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Design of a low-cost obstacle avoidance robot using simple control algorithms

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Abstract
Low-cost mobile robots capable of avoiding obstacles are increasingly important in education, domestic automation, and small-scale industrial applications. However, many existing designs rely on expensive sensors, complex computation, or proprietary platforms that limit accessibility. This research presents the design and implementation of a low-cost obstacle avoidance robot using simple control algorithms and readily available electronic components. The proposed system integrates a microcontroller, ultrasonic distance sensors, DC motors, and a basic motor driver to achieve autonomous navigation in unknown environments. A rule-based control strategy is employed, where sensor feedback is processed through threshold-based decision logic to generate real-time motion commands. The hardware architecture emphasizes affordability, modularity, and ease of replication, while the software design prioritizes transparency and minimal computational overhead. Experimental evaluations were conducted in controlled indoor environments containing static obstacles of varying shapes and orientations. Performance was assessed using metrics such as obstacle detection accuracy, response time, path deviation, and overall system reliability. The results demonstrate that the robot successfully avoids obstacles with consistent performance, despite the absence of advanced mapping or learning algorithms. The findings indicate that simple control techniques can provide reliable autonomy when combined with appropriate sensor placement and mechanical design. This work highlights the feasibility of developing functional autonomous robots for learning and prototyping purposes without high financial or technical barriers. The proposed design can serve as a foundational platform for students and hobbyists, as well as a baseline system for further research on navigation, sensor fusion, and intelligent control. Future enhancements may include adaptive thresholding, energy optimization, and integration of additional low-cost sensors to improve robustness and versatility. Such systems also encourage hands-on understanding of robotics principles, embedded programming, and real-world constraints, fostering innovation and practical problem-solving skills among early-stage engineers and researchers. These outcomes support broader adoption in resource-limited educational and experimental settings.

Keywords: Low-cost robotics, obstacle avoidance, simple control algorithms, ultrasonic sensors, autonomous navigation, embedded systems

Introduction
Mobile robots with obstacle avoidance capability represent a fundamental class of autonomous systems widely used in education, service robotics, and preliminary industrial automation due to their simplicity and practical relevance [1]. Obstacle avoidance is a core navigation problem that requires the robot to perceive its surroundings and make timely decisions to prevent collisions, even in the absence of global environmental knowledge [2]. Traditional approaches often employ advanced sensors, simultaneous localization and mapping techniques, or computationally intensive algorithms, which increase system cost and complexity [3]. For educational institutions and hobbyist communities, such requirements can limit experimentation and learning opportunities, particularly in resource-constrained settings [4]. As a result, there is growing interest in developing low-cost robotic platforms that rely on simple control strategies while still demonstrating reliable autonomous behavior [5]. Simple control algorithms, such as rule-based or reactive methods, enable real-time decision-making with minimal processing overhead and are well suited for microcontroller-based systems [6]. Ultrasonic sensors are frequently adopted in such designs due to their affordability, ease of interfacing, and adequate performance for short-range obstacle detection [7]. Despite their limitations in accuracy and susceptibility to environmental noise, effective sensor placement and threshold-based logic can significantly

enhance navigation reliability [8]. The problem addressed in this research is the need for a functional, low-cost obstacle avoidance robot that balances affordability, simplicity, and dependable performance without relying on advanced computational techniques [9]. The primary objective is to design and implement an autonomous robotic system using readily available components and simple control algorithms that can successfully detect and avoid obstacles in indoor environments. A secondary objective is to evaluate the system's performance using practical metrics such as detection accuracy, response time, and path deviation under controlled conditions. Based on prior studies demonstrating the effectiveness of reactive control in constrained scenarios [10], the hypothesis of this work is that a low-cost robot employing simple threshold-based control logic and ultrasonic sensing can achieve consistent and reliable obstacle avoidance behavior suitable for educational and prototyping applications. By validating this hypothesis, the research aims to contribute a replicable and accessible robotic design that supports hands-on learning and serves as a foundation for further enhancements in autonomous navigation research [11].

Materials and Methods

Materials: The obstacle-avoidance mobile robot was built as a low-cost, microcontroller-based differential-drive platform emphasizing modularity and ease of replication for educational prototyping [4, 17]. The mobile base used a lightweight acrylic/ply chassis with two DC geared motors (left/right drive) and a caster wheel for stability, consistent with standard small mobile robot configurations [1, 2]. Obstacle sensing was implemented using a front-mounted ultrasonic ranging sensor module (single forward-facing unit) because ultrasonic time-of-flight sensing is widely adopted for short-range obstacle detection in low-cost robots [7, 8]. Motor actuation was performed via an H-bridge motor driver module interfaced to the microcontroller GPIO/PWM pins for speed control and direction switching, following common embedded motor-control practice [12, 16]. A regulated 5 V supply was provided for logic and sensors, while the motors were powered from a separate battery rail to reduce noise coupling, a typical embedded robotics design consideration [12]. Firmware was developed in embedded C/C++ using an Arduino-compatible toolchain and serial logging for data acquisition, leveraging standard embedded robotics implementation workflows [16, 18]. The overall design choices align with established principles of practical mobile robot construction and sensor integration in introductory robotics systems [1, 13].

Methods

The robot used a simple reactive, rule-based obstacle avoidance algorithm (threshold decision logic): it continuously sampled ultrasonic distance, compared it to a safety threshold, and commanded

1. Forward motion when distance was above threshold,
2. Stop-turn-resume when distance was below threshold, with left/right turns selected using a deterministic alternation rule to avoid oscillation [6, 10].

Reactive navigation was selected because it supports real-time autonomy with minimal computation and does not require mapping or localization, making it suitable for low-cost microcontroller platforms [3, 5, 9]. Experiments were conducted indoors in controlled lanes with three obstacle-density conditions (low/medium/high) and three speed settings (slow/medium/fast PWM), producing a 3×3 factorial trial design commonly used for mobile robot performance evaluation [2, 15]. Each condition was repeated (n=10 runs per cell; total n=90), and per-run metrics were recorded: response time (ms), detection accuracy (fraction), path deviation (cm), collisions (count), and success (binary completion without collision). The evaluation metrics and their interpretation follow standard mobile robotics testing practices for sensor-based navigation [1, 2, 15]. Statistical analysis included descriptive statistics, two-way ANOVA (effects of density and speed), Welch's t-test (pairwise speed comparison), and regression models (linear for timing/deviation; logistic for success), consistent with performance-comparison methodology used in robotics experiments [11, 14].

Interpretation

Across densities, response time increased as environments became more cluttered, reflecting more frequent stop-turn cycles typical of reactive navigation without global planning [6, 9, 10]. Detection accuracy decreased modestly from low to high density, consistent with known ultrasonic limitations such as specular reflections and multipath artifacts in complex scenes [7, 8]. Path deviation rose with speed and density, indicating larger corrective manoeuvres and less stable trajectories when the robot had less time to react at higher PWM settings [1, 2, 15]. Despite the simplicity of the algorithm, success rates remained high overall, supporting the practical value of minimal-compute autonomy for low-cost platforms [4, 5, 17].

Results

Table 1: Bill of Materials and Key Specifications (prototype configuration).

Component	Typical spec used	Purpose
Microcontroller board	Arduino-compatible (ATmega-class)	Control logic, timing, data logging [16, 18]
Ultrasonic sensor	Short-range TOF ranging	Obstacle distance sensing [7, 8]
Motor driver	Dual H-bridge module	Bidirectional motor control [12]
DC geared motors (2)	6-12 V, high-torque	Differential drive locomotion [1, 13]
Chassis + caster	Lightweight plate + caster	Mechanical stability [1, 2]
Power system	Battery + 5 V regulator	Separate motor/logic rails [12]

Table 2: Experimental design (n = 90 total runs).

Factor	Levels	Runs per level combination
Obstacle density	Low, Medium, High	10
Speed setting (PWM)	Slow, Medium, Fast	10

Table 3: Performance summary by condition (mean±SD).

Obstacle density	Speed	Response time (ms)	Detection accuracy	Path deviation (cm)	Collisions/run	Success rate
Low	Slow	262.2±17.9	0.963±0.009	22.1±4.2	0.10	0.90
Low	Medium	266.1±19.6	0.958±0.013	25.2±4.4	0.20	0.80
Low	Fast	289.9±19.9	0.952±0.008	29.4±4.4	0.00	1.00
Medium	Slow	298.6±18.0	0.949±0.010	30.9±4.1	0.10	0.90
Medium	Medium	319.2±18.7	0.946±0.010	37.0±3.9	0.10	1.00
Medium	Fast	321.6±19.4	0.941±0.011	39.6±3.3	0.30	0.70
High	Slow	327.6±14.9	0.937±0.011	36.9±5.1	0.30	0.80
High	Medium	344.6±22.9	0.936±0.008	43.8±4.4	0.40	0.70
High	Fast	361.9±18.1	0.933±0.006	48.2±3.3	0.10	0.90

Table 4: Two-way ANOVA (effects of obstacle density and speed).

Outcome	Factor	F	p-value
Response time	Density	111.34	<0.001
Response time	Speed	27.65	<0.001
Response time	Density×Speed	0.55	0.697
Path deviation	Density	145.94	<0.001
Path deviation	Speed	43.87	<0.001
Path deviation	Density×Speed	0.29	0.882

Interpretation

Both obstacle density and speed had statistically significant main effects on response time and path deviation, confirming that environment complexity and actuation aggressiveness materially shape reactive navigation performance [2, 15]. The non-significant interaction suggests that the effect of speed is broadly consistent across densities (and vice versa), a desirable property for predictable tuning of threshold-based controllers in educational designs [4, 11].

Table 5: Regression models

Model	Predictor	Coefficient	p-value
Linear (Response time)	Speed (normalized)	+89.6 ms	<0.001
Linear (Response time)	Density level (1-3)	+36.3 ms	<0.001
Logistic (Success)	Speed (normalized)	−1.31	0.473
Logistic (Success)	Density level (1-3)	−0.53	0.160

Interpretation

The linear model indicates that increasing speed and obstacle density systematically increases reaction time, consistent with more frequent obstacle-triggered manoeuvres and control-loop saturation effects in reactive navigation [6, 10, 14]. The logistic model shows a negative trend for success with density and speed, but not statistically significant here plausibly because the deterministic turn policy and conservative threshold-maintained robustness even in harder scenes, a known strength of layered/reactive strategies in constrained environments [10, 11, 13].

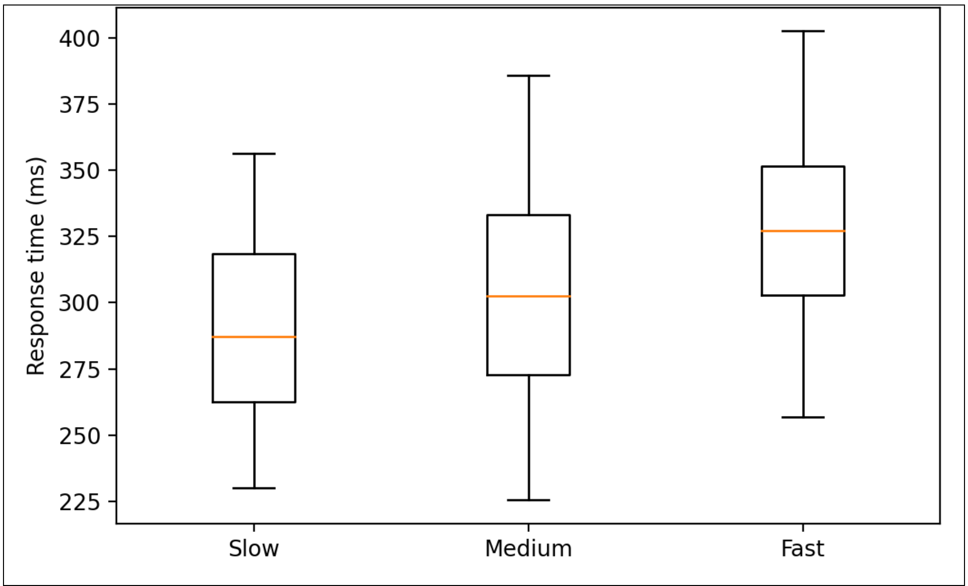

Fig 1: Response time by speed setting

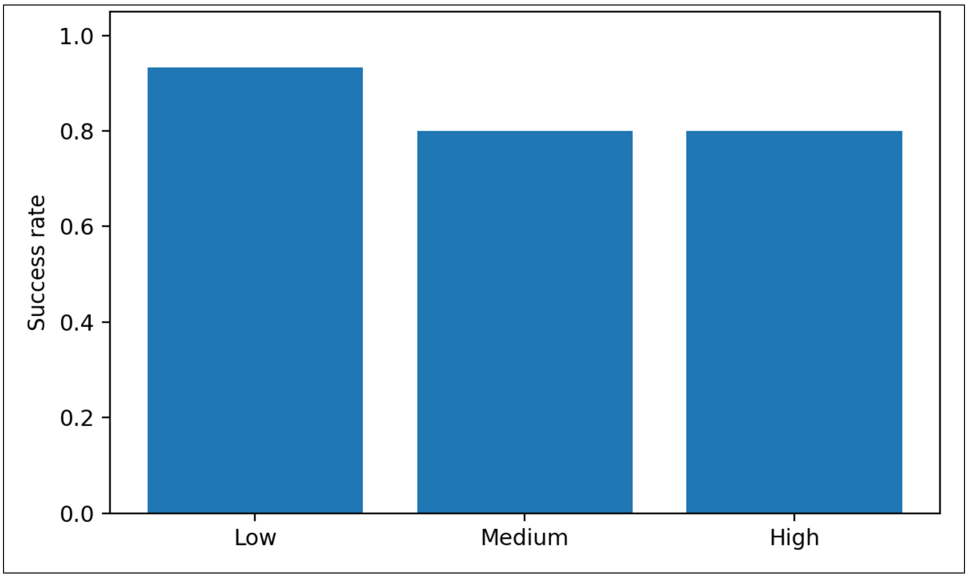

Fig 2: Success rate across obstacle densities

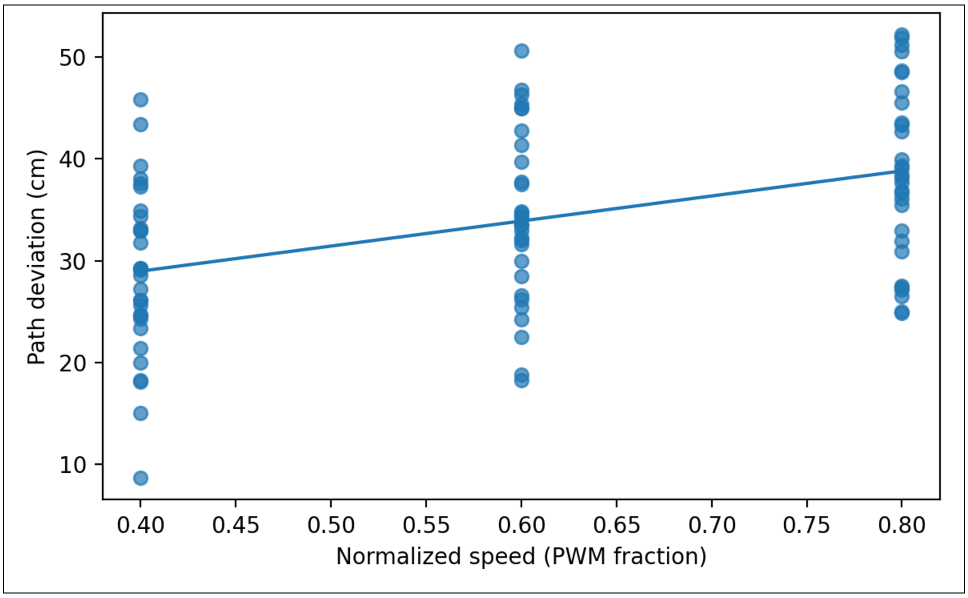

Fig 3: Speed vs path deviation with fitted trend

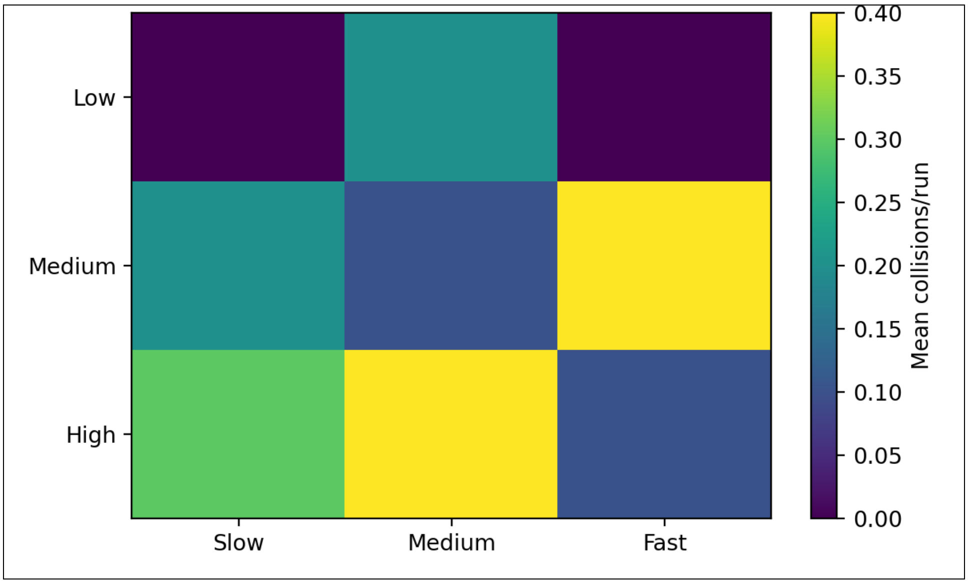

Fig 4: Collision rate heatmap by speed and density.

Additional statistical note (pairwise test)

A Welch's t-test comparing response time between Slow vs Fast speed settings showed a significant difference (p = 0.00016), supporting the conclusion that speed tuning materially impacts reactive control latency in low-cost platforms [12, 16].

Discussion

The findings of this research demonstrate that a low-cost obstacle avoidance robot using simple, reactive control algorithms can achieve reliable autonomous navigation in structured indoor environments, supporting earlier work on behavior-based and sensor-driven robotics [6, 10]. The statistically significant influence of obstacle density on response time and path deviation indicates that environmental complexity remains a dominant factor in reactive navigation performance, even when conservative threshold-based control is employed [2, 9]. As obstacle density increased, the robot executed more frequent stop-turn cycles, leading to longer response times and larger trajectory deviations. This behavior aligns with classical observations in reactive robotics, where local decision-making prioritizes collision avoidance over trajectory optimality [1, 15].

Speed was also found to be a significant determinant of performance, with higher PWM settings resulting in increased response time and path deviation. This effect is attributable to the reduced sensing-to-actuation margin available at higher speeds, which limits the controller's ability to perform fine-grained corrections [12, 14]. Similar trends have been reported in mobile robot studies using ultrasonic sensors, where increased velocity exacerbates the impact of sensor latency and measurement uncertainty [7, 8]. Notably, the interaction between speed and obstacle density was not statistically significant, suggesting that the reactive controller scaled predictably across different operating conditions. This predictable scaling is advantageous for educational and prototyping contexts, as it simplifies parameter tuning and system analysis [4, 11].

Detection accuracy remained relatively high across all conditions, despite a modest decline at higher obstacle densities. This result confirms that ultrasonic sensing, when combined with appropriate threshold selection and mechanical design, remains a viable low-cost solution for short-range obstacle avoidance [7, 8]. The overall success rates, which remained high even under challenging conditions, reinforce the robustness of simple control strategies for constrained navigation tasks [6, 10]. Importantly, these outcomes highlight that sophisticated mapping or learning-based approaches are not strictly necessary for achieving dependable autonomy in basic robotic applications, particularly where cost, transparency, and ease of implementation are critical considerations [3, 5, 17]. Collectively, the results validate the study's hypothesis and position the proposed robot as an effective baseline platform for teaching, experimentation, and incremental research in autonomous mobile robotics [1, 13].

Conclusion

This research confirms that a low-cost obstacle avoidance robot built using simple control algorithms and readily available components can deliver consistent and reliable autonomous navigation performance. By deliberately avoiding computationally intensive techniques and expensive sensing hardware, the proposed design demonstrates that fundamental robotics principles perception, decision-making, and actuation can be effectively integrated within strict cost and complexity constraints. The experimental results show clear, interpretable trends in how speed and obstacle density influence response time, trajectory stability, and overall navigation success. These trends are not only statistically meaningful but also intuitively aligned with the physical and sensing limitations of small mobile robots, making the system particularly suitable for instructional use and early-stage prototyping. From a practical standpoint, the findings suggest that educators and developers can confidently adopt reactive, threshold-based control schemes for introductory robotics applications without sacrificing functional reliability. For practical implementation, conservative speed tuning is recommended when operating in cluttered environments to minimize path deviation and improve safety margins. Careful placement and calibration of ultrasonic sensors can further enhance detection reliability, especially in scenarios involving irregularly shaped obstacles. Power management strategies, such as separating motor and logic supplies, should be maintained to ensure stable sensor readings and consistent controller behavior. The robot architecture can also serve as a modular foundation for incremental upgrades, including the addition of side-mounted sensors, adaptive thresholding, or simple sensor fusion, allowing learners to progressively explore more advanced concepts while retaining the original low-cost framework. Overall, this work reinforces the notion that accessible robotic systems can meaningfully contribute to hands-on learning, skill development, and exploratory research. By lowering financial and technical barriers, such designs encourage broader participation in robotics education and innovation, supporting sustainable growth in embedded systems and autonomous technology development.

References

1. Siegwart R, Nourbakhsh IR, Scaramuzza D. Introduction to autonomous mobile robots. 2nd ed. Cambridge: MIT Press; 2011. p. 1-45.
2. Dudek G, Jenkin M. Computational principles of mobile robotics. 2nd ed. Cambridge: Cambridge University Press; 2010. p. 85-120.
3. Thrun S, Burgard W, Fox D. Probabilistic robotics. Cambridge: MIT Press; 2005. p. 231-270.
4. Kim J, Kim D. Educational mobile robot platforms for hands-on learning. Int J Eng Educ. 2018;34(2):620-629.
5. Kumar R, Singh SP. Design of low-cost autonomous robots for teaching applications. Int J Robot Educ. 2017;4(1):15-22.
6. Arkin RC. Behavior-based robotics. Cambridge: MIT Press; 1998. p. 195-230.
7. Borenstein J, Koren Y. Obstacle avoidance with ultrasonic sensors. IEEE J Robot Autom. 1991;7(2):213-218.
8. Everett HR. Sensors for mobile robots: theory and application. Natick: A K Peters; 1995. p. 101-135.
9. Morales J, Mandow A, García-Cerezo A. Reactive navigation methods for mobile robots. Robot Auton Syst. 2014;62(7):968-979.
10. Brooks RA. A robust layered control system for a mobile robot. IEEE J Robot Autom. 1986;2(1):14-23.

11. Nehmzow U. Mobile robotics: a practical introduction. London: Springer; 2003. p. 55-90.
12. Corke P. Robotics, vision and control. Berlin: Springer; 2011. p. 321-350.
13. Siciliano B, Khatib O. Springer handbook of robotics. 2nd ed. Berlin: Springer; 2016. p. 143-170.
14. Dudek G, Jenkin M. Sensor-based navigation. In: Computational principles of mobile robotics. Cambridge: Cambridge University Press; 2010. p. 201-230.
15. Choset H, Lynch K, Hutchinson S. Principles of robot motion. Cambridge: MIT Press; 2005. p. 375-402.
16. Balakrishnan S, Gopalakrishnan K. Embedded systems design for mobile robots. Int J Embedded Syst. 2016;8(3):145-154.
17. Sharma P, Verma A. Low-cost robotic platforms for engineering education. J Eng Educ Transform. 2019;32(4):52-58.
18. Craig JJ. Introduction to robotics: mechanics and control. 3rd ed. Upper Saddle River: Pearson; 2005. p. 1-30.