IJIRIS: International Journal of Innovative Research in Information Security
Volume 12, Issue 03, March 2026
E-ISSN: 2349-7017
P-ISSN: 2349-7009
https://www.ijiris.com/archives
https://doi.org/10.26562/ijiris.2025.v1203.17

Design and Implementation of a Slam-Based Autonomous Mobile Robot for Indoor Mapping

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Publication History
Manuscript Reference No: IJIRIS/RS/Vol.12/Issue03/ISMR26.MRIS10096
Research Article Open Access| Double-Blind Peer-Reviewed| Article ID: IJIRIS/RS/Vol.12/Issue03/ISMR26.MRIS10096
Received: 31, January 2026, Revised: 14, February 2026, Accepted: 17, March 2026, Published Online: 25,March 2026.
https://www.ijiris.com/volumes/Vol12/iss-03/17.ISMR26.MRIS10096.pdf **BibTeX Key: Dhiviya@2026Design**
Article Citation: Dhiviya,Avishkar,Sabari(2026), Design and Implementation of a Slam-Based Autonomous Mobile Robot for Indoor Mapping,IJIRIS: International Journal of Innovative Research in Information Security, Volume 12, Issue 03 of 2026 pages 167-169 **Doi:>** https://doi.org/10.26562/ijiris.2026.v1203.17
IJIRIS papers should be cited as IJIRIS (International Journal of Innovative Research in Information Security, AM Publications, India 2026, ISSN 2349-7017, https://doi.org/10.26562/ijiris.2026.v1203.17 The journal's official abbreviation is IJIRIS.
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Abstract: This project introduces an autonomous mobile robot aimed at improving indoor spatial analysis by utilizing Simultaneous Localization and Mapping (SLAM). The system integrates spatial sensors for real-time environment monitoring, an Arduino microcontroller for hardware interfacing, and MATLAB for executing complex mapping algorithms. The automated system adjusts its navigation based on detected obstacles, ensuring optimal localization and the generation of accurate, real-time indoor maps.

I. INTRODUCTION

Accurate indoor mapping is essential for navigation, spatial planning, and automation, particularly in complex or dynamic environments. Traditional manual mapping methods often fail to capture environments efficiently or adapt to real-time changes. This paper proposes an autonomous mobile robot that utilizes SLAM technology to monitor the environment in real-time, constructing an accurate floor plan while simultaneously tracking its own position within that space. The system aims to provide a highly efficient, responsive solution for generating dynamic indoor maps, serving as a safer and more precise alternative to manual surveying.

II. SYSTEM OVERVIEW

1. Spatial Data Intake Mechanism

The data intake system is designed to ensure continuous spatial scanning of the indoor environment. It relies on a suite of environmental distance sensors (such as LiDAR or ultrasonic sensors) that scan the surroundings without interruption. This mechanism ensures that fresh spatial data is consistently brought into the system for processing. By providing real-time data on the distance to walls and obstacles, the sensors allow for immediate detection and spatial monitoring, making the robot highly effective at navigating unfamiliar indoor environments.

2. Hardware Control Unit

The hardware control system is an essential component designed to manage the physical movement and raw data collection of the robot. An Arduino microcontroller plays a central role in the system by receiving raw data from the environmental sensors and processing it to control the robot's drive motors. The Arduino ensures that the robot responds promptly to immediate obstacles, optimizing performance and movement efficiency safely.

3. Smart Mapping & Processing

MATLAB is employed as the primary analytical engine for the system. It receives the constant stream of telemetry and distance data routed through the Arduino. Within MATLAB, the SLAM algorithms process the data to make real-time decisions about the robot's localization. The algorithm calculates the robot's precise coordinates while simultaneously drawing the boundaries of the room. This automated processing ensures that the mapping is always optimized according to the live sensor data.

4. Power Efficiency & Mobility

The system is designed with a strong emphasis on energy efficiency, utilizing low-power motor drivers and localized processing to optimize navigation without excessive energy consumption. By using energy-efficient components, the robot can operate for extended mapping sessions, providing continuous area mapping without frequent recharges.

III. Detailed Hardware Specifications

To achieve reliable autonomous mapping, the physical architecture of the robot is divided into sensory, control, and actuation modules:

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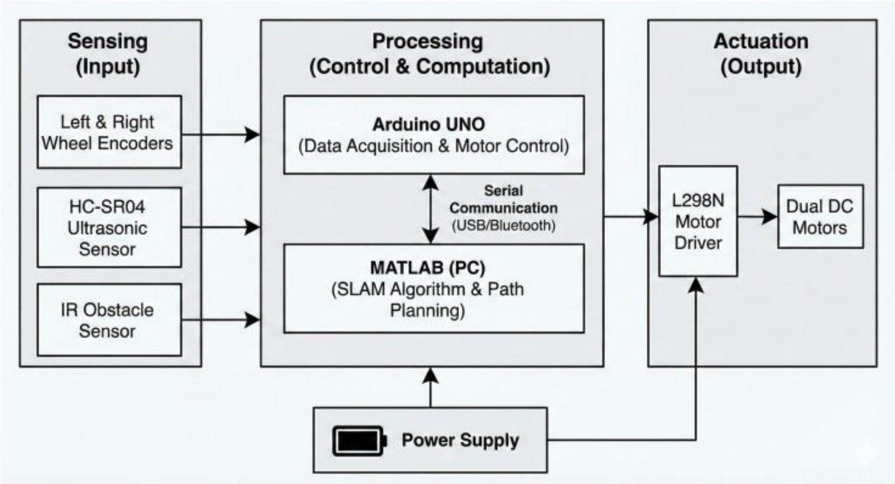


Microcontroller Unit (MCU): An Arduino board serves as the primary low-level hardware interface. It is responsible for high-frequency polling of the sensors and translating directional commands into pulse-width modulation (PWM) signals for the motor drivers.

Distance Sensors: The environment is scanned using distance-measuring sensors. These components return time-of-flight data, which the Arduino scales into metric distances before transmitting the arrays via serial communication to the main processing unit.

Actuation and Odometry: The chassis is driven by DC motors equipped with rotary encoders. These encoders provide essential odometry data measuring wheel rotation to estimate the robot's relative change in position over time.

IV. Software and Algorithmic Framework

The software architecture is split between localized hardware control and heavy computational processing.

Data Acquisition Layer (Arduino): The microcontroller runs a continuous loop that aggregates encoder ticks (for odometry) and sensor pings (for obstacle detection).

SLAM Processing Layer (MATLAB): The aggregated raw data is sent to MATLAB, which handles the probabilistic calculations required for SLAM. The algorithm continually updates the robot's estimated state (pose) and the map. The kinematic state of the robot at any given time step t can be represented by the transition model:

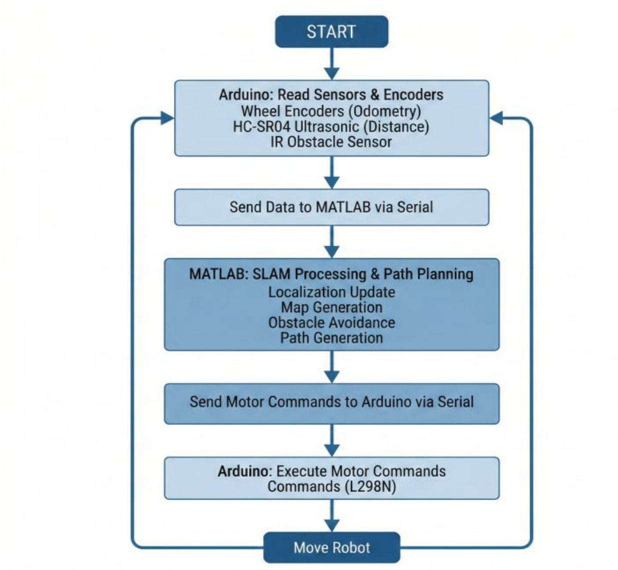
$$x_t = f(x_{t-1}, u_t) + w_t$$

Where x_t is the current state, x_{t-1} is the previous state, u_t is the control input (odometry), and w_t represents the process noise or uncertainty. MATLAB's mapping toolboxes use this data alongside the sensor readings to continually correct the robot's trajectory and plot the environmental boundaries.

V. METHODOLOGY

The system is designed to integrate multiple components that work together seamlessly to map the indoor space in real time. The key workflow is as follows:

Sensors: Continuously monitor the environment to detect the presence and distance of physical obstacles.



Microcontroller (Arduino): Gathers the real-time data from the sensors and handles the low-level locomotion of the chassis, adjusting wheel speed and direction in response to immediate physical barriers.

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Processing Software (MATLAB): Takes the aggregated sensor data to perform the heavy computational lifting required by SLAM. It plots the data points into a cohesive map and calculates the robot's current position within that newly generated map.

VI. RESULTS

The proposed system demonstrated the successful detection of obstacles and the accurate rendering of indoor spaces. The sensors effectively tracked spatial boundaries, while the Arduino and MATLAB integration successfully allowed the robot to navigate and map the environment simultaneously.

VII. DISCUSSION

The proposed automated SLAM robot offers significant improvements over traditional spatial mapping methods. Traditional systems primarily rely on passive or manual measurements, which are time-consuming and prone to human error. In contrast, the automated system continuously maps the area in real-time, providing accurate and timely data on the room's layout. The integration of Arduino and MATLAB allows for continuous data collection and heavy algorithmic analysis. Despite these advancements, the system does have some limitations. One key consideration is the processing overhead required by MATLAB for highly complex environments, which can sometimes introduce latency.

VIII. FUTURE ENHANCEMENTS & ARCHITECTURAL MIGRATION

While the current Arduino and MATLAB integration effectively demonstrates the core principles of SLAM, scaling the robot for more complex, dynamic environments requires a more robust computational framework.

Future iterations of this project will transition the software stack to a Linux-based environment to utilize ROS 2 (Robot Operating System). Moving away from MATLAB, the core SLAM algorithms and navigation nodes will be developed using C++ and Python. This migration will allow for decentralized node communication, better handling of high-bandwidth sensor data (like 3D LiDAR or depth cameras), and the implementation of more advanced path-planning algorithms. By adopting this industry-standard architecture, the robot will achieve a higher degree of autonomy and processing efficiency.

IX. CONCLUSION

This project successfully demonstrates the integration of distance sensors, an Arduino microcontroller, and MATLAB-driven SLAM algorithms to create an advanced autonomous mapping robot. By combining real-time spatial monitoring with efficient locomotion techniques, the system can detect boundaries and navigate indoor environments seamlessly. This approach not only ensures highly accurate floor plan generation but also serves as a robust foundation for more complex autonomous robotics tasks.

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