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Development of Smart Multifunction Floor Cleaning Robot

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ABSTRACT—

Floor cleaning is a repetitive task that requires time and physical effort, particularly when sweeping, wet cleaning, and drying are performed separately. This paper presents the design and implementation of a low-cost Smart Multifunction Floor Cleaning Robot (SMFCR) based on an ESP32 controller. The prototype integrates four-wheel drive mobility, Bluetooth Classic serial control, a water-spraying pump, a rotating microfiber mop, and a forced-air blower. Three ultrasonic sensors have been added to the updated prototype to support front and side obstacle detection and reactive avoidance. The system uses a 12 V battery for the drive and cleaning actuators, with a buck converter providing a regulated logic supply. The paper describes the hardware architecture, control approach, cleaning sequence, and observed prototype performance. The design emphasizes modularity, local wireless operation, and affordability for educational and small indoor-cleaning applications.

Keywords— Floor cleaning robot, ESP32, Bluetooth SPP, ultrasonic sensor, obstacle avoidance, wet mopping, air drying, embedded system.

1. INTRODUCTION

Maintaining clean indoor floors is important in homes, educational institutions, offices, and public buildings. Conventional methods rely on separate tools and manual effort for sweeping, wet mopping, and drying. These stages can increase cleaning time and expose users to repetitive physical work. Commercial autonomous cleaners provide advanced navigation but may be expensive and often depend on proprietary software or network services.

Recent embedded controllers and compact DC actuators make it practical to build smaller, affordable cleaning robots. This work develops a multifunction platform that combines movement, water dispensing, mechanical scrubbing, and forced-air drying. Smartphone commands are transmitted over Bluetooth Classic Serial Port Profile (SPP), allowing local control without Wi-Fi or cloud access. The updated prototype also includes three ultrasonic sensors for reactive obstacle detection.

A. Project Objectives

The objectives are to integrate the cleaning functions on one mobile chassis; provide manual movement and actuator control through a smartphone; add ultrasonic-based front and side obstacle detection; distribute power safely between the controller and higher-current loads; and evaluate the integrated prototype through practical cleaning trials.

2. RELATED WORK

Mobile-robot design literature describes the importance of locomotion control, sensor feedback, and reliable motion estimation for indoor navigation [1]. Low-cost educational platforms commonly use DC gear motors with H-bridge drivers, while ultrasonic ranging provides a simple means of estimating nearby obstacle distance [5]. Bluetooth serial communication is suitable for short-range command transfer when local operation and straightforward implementation are priorities. These methods are less sophisticated than map-based navigation, but can reduce cost and implementation complexity for a student prototype.

The present system differs from single-function sweepers by integrating water spraying, mechanically driven microfiber mopping, and assisted drying in the same chassis. Its navigation is reactive rather than map-based: ultrasonic measurements are compared with a threshold and the robot stops or changes direction when an obstacle is detected. This approach is appropriate for controlled indoor demonstrations, although it does not provide global path planning or room mapping.

3. PROPOSED SYSTEM ARCHITECTURE

The ESP32 acts as the main controller. It receives Bluetooth commands, reads the ultrasonic sensors, and controls the drive motors and cleaning actuators. The drive subsystem uses four DC gear motors connected through an L298N dual H-bridge motor driver. A relay module switches the water pump and blower, while the mop motor is controlled as a separate actuator. A 12 V,

7 Ah sealed lead-acid battery supplies the main power bus; an LM2596 buck converter provides a regulated 5 V rail for compatible logic and sensor modules. Common grounding and suitable wiring are required, and actuator current must remain within the ratings of the driver, relays, and supply.

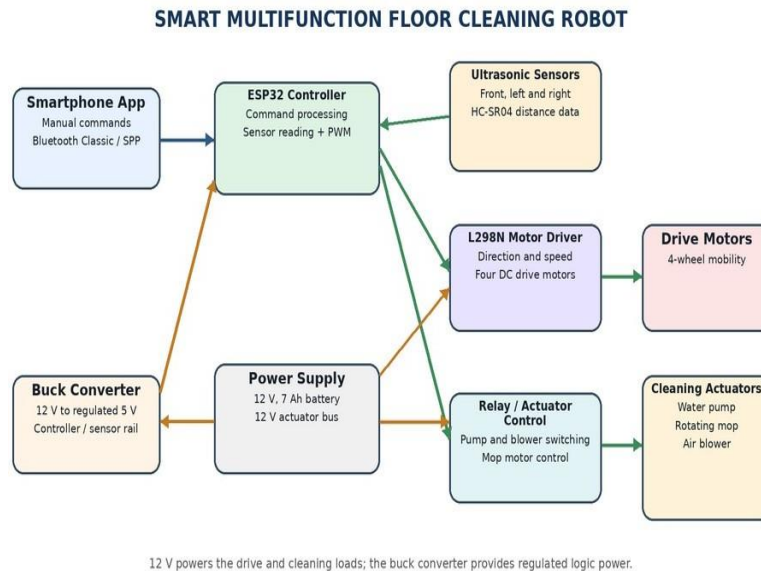


Fig. 1. System-level architecture of the Smart Multifunction Floor Cleaning Robot.

The updated sensing arrangement uses three HC-SR04 ultrasonic modules positioned at the front, left, and right of the robot. The controller obtains distance readings and compares them with a configurable threshold. When the front path is blocked, the robot stops and selects a free direction based on side readings; if neither side is clear, it remains stopped until the path becomes available. Ultrasonic sensors support short-range reactive avoidance but can be affected by surface angle, soft materials, and sensor cross-talk.

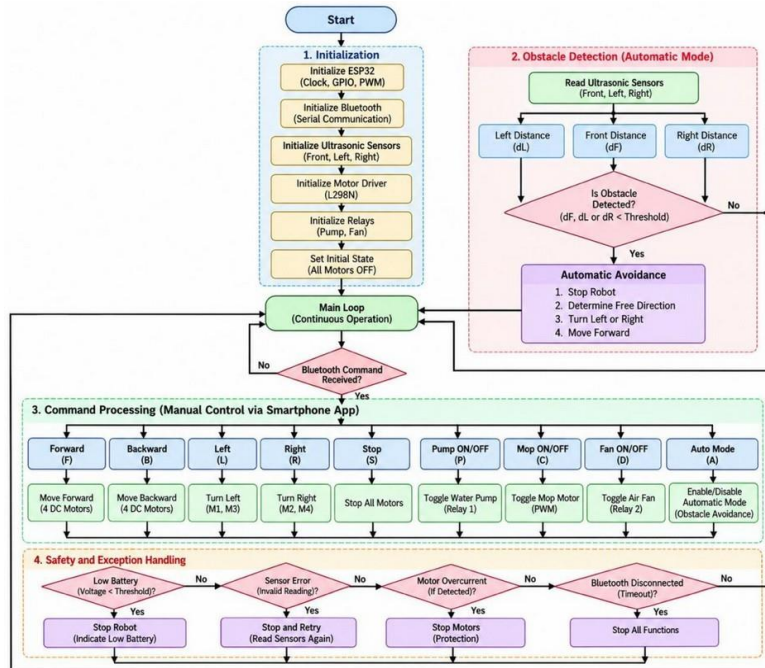


Fig. 3. Software Control Flowchart of Smart Multifunction Floor Cleaning Robot.

Fig. 2. Software control flow, including ultrasonic obstacle detection and command processing.

4.. HARDWARE IMPLEMENTATION

A. Controller and Drive System

The ESP32 DevKit provides GPIO, PWM, and Bluetooth Classic capabilities [2]. The L298N driver [3] receives direction and enable signals from the controller and drives the four-wheel platform through its motor outputs. PWM can be used to adjust motor speed where supported by the wiring and firmware. The motor supply is taken from the 12 V bus; the controller is powered from a regulated supply according to the specific board requirements.

B. Cleaning Actuators

A 12 V R385 diaphragm pump delivers water or cleaning solution to the floor through a nozzle. A DC motor rotates a microfiber mop to provide mechanical scrubbing. After wet cleaning, a 12 V DC blower directs air toward the cleaned surface to assist moisture removal. These functions can be switched individually or operated in sequence. Water flow, mop pressure, and drying performance depend on the floor material, liquid quantity, battery state, and actuator condition.

C. Power and Protection

The battery feeds the actuator bus and the buck converter. The ESP32 GPIO pins should not directly drive high-current loads; the relay module and motor driver provide the required switching interfaces. Protective measures should include secure battery connections, correct polarity, adequate wire gauge, appropriate fusing, and keeping water away from exposed electronics. The final design should be checked against the actual module ratings before extended operation.

5. SOFTWARE AND WIRELESS CONTROL

Firmware is developed in the Arduino IDE using the ESP32 support package [4]. The software initializes GPIO pins, PWM outputs, Bluetooth serial communication, ultrasonic sensing, and actuator states. The main loop repeatedly checks incoming commands and updates motor and actuator outputs. A non-blocking scheduling approach is preferred so that sensor readings and Bluetooth commands remain responsive while cleaning functions operate.

The smartphone interface provides directional commands (forward, backward, left, right, and stop), individual controls for the pump, mop motor, and blower, and an automatic mode for obstacle avoidance. In automatic mode, the controller checks the front and side distances and issues a stop-and-turn response when a nearby obstacle is detected. If Bluetooth communication is lost, the safer behavior is to stop movement and disable cleaning actuators until control is restored.

PHYSICAL PROTOTYPE



Fig. 3. Photographs of the physical prototype showing the assembled chassis and internal components.

6. RESULTS AND DISCUSSION

Prototype trials demonstrated integration of the four-wheel drive, pump-based water delivery, rotating microfiber mop, blower, Bluetooth control, and ultrasonic obstacle sensing. The cleaning sequence consists of movement toward the target area, controlled water spraying, mechanical mopping, and assisted drying. The sequence can be run as a combined cycle or tested by activating each subsystem separately. The supplied cleaning-performance graphic reports higher post-cleaning scores than pre-cleaning scores for dust, mud, liquid spills, oil stains, food particles, and general dirt; these values should be interpreted as project-test observations rather than standardized laboratory measurements unless the test protocol and repeated-trial data are documented.

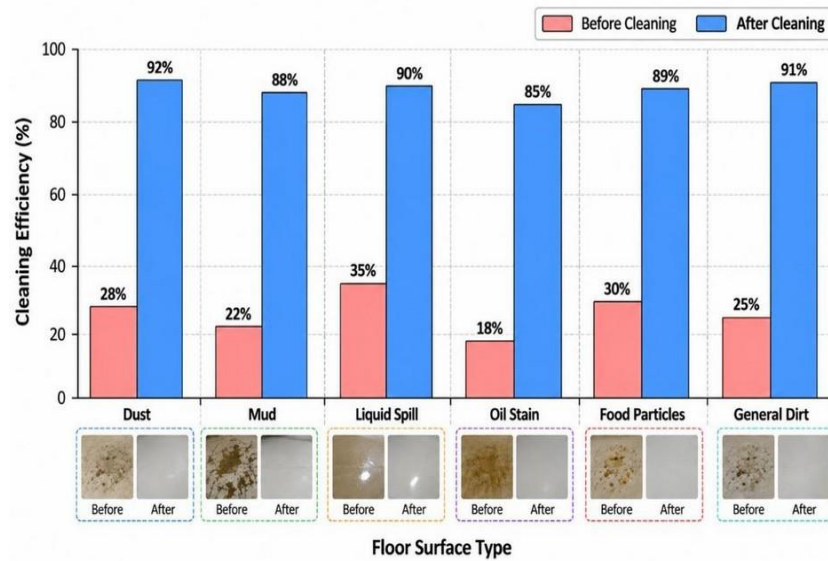


Fig. 6. Cleaning Performance Comparison of Different Types of Floor Contaminants (Before and After Cleaning).

Fig. 4. Reported cleaning-efficiency comparison before and after cleaning for six contaminant types.

The supplied test summary also illustrates that water use and drying time vary by floor surface. Porous or rough surfaces may require more liquid and longer drying than smooth surfaces. Battery voltage decreases as operating time and actuator load increase; simultaneous operation of the drive motors, pump, mop, and blower draws more current than navigation alone. Therefore, actual runtime depends on the selected operating mode and battery condition.

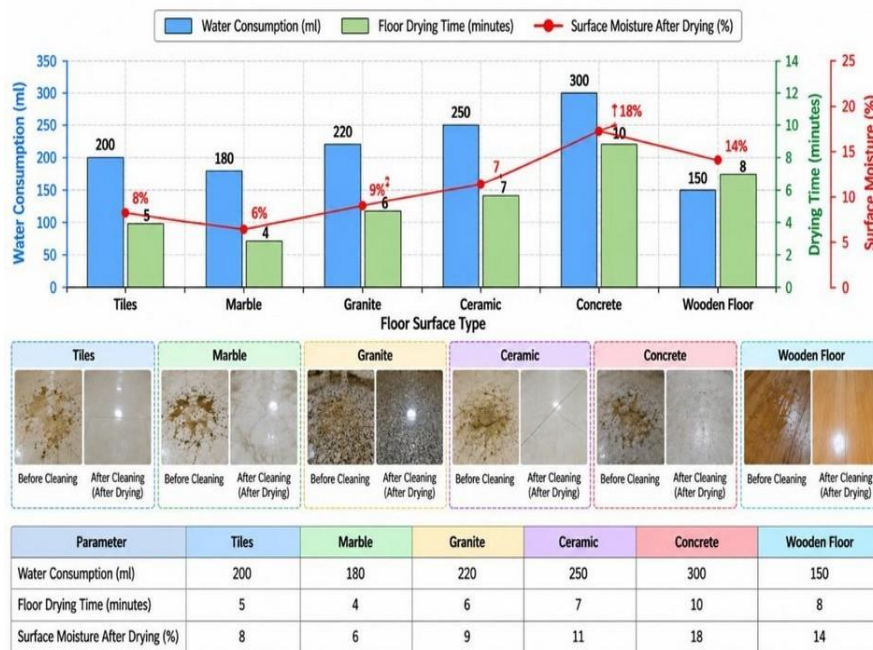


Fig. 8. Water Consumption and Floor Drying Time Analysis for Different Floor Surface Types.

Fig. 5. Reported water consumption, drying time, and residual surface moisture for different floor types.

The project record presents comparative graphics for six contaminant categories and six floor-surface types. However, the available material does not fully specify repeated-trial counts, contaminant mass, test area, water dose, measurement calibration, or uncertainty. The plotted values are therefore reported as preliminary project observations, not as standardized laboratory benchmarks. A stronger evaluation should hold the floor area, contaminant quantity, water delivery, operating time, and battery condition constant, repeat each test several times, and report mean values with variation.

The prototype is intended for small indoor areas and educational demonstrations. It is not a replacement for commercial scrubbers or certified autonomous cleaning systems. Current limitations include reactive rather than mapped navigation, manual charging and water refilling, sensitivity of ultrasonic

readings to surface angle and soft materials, and the need for more repeatable quantitative testing. In addition, the three ultrasonic sensors require careful placement and timing to reduce cross-talk, while the battery, motor driver, relay contacts, and wiring must be rated for the combined actuator load. These limitations define practical priorities for the next development stage.

CONCLUSION AND FUTURE SCOPE

A Smart Multifunction Floor Cleaning Robot has been developed by integrating four-wheel mobility, Bluetooth-based local control, water spraying, rotating microfiber scrubbing, forced-air drying, and three-zone ultrasonic obstacle detection. The modular design provides a practical platform for learning embedded control, motor interfacing, sensor integration, and mobile robotics. The use of Bluetooth avoids dependence on Wi-Fi or cloud services, while the ultrasonic sensors provide basic reactive obstacle avoidance.

Future work can improve navigation with wheel encoders and systematic coverage planning; add water-level and battery monitoring; measure cleaning effectiveness with a repeatable test protocol; optimize pump flow and blower direction; and add a safer charging arrangement. Performance claims should be supported by multiple trials, calibrated measurements, and clearly reported test conditions.

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