IOT - Based Vacuum Cleaning System Using Arduino

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ABSTRACT

This project presents a manually controlled IoT-based Smart Cleaning Robot designed for domestic and small-scale cleaning tasks. Operated via smartphone through Bluetooth using the HC-05 module, control signals are sent to an Arduino microcontroller, which drives the motors for real-time manual navigation. The robot features four DC motors managed by an L298N motor driver, enabling stable movement across various surfaces. An ultrasonic sensor mounted on a servo motor scans for obstacles, offering distance feedback to help users avoid collisions. Though not autonomous, this feature enhances safety in cluttered spaces. A mini vacuum cleaner is integrated into the chassis to collect dust and debris during movement, enabling simultaneous cleaning. The robot's compact design allows it to reach under furniture, making it effective for tight spaces. The system emphasizes user control, responsiveness, and ease of use. Built using affordable, open-source components, the robot is both replicable and educational. It showcases the integration of embedded systems with mobile communication. The design prioritizes cost-efficiency, functionality, and practicality. The robot provides a hands-on approach to smart home cleaning. Its intuitive controls and obstacle feedback system improve usability. The project highlights real-world applications of IoT in daily life. It demonstrates how manual control can still offer smart functionality. The solution is ideal for tech enthusiasts and students.

KEYWORDS

Smart Cleaning Robot, Internet of Things (IoT), Manual Control, Bluetooth Communication, Motors, HC-05 Bluetooth Module, Arduino Microcontroller, L298N Motor Driver, DC Ultrasonic Sensor, Servo Motor, Obstacle Detection, Real-time Navigation.

INTRODUCTION

In today's rapidly advancing technological environment, the integration of automation and smart systems into everyday life is reshaping how we interact with our surroundings. Central to this transformation is the Internet of Things (IoT), a concept where devices are interconnected to collect and act on data. One of the most practical and widely adopted areas of IoT application is home automation, where smart lighting, voice assistants, and connected appliances are becoming commonplace. Among these, automated cleaning solutions stand out as essential tools designed to reduce manual effort and enhance living comfort. Despite their growing popularity, most high-end robotic cleaners are expensive and designed for ideal home conditions, making them less practical for many users. Traditional cleaning methods have long relied on manual effort using basic tools like brooms and vacuum cleaners. While early innovations like electric vacuums reduced the physical burden, they still required direct human operation. The emergence of robotic vacuum cleaners in the late 1990s introduced a degree of automation, with brands like iRobot leading the way. These robots, equipped with sensors and mapping algorithms, have evolved to feature Wi-Fi connectivity, smartphone control, and AI-powered navigation. However, their performance is often hindered by cluttered spaces and irregular floor plans, and their cost places them out of reach for budget-conscious users.

This gap in accessibility highlights the need for a simpler, affordable solution - one that combines the benefits of robotic cleaning with manual control. Individuals such as students, the elderly, or those living in compact spaces often require a cleaning aid that is easy to operate, does not rely on internet connectivity, and performs reliably in real-time. The availability of low-cost components like Arduino boards, HC-05 Bluetooth modules, and ultrasonic sensors has enabled the development of manually controlled cleaning robots that strike a balance between utility and affordability. The proposed project - an IoT-based Manually Controlled Smart Cleaning Robot - addresses this need by offering a mobile robot platform navigated via Bluetooth through a smartphone. The system integrates DC motors and an L298N motor driver for smooth directional control, an ultrasonic sensor on a servo motor for obstacle detection, and a vacuum mechanism for dust collection. This setup empowers users to control the cleaning process while reducing physical effort, making the robot especially useful in scenarios where autonomous systems fail or are impractical due to cost or complexity. Beyond its practical applications, this robot serves as an educational tool for students interested in embedded systems and robotics. It allows learners to apply theoretical concepts in real-world builds, from motor control and wireless communication to sensor interfacing and system integration. The modular nature of the project encourages experimentation and future enhancements, such as app-based control, voice integration, and IoT connectivity, aligning well with academic goals and technological curiosity.

The project scope includes designing and programming the robot using affordable hardware, with a focus on achieving real-time responsiveness and reliable cleaning performance on smooth surfaces. It excludes autonomous features, advanced cleaning functions, and internet-based control to maintain simplicity and cost-effectiveness. Targeted primarily at students, low-income households, and educational institutions, the robot demonstrates how frugal engineering can deliver meaningful solutions within real-world constraints, making smart technology accessible and relevant to a broader audience.

LITERATURE REVIEW

Smart navigation is basic and can't dynamically adjust to changing environments. Power usage and vacuum effectiveness are not addressed in depth. The development of Bluetooth-controlled cleaning robots has been widely explored in recent literature, emphasizing the integration of Arduino-based microcontrollers, wireless modules like HC-05, and basic cleaning mechanisms such as vacuum motors and suction systems. Several studies ([1], [3], [4], [11], [17]) highlight the feasibility of designing cost-effective, user-friendly cleaning robots that can be operated via smartphone applications. These robots demonstrate effective directional control, real-time responsiveness, and straightforward hardware interfacing using components such as the L298N motor driver and ultrasonic sensors. Notably, research like [9], [15], and [19] support the implementation of servo-mounted ultrasonic sensors for manual obstacle scanning and area monitoring, a feature mirrored in the current project. Furthermore, studies such as [5], [13], and [14] contribute valuable insights into mechanical assembly, suction motor optimization, and user-centric chassis design for efficient household use.

In addition, the reviewed literature sheds light on various enhancements and future scalability of Bluetooth-based cleaning robots. Papers such as [2], [6], and [20] emphasize sensor-driven navigation strategies, adaptable cleaning patterns, and real-time feedback, all of which could elevate manual systems into semi-autonomous or fully autonomous robots. Advanced research ([10], [12], [16]) explores IoT-based systems using platforms like Raspberry Pi, offering remote access, data logging, and scheduling features—setting a potential roadmap for upgrading current Arduino-based designs. Across all studies, common challenges like power management, command delay, and integration of control with cleaning mechanisms are addressed, reinforcing the design decisions of the present project and providing a strong foundation for future improvements in functionality, efficiency, and user interaction. The result is a versatile, efficient, and accessible cleaning solution that bridges the gap between fully autonomous robots and basic manual systems.

EXISTING SYSTEM

As the demand for cleanliness, hygiene, and automation increases - both in households and commercial environments various cleaning methods have emerged and evolved. These methods can generally be classified into two broad categories: non-computerized (manual) and computerized (automated or semi-automated). Evaluating these existing methods helps identify the gaps and limitations that justify the need for developing an IoT-based smart cleaning robot like the one proposed in this project.

Non-Computerized Methods

1. Manual Sweeping and Mopping

Manual cleaning is the oldest and most widely practiced method of maintaining floors and surfaces. Using simple tools like brooms, dustpans, and mops, this method relies entirely on human effort. While inexpensive and accessible in all settings, it is extremely labor-intensive and time-consuming. It often results in fatigue for the cleaner and fails to clean hard-to-reach areas such as under furniture or around corners. Additionally, it does not guarantee uniform results, as the efficiency depends on the individual's thoroughness.

2. Handheld Electrical Vacuum Cleaners

These are slightly modernized manual cleaning devices that use suction motors to collect dust. They are electrically powered and are effective in cleaning carpets, sofas, and floors. However, they still require human operation, which means the user must be physically present and actively guide the device. Although they reduce physical strain and improve dust removal, they are not a full automation solution.

3. Human Cleaning Staff

In larger homes, offices, and institutions, human cleaning staff are often employed to ensure regular cleaning. While this method can yield better results compared to manual cleaning by residents, it involves ongoing labor costs and scheduling responsibilities. There's also inconsistency in performance based on the skills and effort of the cleaners. Moreover, in pandemic or health-sensitive environments, direct human involvement in cleaning may pose risks.

Computerized/Automated Methods

1. Fully Autonomous Cleaning Robots

Devices like the iRobot Roomba, Ecovacs Deebot, and Xiaomi Mi Robot are examples of highly intelligent robotic cleaners that can autonomously map rooms, avoid obstacles, and clean floors without any user interaction. They employ multiple sensors (IR, ultrasonic, LIDAR), sophisticated software like SLAM (Simultaneous Localization and Mapping), and sometimes even AI for path optimization. Although effective, they are prohibitively expensive for average users, require careful maintenance, and depend on proper environmental setups to function optimally.

2. Semi-Autonomous Robots

These robots follow predefined cleaning patterns or allow limited user customization. They lack dynamic navigation but are less expensive and simpler to operate than fully autonomous robots. However, their inability to adapt to new layouts or obstacles limits their usability. Most educational or DIY robotic kits fall under this category.

3. Bluetooth-Controlled Cleaning Robots

In this category, an Arduino-based robot is equipped with a Bluetooth module (such as HC-05) and receives commands via a smartphone app. Users can manually control the robot's movement, activate or deactivate the vacuum motor, and sometimes use sensors for real-time feedback. These robots are cost-effective, offer high user control, and are perfect for learning embedded systems and mechatronics. However, they require constant user input and lack intelligence or autonomy.

4. IoT-Enabled Smart Cleaning Systems

These are advanced cleaning robots controlled via Wi-Fi and IoT platforms. Users can control the robot remotely, monitor cleaning status in real time, and even schedule cleanings. Integration with cloud platforms and voice assistants (like Alexa or Google Home) makes them part of modern smart homes. Despite their convenience, these systems are complex to design and build, demand reliable internet connections, and involve additional costs for networking components and backend infrastructure.

PROPOSED METHODOLOGY

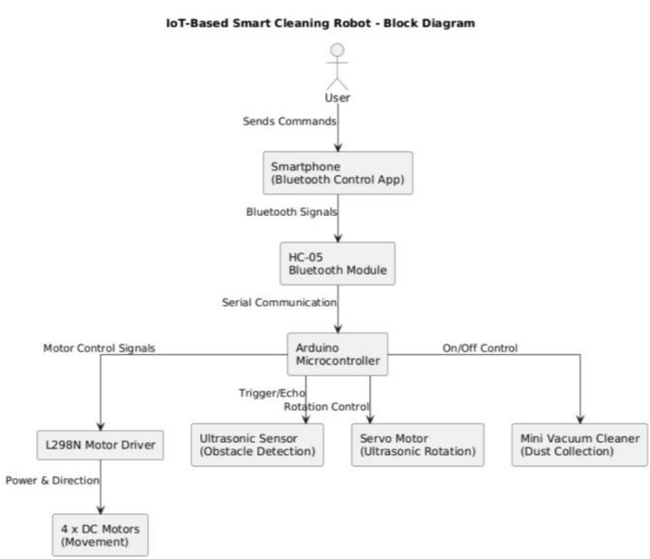

Fig 1: Block Diagram for Vacuum Cleaning Robot

The above block diagram of the IoT-Based Smart Cleaning Robot illustrates a well-organized architecture that integrates user control, wireless communication, sensor feedback, and actuator responses to create a smart, remote-controlled cleaning system. At the top of the hierarchy, the user sends commands through a smartphone app via Bluetooth, which are received by the HC-05 Bluetooth module and relayed to the Arduino microcontroller using serial communication. The Arduino then acts as the central control hub, interpreting each command and triggering various subsystems accordingly. These include the L298N motor driver that controls four DC motors for robot movement, an ultrasonic sensor mounted on a servo motor for obstacle detection and scanning, and a mini vacuum cleaner module for dust collection, all working together to achieve efficient cleaning operations.

Each component in this architecture serves a specific purpose, ensuring modularity, real-time responsiveness, and system expandability. The use of standard communication protocols like UART and PWM allows for smooth and precise control of both sensors and actuators. The robot is powered by a battery pack with appropriate voltage regulation to support all components efficiently. With user commands like forward, backward, vacuum toggle, and ultrasonic rotation, the system delivers an interactive and flexible cleaning experience. The overall setup avoids reliance on internet connectivity, making it ideal for offline use, while offering the potential for future upgrades and automation enhancements.

TOOLS:

1. Hardware Requirements

The design of the *IoT-Based Smart Cleaning Robot* relies heavily on the integration of multiple hardware components, each selected carefully to achieve a balance between cost-efficiency, functionality, power management, and ease of control. The overall hardware system is structured into several key subsystems: control and processing, communication, motion, sensing, cleaning, and power management. Each module interacts with the others in a coordinated way under the direction of the Arduino microcontroller. This section provides a comprehensive breakdown of each major hardware component used in the robot, detailing its purpose, features, interconnections, and how it contributes to the overall design.

- **Arduino UNO R3 (Microcontroller)**
Function: Acts as the central processing unit and control hub.
Key Specs: ATmega328P microcontroller, 14 digital I/O pins (6 PWM capable), 6 analog inputs, Operates at 5V, with 16, MHz clock speed, USB interface for programming and serial monitoring.
- **HC-05 Bluetooth Module**
Function: Enables wireless serial communication between the smartphone and the Arduino.

Key Specs: Operates at 3.3V logic, but supports 5V power supply, Default baud rate: 9600 bps, Range: ~10 meters, Supports Master and Slave modes (used here in Slave mode).

- **L298N Dual H-Bridge Motor Driver Module**

  Function: Drives and controls the direction and speed of the DC motors.

  Key Specs: Supports up to 2A per channel (suitable for 2 motors per channel), Input Voltage: 5–35V, Built-in 5V voltage regulator.

- **DC Motors (x4)**

  Function: Provide locomotion for the robot.

  Key Specs: Operating Voltage: 6V–12V, RPM: 100–300 depending on gear ratio, Mounted with wheels on a 4-wheel chassis

- **Ultrasonic Sensor (HC-SR04)**

  Function: Detects obstacles and measures distance.

  Key Specs: Range: 2cm to 400cm, Accuracy: ±3mm, Operates at 40kHz

- **Servo Motor (SG90 or equivalent)**

  Function: Rotates the ultrasonic sensor to scan different angles.

  Key Specs: Operating Voltage: 4.8V–6V, Rotation Angle: 0° to 180°, Torque: ~2.5 kg·cm

- **Mini Vacuum Cleaner Module**

  Function: Performs the core cleaning function by sucking up dust and debris.

  Key Specs: Operating Voltage: 6V–12V, Small fan-based suction motor, Dust collection container or filter included

- **Power Supply and Battery Pack**

  Function: Provides power to all electronic components and motors.

  Typical Configuration: 12V Li-ion battery pack for motors and Arduino VIN, Onboard regulators (L298N or 7805) to provide 5V to sensors and control units.

- **Chassis and Frame**

  Function: Holds and organizes all components.

  Specs: 4-wheel robot chassis with mounting slots, Acrylic, aluminum, or plastic base plate

- **Connecting Wires, Breadboard, and Mounts**

  Function: Ensure safe electrical connections between all modules.

  Includes: Male-to-male and female-to-female jumper wires, Soldered connections for high-current lines, Breadboard or PCB for signal routing.

2. Software Requirements

The software is the logical backbone of the *IoT-Based Smart Cleaning Robot*, translating user commands into physical movement, sensor interaction, and real-time responses. The software was developed using the Arduino IDE with embedded C/C++ and involves programming the Arduino UNO microcontroller to control motor operations, Bluetooth communication, sensor readings, and actuator outputs.

This section elaborates on the software components, architecture, and functional flow involved in the implementation of the system.

- **Bluetooth Communication Handling**

  Library Used: Software Serial (optional, if not using default UART)

  Module: HC-05

  Communication Protocol: UART (9600 baud rate)

  Process: The Arduino listens continuously for incoming serial data from the HC-05 module. Received characters represent specific commands like:

  1. 'F' – Move Forward
  2. 'B' – Move Backward
  3. 'L' – Turn Left
  4. 'R' – Turn Right
  5. 'S' – Stop
  6. 'V' – Toggle Vacuum ON/OFF
  7. 'T' – Trigger Servo Scan

  The software phrases the each character and calls the corresponding function to handle that operation.

- **Motor Control Logic:** The movement of the robot is controlled via **four DC motors** driven by an L298N motor driver.

  Pins Used: 4 Digital I/O pins (IN1, IN2, IN3, IN4), 2 PWM pins for speed (ENA, ENB)

  Control Logic:

  - Forward: IN1 & IN3 HIGH, IN2 & IN4 LOW
  - Backward: IN1 & IN3 LOW, IN2 & IN4 HIGH
  - Left Turn: Left motors reverse, right motors forward
  - Right Turn: Left motors forward, right motors reverse
  - Stop: All motor inputs LOW or disable PWM

- **Arduino IDE**

  Function: Platform for writing, compiling, and uploading code to the Arduino board.

  Key Specs: Supports C/C++, Includes Serial Monitor for real-time debugging.

- **SoftwareSerial.h**

  Function: Enables serial communication on other digital pins besides default RX/TX.

  Key Specs: Lightweight library for serial communication, Operates commonly at 9600 baud rate.

- **Servo.h**

  Function: Controls servo motor used to rotate the ultrasonic sensor, Simplifies PWM signal generation for angle control.

  Key Specs: Supports 0° to 180° rotation range, Smooth and accurate angular movement, Simple syntax for easy control.

- **HC-SR04 (Ultrasonic Sensor)**

  Function: Detects obstacles by measuring distance using ultrasonic waves.

  Key Specs: Operating voltage: 5V, Range: 2 cm to 400 cm, Accuracy: ±3 mm, Interface: 1 Trigger pin, 1 Echo pin.

- **Serial Monitor (in Arduino IDE)**

  Function: Displays real-time data sent from Arduino.

  Key Specs: Supports ASCII and numerical data, Baud rate configurable (usually 9600), Live feed for troubleshooting and testing.

- **Android Bluetooth App**

Function: Allows users to send commands wirelessly to the robot via Bluetooth.

Key Specs: Communicates using Bluetooth protocol, Sends ASCII characters (F, B, L, R, S, V, U), Pairs with HC-05 module, No internet required; low latency control.

ADVANTAGES

This IoT-based smart cleaning robot project offers several **notable advantages** that make it both practical and educational. It features a **low-cost and affordable design** by utilizing **economical components** like the Arduino Uno, HC-05 Bluetooth module, and basic DC motors, making it ideal for **students and hobbyists**. With **real-time manual control via smartphone**, users can precisely guide the robot through specific cleaning paths, especially in cluttered environments, without the need for complex algorithms. The system's **modular and easily extendable architecture** allows future upgrades such as Wi-Fi, cameras, or additional sensors with minimal effort. For safety, the robot incorporates **obstacle detection** using an **ultrasonic sensor mounted on a servo**, enabling it to scan its surroundings and avoid collisions. It also includes a **functional cleaning mechanism** in the form of a **mini vacuum cleaner** that effectively collects dust and small debris from flat surfaces, transitioning it from a basic robot to a useful cleaning device. The **user-friendly interface**, based on a simple smartphone app, ensures that even non-technical users can operate it with ease. Moreover, the project holds high **educational value** by offering hands-on experience across domains like embedded systems, mobile communication, and robotics. Lastly, its **environmental adaptability** allows it to be manually controlled in diverse and **complex environments**, giving it greater flexibility compared to fully automated counterparts.

APPLICATIONS

This smart cleaning robot has a wide range of applications across various settings. Its primary use lies in **domestic cleaning**, where it can be manually guided to clean under furniture, around corners, and in tight spaces, offering a more efficient alternative to traditional methods. It also serves as a powerful **educational tool for learning IoT and robotics**, helping students understand real-time system control, sensor integration, and Bluetooth communication through hands-on experience. In addition, the robot proves valuable for **cleaning in hard-to-reach or hazardous areas**, reducing human exposure to dust or allergens. It can be used to **demonstrate smart home integration**, showcasing how affordable devices can evolve into Wi-Fi or IoT-based systems using platforms like Blynk or MQTT. Its practicality extends to **office and small workspace maintenance**, performing light-duty cleaning during low activity periods. Moreover, it can significantly benefit **elderly or mobility-restricted individuals**, allowing them to maintain their living space effortlessly with easy smartphone-based control, thus enhancing their independence and comfort.

STIMULATION RESULT

The Fig 2 shows the prototype of the IoT-based smart cleaning robot in its working form. The robot is built on a transparent acrylic chassis with four DC motors and wheels for movement. At the center, the Arduino Uno microcontroller is visible, connected to various modules including the HC-05 Bluetooth module, L298N motor driver, ultrasonic sensor for obstacle detection, and servo motor for rotating the sensor. On the right side, a mini vacuum cleaner made from a plastic bottle is attached, demonstrating the dust collection mechanism. Wires connect all components, showing a fully assembled and functional model of the cleaning robot ready for operation. The setup is powered via a USB connection, indicating it's currently being tested or programmed through a connected system like a laptop or power bank.

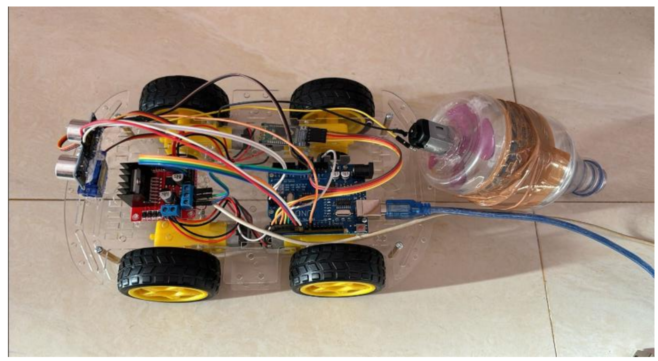

Fig 2: IoT- Based Vacuum Cleaning System

CONCLUSION

The development of the manually controlled IoT-based Smart Cleaning Robot demonstrates the practical application of embedded systems and mobile communication technologies in solving real-world problems. This project successfully integrates an Arduino microcontroller, Bluetooth module, motor drivers, ultrasonic sensor, and a mini vacuum cleaner into a single system that performs efficient and controlled cleaning operations. It offers a low-cost, user-friendly alternative to commercially available smart cleaning robots by allowing users to remotely guide the robot through their smartphones. The obstacle detection system adds a layer of safety and precision, while the cleaning mechanism makes the robot functional for basic dust and debris collection. As a student project, it has achieved its intended objectives by showcasing a working prototype that embodies key concepts in IoT, robotics, and automation.

FUTURE SCOPE

While the current implementation provides an effective and interactive cleaning system, there is ample scope for enhancement and expansion. Future iterations can focus on introducing **semi or fully autonomous navigation** using advanced path-planning algorithms and simultaneous localization and mapping (SLAM) techniques. Replacing Bluetooth with Wi-Fi or GSM modules would allow for **remote internet-based control** and integration with smart home platforms like Google Home or Amazon Alexa. Additional features such as **real-time camera feedback**, **voice commands**, **dustbin full alerts**, and **scheduled cleaning routines** can further increase the system's utility and user experience. Moreover, improvements in hardware like stronger suction mechanisms, better battery capacity, and all-terrain mobility can make the robot more robust and applicable to a broader range of environments, including commercial and industrial settings.

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