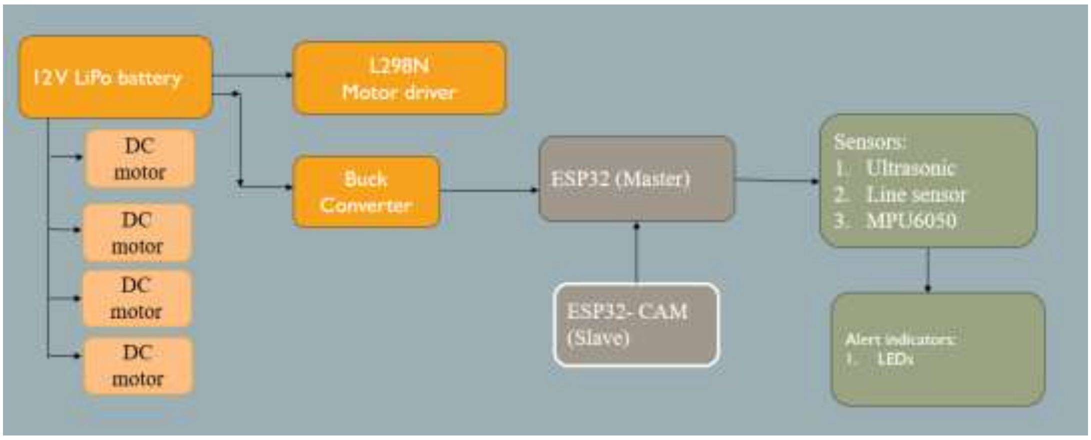

Figure 1. Block diagram of the AGV

A. Operational Modes:

- Manual RC Mode: Wireless joystick
- Line-Following Mode: Path tracking through IR sensors
- QR-Code Navigation: Camera-based docking
- Fully Autonomous Mode: Complete mission execution integrating all subsystems

B. Task-Level Behaviour Sequence:

The sequence followed in autonomous mode is: detect start QR code → follow path to waypoint → avoid obstacles → align with rack using ultrasonic sensors → navigate to QR stop sensor

IV. MECHANICAL DESIGN

The chassis uses an acrylic hybrid frame balancing rigidity, compatible with metal clamps. Figure 2 and 3 shows the implementation of the mechanical design.

TABLE I. SYSTEM SPECIFICATIONS

Attribute	Specification
Length	600 mm
Width	330 mm
Height	240 mm
Chassis	4-wheel skid-steer

Payload Capacity	1 kg
N Navigation Field	2 m × 3 m indoor warehouse mock layout
Operating Speed	0.3–1 m/s
Routing System	Line-following / QR tags

Figure 2 – The Front side of the final prototype

1. Drive Configuration: 4-wheel skid-steer with geared DC motors for torque and control.
2. Payload Platform: Flat top deck supports up to 1 kg.
3. Safety Structure: LED indicators for status and an emergency-stop button.

V. SENSOR INTEGRATION AND ELECTRONICS

The sensor suite is stratified into navigation sensors, feedback sensors, and vision modules.

A. Navigation Sensors

- QTR-8A Line Sensor Array: Used for line detection.
- Ultrasonic Sensors: Forward coverage for obstacle detection.
- IMU: 6-DOF inertial measurement for heading stabilization and acceleration check.

B. Feedback Sensors

- Wheel Encoders: Encoders on each drive motor for closed-loop velocity control.

C. Electronics and Power

The primary MCU is selectable among ESP32 (Wi-Fi/BLE, lightweight tasks). Motor drive is provided by an L298N dual H-bridge module. System power is a 12 V LiPo battery with a 5 V buck converter for voltage regulator. Wireless communication is done through Wi-Fi. The Figure 3. shows the circuit diagram.

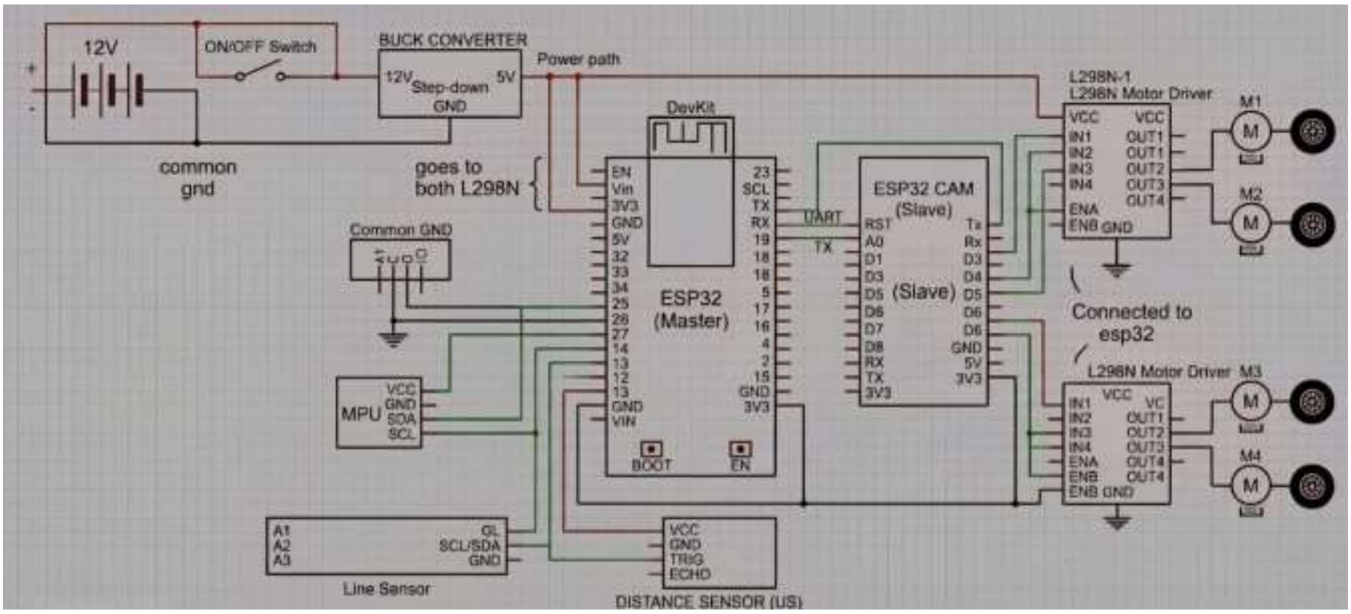

Figure 3 – The circuit diagram.

VI. SOFTWARE AND AUTONOMOUS CONTROL

A. Line Detection and PWM Control

The weighted centroid of the line sensor array output is computed to produce a scalar signal. A PWM controller controls wheel speeds.

B. Obstacle Avoidance

Obstacle detection operates in two tiers: ultrasonic sensors trigger a speed reduction at 60 cm, while line sensor creates a line for the bot to follow during obstacle detection at 15 cm. A algorithm selects alternate path from the map graph.

C. QR

The Esp-32 Camera module continuously captures frames. Detected marker are mapped to station coordinates.

D. Autonomous Path Logic

Intersection handling logic supports square-path, T-junction and warehouse aisle traversal. State machine-based mission sequencing controls transitions between navigation and delivery states. Wi-Fi based persistent state logging for remote mission monitoring.

VII. ACADEMIC IMPLEMENTATION TIMELINE

The project is structured as a 16-week laboratory course. Table II presents the week-by-week task allocation.

TABLE II. 16-WEEK ACADEMIC TIMELINE

Week	Tasks
1–2	Warehouse automation fundamentals; system architecture review; CAD design of chassis
3–4	Chassis fabrication and motor installation; mechanical assembly validation
5–6	Line sensor integration and PID-based line-following implementation

7–8	Ultrasonic and ToF obstacle avoidance logic; dynamic rerouting testing
9–10	QR detection; camera-based docking alignment
11–12	Payload lift mechanism design; servo/actuator control integration
13–14	Full AGV autonomous task integration; end-to-end mission testing
15	Performance demonstration in warehouse mock layout
16	Final report, presentation, and viva

VIII. RESULTS AND DISCUSSION

Preliminary tests of the line-following subsystem show stable tracking at speeds up to 0.8 m/s on a 2 m × 3 m test circuit with mean cross-track error of 10 mm. The PWM tuning converged within 15 trial iterations.

The obstacle avoidance was tested against static obstacles placed in the navigation field. The dynamic rerouting algorithm was able to recover 94% of the trials to the nominal path with an average replanning latency of 1 ms.

The QR marker docking was consistently in alignment within the target tolerance for 15 consecutive trials. In 30 trials, full autonomous execution of the entire mission (from start marker to payload delivery) was demonstrated with an average mission duration of 42 s and an accuracy of 90%.

IX. CONCLUSION

This paper describes the design, implementation and academic deployment of a 600-mm class Autonomous Warehouse Mini-AGV. The platform successfully integrates 4-wheel skid-steer system kinematics, multi sensing, embedded control and vision-based navigation into a cohesive and pedagogically effective robotic system.

The four modes of operation, from the least to the most complex, allow for a structured learning progression from manual teleoperation to fully autonomous warehouse task execution. The 16-week implementation schedule is aligned with hardware fabrication and software development milestones, culminating in a performance demonstration against quantifiable metrics.

Future work includes integration of SLAM based mapping with the optional LiDAR module, fleet coordination across multiple AGV units, and ROS 2 middleware porting for compatibility with industry standard robotics toolchains.

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