International Journal of Innovative Technology and Exploring Engineering (IJITEE)
ISSN: 2278-3075 (Online), Volume-14 Issue-8, July 2025

Design and Implementation of a Voice-Controlled Smart Home Automation System

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Abstract: ***Voice command recognition systems are increasingly becoming integral to domestic and industrial automation, offering a more user-friendly alternative to conventional control panels, which can be complex and difficult to operate. Additionally, many institutions and households in rural areas still rely on manual control systems due to the absence or unreliability of internet connectivity. This research focuses on designing and implementing a user-friendly, voice-controlled smart home automation system to address these limitations. Besides, Traditional home systems primarily depend on manual operation for appliances such as lighting, security alarms, and heating systems, which can be inconvenient and energy-inefficient. This challenge is particularly significant for older people and individuals with disabilities. The proposed system enhances convenience, accessibility, and energy efficiency by enabling voice control of essential household devices, including lighting, air conditioning, and televisions. Unlike many existing solutions, the system operates reliably without an internet connection, making it more affordable and practical. However, the proposed design consists of key components, including a microcontroller as the central processing unit, a voice recognition module, a relay circuit, and auxiliary components. To optimise the design performance, the system was modelled and simulated using Proteus software, allowing for thorough testing before physical implementation. The functionality was programmed in C++ to ensure seamless interaction between components. A prototype was developed and experimentally tested, demonstrating minimal response time delay between simulation and implementation, as well as high command accuracy. Performance analysis, including response time and accuracy, was conducted to evaluate the system's effectiveness in achieving the research objectives.***

Keywords: ***Voice-Controlled Automation, Manual Operation, Traditional Home System, Microcontroller, Household Appliance, Relay.***

Abbreviations:
AMR: Automatic Mobile Recognition
GSM: Global System for Mobile Communication
LCD: Liquid Crystal Display
TV: Television
AC: Air Conditioner
PCB: Printed Circuit Board
IoT: Internet of Things
RF: Radio Frequency
IDE: Integrated Development Environment
VLC: Visible Light Communication
AI: Artificial Intelligence
NLP: Natural Language Processing

Manuscript received on 16 April 2025 | First Revised Manuscript received on 20 May 2025 | Second Revised Manuscript received on 16 June 2025 | Manuscript Accepted on 15 July 2025 | Manuscript published on 30 July 2025.

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I. INTRODUCTION

The home automation system, integrated with voice recognition technology, enables the control of domestic electrical appliances such as televisions, lighting, and air conditioning units, significantly enhancing convenience and energy efficiency. When properly designed and configured, such a system is especially beneficial for individuals with disabilities or physical challenges.

However, home automation is revolutionizing daily life by leveraging technology to simplify tasks and enhance efficiency. Enabling seamless communication between household devices over a network minimizes the need for manual operation. This advancement enhances convenience, security, and overall control of home systems. Leading companies such as Google and Amazon have made significant investments in smart home technology, and the global market for these innovations is projected to expand from USD 46.97 billion in 2015 to USD 121.73 billion by 2022 [1].

In the study presented by [2], advancements in Internet of Things (IoT) technologies were explored for their potential in enhancing the control and monitoring of household electronics, particularly benefiting older people and individuals with disabilities through voice-assisted automation. The researchers highlighted that many existing systems depend heavily on cloud-based platforms, which pose cybersecurity risks and require stable internet connectivity. These dependencies are especially problematic in developing countries, where internet access is often unreliable and voice assistants lack local language support. The authors proposed an offline home automation system designed to address these issues independently of cloud services. Their solution aims to enhance data security, provide faster response times, and incorporate additional features such as power usage tracking and device optimisation.

In [3], the authors presented an intelligent voice control system capable of performing voice activity detection, speech recognition, speaker authentication, command analysis, and automatic response generation. They introduced a novel voice activity detection (VAD) algorithm and a backtracking method to enhance system efficiency.

The system was evaluated using a custom simulation

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DOI: 10.35940/ijitee.F1093.14080725
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corpus, with performance assessed through specifically defined evaluation metrics. The results demonstrated satisfactory accuracy and effectiveness of the proposed approach.

Moreover, Isyanto et al. [4] introduced an IoT-based smart home automation system tailored for individuals with disabilities. Through voice commands, this system enables users to control various electrical appliances, including televisions, lights, and air conditioners. Additionally, integrating Google Assistant with smartphones allows hands-free operation, eliminating the need for physical movement or manual input. The study highlights that the system's performance is influenced by the strength of the internet signal, which affects response times and processing efficiency. The primary objective is to enhance accessibility and ease of interaction with the home environment using voice-controlled Internet of Things (IoT) technology.

Besides, Anuradha et al. [5] proposed a system that utilizes Internet of Things (IoT) technology to facilitate wireless control of devices via internet connectivity, with the NodeMCU development board serving as the core processing unit. Their design integrates a mobile application interface that supports voice commands and hand gesture inputs to control connected devices. Built using the MIT App Inventor platform, the application leverages a cloud-based speech-to-text engine to interpret voice instructions while detecting hand angles to trigger corresponding control actions. The system is specifically designed to support individuals with physical impairments, allowing them to operate machinery with minimal physical effort. Furthermore, the solution demonstrates potential for broader industrial applications by enhancing operational efficiency and enabling remote control of machinery. Its global accessibility through the mobile application enhances usability across various environments, establishing it as a versatile and inclusive intelligent control system.

Furthermore, Sakthidharan et al. [6] proposed a voice-controlled home automation system that leverages Google Assistant to reduce human effort in managing household appliances. Their solution targets not only users seeking luxury and convenience, but also older individuals and those with disabilities who require accessible and intuitive control interfaces. The proposed system incorporates a compact and aesthetically integrated automation board that fits within wall-mounted AC power units. Using voice commands like "Okay Google, turn on the lights," users can interact with and control connected devices seamlessly. The system also features manual switching and timer-based automation, enhancing its versatility and usability in smart home environments.

In [7], home automation solutions designed to assist elderly and physically challenged individuals by creating a secure, safe, and controlled living environment are surveyed. The review covers a range of technologies, including Brain-Computer Interfaces, various Human-Computer Interaction systems, GSM SMS-based controls, Bluetooth connectivity, PIC microcontrollers with ZigBee, voice-activated automation, Electrooculography (EOG)-based interfaces, and assistive Visible Light Communication (VLC). These smart home technologies can significantly improve comfort and ease daily living for users with mobility or cognitive impairments. This paper specifically focuses on addressing the needs of older adults and those with physical disabilities.

In [8], the authors explain that advances in wireless ICT and multi-agent systems have transformed the "smart home" from concept to reality, enabling remote monitoring and automatic control via the Internet or telephone to support individuals with disabilities. Existing environmental control systems utilise voice commands to operate appliances; however, users with impaired mobility or limited hand function still face challenges. To address this, the study proposes a multimodal interface that combines pointing gestures for device selection with voice commands for remote-control functions (e.g., power on/off, channel change, volume adjustment). This hands-free design is designed to provide intuitive and efficient control for quadriplegic users, enabling them to manage home appliances with minimal physical effort.

Also, in [9], the authors develop a voice- and touch-operated home automation system tailored for elderly and disabled users, prioritizing energy efficiency, affordability, and reliability. Built around an Arduino Mega 2560, the system integrates with a smartphone app to control up to 44 devices, including multiple smoke detectors and PIR motion sensors, via Bluetooth. For added convenience, all functions can be accessed through NFC tags. With a total build cost under USD 30 and low power requirements, this solution is economically accessible and energy-saving, offering a practical upgrade for existing homes.

In [10], the researchers note that recent advances in IoT, sensors, smartphones, cloud computing, and digital assistants (e.g., Alexa, Google Assistant, Siri) have fueled widespread conversion of conventional homes into "smart homes," primarily benefiting nondisabled users through enhanced security, energy savings, and remote control of lighting, HVAC, door locks, and appliances. However, most existing systems do not cater to individuals with physical disabilities or limited mobility. To address this gap, the paper proposes a solution that leverages smart plugs, smart cameras, smart power strips, and a digital assistant to interpret natural voice commands from users with disabilities, enabling them to switch household electrical devices on or off with minimal effort.

Likewise, Speech recognition technology is widely applied across various sectors, including telecommunications, automotive, military, aviation, education, and daily life, with a significant impact on smart home automation. It enables intuitive voice-controlled systems that personalize settings, automate household functions like lighting, door access, security lights, plant watering, and water heating, and stream live surveillance via the internet. These systems integrate various home functions, including security, climate control, entertainment, and communication, into a centralised, intelligent platform that enhances convenience and efficiency. Building on this, researchers have developed voice-activated home automation systems that

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incorporate low-power RF wireless communication and microcontrollers, specifically designed to support older adults and individuals with disabilities. These systems operate effectively without altering existing infrastructure, offering a secure, energy-efficient, and practical solution for modern home management, as confirmed through successful experimental validation [11].

Nyiekaa et al. [12] proposed a microcontroller-based voice control automation system leveraging Android smartphones to simplify the operation of home appliances, particularly for the elderly and physically challenged. The study highlights the increasing relevance of system automation in the 21st century, noting its ability to reduce human effort and minimize errors. As society transitions from traditional wall switches to more accessible remote-controlled systems, mobile technology and natural language processing have enabled intuitive control mechanisms. In their implementation, an Arduino Uno microcontroller processes voice commands received through the 'AMR Voice' Android application. A Bluetooth module facilitates wireless communication between the smartphone and the controller, while relays manage the switching of connected appliances. The system allows for hands-free, voice-based control of various household devices, demonstrating the practicality and efficiency of low-cost, smartphone-integrated home automation.

Similarly, Mohamed et al. [13] proposed an IoT-based smart home automation system that integrates voice control, artificial intelligence (AI), and natural language processing (NLP) to enhance operational efficiency and user interaction. In their design, voice commands are issued via an Android or web-based chat interface, interpreted using natural language processing (NLP), and translated into executable instructions through Arduino and Raspberry Pi modules. The system enables users to control appliances, monitor utility consumption, and automate billing, while a machine learning-driven recommendation engine suggests optimal control actions. Experimental implementation demonstrated the system's feasibility, highlighting its potential to improve comfort, efficiency, and safety in home environments.

In a recent study, researchers developed a voice-activated home automation system to support typical users, older people, and individuals with disabilities. The system enables users to control household electrical appliances through voice commands, reducing the need for constant caregiver support. Designed to run on Android smartphones, the solution emphasizes usability and accessibility. It incorporates voice recognition capabilities that can distinguish and validate commands from authorized users, enhancing system security. Notably, the system is accessible to users with visual, hearing, or speech impairments. As part of the research, a prototype was implemented to demonstrate remote control of devices such as lights, doors, and a subwoofer using voice inputs through a mobile application, showcasing the practicality and user-friendliness of the approach [14].

Nonetheless, with the increasing adoption of smart devices, virtual assistants, and related technologies, voice commands have become increasingly popular. Consequently, recent research has focused on evaluating their feasibility for operating system functions [15]. Moreover, voice commands are increasingly gaining popularity in industrial automation. Instead of relying on traditional control panels, which may be complex and less user-friendly, speech recognition systems offer a more intuitive and efficient solution for executing basic commands [16].

A. Novelty of the Proposed Design

The key novelty of this research lies in its ability to operate offline, without the need for internet connectivity, making it particularly suitable for rural environments or areas. Additionally, the system integrates essential components such as a voice recognition module and relay circuits, enabling efficient control of home appliances and electronic devices.

II. MATERIALS AND METHODS

A. System Design, Software and Simulation Analysis

This section outlines the systematic approach to designing and implementing the voice-controlled home automation system. The development process encompassed system design, component selection, programming, and operational testing. Computer-based modelling and simulation were utilised to optimise performance, with Proteus software employed to simulate functionality and validate system operation before physical implementation. The control logic was programmed in C++ to ensure seamless communication between system components. The system enables users to control household devices, including lighting, air conditioning, and televisions, through voice commands.

A microcontroller is the central processing unit, interpreting commands from a voice recognition module. These commands are transmitted through a remote receiver, allowing users to operate appliances from various locations within the home. A relay circuit interfaces the microcontroller with household devices, ensuring safe switching operations. An LCD screen provides real-time feedback by displaying the status of each controlled appliance. This integrated design enhances convenience, enabling effortless home automation through voice control. The software was developed using the Arduino Integrated Development Environment (IDE) due to its user-friendly interface and efficient code compilation for the Arduino Uno microcontroller. C++ was used for programming, enabling precise control over system functions. The compiled code was converted into a Hex file and imported into Proteus Design Suite for simulation. Proteus was selected for its advanced schematic capture and PCB layout features, allowing comprehensive virtual testing before hardware implementation. This simulation process facilitated early detection and resolution of potential issues, ensuring seamless integration of system components, including the microcontroller, relay circuit, power supply, and voice module. The simulation

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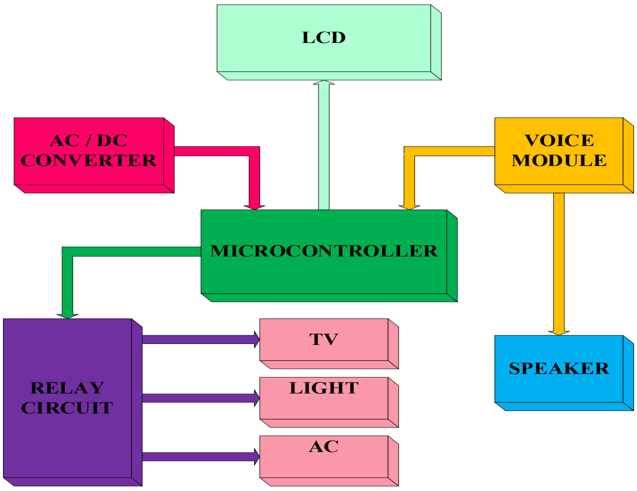
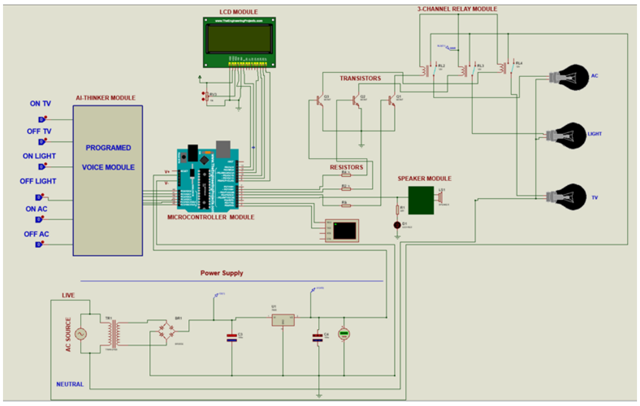
results validated the system's reliability, optimizing performance before real-world deployment.



[Fig.1: The Block Diagram of the Voice-Controlled Smart Home System]



[Fig.2: The Circuit Diagram of Voice-Controlled Smart Home System]

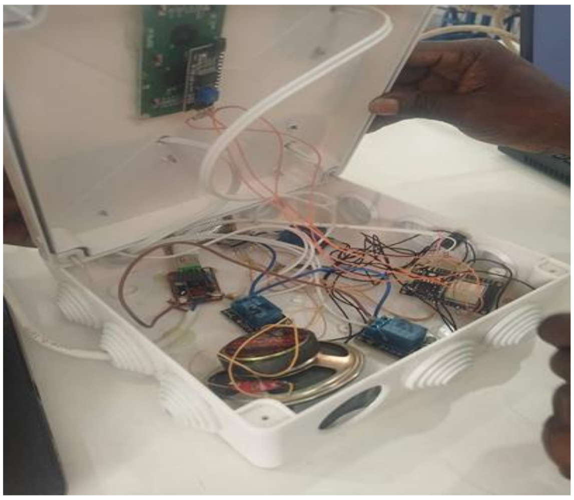
B. Mode of System Operation

The voice-controlled smart home system automates household appliances using verbal commands processed by an integrated voice recognition module. When a user issues a command, the module converts it into a digital signal, which the microcontroller interprets based on pre-programmed instructions. The microcontroller then activates the corresponding relay module, functioning as an electronic switch to control devices such as lights, air conditioners, and televisions. This setup ensures efficient and safe electrical isolation while enabling seamless automation. A stable power supply circuit maintains consistent voltage, ensuring reliable system operation.

C. Construction Procedure

The construction of the voice-controlled smart home system followed a systematic approach to ensure seamless integration and functionality. The process began with assembling the power supply circuit to deliver a stable 5V DC output for the microcontroller and other components. It included a step-down transformer, a bridge rectifier for AC-to-DC conversion, filter capacitors for voltage smoothing, and a steady supply regulator. Once tested and verified, the power circuit was connected to the Arduino Uno. Next, the voice recognition module was integrated with the microcontroller to capture and process voice commands accurately. An LCD was added to provide real-time feedback on recognised commands and the status of controlled devices. Relay circuits were then constructed to switch appliances such as lights, air conditioners, and televisions.

The microcontroller controlled each relay through transistor circuits, which amplified signals to ensure practical switching. Proper electrical isolation techniques were implemented to protect the microcontroller and enhance system safety. After assembling the hardware, the Arduino Uno was programmed to interpret voice commands and execute the corresponding control actions using the Arduino IDE. The system underwent rigorous testing and calibration to verify the functionality of the power supply, voice module, relays, and LCD. Adjustments were made to optimize performance, ensuring accurate command recognition and reliable device control. The final system was enclosed in a protective casing, as shown in Figures 3 and 4, designed for both durability and efficiency. The component arrangement and connectivity were visually inspected to confirm proper functionality.



[Fig.3: Physical Overview of the Connections between the Components]

[Fig.4: Overall Construction of the System]

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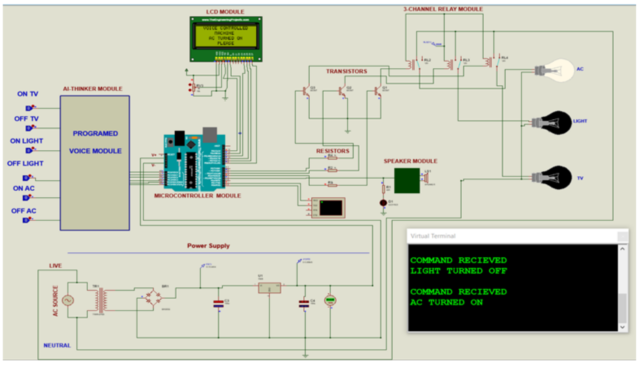
III. RESULTS AND DISCUSSION

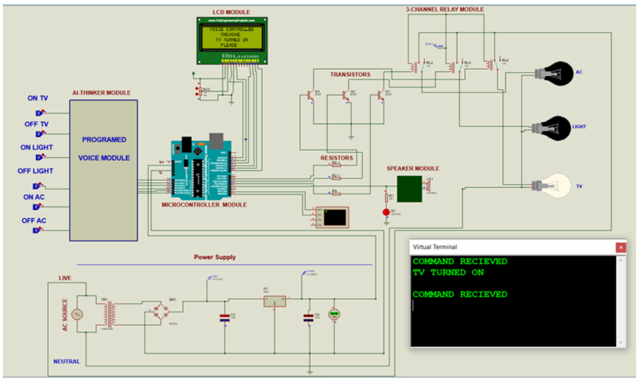
A. Simulation Results

The functionality of the voice-controlled smart home system was validated through simulation in Proteus software before physical implementation. The system successfully processed voice commands to control lighting, air conditioning, and televisions. During the simulation, the voice module captured commands and transmitted them to the Arduino microcontroller for processing. Upon receiving a command, an indicator light blinked three times, confirming successful input recognition. The microcontroller then activated the corresponding relay to switch appliances on or off, with real-time feedback on the LCD screen. A stable 5V power supply ensured the reliable operation of all components, confirming the system's effectiveness before deployment. Additionally, Figure 5 illustrates the simulation setup and results for controlling the air conditioner (AC) using the voice-controlled smart home automation system in Proteus software.



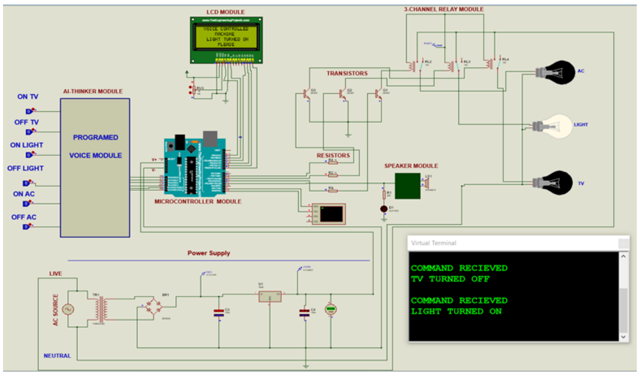
[Fig.5: Simulation Result for Air Conditioner (AC) Control]

Figure 6 illustrates the simulation results for controlling a television using the voice-controlled home automation system in Proteus software. The system processes voice commands such as "ON TV," which are captured by the voice module and transmitted to the Arduino microcontroller. Upon receiving the command, an indicator light blinks three times, confirming successful recognition. The microcontroller then activates the relay to switch the TV on or off, displaying real-time feedback on the LCD screen. A stable 5V power supply ensures reliable operation, validating the system's ability to control the TV via voice commands.



[Fig.6: Simulation Result for Television (TV) Control]

Figure 7 illustrates the simulation results for controlling lights using the voice-controlled home automation system in Proteus software. When a voice command such as "ON LIGHT" is issued, the voice module captures and transmits it to the Arduino microcontroller for execution. An indicator light blinks thrice upon detection, confirming successful recognition and module functionality. The microcontroller then activates the relay to switch the light on or off, displaying real-time status on the LCD screen. A stable power supply ensures consistent voltage, guaranteeing reliable system operation.



[Fig.7: Simulation Result for Light Control]

B. Experimental Results

Figures 8 to 10 illustrate the practical implementation and performance of the voice-controlled home automation system in real-world conditions. Figure 7 specifically demonstrates the system controlling a light during testing. Upon receiving the "Light ON" command, the system activated the light bulb, as evidenced by its illumination. The LCD screen displayed the message "Command Received: Light ON," confirming execution, while an integrated speaker provided audible feedback by announcing, "Light is ON." These results validate the system's effectiveness in automating household appliances through voice commands.

[Fig.8: Picture of the Implemented System for Light Control]

Figure 9 illustrates the practical implementation of the voice-controlled system during the television control testing phase. Upon receiving the "TV ON" command, the system successfully activated the television. The LCD screen

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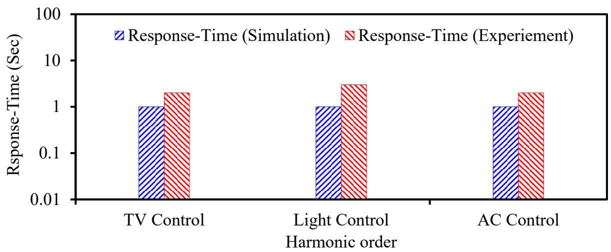
confirmed the action by displaying "Command Received: TV ON," while an integrated speaker provided audible feedback by announcing, "TV is ON." This demonstration validates the system's reliability in executing voice commands for appliance control.

[Fig.9: Picture of the Implemented System for Television (TV) Control]

Figure 10 illustrates the practical implementation of the voice-controlled system during air conditioner (AC) control testing. Upon receiving the "AC ON" command, the system activated the air conditioner. The LCD screen displayed "Command Received: AC ON," providing visual confirmation, while the integrated speaker announced, "Air Conditioner is ON," ensuring both auditory and visual feedback for the user. This validates the system's efficiency in controlling household appliances via voice commands.

[Fig.10: Picture of the Implemented System for Air Conditioner Control]

Figure 11 presents graphs comparing the response times obtained from the simulation and experimental phases.



[Fig.11: Comparison of Response Times Between Simulation and Experimental Results]

Table-I. Comparison of Response Times (Simulation and Experimental Results)

System	Response Time (Simulation) (s)	Response Time (Experimental) (s)
TV Control	1.1	2
Light Control	1.1	3
AC Control	1.1	2

IV. DISCUSSION

The voice-controlled home automation system demonstrated effective performance in simulated and real-world environments. Initial simulations using Proteus software confirmed the system's functionality, as shown in Figures 5, 6, and 7, which depict control of the air conditioner, television, and light. Voice commands were accurately processed by the Arduino microcontroller, which activated the corresponding relays, while the LCD screen provided visual confirmation of successful operations. A consistent response time of 1.1 seconds across all appliances was recorded during the simulation, as indicated in Table 1. This uniformity reflected the efficient execution of control logic under ideal conditions. However, experimental testing introduced real-world variables that affected system performance. As presented in Figures 8–10 and Table 5, response times increased slightly by 2 seconds for the TV and AC, and 3 seconds for the light due to microcontroller delays, ambient noise, and signal interference.

Figure 11 presents a graphical comparison of the simulation and experimental results. The simulation data, represented by a blue line, remains stable at 1.1 seconds. In contrast, the experimental data, shown in red, exhibit fluctuations, highlighting the influence of real-world conditions, particularly on light control, which requires more processing power and energy. Despite these delays, the system maintained high command accuracy and responsiveness. The inclusion of LCD feedback and voice prompts improved user interaction. Microsoft Excel was used to visualise performance trends, aiding in the comparison of results. Overall, the findings underscore the need for further optimisation, including enhanced signal processing, noise-reduction techniques, and improvements in microcontroller efficiency to improve real-world performance.

V. CONCLUSIONS

The voice-controlled home automation system was successfully designed and implemented, effectively managing household appliances, including televisions, lights, and air conditioners, through voice commands. Both simulation and experimental results confirmed its reliability, with minor variations in response time in real-world conditions due to processing delays, environmental noise, and signal interference. Key components, including the microcontroller, voice module, and relay, ensured an affordable and efficient design. Integrating hardware with the Arduino Uno and Proteus-based simulations provided valuable insights, enabling optimisation of system performance before deployment.

Retrieval Number: 100.1/ijitee.F109314060525
DOI: 10.35940/ijitee.F1093.14080725
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DECLARATION STATEMENT

I, the corresponding author, confirm that all authors have contributed equally to this work. To the best of my knowledge, this article has no conflicts of interest. The research was conducted independently and received no external funding or sponsorship. Ethical approval and participant consent were not required, as the study did not involve human or animal subjects. All resources referenced in this study are publicly accessible.

After aggregating input from all authors, I must verify the accuracy of the following information as the article's author.

- **Conflicts of Interest/ Competing Interests:** Based on my understanding, this article has no conflicts of interest.
- **Funding Support:** This article has not been funded by any organizations or agencies. This independence ensures that the research is conducted with objectivity and without any external influence.
- **Ethical Approval and Consent to Participate:** The data presented in this article does not require ethical approval or participant consent, as it falls outside the scope of such requirements.
- **Data Access Statement and Material Availability:** The adequate resources of this article are publicly accessible.
- **Author's Contributions:** The authorship of this article is contributed equally to all participating individuals

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AUTHOR'S PROFILE

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Retrieval Number: 100.1/ijitee.F109314060525
DOI: 10.35940/ijitee.F1093.14080725
Journal Website: www.ijitee.org

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