

Development and Evaluation of an Assistive Voice-Activated Smart Outlet System

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Abstract. This study aimed to develop and evaluate an assistive voice-activated smart electrical outlet. Utilizing an Agile development framework, an assistive voice-activated smart electrical outlet system was designed and developed. Technical system performance, quality attributes, and consumer satisfaction were assessed during simulated and household deployments, with evaluations conducted by 99 respondents selected through purposive sampling. Technical testing revealed that the system successfully passed all parameters for thermal safety, physical spacing, and command latency. The command execution response time across domestically deployed appliances—including a lamp, phone charger, electric fan, and television—consistently ranged from 0.90 to 1.85 seconds. Quality attributes regarding voice control compatibility and operational noise resilience achieved high success rates ranging from 90% to 100%, demonstrating reliable relay execution in a quiet room and in the presence of background television and electric fan noise. As a result, using the offline voice-activated smart outlet yielded high satisfaction with voice-control compatibility (4.34, Strongly Agree) and operational noise resilience (4.25, Strongly Agree). It is concluded that the offline smart outlet stands as a safe, highly responsive, and user-centric automation tool that effectively bridges hardware stability and accessibility. Based on these findings, it is recommended that future researchers utilize smaller electronic components for a more compact structural design, incorporate advanced microphone arrays, and extend long-term deployment testing. Ultimately, this research highlighted the broader impact on home automation. This internet-independent solution eliminates interactions with traditional, manually operated electrical outlets, thereby improving daily living conditions for senior citizens and persons with disabilities.

Keywords: accessibility technology; home automation; senior citizens; smart electrical outlets; voice-activated control

Introduction

In modern residences, home automation has transitioned to a practical necessity for improving energy efficiency and household accessibility (Al-Qahtani et al., 2025). However, in home automation, standard outlets may pose dangers like electric shock and physical strain for senior citizens or persons with disabilities (PWDs), who have mobility impairments and difficulty reaching behind heavy appliances and operating them manually (Vigouroux et al., 2023). Smart home solutions that are available on the market require complex Touchless devices offer major improvements in daily accessibility (Wang et al., 2022; Johnson et al., 2024). However, standard smart appliances rely primarily on cloud-based systems and are therefore difficult to operate during poor network connections (Irugalbandara et al., 2023). Previous research uses offline speech recognition on their devices (Huang et al., 2025). To decode voice instructions locally on device hardware to reduce internet dependence (Malche et al., 2025).

Based on earlier research, this research gap was identified. Traditional outlets are manually operated, posing a risk for sensitive users, and are highly dependent on internet connectivity. To address these gaps, the primary objectives of this study are to develop and evaluate an offline, voice-activated, smart electrical outlet system. This study evaluates an assistive voice-activated smart outlet system in terms of technical performance and quality attributes. The level of satisfaction was also determined during the domestic household deployment.

Ultimately, this research is highly significant as it transforms conventional homes with a touchless device that does not rely on the internet, enabling senior citizens and persons with disabilities to command their living environments safely and autonomously.

Research Questions

The purpose of this study is to design, develop, and assess the engineering performance thresholds of an offline speech recognition module and a 4-channel relay connected with an assistive voice-activated smart outlet system, and to answer the following;

1. What are the technical system performance levels of the assistive voice-activated smart outlet system during simulated deployment?
2. What are the quality attributes of the developed smart outlet system in terms of:
 - 2.1 Voice-control compatibility, and
 - 2.2 Operational noise resilience?
3. What is the engineering system performance of the voice-activated smart outlet command execution response time across domestically deployed appliances?
4. What is the respondent's level of satisfaction in using the voice-activated smart outlet system in terms of:
 - 4.1 Voice-control compatibility, and
 - 4.2 Operational accuracy?

Scope and Delimitation of the Study

This study focuses on the development and evaluation of an offline, assistive voice-activated smart electrical outlet engineered for senior citizens and persons with disabilities, utilizing the HLK VC-02 KIT voice recognition board, which was customized using the voice AI thinker module software platform. This study aims to evaluate specific metrics: command execution latency, thermal safety, structural spacing, voice-control compatibility, and operational accuracy. The product deployment is limited to a household with senior citizens or PWDs. To evaluate their level of satisfaction, the survey was conducted with the active support of the household members of these senior citizens and PWDs. This household-assisted setup provided the primary target end-users to give a precise level of satisfaction.

Literature Review

Physical Accessibility Barriers and Domestic Electrical Hazards

Traditional residential electrical outlets present inherent accessibility and safety challenges for vulnerable household members. Standard wall-mounted outlets require manual insertion and physical touch, which poses dangers of electric shock, physical strain, and unintentional falls, particularly for elderly persons and persons with disabilities who may have mobility problems or poor motor skills. Vigouroux et al. (2023) have identified interfaces for appliance automation that require low effort from users, eliminating uncomfortable reaching postures for individuals with disabilities and older adults when controlling appliances. People with physical and visual disability have great operational challenges in interacting with traditional electrical equipment in dangerous situations. Therefore, they are encouraged to use touchless home automation controls (Wang et al., 2022; Johnson et al., 2024), which suggests that hands-free control is a major improvement in accessibility for daily life. But still, traditional outlet design requires physical contact, exposing household members, most especially senior citizens and persons with disabilities to the persistent danger of electric shock.

Limitations and Connectivity Dependencies of Commercial Smart Homes

Commercial home automation systems have grown rapidly, but most solutions in the market are largely reliant on cloud computing and a constant internet connection. In this context, Irugalbandara et al. (2023) developed a secure voice-controlled smart home automation system with power metering features. However, they noted that speech processing in the cloud results in system latencies when the network is interrupted. Torad et al. (2022) also proposed an AI and IoT-based voice-controlled system. They pointed out that the dependency on servers poses serious impediments to operation in offline or low-bandwidth environments. Al-Qahtani et al. (2025) have presented smart grid frameworks for energy management. Nevertheless, the models are based on constant high-speed internet access. In contrast, this study solves this connectivity issue by designing a stand-alone smart outlet that does not rely on internet infrastructure. For standard residential households—particularly those with vulnerable end-users who may lack complex mobile digital literacy—cloud-dependent, application-heavy automation presents a major barrier to reliable daily appliance management.

Advancement in Touchless Control and Microcontroller Relay Systems

In an effort to reduce the number of accidental incidents caused by direct physical contact with electronic equipment, speech recognition has emerged as the dominant mode for hands-free devices. As



demonstrated by Eduku et al. (2025) with a voice-controlled smart home automation system, it considerably decreases the complexity of the operational process. Supporting this, Xu et al. (2025) suggested that the architecture of voice-interactive control systems in smart home settings considers speech responsiveness and real-time execution to be essential to user acceptance. In addition, Bhaganagare et al. (2025) concluded that voice-controlled solutions for the Internet of Things were foundational to ESP32. The results of this review demonstrated that microcontroller units can translate vocal commands into actions related to hardware relays. However, while these studies prove that voice control works, they mainly focus on general users and overlook the physical mobility barriers, reach limitations, and spatial constraints faced by senior citizens and persons with disabilities.

Offline Edge Computing and Microcontroller Processing Architectures

In recent years, to address internet dependence and network latency caused by the network, the research focus has shifted toward local edge computing and offline speech processing. Huang et al. (2025) proposed a low-latency and energy-efficient voice-controlled smart home design based on offline speech recognition. To promote offline processing for devices, Malche et al. (2025) deployed TinyML on IoT edge devices, enabling offline processing of spoken commands for smart home automation. Most of this research assesses software algorithms in isolated laboratory environments, even though they successfully optimize computational execution speed and offline speech decoding. As a result, the literature on edge computing has not been empirically evaluated for physical hardware safety, thermal relay degradation, and load isolation in the presence of constant high-wattage home loads for local control units.

User Readiness, Technological Adoption, and Assistive Integration

The success of assistive smart devices can be determined based on the users' digital literacy and perceived ease of use across diverse individuals (Panidar et al., 2026). Bais (2026) found that technical skills can affect an individual's level of satisfaction when adjusting to smart gadgets, especially among senior citizens and persons with disabilities. Fernandez (2026) noted that gadgets' simplicity of use and functionality support technology adoption throughout system installation. Safety and functional transparency determine user adoption of technological equipment (Musin et al., 2026). These studies highlight how basic skills, user-centered design, and system trust collectively dictate how effectively individuals interact with automated devices. For these results to be applied to assistive devices, we need systems that are accessible, easy to use and reliable, and do not require complicated operating steps. However, there remains a critical shortage of empirical user-satisfaction data regarding how senior citizens and persons with disabilities interact with offline voice-activated hardware in real-world domestic settings. A comprehensive synthesis of the literature studied finds significant gaps in this research. A physical safety gap, whereby traditional outlets still pose shock and physical strain risks to vulnerable users; a connectivity gap that arises from the existing smart home dependence on internet connectivity and mobile applications; and a user adoption gap with insufficient field-evaluated user satisfaction data from vulnerable users. To address these gaps, the primary objective of this study is to develop and evaluate an assistive, offline voice-activated smart electrical outlet system. This study provides an internet-independent, touchless, and safe home automation solution tailored to enhance domestic independence for all individuals, especially for senior citizens and persons with disabilities.

Methodology

Research Design

This study used a descriptive-developmental research design to develop and evaluate the smart voice-activated outlet system. The developmental section was necessary to focus on the actual assembly of the smart outlet. This part included planning the features, creating the software code, and assembling the hardware parts. On the other hand, the study's descriptive part measures the system's overall performance and user satisfaction during its deployment. Through evaluation checklists and surveys, the smart voice-activated outlet was assessed from users' perspectives on its accuracy, durability, safety, and ease of use. This evaluation demonstrated that the final product directly helps vulnerable individuals—most especially senior citizens and PWDs—by enabling them to operate household appliances safely and independently using voice commands, without the risk of physical strain or electrical hazards. This dual design was chosen to bridge engineering development and empirical evaluation. Incorporating both approaches allowed the researchers to build a voice-controlled system that worked offline and to test it in real-world household settings.

Product Development

The assistive voice-activated outlet system was developed to satisfy the technological requirements of both general users and vulnerable individuals, especially senior citizens and PWDs, while ensuring safety and convenience. The technical development and architecture layout of the system were executed through the 7-Step Agile Systems Engineering Framework:

1. Plan: The main goals of the project were set based on the users' needs for an accessible, hands-free voice-activated device. The system was designed for general use by all individuals to ensure safe appliance use, eliminating the risk of electrical shock because users do not need to touch the outlet physically, with special emphasis on senior citizens and persons with disabilities to ensure the design accommodates their physical limitations for a more independent living setup. The optimal speech detection distances and electrical capacities were determined throughout the planning process. To create a clear chronological roadmap, project scheduling was also devised to avoid operational bottlenecks (Figure 1).

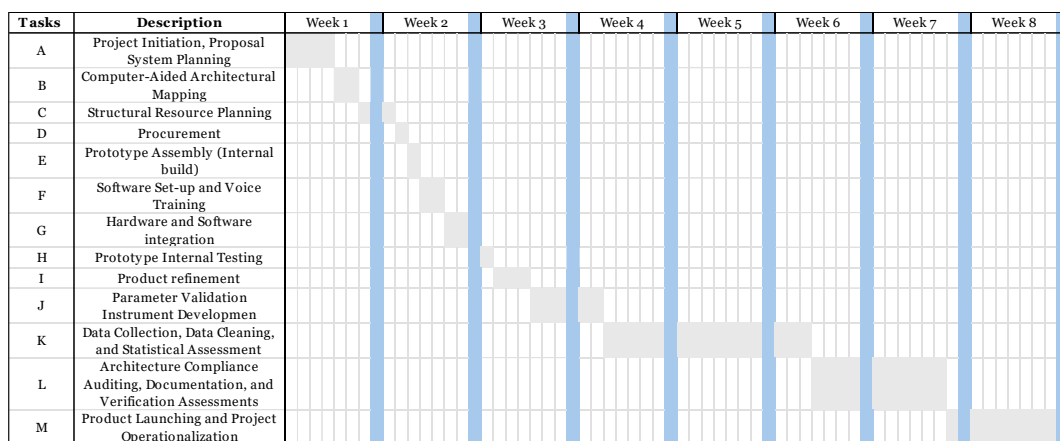


Figure 1: Project Scheduling

2. Design: The physical layout of the smart outlet was the main emphasis of this stage. Computer-aided design software was used to draft the dimensions and physical layout. The outlets are precisely spaced at 12 mm, 20 mm, and 22 mm to maximize physical ergonomics. Additional dimensional information was added to the front, right, and left views to complete the technical housing profile. To ensure a compact arrangement, the faceplate architecture was designed with overall dimensions of 158 mm by 90 mm, as shown in Figure 2.

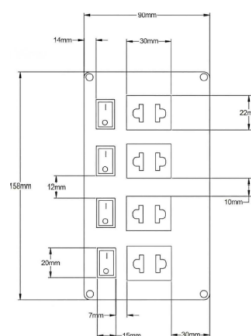


Figure 2: Top View

3. Develop: This is where the material integration and programming happened. The assembly process is divided into 4 phases. Phase 1 (Preparation & Environment Setup), which involves assembling all necessary hardware and installing the CH340 driver to enable workstation connectivity, as shown in Figure 3. The process then proceeds to Phase 2 (Firmware Calibration & Cognitive Testing), which focuses on flashing custom voice commands into the HLK-VC02 module and conducting microphone-and-speaker audio feedback

loops. At this stage, the audio subsystem is assessed for calibration; if it does, the system proceeds straight to Phase 3 (Hardware Integration & Structural Assembly). This third phase involves putting the sub-assemblies inside the electrical box after routing low-voltage signal lines and high-voltage AC wires through the 4-channel relay module. Finally, the process proceeds to Phase 4 (System Testing & Safety Validation), which conducts meticulous electrical continuity checks, load testing, and phase accuracy assessments. If any technical issues arise, the process loops back for technical adjustment, but once validated as 100% safe, the system moves directly to the Final Output, where the box is securely sealed.

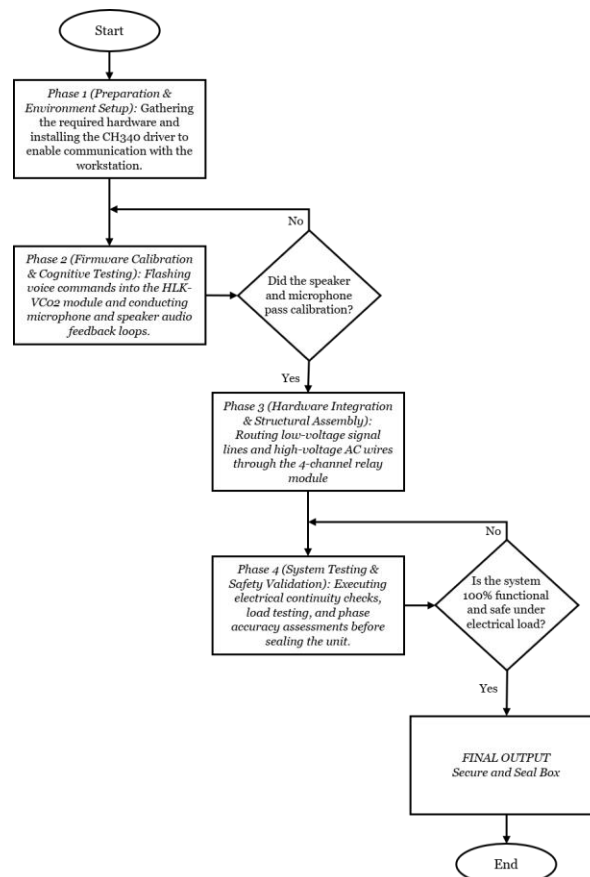


Figure 3: Developmental Process

4. Deployment: Once the product was fully assembled and tested, it was brought to a real home setting for installation and testing. This step allowed the system to experience actual everyday use. Testing the outlet inside a real home ensured it could handle the real electricity from standard appliances and still hear voice commands clearly, even with normal home background noise like appliance sounds or other background noise.

5. Test and System Refinement: To assess system performance, this phase involved intensive hands-on testing. The voice-activated smart outlet was evaluated based on voice command detection accuracy at different distances, command response speed, latency, and the operating temperature of the internal relays under electrical load (Figure 4). Any technical bugs or signal errors found during this stage were immediately fixed by adjusting the software codes and recalibrating the voice recognition sensitivity thresholds.

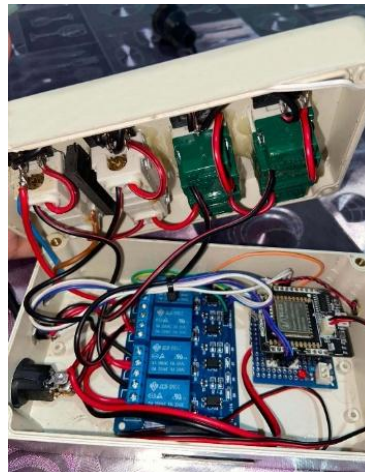


Figure 4: Actual Wiring of Product

6. Review (System Verification & Architecture Compliance): A thorough safety review was carried out following the prototype's refinement. To ensure that the finished circuit layouts, wire insulation, and actual housing openings comply with conventional home electrical safety regulations, the system design was thoroughly reviewed. The item is 100% safe to use for vulnerable household residents because this verification phase made sure that the switch configuration and front-facing speaker features matched the original technical drawings.

7. Launch: In this final engineering milestone, the system was certified as completely stable, fully functional, and ready for deployment. The product design, software parameters, and hardware configurations were finalized and locked, resulting in the actual product shown in Figure 5. This finalized assistive technology provides a reliable, hands-free smart home solution that enables general users, senior citizens, and PWDs to safely and easily control household appliances via voice commands.

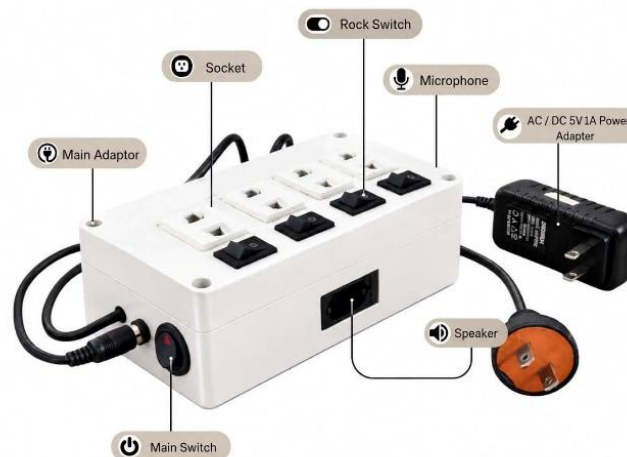


Figure 5: Actual Product

Sampling Design

Using purposive sampling, 99 participants were selected from a total population of 130 registered residents along Kakampi Street, Barangay Batasan Hills, Quezon City. These participants were calculated using Slovin's Formula with a 5% margin of error. The target participants were selected according to the following criteria: (1) registered residents who are senior citizens or persons with physical disabilities (PWDs), (2) living in household-assisted setups, and (3) able to operate or evaluate the smart outlet system through voice commands or assisted feedback. On the other hand, the exclusion criteria were: (1) people with severe cognitive or speech difficulties and (2) people who participated in the first pilot testing to avoid testing bias during actual evaluation.

Research Locale

The systems engineering assembly of the assistive voice-activated smart outlet system was primarily executed within the laboratory of the Industrial Engineering Department at Quezon City University (QCU), located in San Bartolome, Novaliches, Quezon City, Philippines. To test and evaluate the device under domestic constraints, the active deployment, usability assessment, and field surveys were conducted in selected residential households along Kakampi Street, Barangay Batasan Hills, Quezon City, Philippines. The product was tested in these localized households to ensure that the embedded voice processing core, high-sensitivity microphone modules, and real-time cavity speaker feedback loops were rigorously tested against real-world background interference and ambient household noise. This procedure helped the researchers to gather feedback directly in household environments that serve vulnerable residents, including senior citizens and persons with disabilities, ensuring the device safely meets their specific physical and independent living requirements.

Research Participants

The research participants in this study comprised 99 households residing along Kakampi Street, Barangay Batasan Hills, Quezon City. The participants primarily consisted of vulnerable household members, specifically senior citizens and PWDs who face everyday physical mobility limitations or manual coordination difficulties when using standard electrical outlets where full physical autonomy was limited; their primary caregivers or immediate family members living in the same home were included to provide comprehensive, everyday operational feedback.

Research Instrument

To measure the user satisfaction and operational capabilities of the voice-activated smart outlet system, the researchers developed a structured, two-part Survey Questionnaire. The first part is the respondent code and classification. A respondent code was used to ensure data privacy and participant anonymity. A respondent's classification indicates whether the user is a person with disability, a senior citizen, or a household caregiver to verify that they meet the study's target criteria. The second part of the instrument measures respondents' level of satisfaction with voice-control compatibility and operational noise resilience when switching connected home appliances across different domestic environments.

Data Gathering Procedure

The data collection process was initiated by securing department approval. A request letter was submitted to the Barangay Batasan Hills, Quezon City, to conduct the study along Kakampi Street. The researchers executed the data collection in two consecutive phases. The first phase is hardware testing, where the physical product is tested for baseline performance. These tests captured the system's switching accuracy and command execution delay under controlled sound conditions. To accommodate target respondents, the second phase will include one structured testing session per participant at home. Respondents had 20–30 minutes per session to use the offline voice-controlled smart outlet. The respondents tested the device with the assistance of another household member. Next, product evaluation was based on respondents' level of satisfaction when using the device. The informed consent form was duly followed to ensure that their participation was fully voluntary. All information on voice control compatibility and noise resistance during operation was further collected and counted for statistical analysis.

Results and Discussions

Research Question 1: What are the technical system performance levels of the assistive voice-activated smart outlet system during simulated deployment in terms of command latency, thermal safety, and physical spacing?

Table 1. Technical System Performance of the Smart Outlet System

Evaluation Metrics	Part Tested	Testing Parameters	Post-Operation Conditions	Status
Command Latency	HLK-VC02 Chip & 4-Channel Relay	Tested the voice commands right after leaving the device plugged in overnight	The outlet still responded instantly; no lag, delay, or system freezing when giving commands	Passed
Thermal Safety	5V 1A Adapter & Plastic Enclosure	Left the device running with household appliances turned on for 8 hours straight	The junction box felt cool to the touch; no hot spots, melting plastic, or burned plastic smell	Passed

Physical Spacing	Junction Box Faceplate (158 x 90 mm)	Plugged in multiple standard appliance cords together using the 12, 20, and 22 mm spacing	All plugs fit perfectly at the same time; the cords did not crowd or block the manual rocker switches	Passed
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The performance of the assistive voice-activated smart outlet system was assessed under practical domestic conditions, as shown in Table 1. The command latency test on the HLK-VCO2 chip and 4-channel relay, after leaving the device plugged in overnight, demonstrated that the voice-triggered path executes nearly instantly without lag or delay when commands are given (Passed). This kind of reliable response is a result of the system's localized offline architecture, which processes voice triggers directly on the hardware. The technology is completely offline and can recognize voices in a nearby area. This eliminates the need for complicated application installation and constant high-bandwidth internet access, both of which can frequently be a technological hurdle for typical households (Irugalbandara et al., 2023). The integrated cavity speaker transmits audio feedback to provide instant verification of the operational status while command execution is taking place.

The 5V 1A power adapter and plastic enclosure were thermally tested, and no symptoms of thermal deterioration or smell were found after 8 hours of continuous load; the junction box was also cool to the touch. Passed). This suggests that the junction box satisfied the structural safety criteria. This heat resistance during prolonged use meets the regulatory standards for smart home devices and helps to reduce the danger of electrical fires in the home (Xu et al., 2025). Finally, the spacing schemes demonstrated that various standard plugs fit precisely without crowding (passed). The assessments of the technical system provide evidence that the junction box is reliable. Its physical spacing for safety clearance and responsiveness further demonstrate that the junction box is technically suitable for long-term installation in a residential setting.

Research Question 2: What are the quality attributes of the developed smart outlet system in terms of voice-control compatibility and operational noise resilience?

Table 2. Voice Control Compatibility Assessment

Target Distance	Preset Command Phrase	Target Hardware Channel	Successful Voice Recognition (Count/10)	Relay Trigger Output (Success/Fail)	Audio Feedback Confirmation (Success/Fail)	Computed Accuracy Rate (%)
1.0 meter	Open Outlet 1	Relay Channel 1	10/10	Success	Success	100%
2.0 meters	Open Outlet 2	Relay Channel 2	10/10	Success	Success	100%
3.0 meters	Open Outlet 3	Relay Channel 3	9/10	Success	Success	90%
4.0 meters	Open Outlet 4	Relay Channel 4	7/10	Success	Success	70%

The device's voice-control compatibility was assessed by actual distance testing using the preset command phrase "Open Outlet 1" via the HLK-VCO2 module, as shown in Table 2. The system demonstrated perfect phonetic recognition and individual channel isolation, achieving an exceptional 100% accuracy rate at both 1.0 and 2.0 meters (Passed). The system correctly identified distinct voice triggers and routed the digital high/low signal to trigger Relay Channels 1 and 2 without cross-channel interference across 10 experiments at these ranges. This tracking at close range aligns with current human-computer interaction models, which suggest that localized offline acoustic templates display near-perfect signal matching prior to the vocal spatial degradation of the vocal waveform (Vigouroux et al., 2023). However, a slight slowdown at 3.0 meters yields a 90% accuracy rate, which drops to 70% at the maximum test distance of 4.0 meters when triggering Relay Channel 4. This performance drop is technically caused by acoustic attenuation—the natural decrease in vocal decibel intensity with distance—making it difficult for the HLK-VCO2 chip's local offline algorithm to separate the voice frequency from background noise. The decrease in accuracy rate shows that offline voice chips have a natural distance limit, as the device struggles to hear commands clearly when the user moves farther from the microphone (Torad et al., 2022). Finally, these results are relevant because they set a clear 2.0-meter operational radius for uninterrupted reliability, providing senior citizens and people with physical disabilities with a clear boundary for a safe, hands-free household experience.

Table 3. Operational Noise Resilience Assessment

Noise Source Background	Background Noise Level (dB)	Total Input Commands	Successful Relay Executions	Audio Feedback Broadcast
Quiet Room (Standard)	35 dB	10	10	10
Television Noise	65 dB	10	8	9
Electric Fan Airflow	60 dB	10	7	8

According to the results of the operational noise-resilience test displayed in Table 3, the designed smart outlet system exhibits smooth hardware-software synchronization. The system achieves 100% operational accuracy in a typical quiet room setting (35 dB) and maintains 80% operational accuracy with active television noise (65 dB). This high level of environmental noise indicates that local signal filtering can efficiently isolate user commands from the usual background interference in the domestic environment (Eduku et al., 2025). However, the successful relay executions drop to 70% when exposed to direct airflow from an electric fan (60 dB), due to wind-turbulence distortion at the microphone. The slight signal lag in the presence of high-frequency noise, evidenced by the difference between the physical relay executions and the audio feedback responses, serves as a safety buffer by validating user presence before requiring a high-voltage mechanical connection. This particular delay corresponds to safety standards for electrical loads, which incorporate operating relay modules to prevent potentially dangerous unintentional triggers caused by abnormalities in the auditory environment. These results are of great importance because they provide practical guidelines for optimizing voice-recognition accuracy and avoiding accidents in noisy environments, ensuring a safe independent living device for vulnerable groups.

Research Question 3: What is the engineering system performance of the voice-activated smart outlet command execution response time across domestically deployed appliances?

Table 4. Command Execution Response Time Across Domestically Deployed Appliances

Deployed Relay Channel	Appliances	Mean Response Time: ON (Seconds)	Mean Response Time: OFF (Seconds)	Overall Average Mean (Seconds)
Relay Channel 1	Lamp	0.85	0.95	0.90
Relay Channel 2	Phone Charger	1.15	1.25	1.2
Relay Channel 3	Electric Fan	1.45	1.55	1.50
Relay Channel 4	Television	1.80	1.90	1.85

The operational execution speed of the smart outlet system was evaluated across various household appliances to determine mechanical responsiveness under actual electrical loads, as shown in Table 4. The response time for executing commands was from 0.90 to 1.85 seconds, indicating that all devices successfully switched states. At 0.90 seconds, the lamp had the fastest processing time, followed by the phone charger at 1.20 seconds. The average response times for the electric fan and television were 1.50 and 1.85 seconds, respectively. This variation in timing is typical due to the electrical properties of inductive motor loads, which cause transient spikes that the offline processor must regulate prior to connecting the relay. According to Bhaganagare et al. (2025), this steady hardware loop adheres to the specifications of modern home automation, in which offline, voice-controlled relay systems can effectively manage multi-channel load switching without signal dropouts. Ultimately, these findings are highly important because they demonstrate that the voice-activated outlet can safely handle diverse electrical load variations, which ensures a safe, highly responsive assistive utility for daily household management.

Research Question 4: What is the respondent's level of satisfaction in using the voice-activated smart outlet system in terms of voice-control compatibility and operational noise resilience?

Table 5. Respondents' Level of Satisfaction in terms of Voice-Control Compatibility

	Voice Control Compatibility	Mean	Verbal Interpretation
1.	The system responds quickly to voice commands	4.44	Strongly Agree
2.	Voice control works well with different voice assistants.	4.35	Strongly Agree
3.	The system understands voice commands clearly.	4.29	Strongly Agree
4.	The voice control can recognize commands from different users.	4.30	Strongly Agree
5.	The system works even when voice commands are from a short distance.	4.34	Strongly Agree
	WM	4.34	Strongly Agree

As presented in Table 5, the overall evaluation of voice-control compatibility showed strong agreement (WM=4.34, strongly agree). The system received its highest satisfaction score for its ability to respond quickly to voice commands (M=4.44, strongly agree). The localized (offline) architecture of the HLK-VCo2 module is principally responsible for the rapid execution. This finding aligns with Bais (2026), who asserted that implementing locally adapted architectural innovations maximizes efficiency and facilitates high-speed information processing. Following this, respondents highly agreed that the system works well with different voice assistants (M=4.35, strongly agree) and functions properly even when voice commands are given from a short distance (M=4.34, strongly agree). Furthermore, the system demonstrated stable performance in recognizing commands from different users (M=4.30, strongly agree). These positive assessments indicate a high level of satisfaction supports the observation of Panidar et al. (2026) that the success of assistive smart devices depends heavily on matching simple operation with users' digital literacy.

The system's understanding of voice commands received the lowest rating but with a high satisfaction level (M=4.29, strongly agree) due to the HLK-VCo2 chip's localized, offline architecture, which does not require internet connectivity and avoids system lag or transmission to the server side (even with ambient background noise). However, contrary to the findings of Xu et al. (2025), which show that speech recognition is fast and performed in real time, the clarity of speech recognition still varies depending on background noise. Even with these minor hardware limitations in noisy environments, the high ratings still show that the system is truly useful, giving senior citizens and persons with disabilities an easy, internet-free way to control appliances independently.

Table 6. Respondents' Level of Satisfaction in terms of Operational Noise Resilience

	Operational Noise Resilience	Mean	Verbal Interpretation
6.	The system correctly follows voice commands.	4.20	Agree
7.	The smart outlet performs tasks without mistakes.	4.23	Strongly Agree
8.	The response time of the system is fast and accurate.	4.28	Strongly Agree
9.	The system easily understands and follows voice commands	4.34	Strongly Agree
10.	The outlet turns appliances on or off exactly as instructed.	4.19	Agree
	WM	4.25	Strongly Agree

As indicated in Table 6, the evaluation of respondents' level of satisfaction regarding operational noise resilience yielded an overall favorable assessment (WM=4.25, strongly agree). The highest rating among the indicators demonstrated that the system can process and carry out voice commands easily (M=4.34, highly agree). This is followed by the system's fast and accurate response time during operational execution (M=4.28, strongly agree), and its capability to perform assigned functions without operational mistakes (M=4.23, strongly agree). The consistency in accuracy shows that the execution of efficient localized processing algorithms is effective in reducing command latency during real-time executions. When it comes to reducing command latency, this supports Malche et al. (2025) on the reliability of decoding voice instructions on device



hardware to reduce reliance on the cloud. Respondents also agreed that the system properly follows voice commands ($M=4.20$, agree). As Musin et al. (2026) pointed out, some of the most important factors that determine whether users would adopt current technological equipment are safety and the clarity of its functionality.

Conversely, still within a positive evaluation, the outlet switching appliances on or off exactly as instructed ($M=4.19$, agree). The variance in execution accuracy is due to localized acoustic interference, which may be created by ambient background noise, such as televisions or electric fans. Sometimes this interference can impair the capture of speech recognition signals before relay activation. This finding aligns with Wang et al. (2022), who point out that voice-controlled electrical appliances confirm that background environmental noise remains a key operational challenge during real-world household appliance switching. The results show that the voice-activated outlet is functionally reliable and operational in controlled home environments. The high agreement of Voice-Control Compatibility and Operational Noise Resilience suggests the localized speech interface performs well under normal conditions, and it remains reliable even with ambient household noise. This is shown by the fact that the interface works well under standard conditions. Thus, the high evaluation provides evidence that the voice-activated smart outlet can deliver consistent functional performance under highly controlled conditions in the home setting.

Ethical Considerations

This study followed strict ethical rules to protect the participants, particularly the vulnerable group of senior citizens and PWDs. Ethics clearance (QCU-COE-E20260601) has been duly given and signed by the Area Chair of Industrial Engineering to comply with the Data Privacy Act of 2012 prior to data collection. Informed consent was gathered, and the research objectives and the voluntary nature of participation were fully explained. They were told that they had the right to withdraw at any stage without penalty. They were also informed of their right to withdraw at any stage without penalty. To limit the risk of operational discomfort and physical hazards, low-voltage control circuits and protective non-conductive hardware enclosures were provided during testing and deployment. During the testing and survey procedure, the participants were assisted by members of their families or caretakers; the researchers also assisted them in order to make them feel comfortable. To maintain complete confidentiality and anonymity, no personally identifiable information was collected or recorded. All survey responses were tallied and analyzed, and individual identities were kept confidential to ensure complete protection.

Conclusion

Based on the evaluation results, the voice-activated smart outlet system is a highly effective assistive device for older adults and persons with disabilities. The overall evaluation showed strong user agreement in both voice-control compatibility and operational noise resilience. Driven by an offline HLK-VCo2 module, the system achieved its highest performance in quick command execution and smooth voice response without needing an internet connection. This hands-free technology makes daily home management safer and easier. Through voice control, the need for users to bend down or reach wall sockets was eliminated, greatly reducing physical effort and the risk of accidental falls and offering an easy and accessible solution for individuals with limited mobility or low digital literacy. Overall, the results confirm that the smart outlet system is a safe and easy-to-use device, which provides users with the capability to control household appliances using offline voice recognition. This evidence suggests that localized engineering interventions can be effective in overcoming daily operational barriers in the residential setting.

Recommendations

Based on the results, the study recommends that a voice-activated outlet is primarily intended to assist homes with senior citizens and persons with disabilities by enabling accessible, hands-free appliance control that enhances independent living. It enhances functional independence in the house by providing a hands-free means to reduce direct contact with live electrical plugs. The system is also highly recommended for office spaces and healthcare facilities, where touchless interactions help reinforce infection control and minimize direct physical contact with shared electrical fixtures. Academic institutions (universities and colleges), corporate offices, and healthcare facilities (hospitals and clinics) are encouraged to adopt the technology to provide a touchless operational alternative that reinforces campus and hospital infection control protocols by reducing physical contact with shared electrical fixtures. Product designers should focus on maximizing the physical dimensions and operating precision. Future designs should use smaller electronic components to reduce the total size of the physical enclosure. This would ensure that the enclosure fits ordinary wall sockets flawlessly, without obstructing nearby outlets.

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