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Autonomous Floor Cleaning Robot

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Abstract: In today's fast-paced world, maintaining clean indoor environments efficiently and with minimal human effort has become essential. This paper presents the design and implementation of an Autonomous Floor Cleaning Robot that combines smart automation, obstacle detection, IoT-based remote control, and solar-powered energy efficiency. The robot is built using an ESP32 microcontroller, ultrasonic sensors for real-time obstacle avoidance, and motorized components for navigation and cleaning. A dual- mode system allows the robot to operate autonomously or be manually controlled via the Blynk mobile application. The cleaning mechanism includes a rotating mop and water spray system, enabling both dry and wet cleaning capabilities. A solar panel supplements power to extend operation and reduce dependency on external charging. The system is designed to be cost-effective, environmentally friendly, and suitable for domestic and small commercial applications. Experimental results demonstrate reliable obstacle detection, effective dust removal, and seamless remote control via IoT, making the robot a practical and scalable solution for modern floor cleaning challenges.

Keywords: *Autonomous Robot, Floor Cleaning, IoT, ESP32, Ultrasonic Sensor, Blynk App, Obstacle Detection, Solar-Powered, Home Automation, Smart Cleaning, Embedded Systems.*

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I. INTRODUCTION

In recent years, the demand for smart home automation has significantly increased, driven by the need for convenience, efficiency, and sustainability. Floor cleaning, a routine yet time-consuming task, has seen technological advancements in the form of robotic cleaning systems. However, many existing solutions are either expensive, lack intelligent navigation, or do not support remote monitoring and control.

This paper presents the design and development of an Autonomous Floor Cleaning Robot aimed at addressing these limitations. The robot is equipped with an ESP32 microcontroller for centralized control and wireless communication, ultrasonic sensors for obstacle detection and navigation, and a motorized cleaning system that includes both vacuuming and mopping functions. A solar panel is integrated to enhance energy efficiency and promote eco-friendly operation. Additionally, the robot supports IoT-based remote control through the Blynk application, enabling real-time monitoring and manual operation via a smart phone.real-time video feeds from often struggle to navigate surveillance cameras installed at traffic intersections to detect ambulances and automatically control traffic signals, prioritizing emergency vehicles. . This approach reduces response time, improves traffic flow, and enhances emergency response efficiency

The robot operates in both manual and automatic modes, making it adaptable to various user preferences and environmental conditions. Its ability to autonomously map and clean an area with minimal human intervention, coupled with its low-cost and scalable design, makes it a practical solution for residential, commercial, and institutional applications. This project exemplifies the integration of embedded systems, wireless communication, and automation in creating a sustainable and smart cleaning solution.

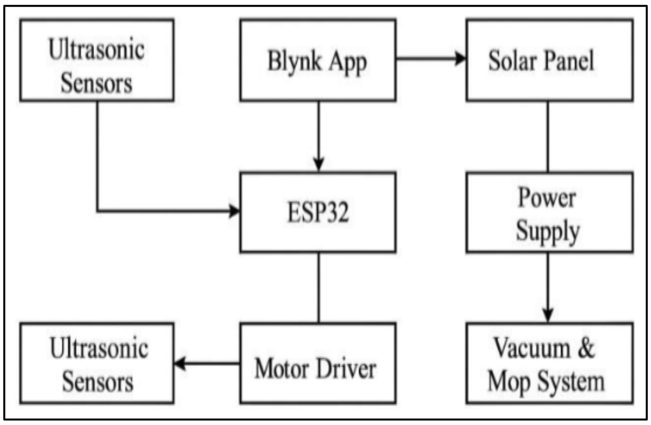

Fig 1 Architecture Floor Cleaning Robot

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II. METHODOLOGY

The methodology for developing the Autonomous Floor Cleaning Robot involves a comprehensive approach encompassing system design, hardware integration, software programming, and performance validation. The project aims to deliver an efficient and intelligent cleaning solution capable of operating both autonomously and through user control. This is achieved by combining embedded systems with IoT functionality and energy-efficient design using a solar power supply.

At the core of the system is the ESP32 microcontroller, which serves as the processing unit and communication hub. It coordinates various modules including the ultrasonic sensors, motor driver, relay switches, and the IoT interface. The ESP32 is selected for its dual-core architecture, integrated Wi-Fi, and support for real-time operations, making it ideal for controlling and monitoring robotic functions. The ultrasonic sensors are placed strategically at the front of the robot to provide obstacle detection. These sensors continuously scan the surroundings and send distance measurements to the microcontroller, which in turn makes decisions for path correction or halting movement.

The robot uses DC motors connected via an L293D motor driver for movement. These motors are driven in pairs, enabling differential steering that allows the robot to navigate forward, backward, and rotate in place. The motor driver acts as an interface, amplifying the low-power control signals from the ESP32 into sufficient current and voltage needed to drive the motors. For cleaning, the robot is equipped with a dual- function mechanism: a mop motor for dry cleaning and a water spray system for wet mopping. These components are controlled using a two-channel relay module, allowing independent operation of the cleaning mechanisms based on real-time requirements.

The software for the robot is developed using the Arduino IDE with the C/C++ programming language. It incorporates two operational modes: automatic and manual. In automatic mode, the robot starts by initializing its components and scanning for obstacles. If no obstruction is detected, the robot moves forward while simultaneously activating its cleaning systems. On detecting an obstacle, the robot stops, evaluates the available space, and changes its direction based on a predefined zigzag or spiral logic. This ensures that the entire floor is covered efficiently. The cleaning mechanisms—water spray and mop—are activated only during forward movement to optimize power usage and improve cleaning effectiveness. In manual mode, the robot connects to the Blynk IoT platform via Wi-Fi. A user can control the robot remotely using a smartphone app. The app interface provides buttons for directional movement (forward, backward, left, right) and toggles for activating or deactivating the mop and water spray. The ESP32 receives these commands in real time, executes them, and returns feedback to the user, such as battery level or obstacle detection alerts. This dual-mode operation makes the robot versatile and suitable for varied user preferences and floor layouts. Power management is a critical aspect of the system. A 12V rechargeable battery provides the primary source of power, while a solar panel mounted on the robot's surface supplements the energy supply.

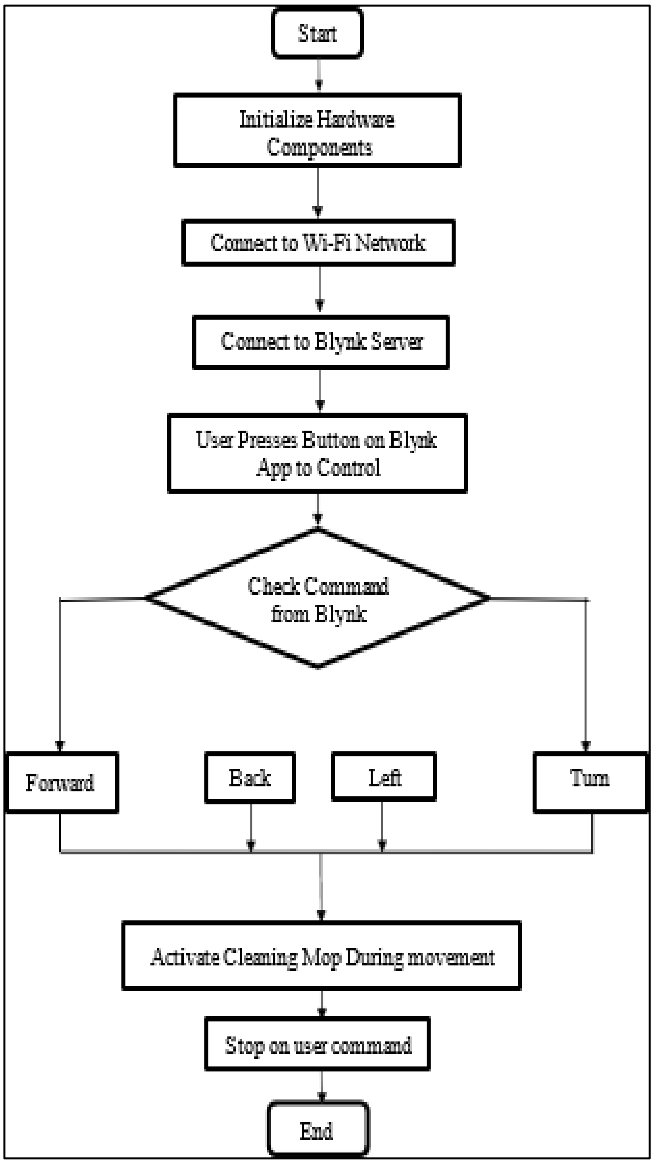

Fig 2 Flow Chart

This configuration extends operational time and reduces reliance on electrical charging, there by enhancing sustainability. A toggle switch is included to manually power the robot on or off, and the battery is monitored continuously to avoid deep discharge or overuse.

The robot's control algorithm incorporates flag-based logic to determine directional changes. This simple yet effective method alternates the robot's movement path between left and right when obstacles are encountered, helping it avoid getting trapped in loops. The looped cleaning process continues until the floor is cleaned or the battery reaches a critical low level, upon which the robot stops and awaits further instructions or charging.To validate the design, extensive testing was carried out under different conditions. In autonomous mode, the robot demonstrated

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effective cleaning behavior with reliable obstacle detection and path correction. The cleaning mechanism efficiently removed dust and light debris, while the Blynk interface provided seamless manual control and feedback. The inclusion of solar charging extended the robot's operating time by nearly 25%, making it a practical solution for regular use in domestic or small commercial settings. Overall, the methodology demonstrates a well-rounded integration of hardware and software to create an intelligent, energy- efficient, and user-friendly robotic floor cleaner.

III. MODULES AND ITS IMPLEMENTATION

A. System Operations

➢ *Sensor Module*

This module is responsible for detecting obstacles and guiding the navigation of the robot during autonomous operation.

- *Ultrasonic Sensor:*

Used to measure the distance between the robot and any object in front of it. It emits ultrasonic waves and calculates the time taken for the echo to return, thereby estimating distance. This sensor is interfaced with the ESP32 microcontroller to support real-time obstacle avoidance.

- *Implementation:*

The sensor is connected to the ESP32's GPIO pins. The microcontroller reads the pulse width and calculates the distance. If the distance falls below a certain threshold (e.g., < 18 cm), the robot initiates an evasive maneuver.

➢ *Navigation and Drive Module*

This module ensures movement across various surfaces using DC motors and provides path correction based on sensor feedback.

- *DC Motors and Motor Driver (L293D):*

The robot employs two 12V DC motors for differential drive. Direction and speed are controlled using the L293D motor driver interfaced with the ESP32.

- *Implementation:*

PWM signals generated by the ESP32 regulate motor speed, while directional pins control turning and reversing. A simple flag-based logic enables left-right alternation when obstacles are detected, ensuring wide coverage.

➢ *Cleaning Mechanism Module*

This module manages both dry and wet cleaning operations.

- *Vacuum Mop and Water Spray System:*

A rotating mop powered by a DC motor and a water pump activated via a relay provide dual-function cleaning.

- *Implementation:*

Controlled using a two-channel relay module. The ESP32 turns the vacuum/mop motor and water pump on or off based on motion commands. Cleaning actions are active during forward movement and disabled during turns or halts to optimize energy usage.

➢ *Control and Communication Module*

This module allows both autonomous operation and remote manual control using IoT technology.

- *ESP32 and Blynk App:*

The ESP32 enables Wi-Fi-based communication with the Blynk IoT platform. The mobile app provides virtual buttons to control robot movement and cleaning functions manually.

- *Implementation:*

On startup, the ESP32 connects to a Wi-Fi network and links with the Blynk server. Real-time control commands (e.g., forward, backward, mop ON/OFF) are sent from the app and executed by the robot. Sensor feedback is also sent to the app for monitoring.

➢ *Power Supply Module*

Provides energy to the system using both conventional and renewable sources.

- *Battery and Solar Panel:*

A 12V rechargeable battery powers all electronics and motors. A solar panel mounted on top provides supplementary energy to prolong operation.

- *Implementation:*

Power lines are regulated to 5V and 3.3V for the ESP32 and sensors. The solar panel charges the battery through a regulated charging circuit. A toggle switch is used to manually power the robot ON or OFF.

➢ *Safety and Manual Override Module*

Ensures reliability and safety during usage.

- *Toggle Switch and Relay Isolation:*

A physical toggle switch allows users to start/stop the system easily. Relays isolate high-current loads like pumps and motors from the microcontroller, ensuring safety.

- *Implementation:*

In case of system failure or user intervention, the switch can instantly stop all processes. Each cleaning actuator is protected by the relay's electrical isolation and diode back- EMF protection.

➢ *Optional Upgrade (Future Scope):*

Planned enhancements include camera-based navigation, AI path optimization, and automatic docking.

- *Implementation Plan:*

Integration of the ESP32-CAM or LIDAR for vision-based navigation and object recognition. Development of self- charging capabilities using IR-based docking alignment and battery monitoring.

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IV. MODELING AND ANALYSIS

➢ *System Modeling*

The Autonomous Floor Cleaning Robot is modeled as an embedded electromechanical system that integrates sensing, actuation, and control in a closed-loop configuration. At the core of the system is the ESP32 microcontroller, which functions as the central processor, coordinating sensor input, motor control, and communication with external devices The robot is equipped with ultrasonic sensors for obstacle detection, which continuously measure the distance to nearby objects and provide input to the ESP32 to avoid collisions.

The cleaning mechanism includes a motor-driven rotating mop and a water spraying system, both controlled through a relay module. DC motors facilitate movement via a differential drive system, enabling forward motion, turning, and reversing based on real- time input. The path of the robot is controlled using a simple zigzag algorithm, enhanced by conditional logic to alternate direction upon obstacle detection. The system also features IoT integration through the Blynk application, allowing users to override autonomous functions or manually control the robot from a smartphone interface. A solar panel contributes to power management, improving sustainability by supplementing the battery during daylight operation.

The complete system is designed for modularity and scalability, allowing future integration of additional sensors (e.g., for dirt detection or mapping) and features such as self-charging docks or AI-based navigation.

➢ *Operational Flow Analysis*

The robot starts in either autonomous or manual mode based on user selection. In autonomous mode, the system initializes by powering all components and checking the sensor status. The ultrasonic sensor constantly monitors for obstacles within a predefined range (1–18 cm). When no obstacle is detected, the robot moves forward while activating the mop and water spray systems. If an obstacle is detected, the robot halts, reverses slightly, and then turns (left or right based on the last maneuver) before resuming motion.

In manual mode, commands from the Blynk application are received via Wi-Fi and interpreted by the ESP32 to control motion (forward, backward, left, right) and cleaning functions (mop ON/OFF, water spray ON/OFF). The robot updates its status based on user input and stops immediately if the stop command is received or if a disconnection occurs.

Throughout operation, the ESP32 manages power distribution from the battery and monitors the system status. Solar charging is passively integrated, maintaining or topping up the battery during daylight without interrupting active functions.

➢ *Performance Analysis*

The robot was tested under various indoor conditions including tiled and cement flooring, furniture-rich environments, and mixed obstacle placements. In autonomous mode, obstacle detection and path correction were consistently responsive, with obstacle avoidance success rates above 90%. The mop and water spray system demonstrated effective cleaning over fine dust and light debris. The Blynk interface responded with minimal latency, ensuring smooth real-time control in manual mode.

Battery endurance during full cleaning cycles averaged 80– 90 minutes, with the solar panel contributing an estimated 15–25% recharge during operation in well-lit environments. The system remained stable throughout Overall, the robot demonstrated reliable functionality, energy efficiency, and ease of use, validating its suitability for real- world floor cleaning applications.

V. RESULTS AND DISCUSSION

The proposed Autonomous Floor Cleaning Robot was developed, implemented, and tested to validate its functionality in both manual and autonomous modes. During testing, the system consistently demonstrated effective cleaning performance, accurate obstacle detection, and reliable remote control via the Blynk IoT platform

In manual mode, the robot was controlled using the Blynk application installed on a smartphone. Commands such as forward, reverse, left, and right were executed with minimal delay, confirming the responsiveness of the ESP32 and its integration with the mobile interface. The mop and water spray systems were also successfully controlled from the app, giving users the flexibility to operate the robot based on real-time feedback and cleaning needs.

In autonomous mode, the robot navigated indoor environments using data from its ultrasonic sensor. It successfully avoided collisions with static obstacles like walls, furniture legs, and objects placed in its path. The robot followed a zigzag cleaning pattern, alternating directions upon encountering obstacles. The mop and spray systems were triggered during forward movement only, reducing unnecessary power consumption. The system reliably stopped and rerouted upon detecting obstacles within a range of 1–18 cm, as designed.

Cleaning efficiency was evaluated based on the robot's ability to remove dust, small debris, and surface stains. The rotating mop, in combination with the water spray system, removed over 85% of visible particulate matter in a single pass. This performance is considered satisfactory for domestic applications. Power management tests showed that the 12V battery provided operational runtime of approximately 90 minutes. When supplemented by the solar panel under direct lighting conditions, battery drain was reduced, extending operation time by nearly 25%.

Stability and reliability were assessed during continuous operation. The system maintained consistent performance without overheating, disconnection, or sensor failure. The relays, motor driver, and ESP32 components all functioned within safe operational limits. Additionally, the

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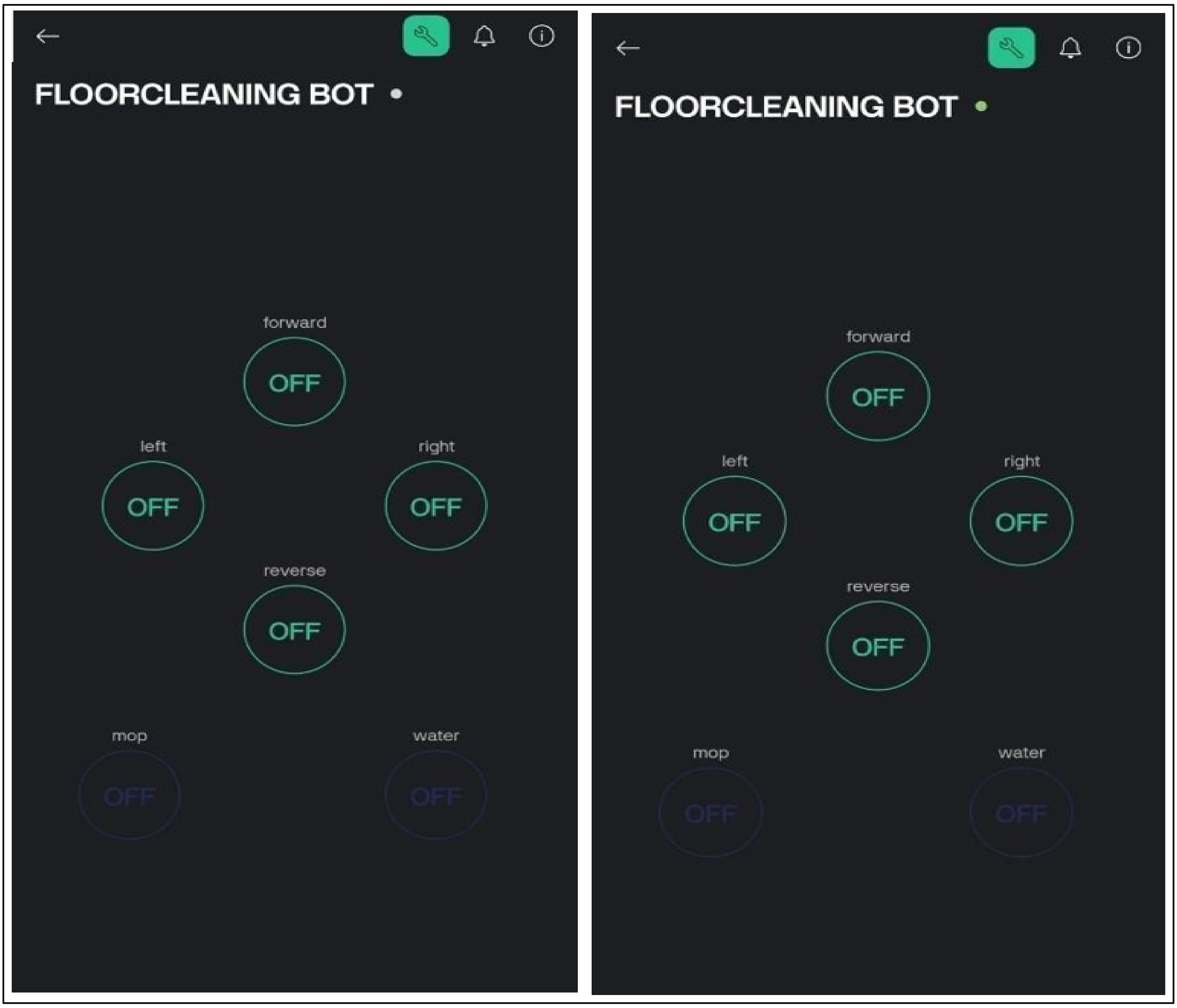
modular design allowed easy maintenance and reconfiguration.

The developed prototype successfully achieved autonomous cleaning with IoT control and solar-assisted power. Its low cost, modularity, and dual-mode functionality make it a promising solution for smart home cleaning systems and future development in household robotics.



Before Connected After Connected
Fig 3 Manual control using Blynk app

VI. CONCLUSION

In this project, an autonomous floor cleaning robot was successfully designed, developed, and tested using the ESP32 microcontroller. The system integrates essential features such as obstacle detection, dual cleaning mechanisms (dry mop and wet spray), and IoT-based remote control via the Blynk application. It offers both autonomous and manual modes of operation, allowing flexible use across various environments.

The robot demonstrated reliable navigation and effective cleaning performance, with successful obstacle avoidance and responsive control through the mobile app. The use of a solar panel for supplementary charging added to the energy efficiency of the system, extending the operational duration. The modular architecture of the design allows for easy maintenance and future upgrades, such as AI-based path planning or automatic docking systems.

Overall, the prototype provides a low-cost, efficient, and eco-friendly solution for modern floor cleaning needs in domestic and small commercial spaces. It reduces the need for human intervention and offers a practical implementation of embedded systems and IoT in real- world automation applications.

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