
IJCRM
International Journal of Contemporary Research In Multidisciplinary

Research Article

Industrial Line Following Robot for Autonomous Material Handling Using QTR-8RC Sensor Array and Arduino-Based Control System

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DOI: https://doi.org/10.5281/zenodo.20545706

Abstract

This paper presents the design and implementation of an industrial line following robot for autonomous material handling in factory and warehouse environments. The robot integrates a QTR-8RC reflectance sensor array for accurate line detection, an Arduino Uno microcontroller for real-time control, and a BTS7960 high-current motor driver to actuate a 6-wheel drive (6WD) chassis. An HC-SR04 ultrasonic sensor enables obstacle detection to enhance operational safety. A 12V 7Ah rechargeable battery powers the system, while an LM2596 buck converter provides regulated voltages for electronics. The proposed system achieves robust path tracking, stable locomotion under load, and reliable operation on typical industrial surfaces. Experimental evaluations demonstrate consistent line tracking, responsive obstacle handling, and practical suitability for indoor material transport. The solution is low-cost, scalable, and well-suited for small and medium industrial facilities seeking to reduce manual handling and improve productivity.

Manuscript Information

- **ISSN No:** 2583-7397
- **Received:** 05-04-2026
- **Accepted:** 02-06-2026
- **Published:** 04-06-2026
- **IJCRM:**5(3); 2026: 618-622
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- **Plagiarism Checked:** Yes
- **Peer Review Process:** Yes

How to Cite this Article

Thakur I B, Inamdar V, Nikam V, Jamdar R. Industrial Line Following Robot for Autonomous Material Handling Using QTR-8RC Sensor Array and Arduino-Based Control System. Int J Contemp Res Multidiscip. 2026;5(3):618-622.

Access this Article Online

www.multiarticlesjournal.com

KEYWORDS: Industrial Automation, Line Following Robot, Arduino Uno, QTR-8RC Sensor Array, Autonomous Navigation, Material Handling, BTS7960 Motor Driver, Embedded Systems.

I. INTRODUCTION

Industrial facilities often rely on manual transport for repetitive intra-plant movements between workstations, contributing to inefficiencies, time loss, and ergonomic risks. Automated guided vehicles (AGVs) and line following robots offer cost-effective pathways to streamline material handling, yet many commercial systems are expensive and over-specified for small and medium enterprises (SMEs).

This work develops a practical, affordable line following robot that autonomously follows predefined tracks using a QTR-8RC sensor array and an Arduino-based controller. The design emphasizes robust tracking, obstacle awareness, sufficient payload traction via a 6WD chassis, and clean power conditioning—targeting dependable performance without specialized infrastructure. Fig. 1 illustrates the overall system block diagram.

II. LITERATURE REVIEW

Prior academic and industrial efforts highlight sensor-array-based line tracking, microcontroller-centered control, and modular motor driving as effective building blocks for low-cost AGVs. Reflectance arrays like QTR-series provide fast, accurate line sensing; Arduino-class controllers offer simplicity and ecosystem support; and high-current H-bridge drivers such as BTS7960 enable multi-motor traction [1].

Studies consistently report improved path stability with multi-sensor arrays over single-sensor designs [2], and enhanced operational safety when supplementing line following with ultrasonic ranging [3]. However, gaps remain in deploying simple, high-traction, low-maintenance solutions adaptable to constrained industrial layouts without complex localization or expensive IoT stacks. This work addresses those gaps with a focused, integrable platform.

III. Problem Statement

Manual, repetitive intra-facility transport increases cycle time and operator burden. Existing AGV solutions may be cost-prohibitive or overly complex for SMEs. There is a need for a low-cost, robust, and maintainable autonomous line following robot that:

- Reliably tracks predefined routes on common industrial floors.
- Provides obstacle detection and basic collision avoidance.
- Offers sufficient traction and stability for moderate loads.
- Uses accessible hardware and open tooling to simplify deployment and maintenance.

IV. Proposed System

A. System Architecture

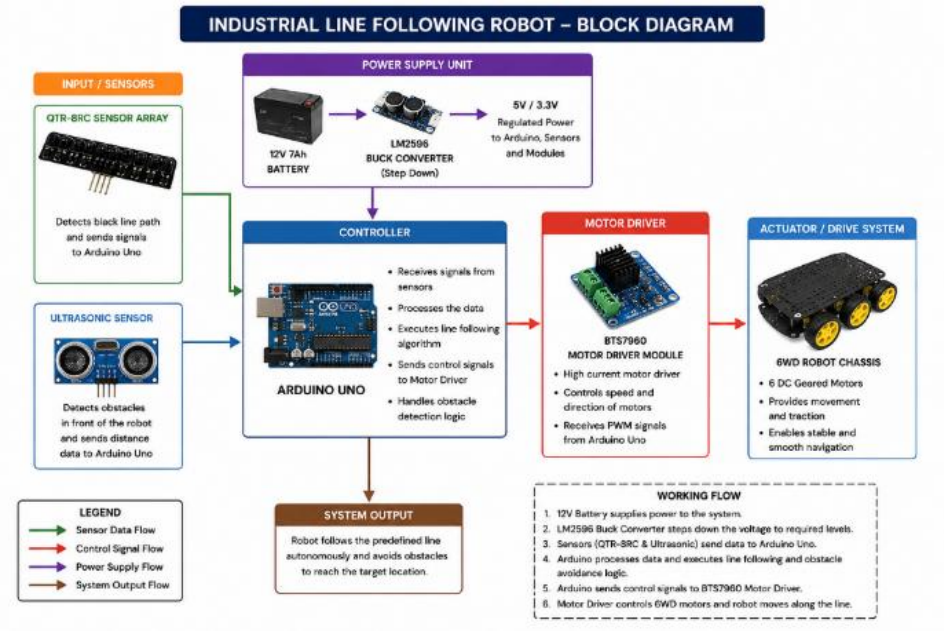
The system comprises four integrated subsystems, as summarised in Table I.

TABLE I: System Architecture Components

Subsystem	Key Components
Sensing	QTR-8RC reflectance array, HC-SR04 ultrasonic sensor
Control	Arduino Uno (ATmega328P)
Actuation	BTS7960 driver, 6WD chassis, DC motors
Power	12V 7Ah SLA battery, LM2596 buck converter

B. Block Diagram Description

The power unit converts 12V from the SLA battery through the LM2596 buck converter to provide regulated 5V rails for the Arduino and sensors, while raw 12V feeds the BTS7960 motor driver. The QTR-8RC array feeds line position data to the Arduino; the HC-SR04 provides distance readings. The Arduino computes corrections and safety stops, and the BTS7960 executes PWM and direction commands to the left and right motor banks on the 6WD frame, as depicted in Fig. 1.



WORKING FLOW

1. 12V Battery supplies power to the system.
2. LM2596 Buck Converter steps down the voltage to required levels.
3. Sensors (QTR-8RC & Ultrasonic) send data to Arduino Uno.
4. Arduino processes data and executes line following and obstacle avoidance logic.
5. Arduino sends control signals to BTS7960 Motor Driver.
6. Motor Driver controls 6WD motors and robot moves along the line.

Fig. 1: Overall system block diagram showing power, sensing, control, and actuation subsystems.

C. Working Principle

The QTR array continuously estimates the line position. A control law adjusts differential motor speeds to minimize lateral error. If the HC-SR04 detects an obstacle below a distance threshold, the controller halts or slows the robot until clearance is confirmed. The BTS7960 applies PWM duty to each motor bank accordingly.

V. Hardware and Software Design

A. Hardware Components

1) Arduino Uno*:* ATmega328P-based MCU operating at 16 MHz. It provides digital I/O, PWM, and serial communication for debugging. The Arduino runs the main control loop, reads sensors, computes control signals, and issues PWM/direction outputs to the motor driver.

2) QTR-8RC Sensor Array: Eight IR reflectance sensors yield rapid RC pulse outputs proportional to surface reflectivity. They provide sub-linewidth position estimation for stable tracking over straights and curves.

3) BTS7960 Motor Driver*:* High-current (up to 43 A peak) H-bridge module. Accepts 5V logic and supports PWM up to ~25 kHz. Drives left and right motor groups with built-in overcurrent protection.

4) HC-SR04 Ultrasonic Sensor: 40 kHz ranging over approximately 2–400 cm with typical ±3 mm resolution. Supplies obstacle distance for stop/slowdown logic.

5) LM2596 Buck Converter: Efficient step-down regulator from 12V battery to a regulated 5V rail for logic and sensors, reducing heat dissipation and protecting sensitive electronics.

6) 12V 7Ah Battery: SLA chemistry provides adequate runtime and current headroom for multi-motor loads under typical warehouse operating conditions.

7) 6WD Robot Chassis: Six-wheel drive increases traction, stability, and load capacity. The chassis accommodates motors, battery, and electronics with balanced mass distribution.

B. Software Environment

The firmware is developed using the Arduino IDE with Embedded C/C++ for real-time control logic, sensor interfacing, and PWM generation. The QTRSensors library handles calibration and line-position computation for the QTR-8RC array. The NewPing library provides efficient ultrasonic timing and filtering for the HC-SR04 sensor.

VI. METHODOLOGY

A. System Flowchart

The control flow proceeds as follows: (1) initialize hardware (Arduino, QTR calibration, ultrasonic, motor driver); (2) read QTR array and estimate line position/error; (3) read ultrasonic distance; (4) if obstacle within threshold, stop and hold—otherwise compute motor commands; (5) apply PWM to left/right motors via BTS7960; (6) loop continuously with timing safeguards. Fig. 2 presents the detailed software flowchart.

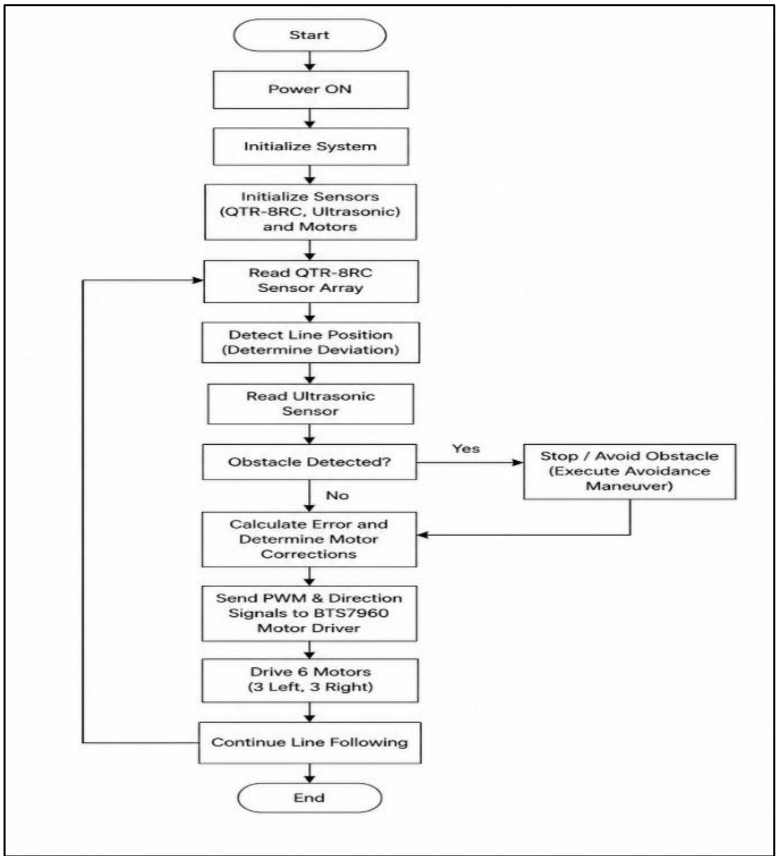


Fig. 2: Software control flowchart for the line following robot.

B. Algorithm

Calibration records baseline black/white values for each QTR channel. Line position is derived as a weighted average across sensors, yielding position p; error e = p − p_ref. The proportional control law computes differential speeds as:

$$v_L = v_{base} - k\cdot e, \quad v_R = v_{base} + k\cdot e \quad (1)$$

where speeds are clamped to [0, PWM_max]. The obstacle rule stops the robot (v_L = v_R = 0) when measured distance $d \le d_{min}$. A failsafe halts the robot if no line is detected for time T_loss and attempts a slow scan to reacquire the line.

C. Sensor Data Processing

QTR raw pulses are filtered with a median or rolling average filter to suppress flicker and electrical noise. Normalization using calibration bounds handles floor surface and ambient lighting variations. Optional hysteresis on “line lost” detection prevents false stops due to chattering.

D. Motor Control Logic

PWM frequency is selected to limit audible noise while maintaining motor torque. Soft-start and soft-stop ramps limit current surges and improve traction during acceleration and braking phases. A proportional gain k is used; future enhancement includes full PID control to reduce overshoot during high-speed cornering.

VII. Experimental Setup and Results

A. Testing Environment

Experiments were conducted on an indoor track with a matte white surface and 18–20 mm wide black line. The track incorporated both straight sections and curves. Testing was performed under normal indoor lighting conditions on a 6WD chassis with typical warehouse-floor friction characteristics.

B. Performance Parameters

The following metrics were evaluated: (1) line tracking accuracy measured as maximum path deviation; (2) response time to deviations and corners; (3) obstacle stop distance and detection latency; (4) battery runtime on 12V 7Ah under nominal load; and (5) motion stability under start/stop cycles and minor surface irregularities.

C. Experimental Results

The robot demonstrated reliable detection of the black path and continuous tracking along straights and curves. Smooth directional corrections were achieved through differential speed control. Obstacle detection triggered clean stops within preset threshold distances. Stable operation was maintained on typical indoor surfaces under normal lighting conditions throughout multiple test runs. Table II summarizes the key performance outcomes.

TABLE II: Summary of Experimental Performance

Parameter	Observation
Line tracking	Consistent on straights and curves
Correction response	Smooth differential adjustment
Obstacle stop	Clean stop within threshold (<20 cm)
Surface stability	Stable on indoor matte floors
Battery runtime	Adequate for pilot-scale shifts

D. Result Analysis

The multi-sensor QTR array enabled robust estimation of line position, outperforming single-sensor schemes in cornering and recovery from minor perturbations. Differential drive with proportional correction delivered smooth tracking; adding integral and derivative terms is expected to improve high-speed cornering. The ultrasonic safeguard prevented collisions but can benefit from temporal filtering to mitigate false echoes. The 6WD drivetrain improved traction and stability, making the platform suitable for moderate payloads and uneven floor joints.

E. Cost Analysis

The controller, sensors, motor driver, and chassis use widely available, low-cost components. The battery and buck converter are economical and reliable. The overall bill of materials aligns with budget-constrained industrial pilots and educational deployments, making the system accessible to SMEs without dedicated automation budgets.

VIII. Comparative Analysis

Compared to typical low-cost line followers, this system combines an 8-element reflectance array, high-current motor drive, and 6WD traction—yielding better stability and payload capacity. Table III compares the proposed system against related approaches.

TABLE III: Comparative Analysis of Line-Following Platforms

Feature	Basic LFR	Vision AGV	Proposed
Sensors	2–3 IR	Camera	8-element QTR
Drive	2WD	4WD / 2WD	6WD
Obstacle detect	None/basic	Vision-based	Ultrasonic
Cost	Low	High	Low–Medium
Payload	Light	Varies	Moderate

Unlike vision-based AGVs or SLAM-enabled platforms, the proposed system avoids high compute and sensor costs, trading off global localisation for simplicity and reliability on predefined routes. For SMEs and warehouses with fixed pathways, the design offers a pragmatic middle ground between manual carts and premium AGVs.

IX. Advantages and Limitations

A. Advantages

- Accurate, stable line following using the QTR-8RC 8-element array.
- Obstacle detection via HC-SR04 for operational safety.
- High-traction 6WD chassis supports moderate loads and uneven flooring.
- Accessible components and open tooling reduce integration and maintenance costs.
- Scalable and adaptable to various plant layouts with minimal infrastructure.
- *B. Limitations*
- Dependence on track visibility; damaged or low-contrast lines degrade performance.
- Battery runtime limits extended shifts without swap or recharge procedures.
- No global localization; constrained to marked paths and predefined routes.
- Ultrasonic sensing is susceptible to specular reflections; benefits from sensor fusion.

X. Future Scope

Several enhancements are planned for future iterations:

- Control: Full PID tuning, feedforward on curves, and adaptive gain scheduling.
- Sensing: Multi-array fusion, IR shielding, and additional proximity sensors (IR/ToF/LiDAR) for robust obstacle avoidance.
- Connectivity: Wireless telemetry, remote monitoring, and basic fleet coordination for multi-robot deployments.
- Autonomy: Junction handling, route scheduling, and simple task queueing for complex workflows.
- Mechanics/Power: Higher-capacity batteries, motor upgrades, and suspension systems for rough floor seams.
- Safety: Emergency-stop circuits, bumper switches, and compliance with industrial safety standards.

XI. CONCLUSION

This paper presented a practical, low-cost industrial line following robot integrating a QTR-8RC sensor array, Arduino-based control, BTS7960 motor driving, and a 6WD chassis. The system demonstrated reliable line tracking, responsive obstacle handling, and stable motion suited for autonomous material handling on predefined routes. The design balances affordability with performance, offering SMEs a credible pathway to reduce manual transport effort. Future enhancements in control, sensing, and connectivity can extend capability toward more complex industrial workflows.

Acknowledgment

The authors express their sincere gratitude to the faculty of the Department of Electronics & Telecommunication Engineering, PES's College of Engineering, Phaltan, for their continuous guidance and support throughout this work. The authors also acknowledge the contributions of the open-source Arduino and robotics communities whose libraries and tools were integral to the development of this system.

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