BLUETOOTH-CONTROLLED ENERGY MANAGEMENT OF ELECTRICAL LOAD USING ARDUINO

Diponkar Sharker[1*], Sakib Chowdhury[1], Golam Rohman[1], Nadem Mahamud[2], Md Sakib Ahmed[1]

[1]Nanjing University of Information Science and Technology, Artificial Intelligence, Nanjing, Jiangsu, China
[2]Nanjing University of Information Science and Technology, Computer Science & Tech., Nanjing, Jiangsu, China

Abstract

This paper outlines the design and improvement of a home automation system operated through Bluetooth using an Arduino Nano microcontroller. The system enables wireless home appliance control, including lighting, fans, and other appliances, using an Android-based application interface. In the center of the new design is the use of a 4-channel relay module for effective device switching, together with an HC-12 Bluetooth module, allowing a significant increase in communication range and transmission reliability compared to the HC-05 module used earlier. The HC-12 is incorporated in a module whereby the range is boosted to 100 m for proper long-range communication at home. For this purpose of system reliability and continuity, EEPROM is used to store the state of the appliances so that the operating configurations of the devices can be regained once the power blackouts. In addition, and due to the risks of threats targeting unauthorized users' data, security mechanisms are also employed to encrypt the transmission between the smartphone and the automation system. The system also integrates high-tech energy control abilities where the user has a command to switch the power supply to all the appliances when not in use, which reduces power consumption. This feature is very important to implement if there is a reduction in energy consumption in contemporary homes. There are plans to improve the performance of this system in the future by including Wi-Fi connectivity coupled with cloud computing services, thereby extending the control range and making the system flexible by enabling remote control and storage of data. This newly evolved system, the researcher states, can be a marginal cost reduction, can be easily scaled up, and has lower energy consumption, making it ideal for meeting the increasing demand for home automation, especially in regions with power constraints.

Keywords: Arduino Nano, Bluetooth, home automation, energy efficiency, relay module, Android, EEPROM

Corresponding author's e-mail: diponkarsharker00@gmail.com

1.0 INTRODUCTION

Growth in home automation systems has greatly changed the control of household appliances, increasing ease, effectiveness, and security. Bluetooth, Wi-Fi, ZigBee, and other wireless communication systems are widely used for giving the capability to the users to control the electrical loads such as lighting, fans, and other appliances within a house. Of these wireless protocols, Bluetooth finds its application in short-range communication in home automation systems owing to factors such as cost, power, and simplicity. Therefore, current Arduino microcontroller platforms are widely used in home automation solutions to affordably and effectively enhance the automation of electrical devices through wireless signal transmission [1][2]. Bluetooth with Arduino enables the controlling of several electrical appliances through the smartphone application, specifically for simplicity, low cost, and easy implementation in an environment [3]. Moreover, the integration of EEPROM means that the system can maintain different appliance states as if there is a power outage, which makes it more convenient for users to use appliances without having to make other appropriate settings [4]. This paper incorporates the design of a home automation system using Bluetooth technology with the Arduino Nano as the microcontroller for operating home appliances with an Android application. This system increases energy use in gadgets by allowing users to turn off gadgets that are not in use, hence saving power and using it efficiently. Moreover, the system can expand to accommodate the control of other appliances within large homes and therefore suits large homes well. Enhancements in this system include the enhancement of Bluetooth range through the use of the HC-12 Bluetooth module, which increases the communication range by up to 100 meters, making it possible to communicate over large halls without interference. Also, the issue of securing data has been addressed since, by using encryption methods, all the data transmitted between the smartphone and the home automation system is encrypted to ensure that unauthorized people cannot gain access to the home automation system. These improvements make the proposed system cost-effective, energy-efficient, and secure for today's modern homes and thus respond to the need for cheaper, manageable, and scalable home automation systems. Further developments of the described system will be the addition of Wi-Fi connectivity and cloud services to extend the control range and transform the smart device into a remotely controllable monitoring and scheduling tool with an integrated cloud storage system[5].

2.0 LITERATURE REVIEW

Bluetooth-supported home automation systems have improved the comfort, efficiency, efficacy, and security of home-related environments. Arduino-based systems, including Arduino Uno and Bluetooth's solution for controlling home appliances remotely at the early stages, did not incorporate sufficient energy-control systems and state retention mechanisms. Therefore, when the electrical supply was switched off, the configuration of the appliances would disappear, hence the system's reliability to the user was compromised [1]. Furthermore, the initial applications targeted unique systems that do not encompass enhanced options, for instance, energy control and security. However, enhancements continued these basic concepts by leveraging Arduino Nano microcontrollers, which are better adapted for low-cost platforms, which should be the characteristics of many ecosystems. Although this change made the systems more inexpensive, these systems still had problems with state persistence. They still reaped the phenomenon of the lost configurations at the power cuts that were a limit to the practicality and realism of the systems [3]. A few systems incorporated ZigBee smart energy management that contributed to device control and energy saving while stressing the effectiveness of energy control in home automation systems. These systems put in place procedures to enhance energy conservation through daily and consistent adjustments in devices [5]. Another successful approach is in using real-time monitoring and smart sensors towards the steady improvement of energy efficiency. Though the smart appliances monitor and give feedback on the usage of the appliances, the consumers get to reduce waste and increase their efficiency. They also tend to incorporate efficient energy-consuming components to support the longevity of home automation systems [6]. Furthermore, it was possible to observe that some of those systems incorporated other security mechanisms like face and fingerprint recognition to

increase safety, and thus, those systems became safer and more general [7]. With the development of smart homes introducing more IoT-based home automation, cloud computing has been implicated as a way of remote access, constant monitoring, and sophisticated data storage. It offers a convenience for users to manage their appliances from a remote location, as well as introducing a flexible schedule for usage and an efficient control mechanism [8]. It explains the possibilities provided by cloud systems for appliance management not only in terms of energy savings but also in data storage for the enhancement of decision-making and automation. Other research has also been directed to cost, which is meager compared to the returns that home automation systems provide to their users. Automation of homes can be achieved by constructing systems using Arduino microcontrollers and Bluetooth modules such as the HC-12 Bluetooth module at a cheaper cost. Such systems include energy management functionality, remote monitoring, and device scheduling capabilities, which makes smart home solutions more affordable for a wide range of people [9][10]. Furthermore, enhancements in security communication protocols guarantee that user data is kept safe from third-party intrusion, solving a key issue of privacy while continuing to afford reliable control of home appliances.

The recent developments in Bluetooth technology have especially improved the range of home automation systems. The HC-12 Bluetooth module, for instance, enhances the communication range up to 100 meters, making the system appropriate for large houses with numerous gadgets. There is little doubt that this extended range makes the system more versatile. In addition, encryption techniques have been incorporated to enhance data security and safeguard possible malicious access when sharing information between smartphones and the home automation system, which has been a difficult task in the previous models developed based on Bluetooth [2][6]. Besides energy management and security, the flexible and modular construction of Bluetooth home automation systems focuses on making them scalable and meeting all new user requirements. With growing complexity and additional devices in home automation systems, the idea of designing the systems as modular makes sense; new devices can be integrated with existing systems without the need to change the entire design. Future improvements will probably involve such additions as cloud ability, Wi-Fi, and more elaborate scheduling options for better management, utilization, and customer satisfaction [6].

Hence, Bluetooth-based home automation systems have graduated from simple device control to sophisticated solutions that involve power control, security, and remote sensing. These systems bring on board Arduino microcontrollers, Bluetooth technologies, and cloud facilities for automating home appliances while enhancing sustainability, cost-efficient mechanisms for operating home electrical appliances, security, and energy conservation. Bluetooth can be expected to further develop autonomy, range, security of data, and scalability of the system to make these systems increasingly more accessible, efficient, and secure.

3.0 METHODOLOGY

System Architecture

The developed architecture for the Bluetooth-based home automation system plays the role of a system controller by incorporating an Arduino Nano microcontroller, with the help of Bluetooth connections, to manage different home appliances. The HC-12 Bluetooth module is used for wireless communication with a range of up to 100 meters, thereby allowing communication over larger distances within the home environment [2]. The Arduino Nano has been interfaced with a 4-channel relay module for switching the on/off state of loads, including lights, fans, and other appliances[1]. Furthermore, data retention is also made possible through EEPROM memory, as this allows the appliance states to be saved, making it possible for the system not to lose configurations in cases where there is a power surge [3]. The users interface with the system through an Android APK file designed using MIT App Inventor, which triggers the HC-12 to send control signals to Arduino Nano. Through Bluetooth, the Android app forwards the command given by the user, it could be to switch on or switch off a device, to the HC-12 module, which in turn communicates the message to Arduino Nano. The Arduino Nano takes the command, switches load states using the 4-channel relay module, and stores these states in the EEPROM to retain in case of power loss. Such a design allows remote control,

energy control, and security with simple, real-time control and monitoring of the devices through the app [6]. In addition, encryption procedures are employed in the app to secure its communication with the Arduino Nano to protect users' information from various threats [8]. This architecture provides a stable, extensible, and efficient home automation solution for improving energy consumption and supplying a safe way of managing the appliances.

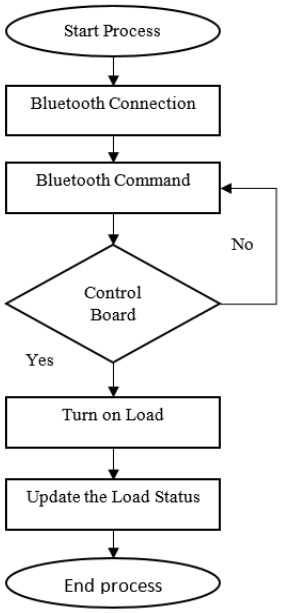

Figure 1: Flowchart

Android Application

The Android application was designed and developed using MIT App Inventor to create an easy-to-use interface for mobile control of appliances. The application is interfaced with the Arduino Nano through the HC-12 Bluetooth module for switching the connected appliances 'On' or 'Off' including the provision for the 'All On' and 'All Off' buttons. The app also gives real-time information on the state of each appliance [8].

A. HARDWARE COMPONENTS

Arduino Nano

In the presented Bluetooth home automation system, the Arduino Nano microcontroller is the primary controller for processing the commands received from the HC-12 Bluetooth module and regulating the Relay module. The controller is equipped with an ATmega328P processor responsible for the necessary computing power for handling various aspects of the system. The Arduino Nano also has 14 digital input/output (I/O) pins which are used to control the relays that turn on or off the different appliances. Also, the system has the EEPROM that enables the storage of the connected load's state and brings the appliances to the previous state after power failure thereby making the system more reliable [11]

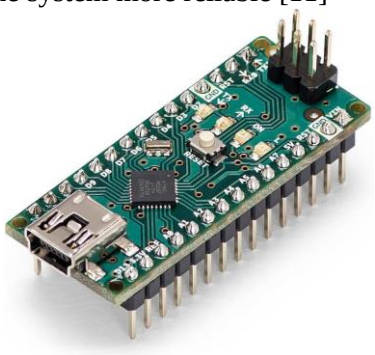

Figure 2: Arduino Nano

HC-12 Bluetooth Module

The HC-12 Bluetooth module is a high-performing Wireless communication module prominently used in home automation systems. Exploiting the frequency of 433MHz, it has two channels with an extended range of up to 100 meters depending on the environment it is used in, which is more advanced features than other previous Bluetooth modules such as the HC-05. In its working, the module incorporates serial communication (UART) and can exist in two modes namely the transparent mode and AT command mode. They can be very effectively coupled with Arduino and other microcontrollers for remotely driving home appliances. The HC-12 is power-friendly, cheap, and has a long range thus is suitable for both small and complex home automation solutions [12].

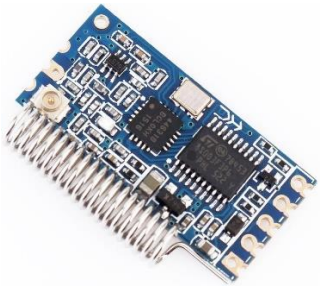

Figure 3: HC-12 Bluetooth

4-Channel Relay Module

The 4-channel relay module makes and receives signals to control the electrical appliances connected to the system. Each of the four relays is like an electric switch that opens or closes by using the Arduino Nano to directly connect or cut off the circuit for a specific appliance. It can handle 10A 250V AC making it well suitable for controlling different loads within the house among them being lighting devices like lights fans and heaters. Using Bluetooth the Android application sends signals to the Arduino Nano which in turn sends signals to the relay module hence allowing for the remote control of the appliances. With modularity enabled, the system is capable of controlling different loads simultaneously, guaranteeing optimum performance and executing complex operations as necessary [13].

Figure 4: 4-Channel Relay Module

EEPROM

EEPROM is used in the system to retain the current state of the 4 connected loads so that the information is saved permanently on the device. Every time that an appliance is switched on or off, the Arduino Nano records the state on the EEPROM. This allows the system to remember or set up every appliance connected to it even if there is a power failure or suddenly there is a power outage. After powering up, the system retrieves the data stored in the EEPROM to maintain the state of each appliance before skipping and improving the robustness of the home automation system[14].

B. SOFTWARE IMPLEMENTATION

Android Application

MIT App Inventor: The MIT App Inventor development environment is known for its simplicity and user-friendly design. It allows users to drag and drop components such as buttons, labels, and images to create Android applications. The platform also provides a visual block interface for programming, making it easy to design and implement functionality without writing complex code. This is particularly beneficial for beginners, as they can understand the logical flow of the application through intuitive visual elements[15]. Bluetooth Communication: Bluetooth is widely used to establish communication between devices without wires, enabling control over external hardware like Arduino boards. This feature is particularly useful for creating applications that allow users to manage hardware devices remotely via smartphones. Integrating Bluetooth communication in MIT App Inventor facilitates the development of systems that can communicate with microcontrollers for home automation, robotics, and other IoT applications.

APK Creation: Once the application is developed using MIT App Inventor, users can compile their project into an APK (Android Package Kit) file, which is the format used for distributing and installing apps on Android devices. The APK file allows for easy installation and distribution, enabling developers to share or sell their apps.

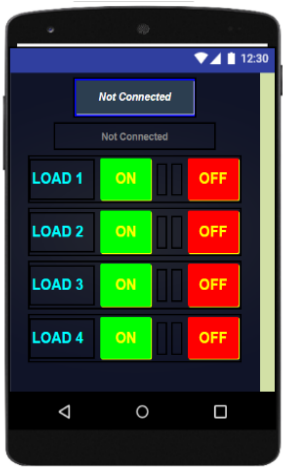

Figure 5: 4-MIT App Inventor

System Operation

The operation of the Bluetooth-based home automation system follows these sequential steps:

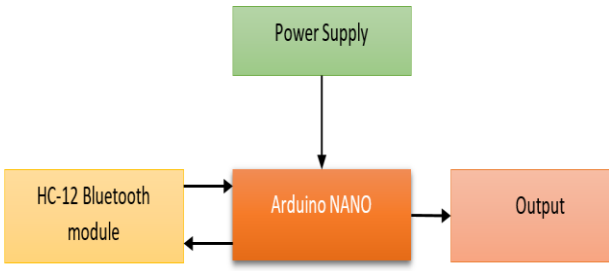

Figure 6: Block Diagram

Command Input

The **Android application's graphical user interface (GUI)** provides an intuitive way for users to give control signals by selecting options to turn on/off various appliances like lamps and fans. This GUI simplifies the interaction with home automation systems, making it user-friendly for non-technical users.

Bluetooth Transmission

Once the user gives a command, the **Android application** translates it into Bluetooth signals and sends the command to the **HC-12 Bluetooth module** connected to the **Arduino Nano**. The **HC-12 module** is responsible for receiving commands and establishing a wireless communication link between the smartphone and the microcontroller, enabling reliable long-range communication.

Relay Control

Upon receiving the command, the **HC-12 Bluetooth module** sends the signal to the **Arduino Nano**, which processes the command and activates or deactivates the corresponding relay in the **4-channel relay module**. The relays are used to control connected appliances, such as lights and fans, providing users with full control over their household devices[16].

State Storage

After processing the command and controlling the appliances, the system stores the appliance state (on/off) in **EEPROM.** This feature ensures that the appliance states are retained even after a power failure, allowing the system to restore appliances to their previous state when power is restored. This increases the **reliability** and **utility** of the system.

4.0 RESULTS AND ANALYSIS

A. Control Accuracy

The control accuracy of the system was tested by issuing several commands using the Android application to manage different household devices. All commands given switching an appliance on or off were equally received by the Arduino Nano through the HC-12 Bluetooth module. The system also significantly retained high accuracy of the appliance activation and responsiveness to the user's inputs with no errors identified. The usage of the 4-channel relay module caused the appliances to be switched without any issues and the user experience was smooth all the time. The ability of the system to react in real time and to possess accurate control, regardless of multiple devices being powered at once was an important way of proving the system's efficacy[6].

B. Energy Efficiency

The energy efficiency of the system was demonstrated by controlling appliances through mobile devices and tablets. Users were able to switch off devices remotely, leading to significant energy savings. The EEPROM stored the specific states of appliances, which helped retain these settings even during a power cut, thus preventing users from accidentally leaving appliances on after a reset. One feature that greatly supported energy efficiency was the ability to remotely manage energy consumption, such as a button that allowed users to switch off all appliances at once. This made it easier for users to monitor and control their energy usage in real-time [10].

Additionally, the system can be expanded to integrate with larger energy-saving networks, such as smart grids or cloud-based energy management systems. This integration would further optimize the control of home appliances to ensure even more efficient energy use. By allowing users to program

appliances based on their behavior, the system could help reduce peak energy demands and promote sustainable energy practices [17].

C. Bluetooth Range

The HC-12 Bluetooth module expanded the range of Bluetooth in the system and the system can have stable operation with Bluetooth within the range of 100 meters in the open area. This extended range made certain that the system could command the appliances in items that are bigger homes or multi-story buildings without the signal being weaker. While compared with common Bluetooth modules whose distance ranges from 10 to 20 meters, the HC-12 module was added making the system more applicable for large applications and providing more flexibility in appliance controlling.

Table 7: Bluetooth Range

Feature	HC-04	HC-05	HC-12
Type	Bluetooth **Slave** (only)	Bluetooth **Master/Slave** (dual mode)	**433 MHz** Wireless Serial Communication
Range	Up to **30 meters**	Up to **30 meters**	Up to **1,000 meters** (varies by environment)
Operating Voltage	**3.3V to 5V**	**3.3V to 5V**	**3.3V to 5V**
Output Recommendation	Low output power, suitable for short-range Bluetooth communication. Best for simple connections nearby.	Moderate output power, suitable for short to medium-range Bluetooth communication. Useful for both master and slave roles.	High output power, ideal for long-range (up to 1 km) wireless communication. Best for remote control and sensor data transmission.

In a real-life environment, the extra range enabled seamless and consistent communication between the Android application and the Arduino Nano, this was especially so, should the users be far from the control center. This feature was very important for users with a large house, houses with more than one floor, or a large coverage area because it would enable good communication within the house.

D. State Persistence

The state persistence will add reliability and continuity to its operation and it is supported by the EEPROM memory. Power: every appliance's on/off state was stored in the EEPROM so, in case of a power outage, or system reboot, the appliance would turn on with its saved state. For instance, in case a user switches off an appliance and then the power goes off at his house, the appliance could turn to an off state when the power supply is restored without the user having to do it manually. This feature eliminated the likelihood of users making some mistakes with the system and allowed it to work in varying power conditions[1]. Another factor of state persistence to the general usability of the system was the fact that the system states will not need to be restored frequently, nor will the user have to input all of the information repeatedly. It was extremely useful in particular where outages are experienced or where users need devices to come right back on in case they had been switched off.

Additional Observations:

i. Security: XOR encryption was used for security in communication so that non-privileged persons had no access to influence the control of the system. It became only possible for a person with the

correct password or code to engage the system, which provided the highest level of data security and privacy[4].

ii. Scalability: The system could also be expanded and worked well since it only required the creation of more relay modules for the control of more appliances. This also made the solution scalable to accommodate an expansion in the appliance control system needs as the setting increased in size[6].

Therefore, it can be concluded that the Bluetooth-based home automation system has ensured good or high control accuracy, energy efficiency, Bluetooth range, and state persistence. All these features when put together with the Data Security enhancements make the system a credible, energy-efficient, and secure home automation system of the modern day. The software and hardware of this system will be optimized in the future by adding features like cloud integration and Wi-Fi connectivity to make the new system even more valuable.

Practical work

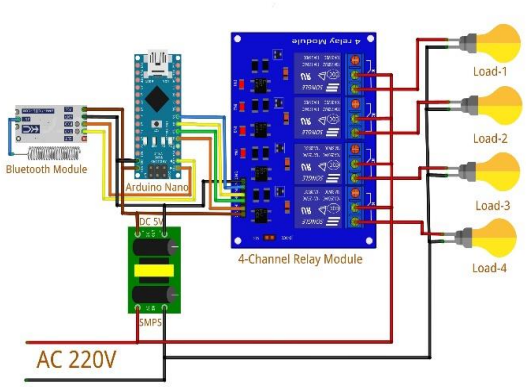

Figure 8: Circuit Diagram

Differences from Other Systems

The **Bluetooth-based home automation system** developed in this paper offers several unique features and improvements compared to other systems in the literature. Below are the key differences:

Enhanced Bluetooth Range with HC-12 Module

Other systems typically use **HC-05 Bluetooth modules**, which offer a limited range of 10-20 meters. This limitation restricts their application to smaller areas or single-room usage.

Our system integrates the **HC-12 Bluetooth module**, which provides an extended range of up to **100 meters**, allowing the system to control appliances over larger areas, such as **multi-floor homes** or **larger households**. This makes the system more **versatile** and **scalable** compared to previous systems.

Security through Encryption

Many existing systems lack strong security measures, making them vulnerable to unauthorized access and control. The communication is often unprotected, which can lead to data interception or system manipulation.

Our system applies **XOR-based encryption** to all Bluetooth communication. This ensures that only users with the correct decryption key can interact with the system, preventing unauthorized access and enhancing **data security**. This encryption is particularly valuable for users who are concerned about the security of their connected devices and personal data.

State Persistence with EEPROM

Many Bluetooth-based systems do not retain appliance states after power interruptions. In the absence of state persistence, users have to manually reset the appliances every time the system is powered up.

In our system, the use of **EEPROM memory** allows for **state persistence**, ensuring that appliances remember their on/off status even after a power disruption. This eliminates the need for manual intervention after power cuts and ensures **continuous and reliable operation**.

Scalability and Flexibility

Other systems may have limitations in terms of scalability, making it difficult to add more devices or expand the system.

Our system is designed with **scalability** in mind, using **modular relay modules** to control up to four devices, with the option to expand to more devices as needed. This flexible design makes the system adaptable to various home setups, allowing for easy upgrades or additions of appliances.

Cost-effectiveness and Accessibility

While **other systems** may offer similar features, they often come with higher costs, especially when incorporating proprietary technologies or more complex setups.

Our system is built using **Arduino Nano**, which is a cost-effective and readily available microcontroller, paired with the **HC-12 Bluetooth module**, making the solution **affordable** for a wide range of users. This cost-effectiveness allows for easy adoption by households seeking **affordable automation solutions** without compromising on performance.

5.0 CONCLUSION

In conclusion, this research introduces a Bluetooth-based home automation system leveraging the Arduino Nano microcontroller and the HC-12 Bluetooth module to enable seamless control of household appliances via a custom-developed Android application. The system effectively addresses the constraints of resource-limited environments while providing a practical, scalable, and economical solution for home automation. The integration of long-range Bluetooth communication through the HC-12 module empowers users to control electrical devices with an extended range of up to 100 meters, making it an ideal solution for larger households or spaces that require broader coverage [2]. The inclusion of the 4-channel relay module allows for the independent control of various appliances, while the EEPROM integration ensures the system's resilience by preserving appliance states even after power disruptions, thus enhancing reliability and stability in diverse real-world conditions [6]. Regarding energy efficiency, the system enables users to make informed decisions about turning appliances on or off to optimize energy usage. The system's design incorporates EEPROM to mitigate energy waste during power outages, thereby contributing to sustained energy conservation[18]. These functionalities align with the broader goals of smart homes, which prioritize energy efficiency and environmental sustainability[4][9]. However, the system's Bluetooth range, though adequate for small to medium homes, remains a limitation in large-scale applications. Despite this, the HC-12 module's extended communication range provides a significant improvement over traditional Bluetooth systems [1]. Future advancements could focus on Wi-Fi integration, enabling global control of appliances, and incorporating cloud-based services to facilitate remote scheduling, data analysis, and real-time energy monitoring. Such upgrades would enhance the system's capability, providing users with a more dynamic and comprehensive home automation experience [2]. The system's cost-effectiveness is one of its most significant advantages, as it is built with affordable components such as the Arduino Nano and HC-12 Bluetooth module, making it an accessible option for resource-constrained households, particularly in developing regions where the demand for smart home solutions is increasing [15]. The modular design of the system allows for easy scalability, enabling users to expand and customize the system based on evolving needs without incurring substantial additional costs[6]. In summary, the Bluetooth-controlled home automation system presented in this research offers a reliable, energy-efficient, and cost-effective solution for managing household appliances. While the system successfully meets the needs of resource-constrained environments, further developments, including Wi-Fi integration, cloud functionalities,

and enhanced security protocols, will increase its flexibility, adaptability, and compatibility with modern smart home technologies, ensuring its relevance and utility in the rapidly evolving smart home landscape [6][19][17][20]

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