Research Article
Digital System and Computing

Development of a Voice-Controlled Smart Home Prototype Using NodeMCU and Internet of Things (IoT) Technology

Muhammad Rifaldi, Apri Siswanto

[The author informations are in the declarations section. This article is published by ETFLIN in Digital System and Computing, Volume 1, Issue 1, 2025, Page 1-5. DOI 10.58920/dsc0101421]

Received: 14 August 2025
Revised: 27 September 2025
Accepted: 22 October 2025
Published: 08 November 2025

Editor: Sri Ratna Sulistiyanti

Keywords: Voice-controlled smart home, Internet of things, IoT, NodeMCU automation.

Abstract: The growing demand for smart home automation calls for affordable, efficient, and user-friendly systems that reduce energy consumption and enhance remote accessibility. This study presents the development and evaluation of a voice-controlled smart home prototype utilizing NodeMCU and IoT technologies. The system integrates Google Assistant, IFTTT, and Adafruit IO to process voice commands, support real-time monitoring, and enable cloud-based control of household devices. A prototyping method was applied, focusing on controlling an LED lamp and a 12V DC fan. Black-box testing was conducted using six voice profiles and a total of 60 command scenarios under both stable and unstable network conditions. Results indicated a 93.3% accuracy with stable internet and 86.7% under weak signals. The system achieved average response times of 1.8 seconds (stable) and 3.4 seconds (unstable), operating without critical failures. However, performance was influenced by internet quality and third-party dependencies. Unlike previous studies that relied solely on single-platform control, this research highlights a low-cost, multi-service integration approach for smart home automation, addressing the gap between affordability and real-time cloud-based functionality. The prototype demonstrates the feasibility of accessible voice-activated automation and lays the foundation for future offline-capable smart systems.

Introduction

The integration of digital technologies into daily life has accelerated progress across various sectors, including healthcare, education, and home automation (1-3). Among these, smart homes, residences equipped with interconnected devices capable of automating and managing household functions, have emerged as a key innovation (4, 5). Despite offering benefits in energy efficiency, convenience, and safety, adoption remains limited due to high costs, infrastructure constraints, and limited accessibility (6). Retrofitting conventional homes often requires rewiring or significant structural changes, making implementation costly and impractical (7). Additionally, everyday habits, such as leaving appliances on unnecessarily, lead to avoidable energy consumption and safety concerns (8). These challenges underscore the need for affordable, user-friendly, and non-intrusive automation systems.

In rapidly urbanizing environments, demand for low-cost, easily deployable, and remotely operable smart home solutions continues to grow. However, most commercial platforms rely on proprietary hardware or complex installations that are less feasible in developing regions (9, 10). Although mobile app–based controls exist, they can pose accessibility issues for elderly or physically impaired users (11). Recent developments integrating Internet of Things (IoT) platforms with microcontrollers such as NodeMCU have enabled lightweight, scalable automation frameworks (12). When combined with voice-based assistants like Google Assistant through services such as IFTTT and Adafruit IO, these systems can deliver real-time control without extensive hardware investment (13-15).

However, existing studies have primarily focused on system design or single-platform implementations without addressing practical performance variations under real network conditions. This gap highlights the need for a more comprehensive approach that evaluates system reliability, response time, and accessibility in dynamic environments.

This study introduces a voice-controlled smart home prototype utilizing NodeMCU and IoT integration to manage basic household devices. The novelty of this research lies in developing a low-cost, cloud-based automation framework that connects Google Assistant commands to physical devices via open-source platforms. Unlike previous studies that emphasize isolated technologies, this work demonstrates an integrated, multi-service approach using NodeMCU, Google Assistant, IFTTT, and Adafruit IO for seamless and remote voice control. Furthermore, the prototype's performance is evaluated across varying network conditions, providing insights into system reliability and responsiveness. The proposed design serves as a practical foundation for future smart home developments, particularly in resource-limited environments.

Methodology

Study Design and Rationale

This study employed a prototyping research design to develop, test, and evaluate a voice-controlled smart home system integrating NodeMCU and Internet of Things (IoT) technologies. The prototyping approach followed an iterative process consisting of five stages: [1] requirement analysis, [2] system design, [3] prototype implementation, [4] evaluation, and [5] refinement. This method was selected because it allows continuous testing and improvement of both hardware and software components under realistic usage conditions. The goal was to simulate real-world interaction and ensure that the system met performance expectations for responsiveness, accuracy, and usability.

Materials and Tools

The system was developed using a combination of hardware and software components selected for their compatibility, cost efficiency, and ease of integration. On the hardware side, the NodeMCU ESP8266 microcontroller served as the central processing unit, equipped with built-in Wi-Fi to facilitate cloud communication and data transmission. A Google Nest Mini smart speaker was employed to receive and interpret user voice commands through Google Assistant, while a single-channel 5V relay module provided safe electrical switching for connected home appliances. To represent typical household systems, an LED lamp and a 12V DC fan were used as the controlled devices for lighting and ventilation functions. Supporting materials such as a breadboard, jumper wires, a power adapter, and a protective casing were included to complete and secure the circuit during testing.

On the software side, the Arduino IDE version 1.8.13 was used for programming and uploading control logic written in C++ to the NodeMCU. The IFTTT (If This Then That) platform acted as middleware that translated Google Assistant voice commands into specific trigger actions, which were then transmitted via webhooks to the Adafruit IO cloud service. Adafruit IO functioned as the central data hub, allowing the NodeMCU to poll the feed at regular intervals using HTTP requests and detect command updates. Meanwhile, Google Assistant served as the user-facing interface, interpreting spoken commands and initiating the automation sequence through the integrated IoT framework.

System Architecture

The overall system architecture was organized into three interconnected functional layers: input, processing, and control. In the input layer, the Google Nest Mini smart speaker captured user voice commands, which were interpreted through the Google Assistant platform. Once processed, the commands were forwarded to IFTTT, which acted as an intermediary between the voice interface and the cloud database. In the processing layer, IFTTT received

Figure 1. Data collection process and hardware setup of the Smart Home prototype.

the interpreted command and triggered a webhook connected to the Adafruit IO platform. This webhook updated a specific data feed that corresponded to the intended device action, such as turning on or off the light or fan.

The control layer involved the NodeMCU microcontroller, which maintained a continuous connection to the internet via Wi-Fi and polled the Adafruit IO feed every three s. When a change was detected in the feed, the NodeMCU interpreted it as an instruction and sent a digital signal to the relay module, thereby activating or deactivating the connected appliance.

The overall communication flow followed a sequential pathway beginning from the user and proceeding through Google Assistant, IFTTT, Adafruit IO, NodeMCU, and finally the relay and controlled appliance. This configuration ensured real-time responsiveness and two-way interaction, allowing users not only to issue voice-based commands but also to monitor the operational status of devices through the Adafruit IO dashboard interface. To enhance clarity, the complete system configuration and data flow are visually represented in **Figure 1**, which illustrates the connection between hardware components and cloud-based services.

Testing and Data Collection Procedures

The prototype was evaluated through black-box testing designed to simulate realistic smart home use and measure performance from an end-user perspective. Testing was conducted under two network conditions, a stable Wi-Fi connection averaging over 20 Mbps and an unstable mobile hotspot with higher latency, to observe the impact of internet quality on responsiveness. Both the LED lamp and 12V DC fan were tested using six different voice profiles to represent varied accents, with ten activation and ten deactivation commands issued per device under each condition, totaling 240 trials conducted over 48 h.

During testing, data were logged for command type, response status, and response time (measured with a digital stopwatch), while anomalies such as delays, misrecognitions, or system failures were noted. User observations regarding ease of use and perceived responsiveness were also collected, allowing the evaluation to capture both quantitative performance metrics and qualitative user

$$\mathrm{RA}\ (\%) = \frac{\text{Successful Commands}}{\text{Total Commands}} \times 100\%$$

Equation 1 | *RA* = recognition accuracy (%).

feedback on system reliability and accuracy.

Data Analysis

The collected data were analyzed descriptively to determine the prototype's performance in terms of accuracy, response time, and reliability. Recognition accuracy (%) was calculated using **Equation 1** to measure the proportion of correctly executed voice commands. The average response time (s) was computed as the mean duration between issuing a command and the corresponding activation or deactivation of the appliance.

Recorded failures were classified as user-related errors (e.g., unclear speech or mispronunciation) and system-related errors (e.g., network delays or unresponsive NodeMCU performance). The 48-hour continuous observation period enabled the assessment of uptime, downtime, and latency variations, providing a comprehensive evaluation of system stability and real-world reliability while ensuring the study's transparency and reproducibility.

Results

System Implementation Results

The implementation phase successfully produced a fully functional voice-controlled IoT prototype for smart home applications. The system enables users to operate household appliances such as lights and fans through voice commands integrated with cloud-based IoT platforms. The prototype was constructed using a NodeMCU ESP8266 microcontroller connected to an LED lamp and a 12V DC fan, representing lighting and ventilation systems, respectively. A 5V relay module managed power switching, while all components were connected using jumper wires and enclosed in a protective casing for safety and stability. Wi-Fi connectivity ensured seamless communication with cloud services for real-time control.

Figure 1 illustrates the physical wiring and data communication pathway, showing the integration among Google Assistant, IFTTT, Adafruit IO, and NodeMCU. The system consistently executed commands across multiple trials, confirming successful implementation and stable operation of the hardware–software interface. The system workflow begins with user voice commands captured through Google Assistant, either via a Nest Mini smart speaker or a smartphone. These commands are sent to the IFTTT platform, which triggers corresponding webhooks that update a control feed on Adafruit IO. The NodeMCU continuously polls this feed every three s; when a change is detected, it activates the 5V relay module to switch the connected devices on or off. The figure also illustrates the physical wiring configuration between the NodeMCU and relay module (pins D1–IN, VCC, and GND), as well as the data flow used during testing and data collection.

The successful implementation of this system demonstrates the practicality of integrating open-source IoT platforms for smart home control. The combination of Google Assistant, IFTTT, and Adafruit IO created a seamless communication flow between cloud-based services and local hardware, validating the feasibility of a low-cost, scalable automation model. This integration supports findings from Sowah *et al.* (2020) and Vikram *et al.* (2017), who emphasized that NodeMCU-based frameworks can achieve high responsiveness and interoperability for domestic automation tasks. The current setup extends their work by integrating multi-service coordination, showing that stable two-way communication can be maintained even under varied network conditions.

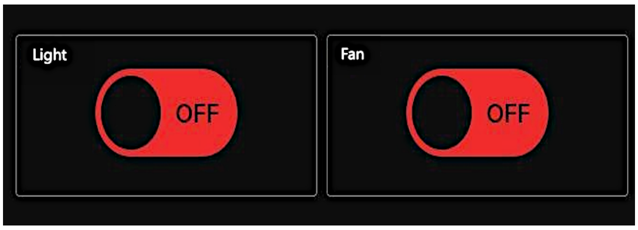

Figure 2. Smart Home monitoring and control interface via Adafruit IO.

System Interface Implementation

The system's interface was deployed using the Adafruit IO dashboard, which provided real-time feedback on the operational status of devices. Voice commands issued through Google Assistant automatically synchronized with the dashboard, updating the "Light" and "Fan" toggles to reflect current ON/OFF states (**Figure 2**). This dual-control mechanism (voice and manual) enhanced user interactivity and transparency of system operation, aligning with previous findings that emphasize usability as a key adoption factor in smart home systems.

This interface allows users to visually confirm device operation and remotely control appliances through either voice or manual input. Continuous feed updates ensure that all command executions, response times, and device states are accurately logged for subsequent data analysis.

Prototype Testing and Evaluation

Performance testing was conducted under two network conditions, stable Wi-Fi (20–25 Mbps) and unstable mobile hotspot (5–8 Mbps), to assess system behavior under real-world connectivity variations. A total of 240 command trials were performed (120 per device, across six voice profiles).

Under stable Wi-Fi conditions, 112 of 120 commands (93.3%) were executed successfully, with an average response time of 1.8 s (SD = 0.4 s). Under unstable hotspot conditions, accuracy dropped slightly to 86.7% (104/120), with a response time of 3.4 s (SD = 0.6 s). These results demonstrate consistent performance despite fluctuations in network quality, confirming the robustness of the communication pipeline.

Device-specific testing showed that both the LED lamp and fan maintained over 90% success rates in stable networks and above 84% in unstable ones. Accuracy was affected more by internet latency than by device type, indicating that the cloud-based communication process was the main limiting factor rather than local hardware performance.

The summarized data in **Table 1** reinforce the consistency of system performance across different environments and highlight the influence of network stability on command execution speed and accuracy.

Voice Command Recognition Performance

Across six voice profiles, recognition accuracy averaged 93.3% in stable networks and 86.7% in unstable ones. At distances up to 2 meters, accuracy exceeded 90%, while

Table 1. System performance summary under different network conditions.

Network Condition	Device	Accuracy (%)	Avg. Response Time (s)	Std. Dev (s)	Error Type (Most Frequent)
Stable Wi-Fi (20–25 Mbps)	LED Lamp	93.5	1.7	0.4	None
Stable Wi-Fi (20–25 Mbps)	12V DC Fan	93.0	1.9	0.5	None
Mobile Hotspot (5–8 Mbps)	LED Lamp	87.5	3.2	0.6	Network delay
Mobile Hotspot (5–8 Mbps)	12V DC Fan	86.0	3.5	0.6	Network

performance decreased slightly beyond 3 meters due to ambient noise interference. The system maintained consistent recognition patterns across voice variations, supporting its use in multi-user households.

Discussion

The quantitative findings validate that the developed voice-controlled smart home prototype performs with high operational accuracy and responsiveness across various testing scenarios. The average command recognition rate of over 93% under stable network conditions is consistent with previous works emphasizing the efficiency of NodeMCU-based IoT home automation frameworks (16-18). These studies also reported that Wi-Fi–enabled microcontrollers can handle cloud communication efficiently, which supports the performance observed in this research. The response time below 2 s under stable conditions demonstrates that the interaction between Google Assistant, IFTTT, Adafruit IO, and the NodeMCU microcontroller was executed with minimal delay, confirming effective synchronization within the multi-platform architecture.

The slight performance degradation under unstable connections (accuracy dropping to 86.7% and response time increasing to 3.4 s) reflects the inherent limitations of cloud-dependent automation systems. Similar observations were reported by Etuk *et al.*, who highlighted that IoT system reliability and latency are directly influenced by network stability and cloud response times. Despite this, the system maintained above 85% operational accuracy under poor connectivity, demonstrating strong robustness and adaptability to variable internet quality, an important factor for smart home deployment in developing regions.

The results also show minimal deviation between repeated trials (standard deviation < 0.7 s), confirming the reproducibility and reliability of the prototype's performance. The ability of the system to recognize multiple voice profiles with over 90% consistency strengthens its usability in shared households or multi-user environments, supporting previous research that underscores user inclusivity as a determinant of smart home adoption (19).

From a technical standpoint, the integration of Google Assistant, IFTTT, and Adafruit IO demonstrates the practicality of combining multiple open-source cloud services within a single control framework. This multi-service approach extends prior NodeMCU-based systems that typically relied on single-platform implementations, contributing to a more flexible and scalable automation model suitable for real-world use.

However, as noted in related studies (20, 21), reliance on third-party cloud platforms introduces potential privacy risks and latency constraints. These limitations were also evident in the current research, where delayed command execution occurred under high-latency conditions. Future work should focus on incorporating local processing or edge computing mechanisms to reduce dependency on cloud connectivity, minimize latency, and improve data privacy.

Overall, the findings confirm that the proposed voice-controlled smart home prototype delivers reliable, low-cost automation with measurable performance consistency. Its ability to maintain acceptable accuracy and responsiveness under different network conditions highlights its feasibility for household applications in developing and resource-constrained environments while providing a foundation for future advancements in hybrid and offline-capable smart home architectures.

Conclusion

This study successfully developed and evaluated a voice-controlled smart home prototype utilizing NodeMCU and IoT technologies. The prototype achieved an overall command accuracy of 93.3% under stable internet conditions and 86.7% under unstable connections, with average response times of 1.8 s and 3.4 s, respectively. These results confirm that the system met its intended performance targets for reliability, responsiveness, and usability.

The findings demonstrate that integrating open-source platforms, Google Assistant, IFTTT, and Adafruit IO, provides a low-cost yet effective framework for real-time smart home automation. This approach offers practical advantages for energy efficiency and accessibility, particularly in developing or resource-limited settings.

However, the system's dependence on continuous internet connectivity and third-party cloud services remains a key limitation, as it affects latency and data privacy. Therefore, future research should explore offline-capable or hybrid (cloud–edge) architectures to minimize these dependencies, enhance scalability, and ensure greater data security. In summary, this research establishes a feasible foundation for affordable, voice-activated smart home systems, bridging the gap between cost efficiency and real-time IoT functionality.

Declarations

Author Informations

Muhammad Rifaldi
Affiliation: Department of Informatics Engineering, Faculty of Engineering, Islamic University of Riau, Pekanbaru, Indonesia.
Contribution: Data Curation, Formal analysis, Visualization, Writing - Original Draft, Writing - Review & Editing.

Apri Siswanto ✉
Corresponding Author

Affiliation: Department of Informatics Engineering, Faculty of Engineering, Islamic University of Riau, Pekanbaru, Indonesia.
Contribution: Conceptualization, Funding acquisition, Methodology, Project administration, Resources, Validation, Writing - Review & Editing.

Conflict of Interest

The authors declare no conflicting interest.

Data Availability

The unpublished data is available upon request to the corresponding author.

Ethics Statement

Not applicable.

Funding Information

The author(s) declare that no financial support was received for the research, authorship, and/or publication of this article.

References

1. Sinha R. The role and impact of new technologies on healthcare systems. Discov Health Syst. 2024 Nov 14;3(1):96.

2. Junaid SB, Imam AA, Balogun AO, De Silva LC, Surakat YA, Kumar G, et al. Recent advancements in emerging technologies for healthcare management systems: A survey. Healthcare (Basel). 2022 Oct 3;10(10):1940.

3. Mauro M, Noto G, Prenestini A, Sarto F. Digital transformation in healthcare: Assessing the role of digital technologies for managerial support processes. Technol Forecast Soc Change. 2024 Dec;209:123781.

4. Strzelecki A, Kolny B, Kucia M. Smart homes as catalysts for sustainable consumption: A digital economy perspective. Sustainability. 2024 May 30;16(11):4676.

5. Torres-Hernandez CM, Garduño-Aparicio M, Rodriguez-Resendiz J. Smart homes: A meta-study on sense of security and home automation. Technol (Basel). 2025 Jul 30;13(8):320.

6. Fakhimi M, Hughes A, Gustavson A. Evaluating smart home usability and accessibility in early detection and intervention of mental health challenges among older adults: A narrative review and framework. J Ageing Longev. 2025 Jan 24;5(1):3.

7. Citadini de Oliveira C, Catão Martins Vaz I, Ghisi E. Retrofit strategies to improve energy efficiency in buildings: An integrative review. Energy Build. 2024 Oct;321:114624.

8. Suneetha K, Sreekanth M. Smart home monitoring and automation energy efficient system using IoT devices. In: Proc Int Conf Emerg Trends Eng Technol Sci (ICETETS). 2020. p. 627–37.

9. Gøthesen S, Haddara M, Kumar KN. Empowering homes with intelligence: An investigation of smart home technology adoption and usage. Internet Things. 2023 Dec;24:100944.

10. Becks E, Zdankin P, Matkovic V, Weis T. Complexity of smart home setups: A qualitative user study on smart home assistance and implications on technical requirements. Technol (Basel). 2023 Jan 3;11(1):9.

11. Zhou C, Zhan W, Huang T, Zhao H, Kaner J. An empirical study on the collaborative usability of age-appropriate smart home interface design. Front Psychol. 2023 Aug 3;14.

12. Singh N, Buyya R, Kim H. Securing cloud-based Internet of Things: Challenges and mitigations. Sensors (Basel). 2024 Dec 26;25(1):79.

13. Irugalbandara C, Naseem AS, Perera S, Kiruthikan S, Logeeshan V. A secure and smart home automation system with speech recognition and power measurement capabilities. Sensors (Basel). 2023 Jun 21;23(13):5784.

14. Mohamed K, El Shenawy A. A smart IoT-based home automation system for controlling and monitoring home appliances. Int Rev Autom Control. 2023 Sep 30;16(5):228.

15. Montoya Benitez AO, Suárez Sarmiento Á, López EMM, Herrera-Ramirez J. Optimization of energy consumption in voice assistants through AI-enabled cache implementation: Development and evaluation of a metric. Technol (Basel). 2025 Jan 2;13(1):19.

16. Sowah RA, Boahene DE, Owoh DC, Addo R, Mills GA, Owusu-Banahene W, et al. Design of a secure wireless home automation system with an open home automation bus (OpenHAB 2) framework. J Sens. 2020 Oct 30;2020:1–22.

17. Vikram N, Harish KS, Nihaal MS, Umesh R, Kumar SAA. A low-cost home automation system using Wi-Fi-based wireless sensor network incorporating Internet of Things (IoT). In: Proc IEEE Int Adv Comput Conf (IACC). IEEE; 2017. p. 174–8.

18. Etuk UE, Omenaru G, Inyang SJ, Umoren I. Towards sustainable smart living: Cloud-based IoT solutions for home automation. J Inf Syst Inform. 2023 Dec 30;5(4):1743–63.

19. Chang S, Nam K. Exploring the sustainable values of smart homes to strengthen adoption. Buildings. 2022 Nov 7;12(11):1919.

20. Vardakis G, Hatzivasilis G, Koutsaki E, Papadakis N. Review of smart-home security using the Internet of Things. Electronics (Basel). 2024 Aug 22;13(16):3343.

21. Bugeja J, Jacobsson A, Davidsson P. On privacy and security challenges in smart connected homes. In: Proc Eur Intell Secur Inform Conf (EISIC). IEEE; 2016. p. 172–5.

Additional Information

How to Cite

Muhammad Rifaldi, Apri Siswanto. Development of a Voice-Controlled Smart Home Prototype Using NodeMCU and Internet of Things (IoT) Technology. *Digital System and Computing*. 2025;1(1):1-5

Publisher's Note

Open Access