Design and Development of an Autonomous Floor Cleaning Robot Using Arduino-Based Control System

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Abstract—This research presents the design, fabrication, and performance evaluation of a low-cost autonomous floor cleaning robot intended for domestic and small commercial environments. The proposed system integrates a microcontroller-based control unit with ultrasonic and infrared sensors for obstacle detection and edge prevention. A rotating brush mechanism combined with a suction unit is used to remove dust and debris from floor surfaces. A zigzag path planning algorithm is implemented to improve coverage efficiency and reduce repeated cleaning of the same area. Experimental testing in different indoor environments demonstrated floor coverage above 90% with satisfactory cleaning performance and stable operation. The developed robot offers an economical and practical solution for automated floor maintenance.

Index Terms—Autonomous robot, Floor cleaning system, Obstacle avoidance, Path planning, Arduino microcontroller, Indoor robotics, Smart cleaning robot

I. INTRODUCTION

Robotics and automation technology have brought about a number of innovations in both domestic and industrial sectors. One of the most mundane activities carried out in homes and offices is the floor cleaning, which can be greatly facilitated through robotics. In the recent years, considerable research interest has been drawn towards autonomous floor cleaning robots, whose operation does not require any direct human participation [1].

Traditionally, cleaning process requires considerable physical labor and time, especially in cases of large indoor areas such as offices, shopping malls, hospitals, and other spaces. However, robots may become an ideal solution to the problem by providing high-quality cleaning services consistently and efficiently. A number of sensors, actuators, and decision-making algorithms enable such robots to detect obstacles, analyze surroundings and plan an optimal way of movement [2].

The floor cleaning robot presented in this paper aims to tackle several crucial issues associated with autonomous cleaning operations. Namely, those include efficient navigation and obstacle detection. This is achieved by using two types of sensors, microcontrollers and motors driving the robot's motion. Moreover, a number of actuators facilitate cleaning process itself through removing dust and dirt from the floor surfaces.

This paper is organized as follows: First, in Section II, the existing technologies in the field of autonomous floor cleaning will be briefly reviewed. Second, the hardware and software design of the proposed robot will be outlined in Section III. In turn, Section IV provides control algorithm of the robot and its navigation strategy.

II. LITERATURE REVIEW

The following research has greatly contributed to the creation of automated floor cleaning machines. Forlizzi and DiSalvo [3] conducted an ethnographic investigation into the Roomba robot vacuum cleaner, as well as studying the robot acceptance by analyzing how people adjusted their behaviors to overcome the constraints of the cleaning robot. Their findings underlined the importance of intuitiveness and reliability in domestic robotic devices.

Moreover, Hasan et al. [4] designed an automated microcontroller-controlled floor cleaning robot using IR sensors and wet cleaning mechanisms. Their experiments showed that the device exhibited satisfactory results on tiles and wooden floors, reaching approximately 80% floor coverage rate. Nevertheless, the robot's inefficient coverage strategy led to repeated covering of some parts of the area.

Jones [5] performed a survey of commercial robotic vacuum cleaners and provided an overview of technology development ranging from reactive robotic cleaners to advanced SLAM navigation based ones. The review pointed out that cost-efficient solutions remain a great challenge because of the high price of such hardware devices as LiDAR and depth cameras for precise localization of robots.

In addition, Tribelhorn and Dodds [6] investigated the capabilities of the Roomba robot and came up with an algorithm improving coverage rates through optimized zigzag and spiral coverage techniques. These techniques are extensively mentioned in subsequent research as efficient solutions for unknown indoor spaces.

Finally, current studies are devoted to the implementation of intelligent machine learning algorithms in the process of automatic floor cleaning using cameras and computer vision [7]. While such technologies enhance cleaning efficiency, they require significant computational power and complex sensor systems, which makes them impractical for low-budget household cleaning robots.

III. METHODOLOGY

The development of the autonomous floor cleaning robot followed a systematic engineering approach consisting of design, fabrication, programming, and performance evaluation stages. The objective of the methodology was to ensure reliable navigation, efficient cleaning, and safe operation of the robot in indoor environments. The process began with identifying system requirements such as mobility, obstacle detection, cleaning mechanism, and power supply. After defining the requirements, suitable hardware components including motors, sensors, microcontroller, and battery were selected based on cost, availability, and performance.

The mechanical structure of the robot was designed using a circular chassis to provide balanced movement and easy turning. Electronic components such as ultrasonic sensors, infrared sensors, motor drivers, and control circuits were integrated into the system. Programming of the microcontroller was carried out using embedded C language to control motor movement, sensor response, and cleaning operation. A zigzag path planning algorithm was implemented to maximize floor coverage while minimizing repeated movement over the same area.

After assembling the system, testing was performed in different indoor environments to evaluate parameters such as floor coverage percentage, cleaning efficiency, battery life, and obstacle avoidance capability. The results were analyzed to verify system performance and identify areas for improvement

IV. SYSTEM DESIGN

A. Hardware Architecture

The robotic system of the floor cleaning robot contains four main systems including the locomotion subsystem, the sensing subsystem, the cleaning subsystem, and the control subsystem. The design of these subsystems is combined together on the circular chassis whose diameter is equal to 30 cm. The architecture diagram of the proposed system is illustrated in Fig. 1.

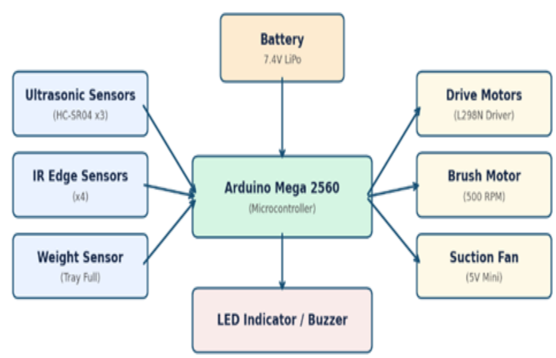

Fig. 1. Block Diagram of Floor Cleaning Robot System Architecture.

The locomotion subsystem uses two DC gear motors with rubber wheels which can be driven independently by using the L298N dual H-bridge motor driver module. This module allows adjusting the speed and the rotation direction of each motor. With the help of such a combination, straight, arc, and even turning around its axis becomes possible.

B. Sensing Subsystem

In order to recognize obstacles located in the range from 2 cm to 400 cm, three HC-SR04 ultrasonic sensors are fixed on the chassis at the front, front-left, and front-right locations. For detecting step edges and preventing robot’s fall from stairs or other raised floors, the system incorporates four infrared proximity sensors which are placed on the bottom edge of the chassis. The robot chassis and all components position diagram can be viewed from Fig. 2.

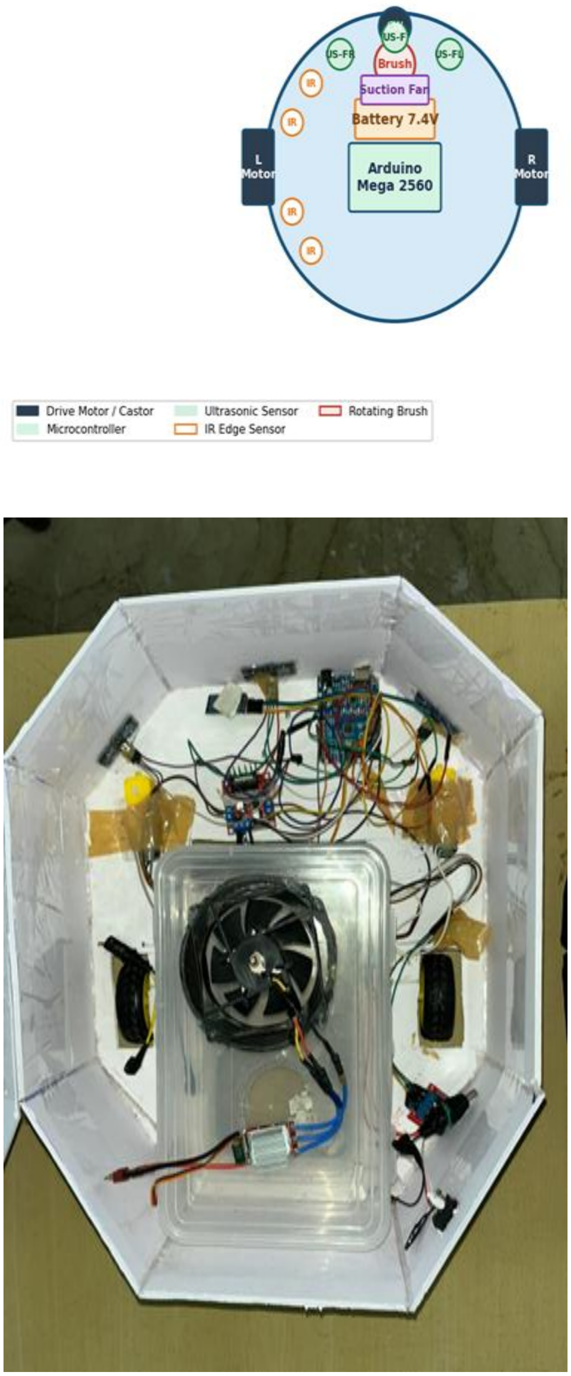

Fig. 2. Top-View Schematic of Robot Chassis and Component Layout.

C. Cleaning Subsystem

The cleaning mechanism involves the use of a nylon rotating brush assembly powered by a small DC motor running at 500 RPM. The brush is mounted at the center-front portion of the chassis and collects dust by sweeping towards a collection tray placed underneath the robot's body. There is also a 5V mini centrifugal fan that creates a suction force to allow fine dust particles to be collected in the collection tray lined with replaceable filter paper.

The brush assembly is easily detached and replaced after cleaning. The size of the collection tray is about 150mL, capable of holding fine dust for about 30 minutes' worth of work in a dusty environment. An LED will illuminate to indicate to the user that the tray needs to be emptied.

D. Control Subsystem

The control subsystem utilizes the Arduino Mega 2560 microcontroller development board, having 54 digital input/output pins, 16 analog inputs, and other serial interfaces like UART, I2C, and SPI. The microcontroller runs the path planning algorithm to direct operation of all subsystems at 50Hz.

The system is powered by a 7.4V 2000 mAh Li-Po battery. Power to the microcontroller and various sensors is provided by a power regulation module delivering 5V and 3.3V output. Monitoring of the battery voltage using an analog input pin enables the robot to recharge from its docking station when battery voltage reaches the low threshold point.

V. CONTROL ALGORITHM AND PATH PLANNING

A. Obstacle Avoidance Algorithm

Obstacle avoidance follows the reactive control model where in case the front ultrasonic sensor detects an obstacle within 20 cm distance range, the robot stops moving forward and calculates the distance on the left side and on the right side. The robot makes a turn towards the side with more clearance. The flowchart of the obstacle avoidance process is illustrated in Fig. 3.

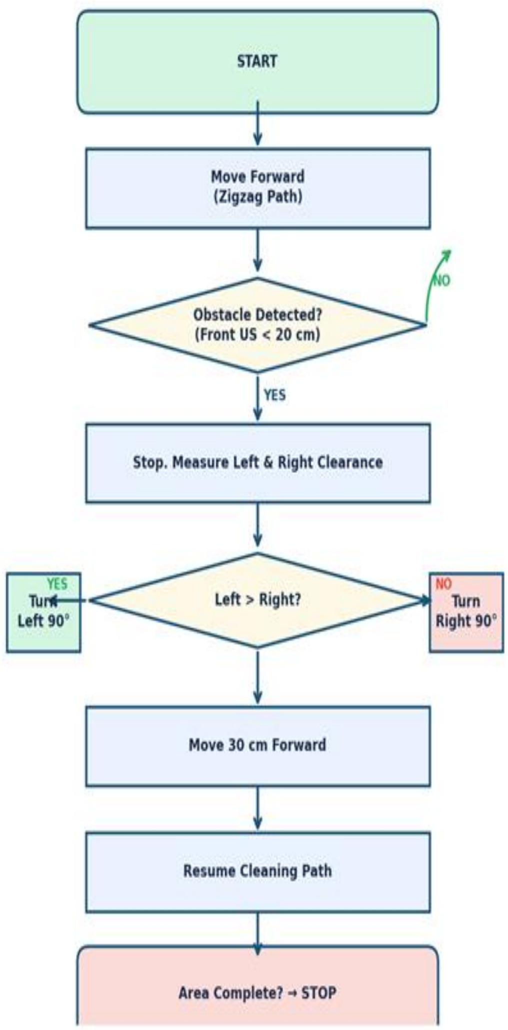

Fig. 3. Obstacle Avoidance Control Flowchart.

The robot performs a 90-degree turn in place and moves along a straight line for 30 cm before returning to its main cleaning path. It prevents the robot from leaving uncovered areas while returning back to the initial path. This method of avoiding obstacles has a recovery timer set for 2 seconds to prevent oscillations when working in a crowded environment.

B. Path Coverage Strategy

The first step in coverage is a boustrophedon (zigzag) covering algorithm that divides the cleaning surface into strips of the same width as the robot's body size. The robot moves along a strip from end to end, and after that, it advances to the next strip of the opposite direction. The illustration of this algorithm is presented in Fig. 4.

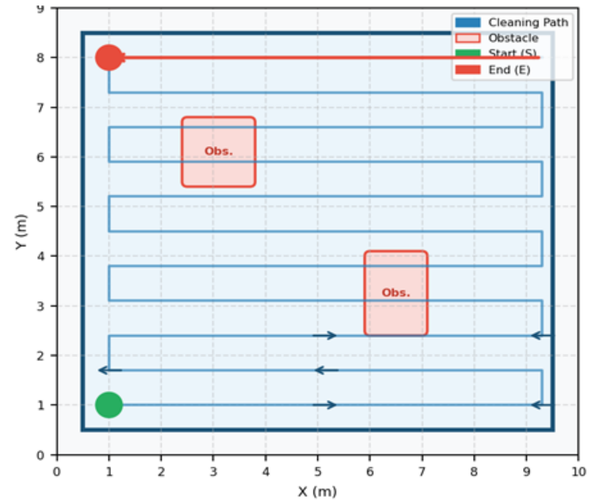

Fig. 4. Boustrophedon (Zigzag) Path Coverage Strategy with Obstacle Avoidance.

Firstly, the robot performs a clockwise perimeter scan of the room and defines the exact dimensions of the cleaning area using wall following algorithm. This information is saved in the microcontroller's memory for further application in the zigzag covering stage. After completing the process, the robot returns to its charging station using the spiral return approach..

VI. FUTURE SCOPE

The developed floor cleaning robot provides a foundation for further improvements and advanced automation features. Several enhancements can be implemented to increase efficiency, intelligence, and user convenience in future versions of the system.

1. Integration of Wi-Fi and Mobile Application Control: Future models can include wireless communication technology to allow users to monitor and control the robot remotely using a smartphone application.
2. Implementation of Camera-Based Navigation: A camera system combined with image processing techniques can be used to detect dirt locations and improve navigation accuracy.
3. Automatic Charging Docking System: The robot can be designed to automatically return to a charging station when the battery level becomes low, ensuring uninterrupted operation.
4. Artificial Intelligence and Machine Learning: Machine learning algorithms can be implemented

to enable the robot to learn room layouts and optimize cleaning paths over time.

5. Improved Cleaning Mechanism: Future versions may include advanced vacuum systems, water spraying units, and mopping functions for enhanced cleaning performance.
6. **Use** of Low-Cost LiDAR or SLAM Technology: Advanced localization techniques can be used to improve navigation accuracy and mapping of indoor environments.

VII. EXPERIMENTAL RESULTS

Three different test environments were chosen for evaluating the floor cleaning robot. They included a 3m x 4m tiled kitchen floor, 4m x 5m carpeted bedroom, and 5m x 6m office space with mixed flooring. Metrics such as floor coverage percentage, cleaning efficiency, operation time, and battery life were considered in the analysis.

In the tiled kitchen floor, the robot covered 93% of the cleaning area within 12 minutes with cleaning efficiency of 88% regarding fine dust particles. In the carpeted bedroom, the robot managed to cover 89% of the floor space within 15 minutes with an efficiency of 79%. As the carpet fibers hindered the rotation of the brushing system, some particles remained on the surface. Finally, in the office environment, the robot covered 91% of the area within 22 minutes with an efficiency rate of 85%. The comparative results of the experiment performed in three environments are illustrated in Fig. 5.

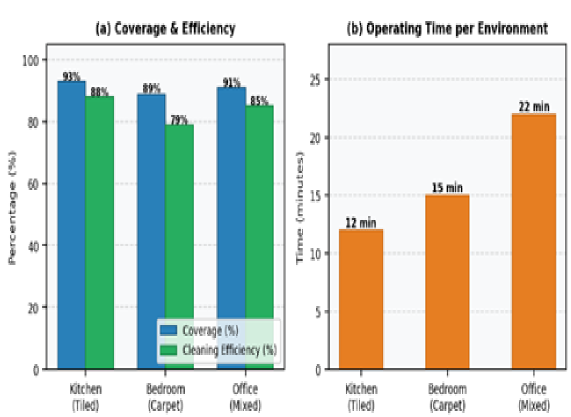

Fig. 5. Experimental Performance Results: (a) Coverage and Cleaning Efficiency, (b) Operating Time per Environment.

The operating time of the battery was calculated to be around 45 minutes under normal conditions. Obstacle avoidance proved to be successful even against static obstacles with zero collision cases during testing. The edge detection sensors effectively prevented any falls from step edges in all tests performed.

A comparative study between the proposed system and low-cost floor cleaning robots [4], [6] suggests that the boustrophedon coverage algorithm with boundary pre-mapping is about 10-15% more efficient in terms of floor surface coverage compared to random walk-type methods. With the cost of the entire set of components being about INR 3,500 (approximately $42), this cleaning robot is quite competitive among the existing commercial low-end alternatives.

VIII. CONCLUSION

This article describes the design and implementation The proposed autonomous floor cleaning robot demonstrates dependable performance for indoor cleaning applications. The combination of ultrasonic and infrared sensors enables safe navigation and effective obstacle detection during operation. The zigzag movement strategy improves coverage efficiency and reduces unnecessary repetition of cleaning paths. Experimental testing confirms that the system provides satisfactory cleaning results while maintaining low manufacturing cost and simple design. The developed robot can serve as a practical solution for automated cleaning in residential and small commercial environments. Further improvements in sensing, communication, and navigation technologies can enhance system performance and functionality in future developments.

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