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Design of Home Automation System with Emergency Control

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Abstract

In today's society, there is a growing demand for smart home solutions that not only enhance convenience but also make a significant impact on affordability and widespread adoption. This paper describes the proposed design of a Node MCU-based Home Automation system with an integrated Wi-Fi module that enables internet-based remote control of home devices. The design utilizes a basic code template to connect with the Tasmota Web interface to configure the ESP module. The system is integrated with Alexa, offering various integration options such as routines, schedules and alarms. Furthermore, it adds a manual control feature for situations where there is no internet connection and an additional level of safety through emergency controls in the event of electronic failure. A comparison of energy usage with and without the use of the proposed system is also reported. A noticeable decrease in daily electricity consumption is observed on using the designed automation system. To ensure cost-effectiveness, locally available components are utilized in the design. Consequently, it ensures that enhanced comfort, convenience, and control over one's living environment are available to a wider audience.

Keywords: Home automation; NodeMCU (ESP8266); Smart assistants; Cost effective design.

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1. Introduction

The Smart Home (SH) concept has long been a staple of science fiction and a subject of creative writing, but it only became a reality in the early 20th century with the widespread adoption of household electricity and rapid advancements in information technology [1]. In today's world, consumers constantly seek technological innovations to elevate their quality of life, often eagerly acquiring home appliances that promise

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such enhancements. Further researchers are trying to look for technologies to seek energy conservation as a critical objective [2].

The proliferation of the Internet in recent decades has played a significant role in automating various sectors, including business, entertainment, education, lifestyle, and tourism, among others [3]. Home automation offers additional benefits, such as reducing electricity consumption and energy expenditures while simultaneously augmenting security and protection through the usage of sensors, actuators, and controllers [4,5]

Designing a home automation system presents multifaceted challenges, that necessitates the integration of multiple technologies to monitor the performance and real-time status of numerous household appliances. This is critical for enabling intelligent remote access and control. To fully realize the potential of home automation, it is essential to simplify the design process, making these systems more affordable and straightforward to construct. The smart home system should offer easy implementation and cost-effective automation, as well as enhanced convenience, such as controlling home appliances using a mobile device or through voice activation. Additionally, the system should cater to the needs of the elderly and disabled persons, enabling them to control household gadgets with ease [6].

Existing literature on home automation system design tends to focus on enhancing the user experience through a multitude of features, often overlooking affordability and widespread adoption. This paper proposes the development of an economical solution for home automation, offering an easy-to-assemble design that utilizes readily available, affordable components and technologies. The design incorporates components such as NodeMCU microcontrollers, Amazon or Google Account, and Smart Assistant-based speakers like Alexa to create a functional prototype of the proposed system.

2. Literature Review

The field of Smart Home technologies has been under exploration since the 1970s. However, technological limitations in earlier times constrained the progress of American hobbyists who developed the first "wired homes" in the 1960s [1]. In 1984, the American Association of Home Builders coined the term "smart house" to describe homes that incorporate automation and advanced technology [7]. Researchers have since proposed various approaches to Smart Home automation, including DTMF and Bluetooth-based systems [8-15]. However, DTMF systems require dedicated PSTN channels to communicate with the main supply units, which is a significant limitation. Bluetooth, on the other hand, is ideal for short-range connectivity and enables access and control through smartphone technology [16-24]. Nevertheless, the operating range of Bluetooth is limited to immediate proximity, which presents a challenge for widespread Smart Home integration [25]. Notably, Anandhavalli *et al*. proposed a SH automation system that leverages GSM and

Bluetooth modules to assist elderly and handicapped individuals in controlling home appliances [26]. Further Arduino Mega 2560 microcontroller with Bluetooth module was used for environmental monitoring and home automation [27].

Over the years, various home automation solutions have been proposed by researchers. Kodali *et al*. presented an ESP8266-based MQTT system that utilized sensors and actuators for home automation [28]. Ganesh proposed a GSM-web-based design [29], while Bhat *et al*. [30] suggested internet-based solutions that utilized smartphones to automate home appliances in a safe and energy-efficient manner. Researchers have also explored the use of sensors for controlling gas, temperature, and fire devices, with LCDs used for feedback purposes [31]. MQTT-based solutions have been used to measure humidity and temperature in rooms, with Raspberry Pi serving as a data access point [13]. Home automation using Arduino and Android-based smartphones has also been proposed [32,33], although the feasibility of complex tasks and multitasking with Arduino is limited. Inexpensive sensors have been used for achieving home automation, with Android-based smartphones used as remote controls [34-38]. Researchers have also proposed security systems that integrate with home automation systems using Android applications, Arduino, and GSM [39-41].

In addition to the aforementioned approaches, Raspberry Pi has also been utilized to control home appliances via web-based interfaces and sensors [42,43]. Furthermore, advancements in voice recognition technology, such as Siri technology from Apple Inc. and Google Assistant API (Application Programming Interface), have enabled control of various home appliances using built-in voice commands [44,45]. RFID (Radio Frequency Identification) tags have been used successfully to identify different components of an intelligent refrigerator, to enhance security in the house [46]. However, this method required several elements to be installed inside the home, such as RFID tags on household items, which posed practical challenges. To address the issue of real-time power monitoring, a SH system based on Ethernet, powered by an Intel Galileo Gen 2 board, has been proposed for use in both homes and community settings [47].

Advances in mobile technology and the decreasing cost of home automation systems have led to an increased interest in research and implementation of such systems [48]. The rise of the Internet of Things has provided an opportunity to integrate various wireless technologies like wifi, Bluetooth, mobile networks, and RFID, enabling remote monitoring and manipulation of smart devices within homes [48,49]. The different layers that make up the Internet of Things have several sub-layers, which incorporate emerging technologies and standards like Zigbee, infrared, and wireless sensors [50-53]. To design controllers, devices like microcontrollers, home gateways, PCB circuits, intelligent routers, and Arduino/Raspberry Pi are being utilized, while user interface design is being achieved through PCs, laptops, web and mobile applications, and smartphones. Researchers are exploring various combinations of these technologies to meet different goals such as affordability, speed, security, ease of use, accessibility, and originality [54-57].

The existing literature on Smart Home systems primarily focuses on the technology used and the comprehensiveness of features for user experience. However, little attention has been given to the simplicity of design, ease of manufacturing, affordability, and adoption. Various studies have proposed different approaches to home automation, including cost-effective solutions using Visual Basic and Microsoft speech recognition software [58,59], Zigbee-based systems [60], and the development of dedicated web pages and servers to control home devices and appliances over the internet [61-65]. However, these approaches have certain disadvantages, such as increased energy consumption and expensive infrastructure installation [62-65].

In light of these limitations, the present study proposes an economical and user-friendly smart home automation system, which is controlled by speech commands through Alexa Assistant. The system aims to provide a practical and accessible solution for controlling common electrical equipment in the home.

3. Proposed Design

The proposed smart home automation system design leverages the capabilities of a NodeMCU (ESP8266) [66] microcontroller with an inbuilt Wi-Fi module. This integration enables the remote control of household devices via the Internet. To facilitate virtual switches and enable voice control through Google Assistant or Alexa, the design requires a Tasmotizer App [67] and its web-based interface. The design flowchart, depicted in Fig. 1, outlines the sequence of actions for controlling various home appliances through voice instructions directed to Alexa Assistant. The information is then decoded and sent to the microcontroller. This, in turn, manages the associated relays, allowing users to turn gadgets on and off, using voice commands. The proposed design aims to provide a simple and economical solution for controlling common electrical equipment within a household through voice commands.

The proposed design represents an affordable and user-friendly solution for smart home automation. By utilizing a voice-controlled Alexa Assistant, the system allows for convenient and remote control of general household electrical appliances. The design incorporates a simple code template which is uploaded to the microcontroller using Tasmotizer and utilizes a user-friendly graphical web-based interface to configure the ESP module. This approach simplifies the assembly process and promotes intuitive usage. Additionally, its integrability provides numerous options for webhooks, Alexa, Google, Telegram, and other features, making the system highly adaptable and versatile. Compared to existing options, the proposed design incorporates locally available components, making it significantly more cost-effective.

Furthermore, our design addresses the challenge of unreliable internet connectivity in many parts of the world. To cater to this issue, we have integrated a manual control system that permits the operation of appliances even in the absence of internet or Wi-Fi. Moreover, it ensures that the system's status is updated on the server when connectivity is restored.

A standout feature of our design is the inclusion of an emergency control system, a distinctive aspect not found in other existing systems. This emergency control system can be activated in the event of a complete electronic failure. Users can access the emergency board by physically opening the designated cover. This innovative feature enhances the practicality, security, and reliability of home automation.

Overall, the proposed design represents a significant advancement over current options that often require extensive programming knowledge and familiarity with complex concepts related to C programming, microcontrollers, and their functions. In the context of smart home automation, our design (Fig. 1) represents the benefits of simplicity, ease of use, affordability, and reliability.

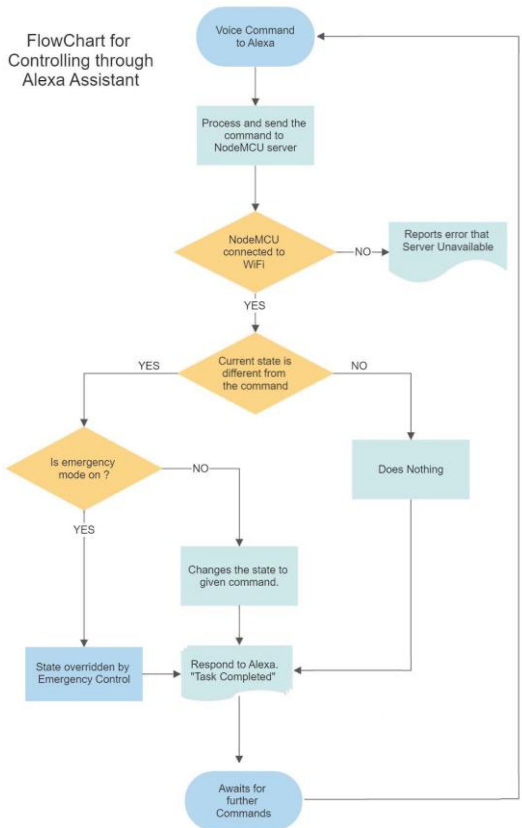

Fig. 1. Flowchart of the proposed android-based design.

4. Specifications of the Components Used

The component specifications and their associated costs for the support of this design are as follows:

Control unit: The primary component responsible for the operation of the system includes the microcontroller, smartphone, relays, and electrical appliances.

Design software: The software components include the Tasmotizer App, Amazon Account, and Alexa Assistant, integrated into an Android device. The Tasmota Web Interface on the Android device connects to the microcontroller to transmit signals received through Alexa over the internet. The system's architectural representation is illustrated in Fig. 2.

NodeMCU (ESP8266): This is an open-source, cost-effective IoT platform utilized to establish internet connectivity, enabling the system to respond to instructions [66]. Approximate cost is 400 INR to 650 INR.

Tasmota firmware: Developed and maintained by Theo Arends, Tasmota is an open-source firmware designed for devices using Espressif products like ESP8266/ESP32. It empowers users to configure and manage any device utilizing the ESP Wi-Fi chip [67]. This is typically free and open-source software.

Relay Module: Serving as an electromechanical switch for electrical appliances [68], the relay module plays a crucial role in the system. Approximate cost is 170 INR to 300 INR per module.

Push button switch: This component is employed for manual switching in situations where internet or Wi-Fi connectivity is unavailable to the circuit. Approximate cost is 100 INR to 250 INR per switch.

DC power supply (5V): Utilized to provide energy to both the microcontroller and relay modules. Approximate cost is 80 INR to 250 INR.

Smart assistant (Alexa): These are software-loaded devices employed to access information, execute tasks, or control other devices. Common choices include smart assistants like Alexa, Siri, Cortana, or Google Assistant. In this design, Alexa is the preferred smart assistant.

Electrical home appliances (to be controlled): These are the devices automated in the design. The system is configured to control a fan, a light bulb, a tube light, and a pair of ceiling lights.

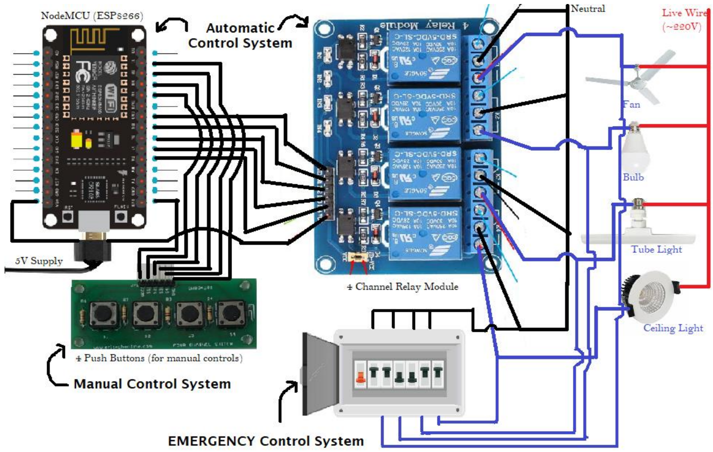

Fig. 2. Proposed system design.

5. Methodology of the Proposed Design

The methodology for implementing the smart home automation system, designed to be cost-effective and user-friendly, involves the following steps:

Setting Up tasmotizer app

Begin by downloading the Tasmotizer app from its official source [67]. Connect the NodeMCU microcontroller to a laptop or computer using a USB cable. In the Tasmotizer app, select the appropriate port to establish a connection with the microcontroller.

Accessing the tasmota web interface

The Tasmota web interface can be accessed by entering the IP address of the locally hosted server in any web browser on a device connected to the same network. This interface serves as the control center for configuring the pins to which the relays and push buttons will be connected.

Configuring pins and components

Once the pins are configured in the Tasmota web interface, proceed to connect all the components accordingly. Additionally, configure device names within the interface to enable their discovery and recognition by Alexa as smart devices. Once configured, this interface provides real-time status updates, reflecting changes triggered by connected push buttons and enabling control of the corresponding relays.

Activating Alexa voice control

To activate Alexa voice control, add the newly configured devices in the Alexa app. Alexa will automatically detect these smart devices within the user's local network and add them to the user's device list. Subsequently, users can control these devices using the Alexa app (refer to Fig. 3).

This methodology streamlines the setup and integration of the smart home system, making it accessible and manageable for users.

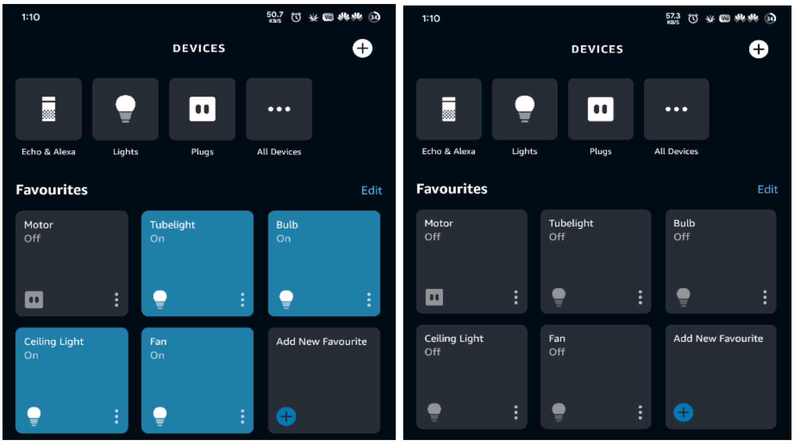

Fig. 3. Controlling through the Alexa App over the Internet.

Our designed prototype was seamlessly integrated with a range of household appliances, demonstrating its versatility and practicality. Specifically, the system was connected to a tube light, a bulb, a ceiling fan, and a pair of ceiling lights (refer to Fig. 4 for an overview of these components).

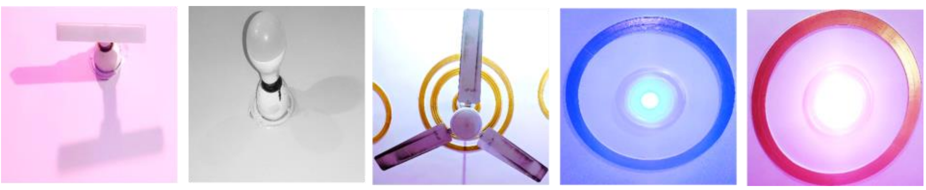

Fig. 4. Electrical devices automated using the proposed design.

Fig. 5 below gives a comprehensive illustration of the hardware implementation of the proposed system.

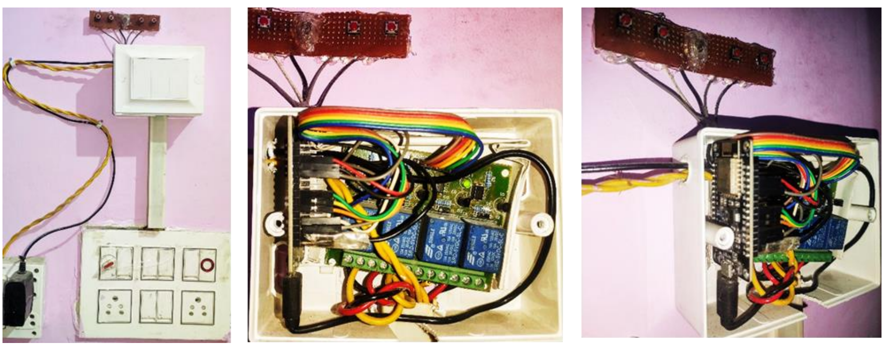

Fig. 5. (a) Domestic Mains board with attached prototype and its power supply, (b) Opened prototype board with push buttons for manual controls. (c) Side view of prototype board showing NodeMCU with ESP8266.

The working of all four appliances (as depicted in Fig. 4) was effectively automated using the implementation of the prototype, as per the design specifications. This automation encompassed not only the remote control of switches but also the management of the appliances via manual push buttons. These manual controls proved invaluable, particularly in scenarios involving internet outages or other events affecting internet availability, as depicted in Figs. 5(b) and 5(c). Notably, these push buttons facilitated state changes in the relays while concurrently providing real-time status updates on the internet and within the dedicated app.

Moreover, the prototype was thoughtfully designed to incorporate traditional switches, as illustrated in Fig. 5(a). These traditional switches were strategically positioned to serve as an emergency control system, ready to intervene in the event of microcontroller failure or any system dysfunction. This redundancy added an extra layer of reliability, ensuring that critical appliances could always be operated even under adverse conditions.

6. Efficiency of the Proposed Design

To evaluate the energy efficiency achieved by our home automation system in comparison to traditional non-automated switching systems, we conducted a comprehensive study. This study involved the installation of an electricity consumption measuring device in a room, 15 days before and 15 days after the implementation of the designed automation system. The data of electricity consumption by all the devices (as depicted in Fig. 4) are recorded, during both periods. Further, recorded data is tabulated in Table 1, providing a clear picture of electricity consumption patterns with and without the utilization of our automation system.

Table 1. Recorded data of electricity consumption of all the devices, with and without using our automation system.

Day	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Without automation [kWh]	8.37	5.65	4.96	6.08	4.26	7.74	5.12	4.50
With our design [kWh]	3.61	3.46	3.88	5.06	4.53	3.15	3.13	3.00
Day	**9**	**10**	**11**	**12**	**13**	**14**	**15**	
Without automation [kWh]	4.43	6.91	5.30	4.33	5.75	3.59	5.38	
With our design [kWh]	3.38	2.87	3.24	3.37	3.09	2.05	2.62	

The comparative graph shown in Fig. 6 highlights the daily electricity consumption of the automated room with and without the implemented design. A distinct reduction in daily electricity consumption is evident when our automation system is in operation.

This remarkable energy efficiency can be attributed to several key factors enabled by our home automation system:

(1) Selective device control: Our automation system allows precise control of individual devices, preventing the simultaneous operation of multiple devices when not required. Traditional non-automated systems lack this level of granularity, often leading to unnecessary energy consumption.

(2) Scheduling and automation: The system's scheduling capabilities enable devices to operate at specific times, optimizing energy usage by aligning device operation with actual requirements. Lights, for example, can automatically turn off during daytime hours.

(3) Remote monitoring and control: Remote access to devices via the internet empowers users to promptly respond to changing circumstances. This remote control prevents unnecessary energy wastage, such as inadvertently leaving devices on.

(4) Energy monitoring: Real-time energy monitoring and reporting, help users identify energy-hungry devices, allowing for informed adjustments to usage habits.

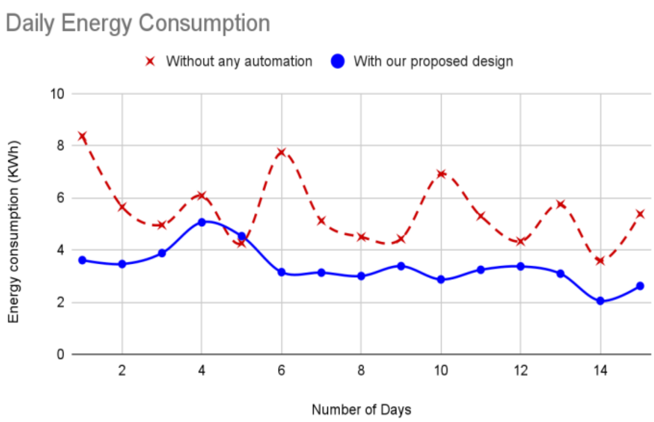

Fig. 6. Daily electricity consumption of the automated room with and without the implemented design.

Upon analyzing the data, it is evident that our system significantly reduces daily electricity consumption in the room. The total monthly consumption, calculated to be 164.74 kWh without automation, was substantially reduced to 100.88 kWh after the installation of our proposed design. In pursuit of energy conservation, our approach proves to be 38.76 % more effective compared to conventional switches. This substantial energy savings underscores the cost-effective aspect of our home automation system, which not only enhances convenience but also contributes to environmental sustainability.

To comprehensively evaluate the efficiency of our home automation system, including its cost-effectiveness, we conducted a detailed analysis comparing it with other available alternatives. This cost comparison underscores the financial advantages of our solution while emphasizing its energy efficiency.

6.1. *Cost Comparison with Other Available Alternatives*

Our home automation system stands out not only for its energy efficiency but also for its affordability. In contrast to many existing alternatives, which often come with a hefty price tag and complex installation, our solution offers a cost-effective and user-friendly approach.

Affordable components

The foundation of our system relies on readily available and cost-effective components, such as the NodeMCU (ESP8266) microcontroller, relay modules, and push buttons. These components are accessible in local markets, significantly reducing the overall system cost.

Ease of assembly

The simplicity of our system's design, coupled with a basic code template and a graphical web-based interface for configuration, ensures ease of assembly and setup. This eliminates the need for specialized technicians or extensive programming knowledge, further reducing installation costs.

Emergency control and reliability

The inclusion of traditional switches as an emergency control system adds an extra layer of reliability to our system. This feature minimizes downtime, preventing the need for costly repairs or replacements in the event of microcontroller failure.

Prices of available alternatives for automation of 4 switches is as follows

(1) Smarteefi WiFi 5: 3200 INR - 3500 INR [69]
(2) HomeMate WiFi 4: 1800 INR [70]
(3) Tata Power EZ Home: 2450 INR [71]
(4) IOTICS 4 Gang Smart Wifi Switch Board: 6900 INR - 7500 INR [72]

The Prices of our design for 4 Switches (with Emergency Control) is within 1000 INR to 1300 INR. Our home automation system not only achieves remarkable energy efficiency but also distinguishes itself through its cost-effectiveness. The utilization of affordable components, straightforward assembly, and significant energy savings contribute to its financial appeal. When compared to other available alternatives, our solution emerges as a practical and economical choice, demonstrating that enhanced comfort, convenience, and control over one's living environment need not come at a premium price.

7. Conclusion and Future Prospects

This paper has successfully achieved its primary objective of developing an affordable and voice-controlled smart home system based on Alexa Assistant, capable of efficiently managing household electrical appliances. The implementation of Home Automation with NodeMCU using Alexa Assistant, as demonstrated by our prototype, allows for effortless remote monitoring of home appliances from anywhere across the globe. Importantly, our system stands out for its cost-effectiveness compared to existing alternatives in the market, which often come with high price tags and complexities during assembly and configuration.

The proposed design significantly simplifies the process, employing a basic code template to connect appliances to a locally hosted web server and utilizing a user-friendly graphical interface for ESP module configuration. Moreover, it offers versatile integration options, including webhooks, Alexa, Google, Telegram, and more. The use of locally available components further enhances its affordability, making it an economically viable choice for users.

One notable feature that sets our system apart is the inclusion of an emergency control system, adding an extra layer of reliability and efficiency. This feature not only enhances the practicality of the system but also addresses the needs of elderly and differently-abled individuals who may struggle to physically reach and operate switches. Additionally, this approach optimizes electricity usage, resulting in cost savings and improved energy efficiency.

As for future aspects, the system's capabilities can be expanded to include advanced home security features, such as capturing snapshots of unauthorized movements around the house and uploading them to the cloud. Furthermore, the system's remote operation potential opens doors to endless possibilities for controlling various devices and appliances remotely, further enhancing its utility and convenience.

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