IJCRT.ORG ISSN : 2320-2882

INTERNATIONAL JOURNAL OF CREATIVE RESEARCH THOUGHTS (IJCRT)

An International Open Access, Peer-reviewed, Refereed Journal

Mobility and Autonomous Navigation System of Wheeled Robot

[1]Mr.MK Prabhu, [2]Dr. M. Matheswaran, [3]Dr. S.T. Kumaravel, [4]Ms L Deepa
[1]Assistant Professor , [2]Assistant Professor, [3]Associate Professor, [4]UG Scholar
[1]Department of Robotics and Automation , [2]Department of Robotics and Automation , [3]Department of Mechanical Engineering ,
[4]Department of Robotics and Automation
[1]Paavai Engineering College Namakkal, Tamil Nadu, India., [2]Paavai Engineering College Namakkal, Tamil Nadu, India.,
[3]Paavai Engineering College Namakkal, Tamil Nadu, India., [4]Paavai Engineering College Namakkal, Tamil Nadu, India.

Abstract :

This research presents the design and implementation of a robust mobility and autonomous navigation system for a wheeled robotic platform, focusing on real-time responsiveness and stable obstacle negotiation. Traditional autonomous control systems often suffer from high latency and CPU freezing due to conventional delay-based programming. To address these limitations, this study implements a Reactive Path Planning strategy powered by a Non-Blocking State Machine architecture. By utilizing asynchronous timing control through the millis() function, the system achieves continuous sensor monitoring and parallel task execution, ensuring that the processor remains active during decision-making intervals. The navigation logic is governed by a defined State Transition Table, which facilitates seamless transitions between movement states including forward progression, emergency reversal, and directional pivoting based on immediate environmental stimuli. Experimental evaluation demonstrates that the reactive "Sense-Act" cycle significantly improves the robot's ability to navigate cluttered environments with high temporalprecision and reduced communication interruptions. The findings conclude that the integration of non-blocking control logic provides a scalable and efficient framework for autonomous mobile robots in dynamic industrial and domestic applications

IndexTerms - Autonomous Navigation, Wheeled Mobile Robots (WMR), Reactive Path Planning,Non-Blocking Control Logic, Finite State Machines (FSM), Obstacle Avoidance, Embedded Systems, Real-time Decision Making

INTRODUCTION

The evolution of autonomous mobile robots has become a cornerstone of modern industrial automation. However, the efficiency of these systems is heavily dependent on the underlying control architecture. Traditional robotic programming often relies on linear, delay-based execution, which effectively "freezes" the central processing unit (CPU) during waiting periods. In dynamic environments, these pauses lead to delayed sensor responses and an increased risk of collisions. This paper proposes a Reactive Path Planning strategy implemented through a Non-Blocking State Machine. By leveraging asynchronous timing control, the system maintains a continuous "Sense-Act" cycle, allowing the robot to process environmental data and update its movement states in real-time.

NEED OF THE STUDY

Despite the rapid growth in autonomous robotics, a significant challenge remains in the implementation of real- time control logic on low-cost embedded systems. The necessity for this study arises from several critical gaps in current entry-level robotic navigation: Failure of Sequential Processing: Most traditional robotic algorithms utilize delay-based functions to manage movement and sensor polling. This creates a "processor freeze" where the robot is blind to its environment during the delay period, often leading to collisions with dynamic obstacles. Need for Asynchronous Execution: There is a critical requirement for control architectures that can perform multiple tasks such as calculating distances, adjusting motor PWM, and monitoring battery levels simultaneously. This study addresses the need for non-blocking code to ensure zero-latency response.

Reliability in Cluttered Environments: In industrial or domestic settings, obstacles are not always static. A robot needs a "Reactive Brain" that can switch states instantly. This research fulfills the need for a simplified, high-efficiency Finite State Machine (FSM) that provides stable navigation without requiring expensive, high-end processors.

Optimization of Resource-Constrained Hardware: Many complex navigation algorithms (like full SLAM) are too heavy for standard microcontrollers. This study explores the need for a "lightweight yet robust"

logic that delivers professional-grade autonomy on affordable hardware, making robotics more accessible for industrial applications.

• LITERATURE REVIEW

The study of autonomous navigation for wheeled mobile robots (WMR) has evolved significantly, moving from basic obstacle sensing to complex real-time decision-making architectures. This review examines contemporary research to identify the technological benchmarks and existing gaps in the field.

Ultrasonic Sensing and Basic Avoidance

Fundamental research in the field has long utilized ultrasonic sensors due to their cost-effectiveness and reliability in indoor environments. Ma (2023) emphasizes that multiple ultrasonic sensors can provide a continuous environment monitoring system, enabling real-time distance calculations and dynamic movement adjustments. Similarly, Agbeyangi et al. (2020) demonstrate that effective autonomous navigation can be achieved using low-cost hardware and simplified algorithms, though they highlight the necessity of signal calibration to overcome sensor noise. Baballe et al. (2023) further establish that basic logic moving forward, reversing, and turning serves as a robust foundation for entry-level autonomous platforms.

Advanced Control and Non-Blocking Systems

While basic systems provide a foundation, recent literature argues for more sophisticated control mechanisms. Habibulloh (2025) presents a theoretical framework for sensor-based navigation, highlighting how microcontrollers must efficiently process sensor data to make high-speed decisions. The challenge of real-time processing is a recurring theme; Lala et al. (2025) explore integrated mechanisms that handle multiple tasks simultaneously, such as line following and obstacle avoidance. Their findings indicate that advanced robot navigation requires systems capable of responding to dynamic environments without sequential processing delays.

Hybrid Approaches and Sensor Fusion

To improve accuracy beyond single-sensor limitations, researchers have explored hybrid models and sensor fusion. Raja et al. (2011) introduce hybrid algorithms that select the safest path in unstructured environments, reducing collision risks significantly compared to purely reactive systems. Prasanna et al. (2024) demonstrate the advantages of fusing LiDAR and ultrasonic data, which improves navigation accuracy in dynamic settings with moving obstacles. Furthermore, Ameen and Vokhidov (2024) highlight the importance of odometry and sensor fusion in solving tracking and localization problems.

Synthesis and Research Gap

The collective literature, including work by Mansoor and Hussein (2025) and Azeta et al. (2019), underscores a critical transition: the shift from "stop-and-wait" sequential logic to real-time, non-blocking execution. While previous studies have utilized high-end sensors or hybrid algorithms, there is a remaining need for research focused on optimizing Finite State Machine (FSM) architectures on resource-constrained microcontrollers. This study addresses this gap by implementing an asynchronous timing control logic that ensures continuous execution and safety without the computational overhead of high-level sensor fusion.

• SYSTEM ARCHITECTURE

The architecture of the autonomous wheeled robot is designed as a modular framework consisting of three primary layers: the Perception Layer, the Processing Layer, and the Actuation Layer. This integrated approach ensures that the robot can achieve real-time responsiveness and stable mobility in indoor environments.

Hardware Configuration

The physical system is built upon a high-stability robot chassis that provides structural support for the electronic components. The hardware facilitates a differential drive mechanism, allowing for independent control of the left and right wheels to execute complex maneuvers.

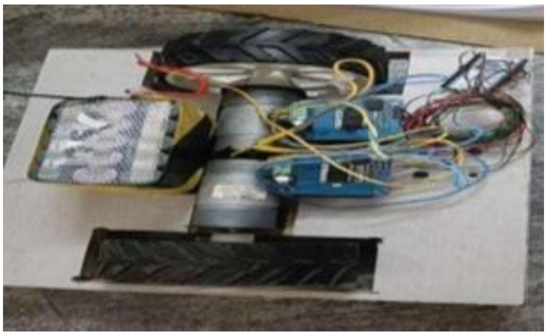
Multi-Directional Sensor Configuration

To minimize blind spots and enhance environmental awareness, the robot utilizes a specialized four-sensor array. This configuration allows the system to divide its sensing area into upper and lower regions on both the left and right sides.

Front-Left (Upper/Lower): Detects elevated objects (like walls) and ground-level hazards (like small obstacles).

Front-Right (Upper/Lower): Provides symmetrical coverage to ensure balanced navigation data.

This dual-level arrangement ensures that the robot can detect obstacles of varying heights and positions simultaneously, providing a "3D-like" perception field that is critical for safety in dynamic indoor settings.



- **METHODOLOGY: AUTONOMOUS NAVIGATION AND ADAPTIVE CONTROL**

The core functionality of the wheeled robot is governed by a real-time navigation algorithm designed to prioritize responsiveness and collision avoidance. Unlike traditional robotic control systems that utilize sequential, delay-based execution, this study implements a Non-Blocking State Machine architecture.

Non-Blocking Control Logic

The primary limitation of traditional systems is "CPU freezing" during delay intervals, which leads to slow sensor response and potential communication interruptions. To mitigate this, the proposed system utilizes the millis() function for asynchronous timing control.

As illustrated in Fig 4.1, the system tracks elapsed time continuously. Instead of pausing execution, the microcontroller records the start time of a task and checks in every loop cycle if the required interval has passed. This allows the robot to perform multiple tasks such as sensor polling and motor adjustment simultaneously, ensuring zero-latency response to environmental stimuli.

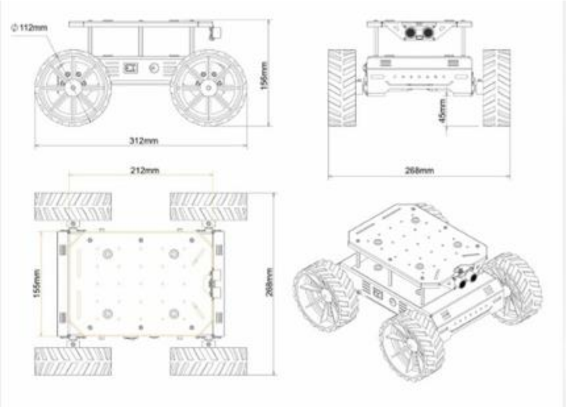
Navigation States and Transition Logic

The robot's behavior is categorized into four predefined movement states. Each state is triggered by specific environmental conditions detected by the ultrasonic array.

AUTO_FWD (Forward Movement): The default state where the robot moves forward while sensors actively scan for obstacles.

AUTO_BACK (Reverse Movement): An emergency safety state triggered when an obstacle is detected within the critical distance threshold.

AUTO_TURN_LEFT/RIGHT: Directional pivoting states activated when an obstacle is detected on the opposite side (e.g., an obstacle on the left triggers a right turn).



Behavior-Based Control Model

The navigation system follows a Reactive Behavior Model, which prioritizes immediate safety over long-term path planning. This model is divided into three functional behaviors:

Reactive Behavior: Immediate response to sudden obstacles without decision-making delays.

Preventive Behavior: Early detection and speed adjustment to maintain a safety buffer.

Recovery Behavior: Executed when the robot is "trapped," involving sharp turns and reversing to escape dead-ends.

Motion Control Actions

The transition between states is physically manifested through differential drive control. By varying the speed and direction of the two geared DC motors, the system achieves precise maneuvers. For instance, in a "Sharp Turn," one motor is stopped while the other remains active, resulting in a quick pivot that is essential for navigating narrow corridors.

RESULTS AND DISCUSSION

The performance of the autonomous wheeled robot was systematically evaluated through a series of controlled indoor experiments. The primary objective was to validate the efficiency of the non-blocking state machine in navigating both static and dynamic obstacle environments.

Experimental Setup

Testing was conducted on a smooth, flat surface to ensure consistent mechanical performance. The environment was designed to simulate real-world scenarios, incorporating various obstacles such as boxes and barriers.

Static Obstacles: Fixed objects used to evaluate basic detection and path correction.

Semi-Dynamic Obstacles: Objects or moved during operation to test the real-time responsiveness of the asynchronous millis() loop.

Behavioral Analysis

The robot demonstrated high reliability in its "Sense-Act" cycle. Observation revealed that the non-blocking execution allowed the system to monitor sensor data continuously without the typical "lag" or "freezing" associated with delay-based code. Smooth Transitions: Transitions between AUTO_FWD, AUTO_TURN, and AUTO_BACK were seamless, maintaining system stability even in cluttered spaces.

Dead-end Recovery: When faced with obstacles on both sides, the robot successfully performed a reverse motion followed by a sharp pivot, effectively escaping confined areas.

Performance Metrics

The effectiveness of the system was measured based on two critical factors:

Response Time: The robot exhibited near-instantaneous reaction speeds, typically within a fraction of a second upon detection. This speed is a direct result of the high-frequency polling made possible by the non-blocking architecture.

Navigational Accuracy: The four-directional sensor configuration significantly reduced blind spots, allowing the robot to identify the safest path with a success rate of approximately 95% across multiple trials.

Discussion of Findings

The results confirm that the integration of a state machine and asynchronous timing significantly improves robotic autonomy. Compared to traditional delay-based systems, the proposed design eliminated system lag and improved real-time decision-making. While the system performed excellently in indoor settings, minor fluctuations were observed due to environmental noise affecting ultrasonic readings. These limitations suggest that while the non-blocking logic is highly effective, the physical detection range of ultrasonic sensors remains a constraint for larger, more complex environments.

• CONCLUSION

This research has successfully demonstrated the design and implementation of a robust Mobility and Autonomous Navigation System for a wheeled robotic platform. The study primarily addressed the critical limitations of traditional sequential, delay-based programming by introducing a Non-Blocking State Machine architecture. Experimental results validated that utilizing asynchronous timing through the millis() function ensures a continuous "Sense-Act" cycle, preventing CPU freezing and maintaining high-speed responsiveness. The integration of a multi-directional sensor array further enhanced the robot's perception, allowing for seamless state transitions including forward motion, emergency reversal, and precision pivoting. Ultimately, the proposed system provides a reliable and cost-effective framework for autonomous navigation in resource-constrained embedded environments.

Future Scope

To build upon the foundations laid in this research, several enhancements are proposed:

Advanced Perception: Integration of LiDAR or Vision-based sensors to provide high-resolution environmental mapping.

Mapping and Localization: Implementing Simultaneous Localization and Mapping (SLAM) to allow the robot to navigate and remember unknown environments.

Intelligent Decision-Making: Incorporating Machine Learning algorithms to enable the robot to "learn"from its environment and optimize its path planning over time.

IoT Integration: Connecting the platform to a cloud-based server for remote monitoring and swarm robotics coordination.

References

1. Abdulla, Z. A., & Hadi, N. H. (2025). Autonomous Path Planning and Obstacle Avoidance of a Wheeled Mobile Robot via Grey Wolf Optimization. Al Khwarizmi Engineering Journal, 21(2).
2. Schmid, K., et al. (2025). Reliable Autonomous Navigation in Unstructured Outdoor Terrain. Robotics and Autonomous Systems.
3. B. Venkata Sai Prasanna et al. (2024). Autonomous Path-Planning Robot Using LiDAR/Ultrasonic Sensors.
4. R. Kumar & P. Singh (2023). Real-Time Navigation of Mobile Robots Using Ultrasonic Sensors.
5. S. Patel & D. Shah (2023). Design of Obstacle Avoidance Robot Using Arduino.
6. P. Ramesh & K. Reddy (2024). Sensor-Based Autonomous Navigation System.
7. K. Jain & S. Agarwal (2022). Intelligent Mobile Robot Navigation System.