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Design and Development of a Model Smart Home Automation System for Electronics Control

Idama Omokaro[1,*], Canice Mezue[2], Jonah Micaiah Dogarah.[3], Wunukhen Shehu Awudu[3]

[1]Computer Engineering, Delta State University of Science and Technology, Ozoro, Nigeria
[2]College of Technology, Wilmington University, New Castle, DE, United States
[3]Computer Engineering. Federal University Wukari, Nigeria

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Abstract
This work presents the design and development of a model smart home automation system using the Internet of Things (IoT) for convenient electronics control. Conventional wired systems can be costly to retrofit, prompting the exploration of alternative solutions. This IoT-based system allows users to control home appliances remotely and through voice commands. The system utilizes a NodeMCU board, relays, and sensors to enable functionalities like remote monitoring and control, voice activation, sensor integration, automation scenarios, and security and safety. The developed system demonstrates the feasibility of convenience, efficiency, and safety for users using an IoT approach.

Keywords: *Wireless home automation, internet of things, sensor integration, remote control, Security and safety*

1. Introduction
Home automation refers to the use of tools and methods that allow for the processing of written, visual, and sound data related to home activities in a computer-aided manner [15]. A single machine can control all household devices and appliances in a networked home, simplifying their management and use [6]. In an automated home, the information from each device is interconnected, which facilitates better operations. The use of an electronic control system in home automation allows electronic gadgets to be controlled from any part of the world using the internet through a mobile phone or personal computer [3]. Integrating home automation with the Internet of Things (IoT), which is a new revolution in the Internet, provides better flexibility in managing and controlling household appliances on a wider scale [4, 5]. The IoT is comprised of wireless technology, microelectromechanical systems, microservices, and the internet as an extension of internet connectivity into everyday objects and devices that are embedded with electronics, internet connectivity, and other types of hardware (like sensors) so they can talk to each other and be controlled and monitored from afar over the internet. This system guarantees the effective usage of household objects through intelligent monitoring and control, allowing for routine responsibilities to be handed over to a smart system and reducing the cost of human error [9, 11].

Most home appliances and devices used for domestic activities rely on electricity, drawing power from various sources like the national grid, chemical batteries, generators, and solar panels [2]. However, electrical fires in structural and functional buildings can result from lightning ground flashes that strike electrical lines and installations, leading to very high voltages that can cause the burning of electrical wires and other equipment installed in houses. This can result in property losses, human injuries, and loss of life, making it essential to take precautionary measures [1, 10]. The use of authorized power strips, surge protectors, and installation interrupters for ground-fault circuits that protect the appliances is a safety approach to addressing this challenge. Additionally, powering off appliances when not in use is a crucial step in safe appliance handling and curbing human errors in electrically powered devices [1]. Simultaneous control of the appliances can take care of appliance switch-off oversight due to human error and the natural hazard factor. This is one of the advantages that IoT-based home automation offers [7, 10]. Other advantages of home automation adapted to IoT technology include the provision of information

*Corresponding author: abissanjonah@gmail.com

on atmospheric conditions, such as the temperature and humidity of the environment, and applications that secure the home from theft or hazards through the voice command and control system. A home automation system makes the operation of various home appliances more convenient and saves energy, enabling the user to constantly monitor the house's electricity consumption rate via the graphical user interface [8, 13].

Every research project is designed to solve problems and always relies on previous research. Therefore, some research works were reviewed to provide a springboard for the success of this research. Raj [14] built an automated home where all electronics are controlled electronically, with security done using connected IoT devices and sensors for motion, fire, gas, and smoke detection. However, the system's inability to send users SMS had a limit on its work. Usman's [16] IoT-based smart home security and monitoring system could help secure, monitor, and control home appliances from any location, but the lack of access from a personal computer presented a challenge. Muhammad [12] developed an IoT-based farm automation system that automates major farming procedures and helps monitor farm produce from home to carry out irrigation on the farm from any location. However, the system cannot tell when a plant is due for harvest. Murdan and Gunness [13] presented an approach to the design and development of a low-cost IoT-based, energy-efficient system for home automation using web services and cloud computing. The monitoring and control of devices are affected in real time using web services and cloud computing. However, the system could not store large amounts of data during the implementation of the study.

Based on the gathered data, it appears that many households rely on manual methods for managing, monitoring, and regulating their electronic appliances. This can be inconvenient, particularly when individuals are away but wish to turn devices on or off or monitor their home's activity at a specific time. Moreover, theft is a major concern, with homeowners often unaware of intruders and suffering significant asset losses. Additionally, many have suffered electric shocks from switches, resulting in severe injuries. While some home automation systems exist, they cannot be controlled via voice command, requiring users to rely on a computer. Our proposed design aims to address these issues by implementing a voice-assisted electronic control system that promotes safety, reduces home disasters, and allows users to easily manage their electronic appliances from the comfort of their homes.

2. Materials and Methods

The research methodology utilized for this project is the prototyping methodology (Figure 1). This approach, as defined by Davis [5], involves the creation of segments of the solution to showcase functionality and make necessary adjustments before the final solution is developed. This technique is a time-efficient way to reduce rework, as users have the opportunity to see the product upfront. It is also an effective way for the development team to confirm their understanding of the requirements and ensure that the proposed solution aligns with business expectations.

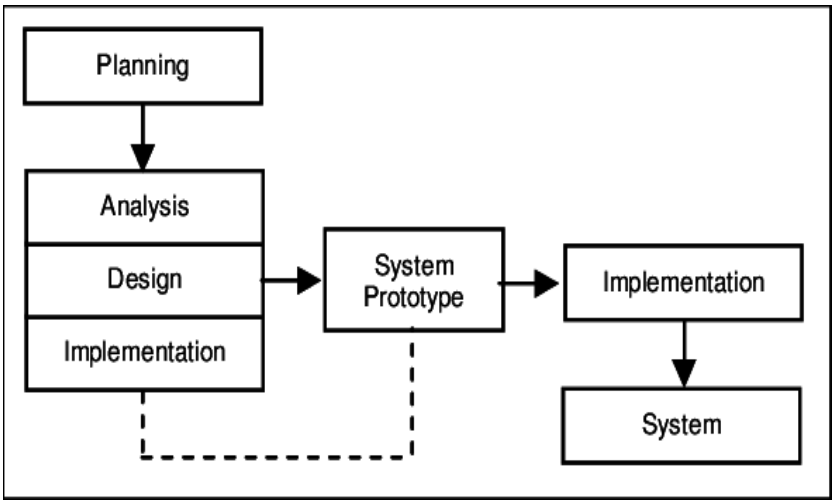

Figure 1. Prototyping methodology

The phases of the prototyping model for this project entail:

i. Identifying the model requirements: outlining the primary requirements for the system that comprise the main input and output information.
ii. Developing the initial prototype: creating a rudimentary prototype that solely consists of UI screens.
iii. Reviewing the prototype: allowing for end users and SMEs to review and provide feedback for improvements and enhancements.
iv. Revising and enhancing the prototype: modifying the scope based on the feedback from end users, and refining the prototype to accommodate user feedback.

Design Requirement Analysis

Hardware components included a NodeMCU ESP8266 module, relays, jumper wires, power supply, camera, motion sensor, and breadboard.

Software development utilized the Arduino IDE with C++ programming and the Blynk application for smartphone control.

System Description

The system design architecture comprised a NodeMCU board interfaced with relays to control various appliances. A smartphone app with voice control capabilities allowed users to interact with the system.

Component Specification

To design this system, we used the following components:

NodeMCU board: The system uses an open-sthece IoT platform, NodeMCU. This platform features hardware based on the ESP-12 module and firmware that runs on Expressif Systems' ESP8266 Wi-Fi SoC. Instead of referring to the development kits, the firmware is commonly known as "NodeMCU." The firmware employs the Lua scripting language (Figure 1a).

Relay: The system includes relays, which are electrical switches that can be turned on or off, allowing electricity to flow or not. Relays can be controlled with low voltages, such as the 5 volts provided by Arduino pins. As shown in Figure 1b, controlling a relay module with an Arduino is as simple as controlling any other output.

Jumper wire: The system also involves jumper wires, which are electrical wires or cables with connectors or pins at each end. These wires are commonly used to internally connect parts of a breadboard or other prototype or test circuit, or to connect with other machinery or components without the need for soldering (Figure 1c).

System Design Architecture

The system design architecture outlines the fundamental components, their interrelationships, and how they operate together in a conceptual model. This architecture includes the system's modules, components, interfaces, and the data they process, which were all carefully considered during the design process. For this project, a graphical architecture and a flowchart were utilized, as demonstrated in Figures 2 and 3, to serve as our system design architecture.

Diagramming System Connections

The system diagram connection refers to a block diagram used to visualize the components and properties of a circuit design, along with how they are connected via lines and arrows. This powerful tool highlights critical elements and connections, making it easier to measure the relationships between variables (Figure 4).

(a) NodeMCU Board

(b) Relay module

(c) Jumper wire

Figure 1. Design components

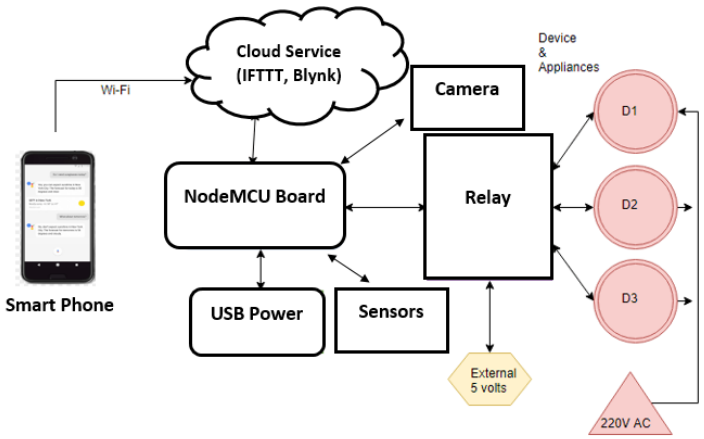

Figure 2. System design architecture

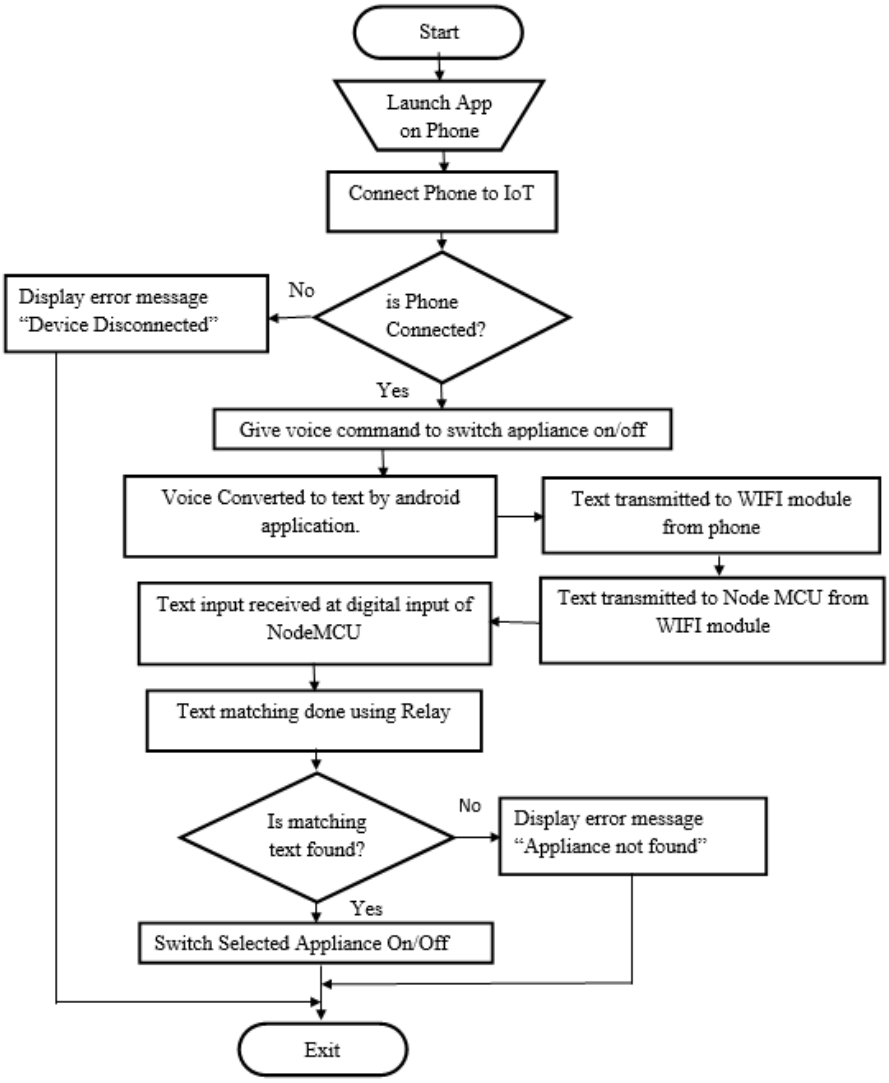

Figure 3. System flow chart

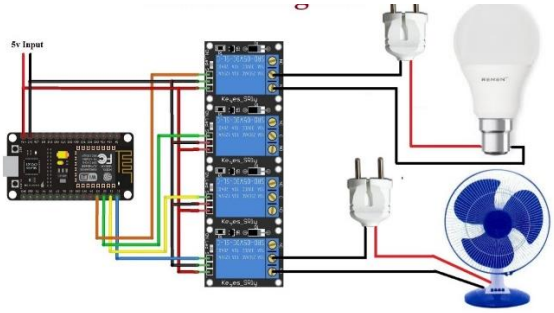

Figure 4. Circuit design connection

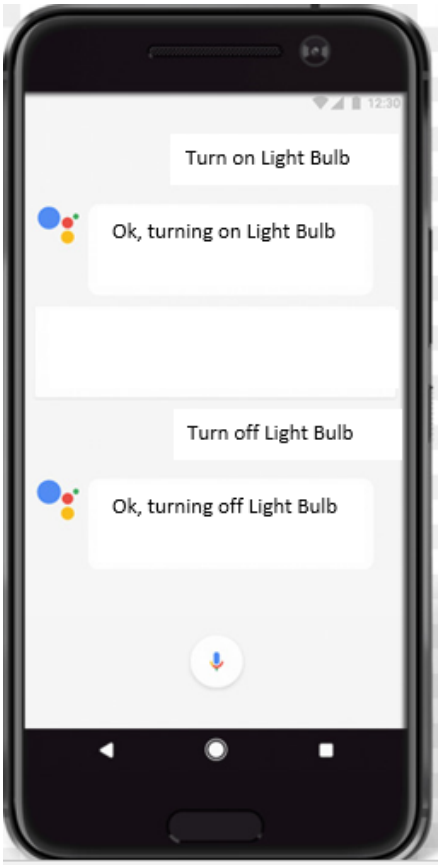

Figure 5. System voice control interface

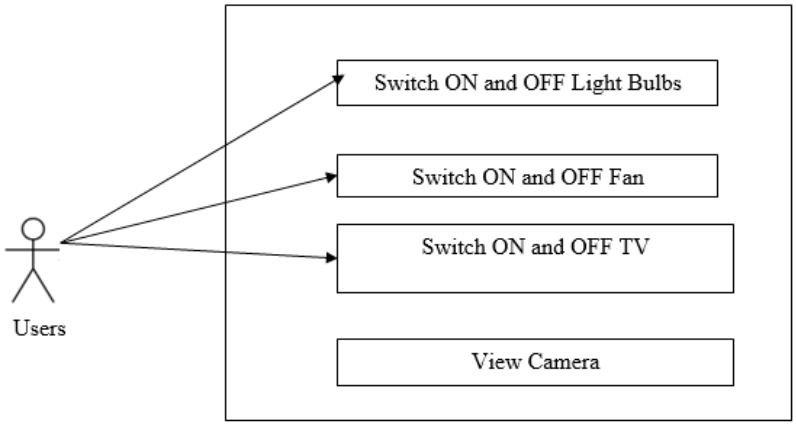

Figure 6. Use case diagram

Designing Software

The software design process involves translating user requirements into a suitable form that can be used during the coding and implementation of software. While the software requirements specification document is created to assess user requirements, more specific and detailed requirements are created to aid in the actual coding process. The output of this process is used directly in programming language implementation.

Creating User Interfaces

The user interface is the visual aspect of a software or computer application through which users interact. It determines how users issue commands to the computer or program and how information is displayed on the screen. In this study, A voice user interface was implemented using a smartphone app to enable users to control the system through spoken commands (refer to Figure 5).

Mapping Use Cases

Use-case diagrams provide a high-level overview of a system's scope and functions. They depict interactions between the system and its users, illustrating what the system does and how users utilize it, without showing how it works within (Figure 6).

Choice of Programming Language/Framework

For the programming language and framework used in this research design, we opted for the Arduino IDE with the C++ language and the Blynk app. C++ is a versatile, streamlined, and secure language that empowers developers to create a vast array of applications. With C++, you can also design steadfast system-level components, thanks to its extensive range of features such as full COM/Platform support, garbage collection, type safety, intrinsic code-trust mechanisms for security, and comprehensive support for extensible metadata concepts.

3. Results and Discussion

Functionality and Performance

The developed model smart home automation system for electronics control successfully achieved its objectives of providing an efficient and user-friendly solution for managing household appliances remotely. The functionality and performance of a developed smart home automation system was evaluated. A comprehensive testing method was employed to assess the core features of the system, including remote appliance control, voice control, sensor integration, and hardware and software effectiveness. The remote appliance control feature enables users to manage a wide range of electronic appliances within their homes through a dedicated smartphone application and eliminates the need for physical presence and offers remarkable convenience and flexibility to users. The system employs secure communication protocols to ensure reliable and continuous interaction between the user's smartphone and the appliances, safeguarding against unauthorized access or tampering. An integral feature of the system is its voice user interface, which empowers users to interact with the automation system using natural spoken commands. The system leverages cutting-edge speech recognition technology to accurately interpret user commands, promoting accessibility and convenience. The system effectively integrates with a diverse array of sensors to enable intelligent automation based on environmental conditions. By harnessing real-time data from these sensors, the system can autonomously trigger actions such as adjusting thermostat settings, activating lighting systems, or initiating security protocols in response to detected events or changes in the surroundings. The selection of the NodeMCU hardware platform, coupled with the Arduino IDE and Blynk application, has proven highly effective in realizing the functional capabilities of the smart home automation system. The use of the C++ programming language further enhances the system's robustness and versatility, enabling efficient resource management, low-level hardware interaction, and seamless integration with third-party libraries and frameworks. The combination of the chosen hardware platform and software tools has proven instrumental in realizing a highly functional and performant smart home automation system. The system's adherence to industry best practices and standards ensures reliability, security, and scalability, positioning it as a cutting-edge solution for modern home automation needs.

Evaluation and User Experience Analysis

The absence of a formal user study is a common limitation in the development of interactive systems. However, it is crucial to note that user feedback plays a critical role in shaping the user experience of such systems. The iterative prototyping methodology employed in the development of the system under investigation facilitated the integration of user feedback, leading to continuous refinement and improvement of the system's design and functionality. The project team engaged with stakeholders and end-users throughout the development cycle, gaining

valuable insights into user preferences, pain points, and usability challenges. This iterative feedback loop allowed for the identification and resolution of usability issues in real-time, leading to the creation of a more intuitive and user-friendly interface. There is significant scope for future research to conduct comprehensive user testing with a broader audience. By engaging with a diverse pool of users representing various demographics, backgrounds, and technical proficiencies, researchers can gather more comprehensive feedback on usability, performance, and the overall user experience. Structured user testing protocols can be employed to systematically evaluate key aspects of the system, including ease of use, learnability, efficiency, satisfaction, and accessibility. Innovative research approaches such as contextual inquiry, ethnographic studies, and participatory design workshops can be explored to gain deeper insights into user needs and behaviors in real-world contexts. These approaches can uncover nuanced insights and identify opportunities for innovation and improvement. While the absence of a formal user study represents a limitation of the current research, future work holds significant promise for conducting comprehensive user testing and evaluation. By prioritizing user-centered design principles and actively engaging with end-users throughout the development lifecycle, researchers can create interactive systems that are not only technologically sophisticated but also genuinely user-centric and impactful.

Comparison with Existing Systems

The smart home automation system prototype developed in this study is a notable advancement over existing solutions examined in prior research. It successfully addresses several limitations noted in prior studies, thereby providing a more comprehensive and user-centered approach to home automation. One of the key improvements made over existing systems is the integration of voice control capabilities, as highlighted in Raj's [14] study. While previous solutions have been restricted in this regard, our system offers users the ability to interact with the automation system through natural spoken commands. This advancement significantly enhances the user experience by offering a more intuitive and hands-free interaction model. Moreover, the model developed in this study overcomes restrictions associated with specific control methods, as observed in Usman's work [16]. By enabling control via a smartphone application, our system provides users with greater flexibility and convenience in managing their smart home devices. This approach eliminates the need for proprietary control interfaces and ensures seamless integration with existing mobile platforms, enhancing interoperability and user adoption. The system's development prioritized efficiency and affordability without compromising functionality, aligning with the principles of cost-effective IoT-based automation advocated by Murdan and Gunness [13]. However, we acknowledge that there is an opportunity for improvement in the area of data storage capabilities. While our system effectively captures and processes real-time data from sensors and devices, future iterations could explore mechanisms for enhancing data storage capacity and scalability. This would enable more extensive data analysis and long-term storage of historical data, facilitating deeper insights into home automation trends and patterns. Thus, this study presents a smart home automation system that represents a significant step forward in the field, offering enhanced functionality, usability, and affordability compared to existing solutions. By addressing key limitations identified in prior research and aligning with emerging trends in IoT-based automation, our system demonstrates promise for widespread adoption and continued innovation in the smart home ecosystem.

4. Conclusion

This study made significant steps in the area of home automation by creating an advanced smart home automation system that utilizes IoT technology. This innovation empowers users to manage their electronics remotely and through voice control, resulting in a more convenient and enjoyable user experience. By integrating a NodeMCU board, relays, sensors, and voice control interface, this system can automate appliance control, respond to environmental conditions, and improve security measures. The iterative prototyping approach incorporated user feedback, which streamlined development and enhanced the system's overall performance. While the current prototype displays a variety of impressive functionalities, there is still room for refinement and expansion. Future research should prioritize improving security protocols, enhancing scalability to accommodate a broader range of devices, incorporating data storage and analysis to optimize energy usage, and creating a dedicated mobile application for a more user-friendly experience. By addressing these areas, the smart home automation system model can continue to evolve and meet the ever-changing needs of users in the expanding world of IoT-driven smart homes.

Limitations and Future Work

The current prototype represents a basic model and can be further enhanced in several ways:

i. Security considerations: Implementing robust security protocols is crucial for protecting the system from unauthorized access and cyberattacks.
ii. Scalability: The system's architecture should be designed to accommodate a wider range of appliances and sensors for increased functionality.
iii. Data storage and analysis: Integrating data storage mechanisms would allow for monitoring energy consumption patterns and optimizing appliance usage.
iv. Mobile app development: Developing a dedicated mobile app with a user-friendly interface can improve user experience and facilitate system control.

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