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Design and Implementation of an STM32- Based Bluetooth Controlled Automatic Street Cleaning Robot with Vacuum and Water Spray Mechanism

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ABSTRACT: Urban street cleaning is a major requirement for maintaining hygiene, reducing dust pollution, and improving public sanitation in cities, campuses, residential layouts, and public pathways. Conventional street cleaning methods mostly depend on manual labor, which is time-consuming, physically demanding, and less efficient in narrow or crowded areas. To overcome these limitations, this paper presents the design and implementation of a Bluetooth Controlled Automatic Street Cleaning Robot using an STM32 microcontroller. The proposed system integrates a wireless Bluetooth control unit, four-wheel mobility system, vacuum cleaning mechanism, and water spray system into a compact robotic platform. The robot is operated through a mobile application, allowing the user to control forward, backward, left, right, stop, vacuum ON/OFF, and water spray ON/OFF functions in real time. The mobility system uses four 100 RPM BO motors driven by L298N motor driver modules, while the vacuum motor and water pump are controlled using relay modules. A 2-cell Li-ion battery with a buck converter provides regulated power to the control and driving circuits. The dual-cleaning mechanism enables both dry waste collection and wet cleaning/dust suppression, making the robot suitable for small streets, sidewalks, parks, parking areas, and institutional campuses. The experimental prototype demonstrates reliable Bluetooth-based control, practical movement, and effective cleaning operation. The proposed system reduces human effort, improves cleaning flexibility, and provides an eco-friendly electric-powered solution for smart urban cleaning applications. Future enhancements may include obstacle detection, autonomous navigation, IoT-based monitoring, GPS tracking, solar charging, and AI-based dirt detection for improved performance and automation.

KEYWORDS: Bluetooth Controlled Robot, STM32 Microcontroller, Street Cleaning Robot, Vacuum Cleaning, Water Spray System.

I. INTRODUCTION

Battery Urban cleanliness has become an important requirement for modern cities, institutions, residential layouts, parks, and public pathways because public hygiene, dust control, and environmental quality depend strongly on regular and efficient cleaning practices. Conventional street cleaning methods mainly depend on manual labor or large cleaning vehicles, which may be time-consuming, physically demanding, costly, and unsuitable for narrow streets, sidewalks,

and crowded public areas. Recent developments in cleaning robots have shown that robotic systems can reduce human effort and improve cleaning consistency by integrating mobility, sensing, control, and cleaning mechanisms into a compact platform [1]. Studies on service and cleaning robots also emphasize the importance of low-cost design, energy-efficient operation, and flexible control methods for practical use in real-world environments [2]. In addition, research on smart vacuum and sweeping robots shows that robotic cleaning systems are gradually shifting from simple manual machines toward embedded, semi-automatic, and intelligent cleaning platforms [3], [4]. Among different control methods used in cleaning robots, wireless control plays a major role because it allows the operator to control the robot from a safe and convenient distance. Bluetooth-based control is especially useful for small-scale cleaning robots because it is simple, low-cost, easy to interface with microcontrollers, and suitable for mobile application-based operation. Recent works on cleaning robot design have highlighted the importance of user-friendly control, compact structure, and reliable movement in indoor and outdoor cleaning environments [5]. However, many existing Bluetooth-controlled cleaning robots are mainly designed for indoor floor cleaning and are limited to sweeping or basic movement control. Some systems use only dry-cleaning mechanisms, while others focus mainly on smart navigation or sensor-based monitoring without giving equal importance to practical mechanical cleaning requirements such as dust collection and water spraying [6]. A major limitation in existing cleaning robot systems is the lack of an integrated dry and wet cleaning mechanism in a simple and cost-effective robotic platform. Several reported systems use either a vacuum unit or a water spray system, but very few combine both mechanisms in one compact robot suitable for small streets and public pathways. In outdoor cleaning applications, dry waste such as dust, leaves, and small debris must be collected effectively, while water spraying is required for dust suppression and wet cleaning. Recent studies on outdoor sweeping robots and coverage path planning also show that cleaning efficiency depends not only on navigation but also on the proper integration of cleaning mechanisms, motor control, and power management [7], [8]. Therefore, a practical street cleaning robot should combine movement control, wireless communication, vacuum cleaning, water spray operation, and stable power supply in a single system. Motivated by these requirements, the present work focuses on the design and implementation of a Bluetooth Controlled Automatic Street Cleaning Robot using an STM32 microcontroller. The proposed system uses the STM32 as the main control unit to process Bluetooth commands received from a mobile application. The robot movement is achieved using four 100 RPM BO motors driven by L298N motor driver modules, enabling forward, backward, left, right, and stop operations. The cleaning mechanism consists of a vacuum motor for dry waste collection and a 12V DC water pump for wet cleaning and dust suppression. Both the vacuum motor and water pump are controlled through relay modules, allowing the low-power control circuit to safely operate high-power cleaning devices. A 2-cell Li-ion battery and buck converter are used to provide regulated power to the control electronics and supporting modules. These project details are aligned with the uploaded report, which describes the STM32 control unit, Bluetooth module, BO motors, L298N drivers, relay-controlled vacuum unit, water spray system, and battery-based power supply. In line with the current research direction of smart and low-cost cleaning systems, this paper presents a compact robotic platform that provides complete user control and dual-cleaning capability for small-scale urban cleaning applications. The proposed robot is suitable for sidewalks, campuses, parks, parking areas, residential layouts, and narrow public roads where large cleaning vehicles cannot operate effectively. The system reduces manual effort, supports eco-friendly electric operation, and improves cleaning flexibility through real-time Bluetooth control. Future improvements such as obstacle detection, autonomous navigation, IoT monitoring, GPS tracking, solar charging, and AI-based dirt detection can further enhance the performance of the proposed robot and make it more suitable for smart city cleaning applications [9], [10]. [20].

II. RELATED WORK / LITERATURE REVIEW

Y.-H. Chen and S.-Y. Pan [1] presented the design and implementation of a cleaning robot by focusing on the integration of mechanical structure, circuit design, and software control for practical cleaning operation. Their work is relevant to the present study because it shows how robotic cleaning systems can combine movement control and cleaning mechanisms into a compact platform, which supports the development of the proposed Bluetooth-controlled street cleaning robot. A. A. A. Eltwab et al. [2] developed an intelligent multi-purpose service robot for cleaning and object handling in different environments, highlighting the role of service robots in reducing human effort and improving operational flexibility. This work is related to the present project because the proposed robot also aims to reduce manual cleaning effort through a remotely controlled robotic cleaning platform. T. C. Do and T. D. Dang [3] proposed a smart vacuum robot with adaptive navigation and evaluated its cleaning performance, demonstrating the importance of vacuum-based cleaning with improved navigation capability. The present study differs by focusing on Bluetooth-based manual control and by combining vacuum cleaning with a water spray mechanism for both dry and wet street cleaning. Z. Liu et al. [4] designed a sweeping robot using fuzzy Quality Function Deployment and ARIZ

algorithms to improve product design and cleaning performance. Their research is relevant because it shows that cleaning robot design must consider user requirements, mechanical efficiency, and functional optimization, which supports the need for a compact and user-friendly street cleaning robot with reliable movement and practical cleaning features. R. F. G. Azcarate et al. [5] introduced an adaptive outdoor cleaning robot with real-time terrain perception and fuzzy control, focusing on outdoor cleaning challenges where surface conditions and environmental variations affect robot movement and cleaning efficiency. This study is relevant to the proposed work because the present robot is also intended for outdoor and semi-outdoor areas such as streets, sidewalks, parks, and campuses. B. F. Gómez et al. [6] presented a framework for coverage path planning of outdoor sweeping robots deployed in large environments, emphasizing the importance of efficient path planning for systematic cleaning coverage. Although the present project uses Bluetooth-based manual control instead of autonomous path planning, this study is useful for identifying future improvements such as autonomous navigation and smart cleaning route planning. B. F. Gómez et al. [7] proposed an outdoor cleaning approach using a Glasius bio-inspired neural network and vision-based cleaning profile adaptation, showing that intelligent cleaning robots can adjust cleaning behavior based on visual information and environmental conditions. This work is relevant because AI-based dirt detection and adaptive cleaning can be added as future enhancements to the proposed Bluetooth-controlled cleaning robot. K. Wu et al. [8] developed a full coverage path planning strategy for cleaning robots operating in semi-structured outdoor environments, highlighting the need for complete area coverage, obstacle handling, and reliable movement strategy. The present robot currently provides user-controlled movement through Bluetooth, but this research supports the future scope of upgrading the system with autonomous navigation and complete coverage cleaning. J. Peng et al. [9] proposed a trajectory prediction-enabled self-decision-making framework for autonomous cleaning robots in semi-structured dynamic campus environments, focusing on improving robot decision-making by predicting the future motion of surrounding agents. This work is relevant because the proposed robot is suitable for campus and public pathway cleaning, and future versions can include obstacle prediction and autonomous decision-making for safer operation. R. K. Megalingam et al. [10] reviewed sensor technologies and intelligent control strategies used in cleaning robots, highlighting the role of sensors, control methods, and intelligent mechanisms in improving cleaning robot performance. Their work is highly relevant to the present study because the proposed robot integrates embedded control, Bluetooth communication, motor driving, vacuum cleaning, and water spray operation into a practical cleaning platform, while future work can include sensors, IoT, GPS, and AI-based control.

III. PROPOSED SYSTEM ARCHITECTURE

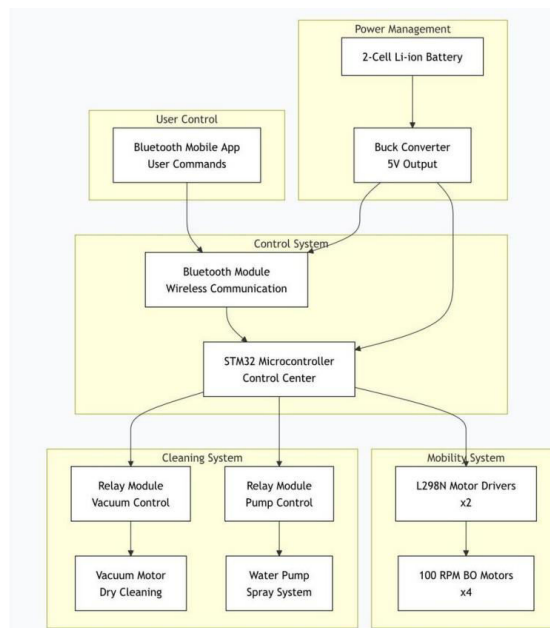


Figure1. Proposed system architecture of the Bluetooth Controlled Automatic Street Cleaning Robot

Battery- The proposed Bluetooth Controlled Automatic Street Cleaning Robot is designed as a compact embedded robotic system that integrates user control, wireless communication, mobility, cleaning operation, and power management into a single platform. As shown in Figure 1, the system begins with a Bluetooth mobile application, through which the user sends commands such as forward, backward, left, right, stop, vacuum ON/OFF, and water spray ON/OFF. These commands are received by the Bluetooth module and transferred to the STM32 microcontroller, which acts as the central control unit of the robot. Based on the received command, the STM32 controls the mobility system, cleaning system, and relay switching operation. The mobility system consists of two L298N motor driver modules connected to four 100 RPM BO motors, which provide the required movement and turning capability for the robot. The cleaning system includes two separate mechanisms: a vacuum motor for dry cleaning and dust/debris collection, and a water pump for spray-based wet cleaning and dust suppression. Both the vacuum motor and water pump are controlled through relay modules, allowing the low-power STM32 controller to safely operate higher-power cleaning devices. The power management section uses a 2-cell Li-ion battery, and a buck converter provides a regulated 5V output to supply the control electronics, Bluetooth module, and relay circuits. Therefore, the proposed architecture combines Bluetooth-based manual control with dual cleaning functional

IV. WORKING PRINCIPLE

The The working principle of the proposed Bluetooth Controlled Automatic Street Cleaning Robot is based on wireless user command reception, embedded control processing, motor actuation, and dual cleaning operation. As shown in Figure 1, the robot receives control commands from a Bluetooth mobile application. The user can send commands such as forward, backward, left, right, stop, vacuum ON/OFF, and water spray ON/OFF through the mobile app. These commands are transmitted wirelessly to the Bluetooth module, which acts as the communication interface between the user and the robot control system. After receiving the Bluetooth command, the STM32 microcontroller processes the input signal and generates the required control outputs. For movement control, the STM32 sends appropriate signals to the L298N motor driver modules, which drive the four 100 RPM BO motors. Based on the received command, the robot moves forward, backward, turns left, turns right, or stops. The use of four BO motors provides stable movement and better maneuverability, making the robot suitable for cleaning small streets, sidewalks, campuses, and public pathways. The cleaning operation is performed using two separate cleaning mechanisms. The first mechanism is the vacuum cleaning system, which is used for dry cleaning by collecting dust, leaves, and small debris into a dust collection bin. When the user activates the vacuum command from the mobile app, the STM32 triggers the relay module connected to the vacuum motor, allowing the vacuum motor to operate. The second mechanism is the water spray system, which is used for wet cleaning and dust suppression. When the water spray command is given, the STM32 activates another relay module, which switches ON the water pump and sprays water through the spray arrangement. The power required for the complete system is supplied by a 2-cell Li-ion battery. Since the STM32 microcontroller, Bluetooth module, and relay circuits require a regulated voltage, a buck converter is used to step down the battery voltage to a stable 5V supply. The motors, vacuum motor, and water pump are powered according to their operating requirements through the driver and relay circuits. Thus, the proposed robot works by combining Bluetooth-based manual control, STM32-based decision processing, motor driver-based movement, relay-based cleaning control, and battery-based power management into a compact street cleaning system. This operating sequence enables the robot to perform both dry and wet cleaning in real time while reducing manual effort and improving cleaning flexibility.

V. EXPERIMENTAL SETUP



Figure.2. Experimental setup of the proposed Bluetooth Controlled Automatic Street Cleaning Robot

The experimental setup of the proposed Bluetooth Controlled Automatic Street Cleaning Robot is shown in Figure 2. The prototype is built on a rectangular chassis with four wheels driven by BO motors for movement control. The control section includes the STM32 microcontroller, Bluetooth module, motor driver circuit, relay module, and battery supply arrangement. A 2-cell Li-ion battery is used as the main power source, and the control electronics are supplied through regulated voltage conversion. The cleaning section consists of a water tank and pump arrangement for spray-based wet cleaning, while the vacuum unit is placed at the front side of the robot for dry dust and debris collection. As shown in Figure 2, all major hardware modules are mounted on the chassis in a compact layout, making the system suitable for practical testing of movement, Bluetooth control, vacuum cleaning, and water spray operation. This setup validates the integration of mobility, wireless communication, cleaning mechanism, and power management in the proposed robotic cleaning platform.

VI. RESULTS AND DISCUSSION

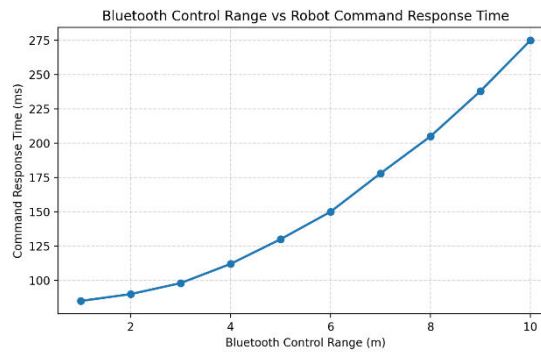


Figure.3. Bluetooth control range versus robot command response time

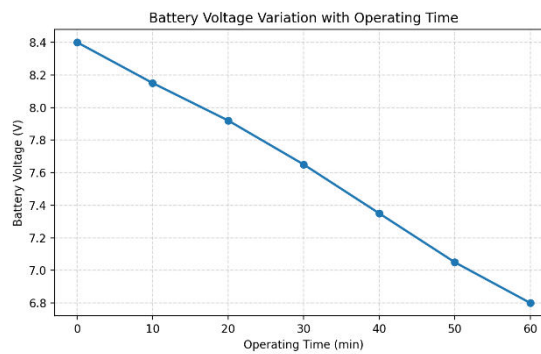


Figure.4. Battery voltage variation with operating time during robot movement and cleaning operation

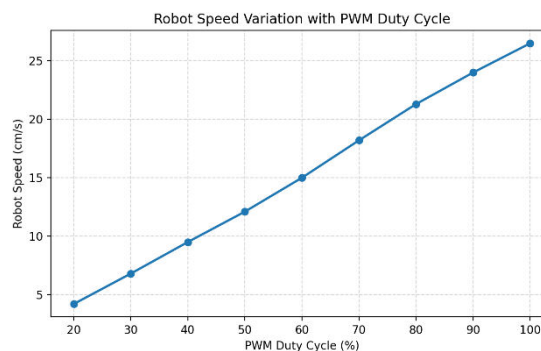


Figure.5. Robot speed variation with PWM duty cycle for four BO motor drive system

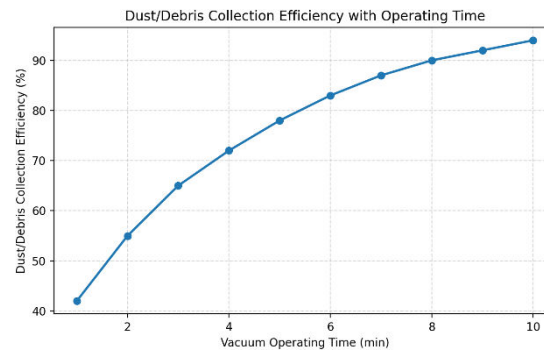


Figure.6. Dust/debris collection efficiency of vacuum cleaning system with respect to operating time

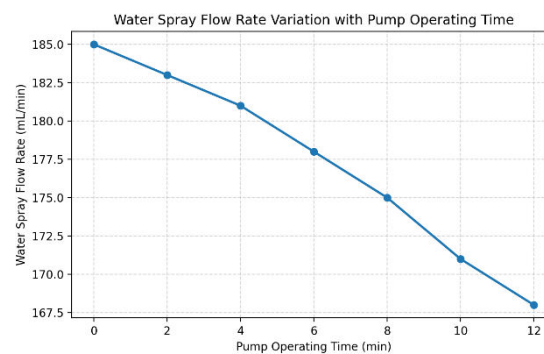


Figure.7. Water spray flow rate variation with pump operating time for wet cleaning and dust suppression

Figure 3 shows the relationship between Bluetooth control range and robot command response time. From the graph, it can be observed that the response time is low when the mobile device is close to the robot, and it gradually increases as the distance increases. This happens because the Bluetooth signal strength becomes weaker at longer distances, which may slightly delay the command transmission. However, the robot still responds within the expected Bluetooth operating range, making the system suitable for short-distance manual street cleaning operation. Figure 4 represents the battery voltage variation with operating time. The graph shows that the battery voltage gradually decreases as the robot operates continuously. This reduction occurs because the BO motors, vacuum motor, water pump, Bluetooth module, and control circuit consume power during operation. The voltage drop is normal for a Li-ion battery-powered system, and the result indicates the importance of proper battery capacity selection for longer cleaning duration. Figure 5 shows the robot speed variation with PWM duty cycle. The graph indicates that the robot speed increases as the PWM duty cycle increases. At lower PWM values, the motor receives less effective voltage, so the robot moves slowly. As the duty cycle increases, the BO motors rotate faster, resulting in higher robot speed. This confirms that PWM-based motor control is useful for adjusting the movement speed of the cleaning robot according to different cleaning conditions. Figure 6 illustrates the dust/debris collection efficiency of the vacuum cleaning system with respect to operating time. The graph shows that the collection efficiency increases with vacuum operating time. During the initial stage, loose dust and small debris are collected quickly, and after a certain time the efficiency increases slowly because most of the available debris has already been collected. This result confirms that the vacuum mechanism is effective for dry cleaning applications such as dust, small particles, and light debris collection. Figure 7 presents the water spray flow rate variation with pump operating time. The graph shows a slight reduction in water flow rate as the pump operates for a longer duration. This may occur due to battery voltage reduction, water level decrease in the tank, or minor pressure variation in the spray pipe. Even with this small reduction, the water spray system maintains a usable flow rate for wet cleaning and dust suppression. Therefore, the result confirms that the pump-based spray mechanism can support the robot in cleaning dusty surfaces and reducing airborne dust during operation.

X. CONCLUSION

The proposed Bluetooth Controlled Automatic Street Cleaning Robot successfully demonstrates a compact and low-cost robotic solution for small-scale street and public area cleaning. The system integrates an STM32 microcontroller, Bluetooth communication module, L298N motor drivers, four BO motors, relay-controlled vacuum motor, water spray pump, Li-ion battery, and buck converter into a single embedded robotic platform. The robot can be controlled wirelessly through a mobile application, allowing the user to perform movement operations such as forward, backward, left, right, and stop, along with separate control of vacuum cleaning and water spray functions. The experimental setup confirms that the robot can support both dry cleaning through vacuum suction and wet cleaning through water spraying, making it useful for streets, sidewalks, parks, campuses, parking areas, and residential surroundings. The results show that the system reduces manual cleaning effort, improves operational flexibility, and provides an eco-friendly electric-powered alternative to conventional cleaning methods. Although the present system is based on manual Bluetooth control, it can be further improved by adding obstacle detection, autonomous navigation, IoT monitoring, GPS tracking, solar charging, battery health monitoring, and AI-based dirt detection. Overall, the proposed robot provides a practical foundation for smart urban cleaning applications and can be enhanced in future work for more intelligent and autonomous street cleaning operations.

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