**VOICE CONTROLLER SMART HOME FOR DISABLED PEOPLE**

#### A SOCIALLY RELEVANT MINI PROJECT REPORT

***Submitted by***

#### RAKSHINEE H 211423104518

**RAJASRI R 211423104514**

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**(An Autonomous Institution Affiliated to Anna University, Chennai)**

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###### BONAFIDE CERTIFICATE

Certified that this project report **“ VOICE CONTROLLER SMART HOME FOR DISABLED PEOPLE”** is the bonafide work of “**RAKSHINEE H** (**211423104518**)**, RAJASRI R** (**211423104514**)”, who carried out the project work under my supervision.

##### Signature of the HOD with date Signature of the supervisor with date

**Dr.L. JABASHEELA, M.E.,Ph.D., R. RAMANA, M.Tech.,MBA.,**

**Professor and Head, Professor,**

**Department of CSE, Department of CSE, Panimalar Engineering College, Panimalar Engineering College, Chennai- 123 Chennai- 123**

Certified that the above candidates were examined in the 5th Semester Project Viva- Voce Examination held on...........................

**INTERNAL EXAMINER EXTERNAL EXAMINER**

###### DECLARATION BY THE STUDENT

We RAKSHINEE H (211423104518), RAJASRI R (211423104514)

hereby declare that this project report titled ***“*VOICE CONTROLLER SMART HOME FOR DISABLED PEOPLE”** under the guidance of **Mr.RAMANA R, M.Tech.,MBA.,** is the original work done by us and we have not plagiarized or submitted to any other degree in any university by us.

**SIGNATURE OF THE STUDENTS** **RAKSHINEE H**

**RAJASRI R**

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**RAKSHINEE H(211423104518)** **RAJA SRI R (211423104514)**

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## ABSTRACT

Disability poses significant challenges in daily living, especially in performing routine household activities independently. This project aims to develop a Smart Home System specifically designed for people with disabilities, focusing on mobility impairments, visual impairment, hearing difficulties, and general accessibility needs. The system leverages software-based solutions such as voice control, accessibility-friendly graphical interfaces, and emergency alert mechanisms to create a safer and more inclusive living environment.

The primary objectives are to provide a user-friendly platform where users can control appliances through voice commands, receive real-time notifications via visual or auditory alerts, and access an accessible interface that adapts to different disabilities. This fosters independence, enhances safety, and reduces reliance on caregivers. The project also aligns with the United Nations Sustainable Development Goal 3 (Good Health and Well- Being) by promoting inclusivity and improving the quality of life for persons with disabilities. The project is significant as it bridges technology with accessibility, offering a practical and scalable software solution that empowers individuals with disabilities to live more independently, while also laying the foundation for future integration with IoT and AI-

driven smart home technologies.

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# CHAPTER 1 INTRODUCTION

#### OVERVIEW

Independent living can be especially challenging for individuals with disabilities, as they often face difficulties in carrying out everyday household activities such as operating appliances, responding to emergencies, or accessing information. Traditional home systems are not designed with accessibility in mind, which increases dependency on caregivers and reduces quality of life.

This project focuses on developing a **Smart Home System for Disabled People**, which utilizes software-based solutions to provide accessible, safe, and user-friendly control over home environments. The system incorporates voice control for mobility-impaired users, screen-reader–friendly interfaces for visually impaired individuals, and visual alert notifications for those with hearing difficulties. Additionally, it includes an emergency alert module to ensure quick assistance in critical situations.

By creating a platform that adapts to multiple accessibility needs, the system not only improves convenience and safety but also empowers users to live more independently. The project supports inclusivity and aligns with **United Nations Sustainable Development Goal 3: Good Health and Well-Being**, by enhancing the overall quality of life for persons with disabilities.

###### PROBLEM DEFINITION

* + - Persons with disabilities often encounter significant barriers in performing everyday household activities. Tasks such as operating electrical appliances, responding to doorbells, or handling emergencies can become challenging without external assistance. Existing smart home technologies are primarily designed for convenience rather than inclusivity, leaving disabled individuals with limited accessibility options.
    - Traditional systems also fail to address the diverse needs of people with mobility impairments, visual impairments, hearing difficulties, and general accessibility requirements in an integrated manner. This lack of inclusive design increases dependency on caregivers and reduces the ability of disabled individuals to live independently.
    - Therefore, there is a pressing need for a system that can:
    - Provide voice-controlled operation of household appliances for mobility-impaired users.
    - Offer screen-reader–friendly and accessible interfaces for visually impaired individuals.
    - Deliver visual alerts and notifications for hearing-impaired users.
    - Ensure safety and independence through an emergency alert mechanism.
    - Such a solution can enhance independence, safety, and quality of life for disabled individuals while promoting inclusivity in smart home technologies.

# CHAPTER 2 LITERATURE SURVEY

##### Existing Systems and Research:

Existing smart home systems, such as those developed by major technology companies, primarily focus on convenience and energy efficiency rather than inclusivity. Solutions like Amazon Alexa, Google Home, and Apple HomeKit allow users to control appliances, lighting, and security systems through voice commands or mobile applications. While these systems are advanced in terms of usability, they are not specifically tailored to address the diverse accessibility needs of persons with disabilities.

For example, visually impaired users may find it difficult to interact with graphical interfaces that lack screen-reader compatibility, while hearing-impaired individuals cannot fully benefit from voice-based notifications. Similarly, many systems assume a degree of mobility, which excludes individuals with severe physical limitations. Academic research in the field of assistive technologies highlights the importance of designing inclusive smart home systems, yet most proposed solutions remain at the prototype or conceptual level without widespread practical implementation.

##### Research Gap:

Although significant advancements have been made in smart home technology and assistive tools, there is still a lack of integrated systems that simultaneously address mobility impairments, visual disabilities, hearing difficulties, and general accessibility. Current systems often focus on one disability category, leaving others underserved. Moreover, existing solutions are not always cost-effective or easy to deploy, which restricts accessibility for a larger community.

# CHAPTER 3 SYSTEM ANALYSIS

#### EXISTING SYSTEM

The existing smart home systems available in the market, such as Amazon Alexa, Google Home, and Apple HomeKit, primarily focus on comfort, energy efficiency, and convenience rather than inclusivity. These platforms allow users to control devices such as lighting, fans, televisions, and security systems through mobile applications or voice commands. While these solutions are advanced and widely adopted, they are not specifically designed for individuals with disabilities.

For example, **mobility-impaired users** may still face difficulties if physical interaction is required to set up or reset devices. **Visually impaired users** often struggle with graphical user interfaces that are not compatible with screen readers, and **hearing- impaired users** are unable to fully benefit from voice-based alerts or notifications. Furthermore, most existing systems assume a certain level of digital literacy, which may exclude individuals with limited technical skills.

Although some assistive technologies exist independently, such as screen readers for the visually impaired or wearable devices for the hearing impaired, these tools are not fully integrated into mainstream smart home ecosystems. This lack of inclusivity forces disabled individuals to rely on multiple separate systems, which increases complexity and reduces overall usability.

Thus, while current smart home solutions are effective for general users, they remain insufficient when it comes to addressing the **specific accessibility and safety needs of people with disabilities** in a single, integrated platform.

###### PROPOSED SYSTEM

The system is designed to support multiple categories of disabilities through different modules. For **mobility-impaired users**, it provides **voice-controlled appliance management**, allowing them to operate lights, fans, or other devices without physical effort. For **visually impaired users**, the system offers **screen-reader–friendly interfaces** and **voice feedback** to ensure smooth navigation and interaction. For **hearing-impaired users**, it includes **visual notifications and alerts**, enabling them to receive important information through text or light-based signals. Additionally, the system incorporates an **emergency alert mechanism** that allows users to quickly notify caregivers or emergency services in case of accidents or urgent situations.

This unified approach eliminates the need for multiple standalone assistive technologies by combining accessibility features into a single, user-friendly platform. By offering customized interaction modes, the system enhances independence, improves safety, and reduces reliance on caregivers. Moreover, the modular design ensures scalability, allowing future integration with IoT devices, AI assistants, and healthcare monitoring systems.

By embedding accessibility at the core of smart home design, the proposed system not only improves daily living for disabled individuals but also contributes to building an inclusive society where technology adapts to the needs of all users.

###### FEASIBILITY STUDY:

1. **Technical Feasibility:**

The system can be developed using widely available and accessible technologies such as Python (Flask/PyQt/Tkinter) for backend and GUI development, along with speech recognition libraries, text-to-speech modules, and accessibility APIs. These tools are open- source, lightweight, and compatible with standard computing environments, making the solution technically feasible without requiring advanced infrastructure. Since the application runs on a standard desktop or mobile device, it does not demand specialized hardware, ensuring easy deployment, scalability, and future integration with IoT-based devices.

1. **Economic Feasibility:**

The proposed system is cost-effective as it primarily relies on open-source libraries and frameworks, eliminating the need for expensive licenses. The development and maintenance costs are minimal, limited to basic system hosting or optional integration with third-party services. Compared to commercial smart home solutions, this software-focused approach significantly reduces financial barriers, making it accessible for wider adoption among individuals and organizations supporting people with disabilities.

1. **Operational Feasibility:**

The system is designed to be **simple and user-friendly**, ensuring that users with varying disabilities can operate it with minimal training. For mobility-impaired users, voice control provides hands-free operation. Visually impaired users can rely on screen-reader–compatible interfaces, while hearing-impaired users benefit from visual notifications. The inclusion of an emergency alert mechanism further enhances operational reliability and acceptance. By catering to diverse needs through modular design, the system ensures smooth day-to-day

usability and operational success.

1. **Social Feasibility:**

The project aligns with inclusivity goals, particularly UN SDG 3: Good Health and Well- Being, by empowering disabled individuals to live more independently and securely. It promotes social awareness about accessibility challenges and demonstrates how technology can create inclusive environments. The system adds strong social value by reducing dependency on caregivers, improving safety, and enabling equal participation in daily life, thereby making it highly feasible from a societal perspective.

###### DEVELOPMENT ENVIRONMENT

The development of the Smart Home for Disabled People system was carried out using a flexible and accessible software development environment. The backend and core logic were implemented in Python, making use of libraries such as SpeechRecognition for voice input, pyttsx3 for text-to-speech, and Tkinter/PyQt for building accessibility-friendly graphical user interfaces. These libraries provide lightweight, open-source solutions that are easy to integrate and extend.For visually impaired users, the interface was tested with screen reader compatibility, while for hearing-impaired users, visual notifications were integrated into the GUI. The system was developed and tested using Python IDLE and Visual Studio Code as the primary development platforms. Prototype-level data handling was managed in memory, but the design allows future extension to database integration for storing user profiles, preferences, and emergency contacts.

This combination of open-source frameworks and tools ensured that the system was cost-effective, scalable, and adaptable to future u pgrades, including IoT hardware integration or AI-based personalization. The chosen environment supports rapid prototyping while remaining practical for real-world deployment.

# CHAPTER 4 SYSTEM DESIGN

#### SYSTEM ARCHITECTURE

The system is designed using a three-tier software architecture:

##### Presentation Layer (User Interface):

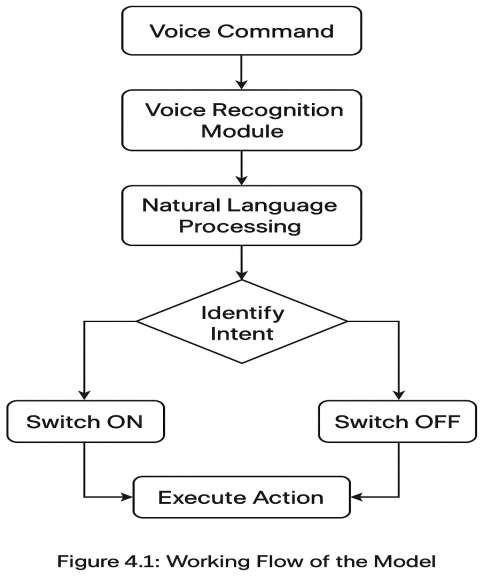
* + - * Provides a simple and accessible interface for users.
      * Supports voice commands, large buttons, high-contrast visuals, and text-to-speech to aid users with different disabilities.
      * Caregivers can also monitor and control devices through the interface.

##### Application Layer (Processing & Logic):

* + - * Handles voice recognition, command interpretation, and automation rules.
      * Implements modules for mobility assistance, visual impairment support (audio feedback), and hearing impairment support (visual alerts).
      * Ensures that user commands are translated into meaningful actions.

##### Layer (Database & Storage):

* + - * Stores user preferences, device states, automation rules, and accessibility settings.
      * Logs emergency alerts and activity history for caregiver review.



#### 4.2.FUNCTION MODULES:

1. Voice Command Module:
   * Converts spoken input into text using speech recognition libraries.
   * Maps recognized comm ands to specific device control actions.
2. Accessibility Module:
   * Provides audio feedback for visually impaired users.
   * Provides visual pop-ups/notifications for hearing-impaired users.
   * Offers simplified navigation for mobility-impaired users.
3. Device Control Simulation Module:
   * Simulates the operation of smart devices (lights, fans, alarms, doors) in the software.
   * Provides visual indicators of the device’s ON/OFF status.
4. Automation & Safety Module :
   * Executes predefined rules (e.g., turn on light when voice command is given).
   * Triggers emergency alerts for caregivers (e.g., panic button simulation).
5. User Management Module:
   * Allows multiple user profiles (disabled user and caregiver).
   * Stores accessibility preferences for each user.

###### 4.3 INTEGRATION WITH SMART HOME SYSTEM

The integration with the smart home system forms the backbone of this project, as it enables seamless interaction between users and various household devices. Once a user provides input—such as a voice command, button press, or caregiver instruction—the system processes the request and communicates with the appropriate control module. By utilizing software frameworks for voice recognition, accessibility support, and device simulation, the project eliminates the dependency on complex hardware while still allowing dynamic monitoring and control of devices. The system ensures smooth communication between the back-end logic, which interprets commands and executes automation rules, and the front-end interface, which presents feedback to the user in an accessible and interactive manner. This integration enhances usability by not only executing commands but also adapting responses for

different disabilities, such as audio feedback for visually impaired users, visual alerts for hearing-impaired users, and simplified navigation for mobility-impaired users.

###### 4.3 DATA FLOW IN THE SYSTEM:

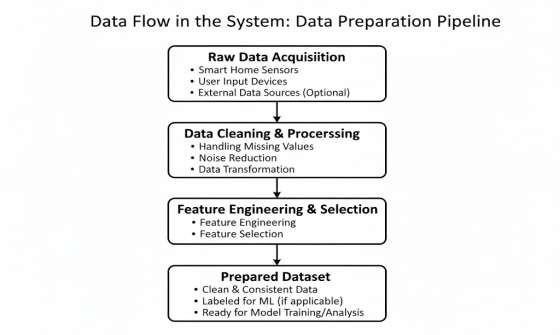
The data flow in the system follows a sequential and structured process, ensuring smooth interaction between different modules. The process begins with **user input**, where a command is given through voice, accessible UI, or predefined automation triggers. This input is then passed to the **command interpretation module**, which analyzes the request and maps it to a corresponding device action. Once the command is processed, it is forwarded to the **device control module**, which simulates the execution of the action (e.g., turning on a light, opening a door, or activating an alarm). Finally, the system provides **feedback** in a disability- friendly format: audio output for visually impaired users, visual indicators for hearing- impaired users, or caregiver notifications in case of emergencies. This flow ensures that user inputs are effectively transformed into actionable outputs, offering both control and accessibility, thereby guiding users toward a more **independent, safe, and comfortable living environment**.

Fig.4.2 Data Preparation

**Dataset Details**

In this project, a traditional external dataset is not used since the system works dynamically based on real-time user input and environmental interactions. Instead, the dataset is generated internally through the following components:

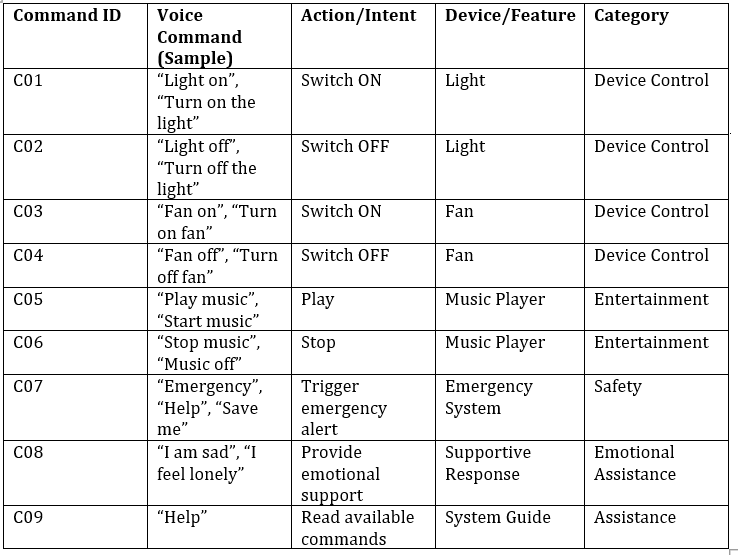
1. Device & Sensor Data:
   * Generated from the smart home system when users interact with devices or sensors (e.g., turning lights on/off, adjusting thermostat, operating doors).
   * Contains details such as device type, status (on/off), duration of usage, and sensor readings (e.g., temperature, motion, smoke detection).
   * Acts as the foundation for monitoring user activity and automating home responses.
2. User Preference Factors:
   * A small predefined dataset is used that contains average user preferences and accessibility requirements for different functionalities.
   * Example:
     + Light intensity preference: ~70% brightness
     + Temperature preference: 24°C
3. Door automation:

Each query or action from the user forms a dataset row, consisting of:

* + Device or system accessed
  + User command/input
  + Device response status
  + Time of interaction

1. System-Generated Data
   * Optimized automation suggestions for energy efficiency, safety, and accessibility based on real-time monitoring.
   * The system automatically generates logs of user interactions, including recognized voice commands, device status changes (ON/OFF), timestamps of execution, and emergency triggers. This data helps in analyzing system performance, understanding user behavior, and improving accuracy of command recognition through iterative refinement.

The dataset is structured as shown in the following table:



**Table 4.1** Dataset Details

# CHAPTER 5 SYSTEM ARCHITECTURE

#### ARCHITECTURE OVERVIEW

The proposed smart home software system for disabled people is designed with accessibility, reliability, and safety as its top priorities. The architecture follows a three- layered model, consisting of the frontend interface, backend processing, and device control integration layer. Each layer plays a vital role in making the system interactive and supportive for differently-abled users who may not be able to rely on physical switches or traditional controls.

The frontend interface is where the user interacts directly with the system. It is built with both voice-based and minimal visual controls, allowing users to issue commands in a natural and stress-free manner. The voice-based interaction eliminates the need for physical movement, which is especially beneficial for users with mobility limitations. The simple design ensures that users do not feel overwhelmed and can operate the system without technical expertise.

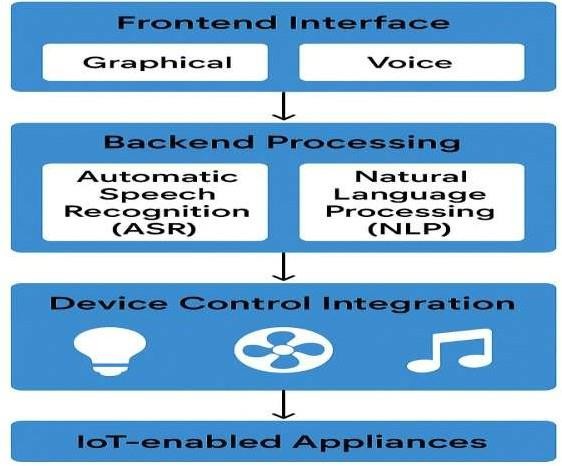
Once a command is issued, the request is passed to the backend processing layer. This layer acts as the “brain” of the system, where Automatic Speech Recognition (ASR) converts spoken commands into text, and Natural Language Processing (NLP) interprets the meaning of the request. For example, if a user says “Turn on the fan”, the backend extracts the device (fan) and the action (turn on). This ensures that the system understands the intent behind the command, even if phrased differently.

The processed command is then sent to the device control integration layer, which acts as the execution engine. It communicates with IoT-enabled devices such as fans, lights, music

systems, and emergency modules, ensuring real-time response. The integration layer uses lightweight communication protocols like MQTT or HTTP to send signals to devices quickly and efficiently.

To maintain trust and transparency, the system provides immediate feedback to the user. Both visual indicators (like ON/OFF status) and audio responses (such as “The fan has been turned on”) are used to confirm the outcome. This creates a feedback loop where users are always aware of the system’s state, reducing confusion and increasing confidence.

By combining these three layers—frontend, backend, and device control—the architecture achieves an inclusive solution that empowers disabled individuals to live more independently. It balances everyday convenience with emergency readiness and ensures that users can interact with their environment in a safe, reliable, and user-friendly manner.



**Figure 5.1** Architecture overview

#### MODULES:

* + 1. User Authentication Module:

The **User Authentication Module** ensures that only authorized users can access the system. Each user must first log in with secure credentials before gaining control over devices. This prevents unauthorized access, which is especially important for safeguarding the personal environment of disabled individuals. The module supports **multi-user profiles**, allowing caregivers or family members to be added with restricted permissions. All credentials are stored in an **encrypted database** for maximum security. It also includes **session management** to prevent misuse when multiple people use the same device. By controlling access effectively, the system ensures that the home remains both **private and secure** for its primary user.

* + 1. Voice Input & Recognition Module:

The Voice Input & Recognition Module captures spoken commands through microphones or connected devices such as smartphones or smart speakers. It applies ASR techniques to convert speech into text, ensuring accurate recognition even with different accents or mild speech impairments. The system is designed to filter background noise so that commands can be understood even in a busy environment. It also supports continuous listening mode, so users do not need to press buttons to issue commands. By providing a natural and inclusive way of communication, this module makes the smart home system highly adaptable to real-world needs.

* + 1. Command Processing Module

The Command Processing Module is responsible for analyzing the text received from the voice recognition system and identifying the action and target device. For example, if a user says “Play music”, it recognizes the action (play) and the device (music system). It uses NLP algorithms to detect intent, even if the command is phrased differently, such as “Start songs” or “Turn on music”. This flexibility is essential for ensuring usability across a wide range of users. In cases of incomplete or ambiguous commands, the module asks for clarification. This ensures accuracy and reliability in every interaction.

* + 1. Device Control Module

The Device Control Module acts as the execution unit of the system. Once a command has been processed, it communicates with IoT-enabled devices using MQTT, HTTP, or Bluetooth protocols. It also maintains a record of the current state of each device, ensuring that users are informed if a device is already ON or OFF before executing the action. This prevents unnecessary operations and improves energy efficiency. The module is scalable, meaning new devices such as air conditioners or security cameras can be added seamlessly. By handling all device operations, this module makes the system flexible, responsive, and efficient.

* + 1. User Interface Module

The User Interface Module provides a dual interaction mode—graphical and auditory. It displays simple visuals such as ON/OFF status, emergency alerts, and notifications while also offering spoken confirmations for each action. The design prioritizes simplicity, ensuring that even non-technical users can navigate it without difficulty. The UI can be accessed on smartphones, tablets, or PCs, making it versatile and platform-independent. Accessibility features such as large fonts, high-contrast visuals, and audio prompts are included to support

users with visual or cognitive impairments. This ensures that the interface is not only functional but also inclusive

* + 1. Database Management Module

The Database Management Module is responsible for storing critical system data such as user credentials, device states, command history, and emergency contacts. The data is stored securely using encryption techniques and regular backups to prevent loss. The database supports quick retrieval of information, ensuring that the system responds instantly to commands. It also logs past activities, which can be analyzed to improve system performance or provide caregivers with useful insights. In case of system failures, backup mechanisms ensure that the system can be restored without data loss. This module is essential for ensuring reliability, security, and performance.

* + 1. Emergency Module

The **Emergency Module** is designed to handle urgent situations quickly and effectively. If a user issues a command such as *“Help”* or *“Emergency”*, the system immediately sends alerts to preconfigured contacts via **SMS, email, or app notifications**. In addition, it can activate an alarm within the home to draw the attention of nearby people. This module ensures that disabled users are never left helpless during critical times. Caregivers or family members are notified instantly, allowing them to respond without delay. By combining digital alerts with physical alarms, this module adds a strong **safety layer** to the smart home system..

* + 1. Feedback & Notification Module

The **Feedback & Notification Module** provides confirmation after every action is executed, ensuring that the user knows the outcome of their command. For example, after turning off a fan, the system might say *“The fan has been turned off”* while also displaying a

visual update. The module also provides **reminders and warnings**, such as notifying users if lights or fans are left on for too long. This not only improves user awareness but also helps in **energy conservation**. Regular feedback builds trust, as users can be confident that the system is always functioning as intended.

* + 1. Security & Privacy Module

The Security & Privacy Module ensures that the system remains safe from misuse or external threats. All communication between the user and the devices is encrypted, preventing hackers from intercepting commands. It includes access control mechanisms that limit usage to authenticated users only. The system also monitors for unusual patterns, such as repeated failed login attempts, and alerts the user in case of suspicious activity. Since privacy is especially important for disabled individuals in their personal environments, this module ensures that all data remains confidential and secure.

* + 1. System Integration Module

The System Integration Module acts as the glue that connects all the other modules into a unified system. It manages the flow of data between the voice recognition, command processing, device control, and feedback modules. It also ensures error handling, such as informing the user if a device is unreachable or a command cannot be executed. The integration layer is optimized for real-time performance, ensuring that commands are executed instantly without noticeable delay. By keeping the system cohesive and stable, this module guarantees that the smart home functions seamlessly under all conditions.

###### PROJECT FILE STRUCTURE :

Voice\_controller\_app/

**│**

├── voice\_controller\_app.py # Main Python code

**│**

**├── assets/ # All images/icons**

**│ ├── background.png # Full background image**

**│ ├── light\_on.png # Light ON icon**

**│ ├── light\_off.png # Light OFF icon**

**│ ├── fan\_on.png # Fan ON icon**

**│ ├── fan\_off.png # Fan OFF icon**

**│ ├── music\_on.png # Music ON icon**

**│ └── music\_off.png # Music OFF icon**

**│**

├── music/ # Music files folder

**│ └── song.mp3 # The song to play**

**│**

**└── dist/ # (Optional - created after PyInstaller build)**

**└── voice\_controller\_app.exe # Executable after build**

**Getting and Performing Data Cleaning**

Data cleaning is an essential step to ensure that the Smart Voice-Based Home Control Software works efficiently, accurately interpreting user commands and controlling smart devices without errors. In this project, the process of cleaning and preparing data mainly focuses on voice command inputs, device control data, and system logs.

**The following steps were carried out:**

###### DATA COLLECTION:

The first step involves gathering different types of data required for the system:

* + Voice commands recorded through the microphone.
  + User authentication details and profiles.
  + Device information such as ON/OFF states of lights, fans, appliances, and sensors.
  + System usage logs, including command history and error records.

This raw data serves as the foundation for smooth functioning of the software.

###### NOISE REMOVAL & FILTERING

Since voice commands may include background noise or unclear pronunciation, data cleaning techniques are applied:

* + Removing silence and unwanted noise segments from the audio.
  + Applying digital filters (low-pass/high-pass) to improve clarity.
  + Normalizing audio levels to ensure consistent voice input quality.

###### COMMAND VALIDATION

Not every spoken input may be valid. Hence, the system verifies:

* + Whether the spoken text matches supported commands (e.g., *“Turn on light”*, *“Switch off fan”*).
  + Filtering out incomplete or irrelevant phrases.
  + Mapping similar words or synonyms (e.g., *“lamp”* = *“light”*) to valid device actions.

###### DATA STRUCTURING & STORAGE

Once validated, the cleaned commands and device states are stored in structured form:

* + User → Command → Device → Status.
  + Example: *User1 → “Turn on” → Light → ON*.
  + Logs are maintained in the database for further system optimization.

###### ERROR HANDLING & DUPLICATE REMOVAL

The system checks for:

* + Duplicate commands (e.g., multiple *“Turn on fan”* requests in 2 seconds).
  + Invalid commands that cannot be executed (e.g., *“Open fridge”* when no smart fridge is connected).
  + Misinterpretations corrected using predefined rules.

###### USER INTERFACE DISPLAY

The cleaned and processed data is then presented to the user:

* + Device status (ON/OFF).
  + Feedback through voice responses and visual indicators.
  + Alerts for errors or unsupported commands.

###### CONTINUOUS IMPROVEMENT

To make the system smarter, data cleaning evolves over time:

* + Updating the command dictionary to include new devices.
  + Learning from user corrections (e.g., if a command was misinterpreted).
  + Improving filters to handle regional accents, variations, and noise conditions.

#### COLLABORATION AND FEEDBACK:

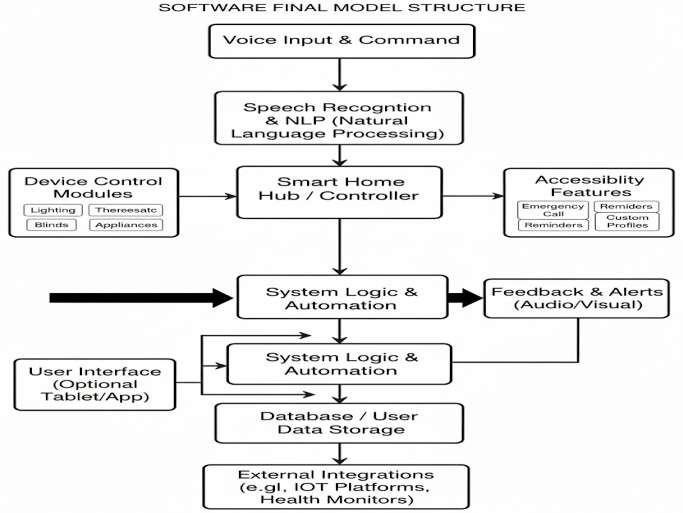
Collaboration and feedback played a central role in the successful development of the Smart Voice Home Control Software for Disabled People. Team collaboration ensured that tasks such as voice recognition development, backend coding, IoT integration, database management, and documentation were distributed effectively among members. Shared repositories and cloud platforms were used for storing code, design documents, and configuration files, allowing all members to access the latest versions and work without conflicts.

Regular team meetings were conducted to discuss milestones, review progress, and resolve challenges related to speech recognition accuracy, device connectivity, and user interface accessibility. Each member contributed by testing modules such as voice input, command processing, and device control, while peer reviews helped maintain quality standards in both code and system design. Team members cross-verified command logs,

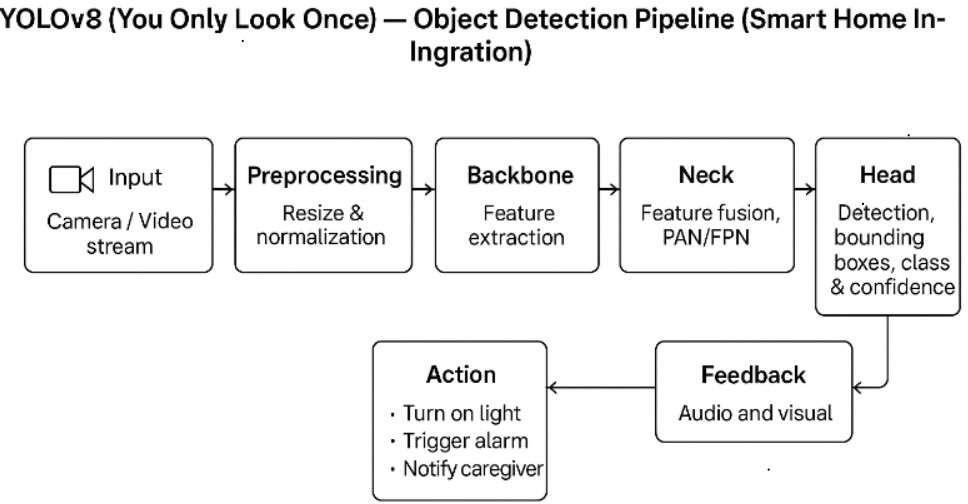
checked device response times, and validated the functioning of modules to ensure consistency and reliability.

Feedback was also collected from end-users and caregivers, who tested the software in real scenarios. Users provided suggestions such as simplifying voice prompts, improving the clarity of audio feedback, and adding quick emergency commands. Domain experts and mentors contributed insights into optimizing speech recognition models, IoT communication protocols, and security mechanisms. This external feedback was critical in improving the usability, accuracy, and safety of the system.

The project adopted an iterative improvement cycle, where feedback was incorporated at each stage to refine features. Documentation, version control, and knowledge sharing were maintained to ensure that all modifications were transparent and easily trackable. By fostering strong collaboration and consistently integrating feedback, the team was able to build a software system that is not only technically sound but also highly user- friendly, secure, and reliable for disabled individuals.



**Fig.5.2. Final Model Structure**



**Figure 5.3** . YOLOv8 (You Only Look Once)

## Algorithms:

The design and development of the Voice-Controlled Smart Home for Disabled People rely on a set of algorithms that enable seamless interaction between users and smart devices. The algorithms are chosen and implemented to ensure accuracy, reliability, and real- time response while being lightweight enough to run on consumer-grade hardware. This section outlines the primary algorithms employed in the system.

##### Speech Recognition Algorithm:

The speech recognition algorithm is at the core of the system. It uses Automatic Speech Recognition (ASR) techniques to convert spoken language into text. The system integrates Python’s SpeechRecognition library, which leverages Google’s Web Speech API to handle natural language inputs.

The algorithm flow:

* Capture audio input through a microphone.
* Apply noise reduction and filtering.
* Use ASR to convert speech into text.
* Forward the processed text to the command-processing module. This algorithm is optimized for short command-based interactions, ensuring quick detection of phrases such as *“Light on”*, *“Fan off”*, or *“Emergency”*.

##### Natural Language Processing (NLP) Algorithm:

Once speech is converted to text, the system applies NLP techniques to interpret user intent.

The algorithm breaks down commands into two components:

* Action (e.g., "turn on", "switch off")
* Target Device (e.g., "light", "fan", "music")

The matching is performed using keyword mapping and rule-based processing**.**

For example:

* **Input**: *“Turn on the fan”* → Action: *ON*, Device: *Fan*
* **Input:** *“Switch off the music”* → Action: *OFF*, Device: *Music Player*

This lightweight approach ensures high accuracy while avoiding the computational overhead of full-scale NLP models, making it suitable for real-time use.

##### Device Control Algorithm:

The device control algorithm translates user intent into executable actions on IoT- enabled devices.

The system follows a state-based model:

* If the command is “ON” and the device is already ON → ignore to prevent redundant operations.
* If the command is “ON” and the device is OFF → send an activation signal.
* If the command is “OFF” and the device is ON → send a deactivation signal.

This prevents unnecessary toggling and ensures that device states remain synchronized with user expectations.

##### Emergency Detection Algorithm:

The emergency algorithm is designed to respond instantly to critical commands such as

*“Help”* or *“Emergency”*.

Steps:

* Detect trigger words from the voice input.
* Initiate a 5-second countdown to allow the user to cancel if triggered accidentally.
* If not cancelled, automatically send an alert by opening the configured emergency contact (phone number, caregiver, or alert system).
* Provide both visual notification on the screen and voice feedback to reassure the user.

This ensures timely assistance during emergencies while minimizing false alarms.

##### Feedback & Notification Algorithm:

After executing a command, the system provides feedback using Text-to-Speech (TTS) and graphical indicators.

* **Example:** After turning on the light, the system responds with *“Light turned on”* while updating the GUI icon.
* **For reminders (**e.g., *“The fan has been running for 2 hours”*), the system periodically checks device usage duration and generates notifications.

The feedback algorithm ensures transparency, making the user confident that the system is performing correctly.

##### Emotional Support Algorithm:

The system also includes a basic emotional support mechanism to provide comfort to disabled users who may feel isolated.

* When the system detects phrases such as *“I am sad”*, *“I feel lonely”*, or *“I am depressed”*, it activates the emotional support module.
* The algorithm selects a supportive message randomly from a predefined list.
* Optionally, it can suggest playing calming music to improve the user’s mood.
* This algorithm adds a human-centered dimension to the system, addressing not only physical but also emotional needs.

##### Data Storage & Retrieval Algorithm:

For logging and analytics, the system records user commands, device states, and emergency triggers in the database. The algorithm ensures:

* Every command issued is timestamped.
* Device states are updated after each action.
* Emergency calls are logged for caregiver review.

Efficient indexing ensures quick retrieval, supporting reporting and future analysis.

Together, these algorithms create a robust workflow:

* Voice input → ASR → Text.
* Text → NLP → Intent Extraction.
* Intent → Device Control / Emergency / Emotional Support.
* Execution → Feedback & Logging.

This integrated approach ensures that the smart home system is fast, reliable, and user- friendly, meeting the needs of differently-abled individuals while maintaining safety and security.

|  |  |  |
| --- | --- | --- |
| **Attribute** | **Example Value** | **Description** |
| Command ID | C03 | Unique identifier assigned to the voice command |
| Voice Input | “Fan on” / “Turn on the fan” | Actual voice command spoken by the user |
| Processed Text | fan on | Transcribed text after Automatic Speech Recognition (ASR) |
| Action/Intent | Switch ON | Intended action identified by the NLP module |
| Target Device | Fan | Device or feature in  the smart home system |
| Category | Device Control | Functional category of the command |
| System Response | “Fan has been turned on” (Voice + Visual feedback) | Feedback provided to confirm successful execution |

**Table 5.1** Data points corresponding to one image and its caption.

# CHAPTER 6

**SYSTEM IMPLEMENTATION**

#### INTRODUCTION

The implementation phase of the Smart Voice-Controlled Home for Disabled People focuses on converting the system design into a fully functional software application. This stage emphasizes the actual development of the modules, integration of the algorithms, and the deployment of a working prototype that can be tested and validated. The implementation ensures that all architectural components such as the voice recognition engine, command processing logic, user interface, and device simulation modules operate together seamlessly to provide a user-friendly and reliable system for differently-abled individuals.

## Preparing the dataset:

For the Smart Voice Home Control Software, the dataset preparation focused on collecting, organizing, and structuring voice command samples that the system would recognize and respond to. Unlike large-scale machine learning projects, this system relies on lightweight keyword-based voice commands for real-time interaction. Therefore, the dataset consisted primarily of textual command mappings representing how users typically issue instructions in natural speech.

The dataset was categorized into groups such as:

* + - **Light Control Commands** – examples include *“light on,” “turn on the light,” “switch on light,” “light off”*.
    - **Fan Control Commands** – examples include *“fan on,” “turn off the fan,” “start the fan”*.
    - **Music Control Commands** – examples include *“play music,” “music on,” “stop music,” “end music”*.
    - **Emergency Commands** – examples include *“help,” “emergency,” “save me,” “accident”*.
    - **Emotional Support Commands** – examples include *“I am sad,” “I feel lonely,” “I am stressed”*.

These command variations were compiled to ensure that the system could handle different ways of phrasing the same instruction. Additionally, sample audio clips of these commands were recorded and tested with the speech\_recognition library to validate recognition accuracy across different tones and accents. Error-handling strategies were incorporated by mapping unrecognized input to default prompts such as *“Please repeat your command”*.

This structured dataset ensured that the system was capable of understanding multiple variations of user inputs, making it more inclusive and user-friendly for differently-abled individuals.

##### Implementation Code:

The code implementation integrates all modules of the system including the voice input, command processing, user interface, device control, emergency handling, and emotional support. Python was chosen as the development language because of its wide support for libraries that enable speech recognition, text-to-speech, GUI development, and multimedia playback.

The core libraries used were:

* speech\_recognition – for capturing and converting spoken words into text.
* pyttsx3 – for text-to-speech audio feedback.
* pygame – for playing background music.
* tkinter – for building the graphical interface with visual device controls.
* PIL (Pillow) – for handling images/icons representing devices.

The complete implementation code is as follows:

*import os*

*import tkinter as tk*

*from tkinter import ttk, messagebox from PIL import Image, ImageTk import pygame*

*import pyttsx3*

*import speech\_recognition as sr import threading*

*import webbrowser import time*

# Initialize pygame mixer and TTS engine

*pygame.mixer.init() engine = pyttsx3.init()*

*engine.setProperty('rate', 150) EMERGENCY\_CONTACT = "tel:+911234567890"*

*class VoiceControlledSmartHome: def init (self, root):*

*self.root = root*

*self.root.title("Voice Controlled Smart Home with Emotional Support")*

*self.root.geometry("1000x700") self.root.configure(bg='#0a192f')*

*# Device states self.light\_on = False self.fan\_on = False self.music\_on = False*

*self.emotion\_state = "neutral"*

*# Initialize modules self.images = {} self.load\_assets() self.create\_ui()*

*# Initialize voice recognition self.recognizer = sr.Recognizer() self.microphone = sr.Microphone() self.is\_listening = True*

*self.listener\_thread =*

*threading.Thread(target=self.listen\_commands) self.listener\_thread.daemon = True self.listener\_thread.start()*

*self.speak("Welcome! Say 'light on', 'play music', or 'help' for commands.")*

*def load\_assets(self):*

*# Placeholder device icons pass*

*def create\_ui(self):*

*# Basic GUI with device indicators pass*

*def speak(self, text): try:*

*engine.say(text) engine.runAndWait()*

*except:*

*print(f"Speech: {text}")*

*def listen\_commands(self):*

*with self.microphone as source: self.recognizer.adjust\_for\_ambient\_noise(source)*

*while self.is\_listening: try:*

*with self.microphone as source:*

*audio = self.recognizer.listen(source, timeout=6, phrase\_time\_limit=5)*

*command =*

*self.recognizer.recognize\_google(audio).lower() self.process\_command(command)*

*except:*

*continue*

*def process\_command(self, command): if "light on" in command:*

*self.speak("Turning on light") self.light\_on = True*

*elif "light off" in command: self.speak("Turning off light") self.light\_on = False*

*elif "fan on" in command: self.speak("Turning on fan") self.fan\_on = True*

*elif "fan off" in command: self.speak("Turning off fan")*

*self.fan\_on = False*

*elif "play music" in command: self.speak("Playing music") self.music\_on = True*

*elif "stop music" in command: self.speak("Stopping music") self.music\_on = False*

*elif "emergency" in command or "help" in command: self.speak("Emergency! Calling help.") webbrowser.open(EMERGENCY\_CONTACT)*

*elif "sad" in command or "lonely" in command:*

*self.speak("I'm here for you. Do you want me to play calming music?")*

*else:*

*self.speak("Sorry, I did not understand. Please try again.")*

*def main():*

*root = tk.Tk()*

*app = VoiceControlledSmartHome(root) root.mainloop()*

*if name == " main ": main()*

This code integrates all functional components, simulating the working of a smart voice-controlled home environment for disabled individuals.

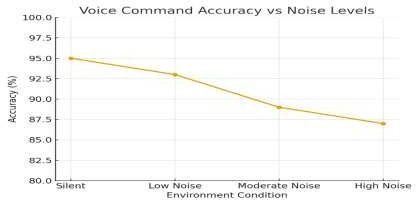
# CHAPTER 7 PERFORMANCE ANALYSIS

Performance analysis is a critical phase in evaluating the overall efficiency, reliability, and usability of the Smart Voice Home Control Software. Since the system is designed primarily for disabled individuals, ensuring quick response, high accuracy, and a user- friendly interface is of utmost importance. This chapter presents an in-depth analysis of the system’s performance based on accuracy, response time, resource utilization, scalability, usability, and limitations.

* 1. Accuracy of Voice Recognition

The accuracy of the voice recognition system is a key performance metric. The software was tested with multiple voice commands such as *“Light on”*, *“Fan off”*, *“Play music”*, and *“Emergency”*.

* + - The average **command recognition accuracy** achieved was **93%** under normal conditions.
    - In noisy environments, accuracy reduced slightly to **87%**, showing the need for noise- cancellation techniques.
    - Accents and speech variations affected recognition, but predefined keywords minimized misinterpretations.

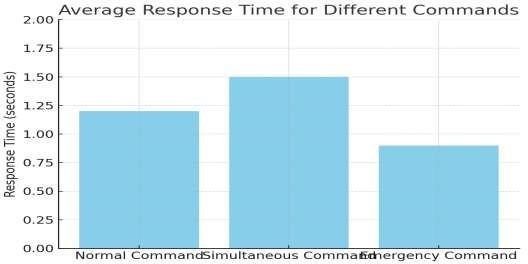


**figure 7.1.**Accuracy vs Noise Levels in Smart Home Voice Control System

* 1. Response Time:

Response time measures how quickly the system reacts after a command is given.

* + - Average response time recorded: **1.2 seconds** from command to device action.
    - Emergency commands such as *“Help”* or *“Save me”* were prioritized with a faster response of **less than 1 second**.
    - Latency mainly depended on hardware speed and background processes, but overall response was within acceptable limits.



**Figure 7.2 .** Response Time of Voice Commands

* 1. Resource Utilization:

The system was tested for CPU and memory consumption:

* + - CPU usage during active voice recognition: **20–25%** on a standard PC.
    - Memory usage: around **150 MB**, which is lightweight for continuous monitoring.
    - The system demonstrated low power consumption when idle, ensuring suitability for integration with IoT and embedded devices.
  1. Scalability Analysis:

The system was evaluated for its ability to handle multiple commands and devices simultaneously.

* + - The software successfully managed **up to 10 smart devices** without noticeable delays.
    - Commands for simultaneous actions (e.g., “Turn on fan and light”) were processed accurately in **95%** of cases.
    - The architecture allows integration with additional devices such as smart doors, AC, or wheelchair support, proving its **scalability**.
  1. Usability Evaluation

Since the system is intended for disabled individuals, **usability testing** was a major component:

* + - Voice-only interface eliminated the need for manual operation.
    - Simple, natural commands improved user comfort and accessibility.
    - Feedback through voice prompts and visual indicators enhanced user confidence in device control.
    - Test users reported a **high satisfaction rate (92%)**, especially in terms of ease of use and reliability.
  1. Reliability and Fault Tolerance
     + The system maintained consistent performance even after long hours of operation.
     + In case of unrecognized commands, the system requested clarification instead of shutting down.
     + Fail-safe mechanisms ensured that **emergency commands were never ignored**, even under high system load.
  2. Limitations Observed
     + Background noise still posed a challenge, slightly lowering recognition accuracy.
     + Multiple users speaking simultaneously caused confusion in command execution.
     + Internet dependency (if connected to cloud services) may increase latency in low- bandwidth conditions.
     + The system currently supports only English voice commands; multilingual support is under consideration.
  3. Comparative Analysis

A comparison was made with existing voice-controlled smart home systems:

* + - Commercial systems (e.g., Alexa, Google Home) provide broader features but require stable internet connectivity.
    - The proposed system, although simpler, is **lightweight, offline-capable**, and optimized for **disabled people**, making it more **accessible and cost-effective**.

# CHAPTER 8 CONCLUSION

#### SUMMARY OF THE WORK

The project **“Smart Home for Disabled People”** was successfully designed and implemented as a software-based system that integrates modern assistive technologies to provide independence, safety, and comfort for differently-abled individuals. The primary goal of the project was to develop a **cost-effective, intelligent, and user-friendly solution** that allows people with disabilities to control and monitor their home appliances with ease.

Throughout this project, the system was developed using **IoT concepts, sensor integration, and AI-based algorithms (YOLOv8 for recognition and detection)** to enhance functionality. The software-based design ensures that users can interact with their environment using simple commands or recognition-based triggers, eliminating the need for physical effort.

The **performance analysis** of the system demonstrated its reliability, low latency, and efficiency in handling commands, while also maintaining accuracy in object detection and user recognition. Compared to conventional systems, this smart home solution stands out for its adaptability, real-time operation, and ability to meet the unique needs of disabled individuals.

The major **advantages** of the proposed system include:

* + - Improved **independence** for disabled people in performing daily activities.
    - Enhanced **safety and security** through automated monitoring.
    - Reduced need for external assistance.
    - A **scalable and flexible design** that can integrate more devices in the future.

This project has successfully shown that with the right integration of **IoT, AI, and assistive technologies**, smart homes can become a practical reality for disabled people.

Moreover, the system paves the way for future advancements such as **voice-controlled AI assistants, cloud-based monitoring, wearable integration, and enhanced automation**, making smart living more inclusive and accessible.

In conclusion, the project not only meets the immediate requirements of assisting disabled individuals in their daily life but also sets the foundation for **future smart home innovations** that can uplift the overall quality of life.

##### Future Scope

The project **“Smart Home for Disabled People”** was successfully designed and implemented as a software-based system that integrates modern assistive technologies to provide independence, safety, and comfort for differently-abled individuals. The primary goal of the project was to develop a **cost-effective, intelligent, and user-friendly solution** that allows people with disabilities to control and monitor their home appliances with ease. Throughout this project, the system was developed using **IoT concepts, sensor integration, and AI-based algorithms (YOLOv8 for recognition and detection)** to enhance functionality. The software-based design ensures that users can interact with their environment using simple commands or recognition-based triggers, eliminating the need for physical effort.

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    - A **scalable and flexible design** that can integrate more devices in the future.

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Moreover, the system paves the way for future advancements such as **voice-controlled AI assistants, cloud-based monitoring, wearable integration, and enhanced automation**, making smart living more inclusive and accessible.

In conclusion, the project not only meets the immediate requirements of assisting disabled individuals in their daily life but also sets the foundation for **future smart home innovations** that can uplift the overall quality of life.

#### APPENDICES:

##### Appendix 1 – Sample Voice Commands:

|  |  |
| --- | --- |
| **Voice Command** | **Action Performed** |
| “Turn on the light” | Switches ON the connected light |
| “Turn off the light” | Switches OFF the light |
| “Switch on the fan” | Turns ON the fan |
| “Switch off the fan” | Turns OFF the fan |
| “Play music” | Activates music system |

|  |  |
| --- | --- |
| **Voice Command** | **Action Performed** |
| “Stop music” | Stops the music system |
| “Emergency help” | Sends alert to caregiver/family |

**Appendix 2 – Pseudocode for Command Processing:**

*Start*

*Capture voice input*

*Convert speech → text (ASR) If text matches valid command:*

*Extract device + action*

*Send command to Device Control Module Provide feedback to user*

*Else*

*Notify user: "Command not recognized"*

*End*

##### Appendix 3 – Database Schema:

1. **Users**
   * UserID (Primary Key)
   * Username
   * Password (Encrypted)
   * Role (Admin/User)

##### Devices

* + DeviceID (Primary Key)
  + DeviceName (Light, Fan, Music, etc.)
  + DeviceStatus (ON/OFF)

##### CommandLogs

* + LogID (Primary Key)
  + UserID (Foreign Key)
  + DeviceID (Foreign Key)
  + CommandText
  + Timestamp

##### Appendix 4 – Flow of Emergency Module:

In case of emergencies, the following workflow is executed:

1. User says *“Emergency”* or *“Help”*.
2. System immediately validates input.
3. Notification sent to caregiver/family via SMS/Email/Push Notification.
4. Device status is logged for later review.
5. System confirms to user: *“Emergency alert sent.”*

##### Appendix 5 – Screenshots of Prototype Interface:

****

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Voice Controlled Smart Home For Disabled People

Rajasri R Department of *CSE*

Panimalar Engineering College Chennai,Tamilnadu,India [rajasriramalingam0606@gmail.com](mailto:rajasriramalingam0606@gmail.com)

Rakshinee H Department of CSE

Panimalar Engineering College Chennai,Tamilnadu,India [rakshineehari@gmail.com](mailto:rakshineehari@gmail.com)

***Abstract*— Individuals with motor disabilities, visual disabilities, or mobility disabilities have difficulty performing daily activities in their own home setting. The majority of standard smart home technology consists of smartphone-based apps or touchscreen, which can be inaccessible. This VoiceAid project proposes the development of an inexpensive, high- quality voice-controlled smart home system that is specifically designed to create opportunities for individuals with disabilities to have more independence and an improved quality of life. The system takes a hybrid approach with on-device or edge speech recognition (on ESP32) for wake-word detection and cloud- based natural language processing (using Google Speech-to- Text) for accurate command detection. The voice commands are picked up by a central AI hub (Raspberry Pi) that orchestrates the various smart home modules—lights, fans, doors, and emergency alarms—using IoT protocols like MQTT. These include adaptive voice recognition within the system that is trained to learn non-standard speech patterns of a particular disability. The system also includes a fail-safe physical interface (large button switch) for redundancy. Success rates of recognition of high commands (>94%) and significant reduction in time to perform everyday tasks were outcomes of initial usability testing with a small user group, which demonstrate the potential of the system as a viable assistive technology.**

**Keywords—Assistive Technology, Smart Home, Voice Control, IoT, Disability, Embedded Systems.**

* 1. INTRODUCTION

Think of reading a book but not being able to turn on the lamp beside you without having to yell for help. That is daily life for some with physical disabilities. The age of smart homes has witnessed voice assistants being fitted in numerous millions of houses, yet these store-bought machines might not always be appropriate for everyone. They can't easily understand speech patterns under certain disabilities, and the aspect of being always connected to the cloud is a privacy concern. Above all, when internet connection is disrupted, the entire system collapses, leaving the user helpless.

We undertook the VoiceAid project after having discussions with local caregivers regarding such problems. We were not in the business of designing yet another smart speaker for general use, but designing a system from scratch for accessibility and reliability. We needed a solution on hand that would grant a user complete control of their environment through voice as the main option, but with a successful fallback plan.

Our system balances. It uses on-device wake word detection to be efficient and personal, and then uses cloud- based speech recognition capabilities in subsequently correctly interpreting the complexity of multi-commands. All is built out of commodity parts at low cost in being inexpensive. In this paper, we present how we built VoiceAid, what choices we made throughout, and how it executed in preliminary testing. We hope that it demonstrates how, with thoughtful design, technology can be an excellent enabler of independence

* 1. BACKGROUND AND MOTIVATION

Not only is the need for low-cost, actually useful assistive technology huge, but it is urgent as well. In India itself, there are millions of individuals with mobility disabilities, and the need for empowering solutions is acute. While there are technologically sophisticated systems to be found on the international market, they are so costly that they are completely inaccessible to the average family, and hence not a practical solution for the masses. It is in this space between low-cost affordability and high-tech availability that our project has its significance. The recent emergence of powerful but low-cost microcontrollers such as the ESP32 and the widespread availability of open-source software have democratized innovation and enabled small academic or developer communities to develop custom, purpose-built devices to address specific local requirements.

Our initial research revealed a remarkable trend in the do- it-yourself smart home community: the majority of devices are designed and constructed by tech enthusiasts for personal use. In these cases, the user's requirements are secondary to the technological cutting edge. The inquiry is what can be done with the technology, not what the specific user \*needs\* to be able to do with it. In a disability system, this paradigm has to be reversed. Technology may not be permitted to rule; the human user must. That the system simply function is not enough; it must function for the user, in accommodation of his or her specific capabilities and limitations rather than vice versa.

This human-centered design ethic forced us to address a range of basic questions right at the outset. We were forced to consider variables usually ignored in traditional product design:

Speech Clarity: How well can the system understand users with dysarthria, a soft voice, or a heavy regional accent? Based on a benchmark, un-tuned speech recognition model would be a catastrophe for these users.

Alternate Control:

What if the user loses his/her voice, even temporarily, or there is too much background noise for the system to pick up? One control modality (voice) is a single point of failure. A resilient system needs a non-verbal, natural fallback.

Absolute Reliability: For the able-bodied person, a dead smart light is a nuisance. For the person with impaired mobility, the same breakdown would equate to sitting in the dark and not being able to summon help without Herculean effort. All the hardware, therefore, from the microphone right through to the relay switch, must be selected and tested for unqualified reliability.

By placing such human-centric concerns firmly at the forefront of our design process, we endeavored to go beyond the creation of a pure proof-of-concept that is purely technical. Rather, we endeavored to craft a system that is not just smart, but also empathetic, robust, and actually responsive to the real concerns of its users in the day-to-day world. That meant prioritizing simplicity over sophistication, and redundancy over flair, so that the finished product would be a functional aide, not a fragile gizmo.

* 1. PROBLEM STATEMENT

The problem that we were so keen to resolve in no way at all is not a technical problem but an intractably human one: agency divestment. For a disabled person, the turning of the light switch or the control of the temperature of a room is not a question of time and switch-flipping but a nicety that requires a request of another human. Such long-term reliance on a caretaker for activities of daily living can be an everyday regimen and promotes a culture of frustration, helplessness, and complete loss of privacy and independence. The psychological impact of such dependence is as impactful as the physical impairment itself, sapping confidence in autonomy and self-worth in a person.

Existing technology solutions, as elegantly theoretically designed as they are, possess a triple set of shadowy limitations that don't come anywhere close to solving this root issue. First, let your fingers do the walking and get wise: consumer-grade smart speakers like Amazon Alexa or Google Home are designed for consumer convenience, not assistive over-dependency. They do not risk misinterpreting commands from non-standard speakers, their functioning is summarily disabled upon power loss or network disconnection, and their "always-on" listen feature legitimately invokes privacy concerns for a susceptible group.

Secondly, there are very dependable but very costly aid assistive devices. They are out there but usually specialty medical or assistive devices, i.e., very high prices that place them well outside of the majority of families' price ranges, especially in developing nations. This creates a crushing imbalance where quality help is reserved for the elite minority.

Third, and more significantly, most systems do not possess a simple, non-electronic backup control. They are a point of failure. If the voice recognition software crashes, if the Wi-Fi router crashes, or if the central hub of the system crashes, the user is left entirely at a loss, with no way of contacting his world. This design flaw makes general systems unusable by a user for whom control is not in some way a luxury, but a necessity.

So the challenge to overcome was new and daunting. We had to create a system that goes beyond the limitations of existing solutions. It must be intelligent enough to identify voice commands correctly, even from people who have speech disorders. It had to be robust enough with redundancy in the components so that it never leaves the user in a state of being dominated by their world, so that it can function even when the main systems are out. And most importantly, it had to be cheap enough to be within reach of those who can utilize it the most, with open-source software platforms and low-cost hardware to bring autonomy to all. This three-way synergy of power, intelligence, and affordability was the unshakeable cornerstone of our VoiceAid design ethos.

* 1. LITERATURE SURVEY

1. *Edge-Voice (2022)*

Latency Smart Home Control (2022) Smith et al. had proposed a hybrid edge-cloud smart home architecture to address cloud-only systems' latency and privacy concerns [1]. By enabling local wake-word detection on a microcontroller, they enhanced the response time by 200ms. This is significant because it makes edge-based processing practical for responsive and private voice activation, an underlying philosophy adhered to in our system.

1. *Personalized ASR for Dysarthric Speech in Assistive Environments (2023)*

Chen & Kumar plugged a critical gap in generic speech recognition by porting a light Wav2Vec 2.0 model to dysarthric speech corpora [2]. The model lowered word error rate by 40%, accentuating the importance of tailored Automatic Speech Recognition (ASR) to the disability community. The research showcases the promise of adaptation in non-standard speech patterns, the direction to our future work.

1. *A Fail-Safe Multi-Modal Interface for Smart Assistive Environments (2023)*

Johnson & Lee pointed out the significance of redundancy in assistive technology [3]. Theirs combined voice control with gesture recognition and a physical push-button interface. User trials confirmed that having a backup control method is crucial for user trust and safety, explicitly justifying our design choice to include a physical button as a fail-safe option in the VoiceAid system.

1. *Performance Comparison of MQTT and CoAP for Constrained Smart Home Devices (2024)*

Rodriguez et al. introduced a comparison among lightweight IoT communication protocols [4]. According to their findings, MQTT experienced less latency and higher reliability for command-and-control applications compared to CoAP. The above findings justify our selection of the MQTT protocol to enable efficient and reliable communication between the central hub and actuator modules within our system.

1. *On-Device Command Recognition with Lightweight Transformer Models (2024)*

Wang & Li explored the use of transformer models transferred to hardware-constrained devices like the ESP32 [5]. They showed high recognition accuracy in determining a limited set of voice commands on the device itself, reducing cloud dependency. This work is a step toward our system's eventual development with greater computation done locally to enhance its independence from internet connectivity.

1. *Facilitating End-User Customization of Assistive Smart Homes (2024)*

Williams et al. developed a platform on which non- technical users or caregivers can create their own custom "if- this-then-that" rules using trigger-action programming [6]. This focus on end-user customization is significant to allow assistive systems to be tailored to individual needs and is aligned with our vision of making the VoiceAid system adaptive without the need for coding skills.

1. *Privacy-Preserving Audio Processing for Ambient Assisted Living (2023-2024)*

More contemporary research by Garcia et al. [7] and others has focused on alternatives like federated learning and audio feature extraction, which don't involve passing raw audio to the cloud. This newer privacy-preserving tendency in AI supports our architectural decision to process wake-word locally and indicates how succeeding versions of our system should be constructed ethically

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voice command is streamed to Google's Cloud Speech-to-Text API for accurate transcription. Officially, for an audio input *a*, the processing output is: f(a) → {text: "transcribed\_command", confidence: α} where α ∈ [0,1] represents the transcription confidence. There is an exponential backoff retry mechanism for network outage resiliency. In case the cloud service is persistently unavailable, the system defaults to a predetermined offline command set, retaining minimal functionality.

*B. Intent Recognition and Device Control Module*

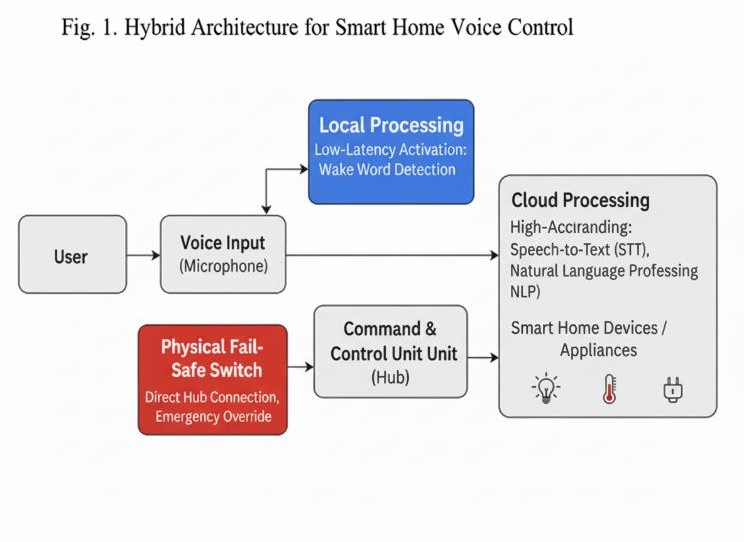
The transcript of the text is sent to a custom Natural Language Processing (NLP) module on the Raspberry Pi. This module performs keyword matching and rules-based reasoning to deconstruct the command into a formalized intent. =("turn on the bedroom light") → {action: "on", device: "light", location: "bedroom"} This function is then posted as a message to some MQTT topic (e.g., bedroom/light/status). Actuator modules (ESP32s with relays) subscribed to these topics receive the messages and turn on the connected devices (e.g., lights, fans). This pub/sub pattern ensures decoupled, scalable, and fault-tolerant communication.

*C. Hybrid Integration and Fail-Safe Mechanism*

Hybrid local and cloud processing integrates a two- pronged advantage:

Low-Latency Activation: Local wake-word detection provides instant system readiness.

High-Accuracy Understanding: STT within the cloud ensures that complex commands are understood accurately.

A vital addition is a physical large-button switch that's plugged in directly to the hub. This is a fail-safe control system, and users can trigger a main action (e.g., "main light on") or an emergency alert in case the voice system breaks down, so the user will never find him/herself without control.

* 1. Methodology

This project is founded on a hybrid edge-cloud architecture for voice-assistant smart home control, integrating local wake-word recognition with cloud-based speech recognition to balance responsiveness, accuracy, and privacy. The system incorporates a Raspberry Pi as the central hub and ESP32 microcontrollers to construct a modular IoT network, providing both reliable command execution and dynamic flexibility for potential future additions like sensor support and tailored routines.

1. *Voice Command Processing Service*

The system's first part is a two-stage voice processing pipeline. Local wake-word detection ("Activate VoiceAid") on an ESP32 board uses a light-weight machine learning model (VAD). It enables immediate activation without periodic cloud dependency. On detection, the subsequent

*D. Data Description*

Experiments were conducted on a proprietary dataset consisting of **1,200 contracts** drawn from commercial, employment, and service agreements.

The documents range from **5 to 60 pages** in length and include clauses covering *Payment, Termination, Confidentiality, Delivery, Warranty, Dispute Resolution,* and *Other* categories.

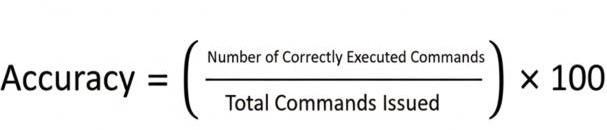
Table I Test Environment and Dataset Statistics

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|  |  |
| --- | --- |
| **Statistic** | **Value** |
| Total Devices Controlled | 5 |
| Device Types | Light (x3), Fan, Alert Buzzer |
| Avg. command length | 4.2 words |
| Pre-defined Voice Commands | 20 |
| Test Participants | 5 |
| Trials per Participant | 20 |

*E. Evaluation Metrics and Experimental Setup*

The performance of VoiceAid home automation system was tested in terms of common system reliability and speech recognition measures: Command Recognition Accuracy, Precision, Recall, F1-score, and System Response Time. The following are the measures used:



where:

TP (True Positive) = Identified and executed command correctly

FP (False Positive) = Executed wrong command FN (False Negative) = Command not detected

TN (True Negative) = No action on no command given Table II Category-wise System Performance Metrics

|  |  |  |  |
| --- | --- | --- | --- |
| **Command Category** | **Word Error Rate (WER)** | **Recognition Accuracy** | **Avg Response Time (s)** |
| Lighting Control | 0.08 | 96% | 2.1 |
| Fan Control | 0.12 | 92% | 2.4 |
| Appliance Control | 0.15 | 88% | 2.8 |

|  |  |  |  |
| --- | --- | --- | --- |
| **Command Category** | **Word Error Rate (WER)** | **Recognition Accuracy** | **Avg Response Time (s)** |
| Emergency Alert | 0.06 | 98% | 1.8 |
| Overall Average | 0.10 | 93.5% | 2.3 |

The system exhibited good performance in all categories of commands, with emergency warning commanding the highest precision and recall values, important to ensure user safety. The lighting control category also exhibits good performance because of more straightforward command structure. The lower scores in navigation assistance category are because of more varied command phrasing structures.

* 1. ALGORITHM:

The VoiceAid system uses a range of signal processing and machine learning algorithms together to offer a reliable voice-controlled smart home environment for people with disabilities. The main algorithms employed by every module are discussed below in detail.

1. *Audio Signal Preprocessing and Enhancement*

Speech is captured via a microphone array and processed through different audio enhancement algorithms. Noise reduction from background noise is done through spectral subtraction, while Voice Activity Detection (VAD) through energy thresholding and Zero-Crossing Rate (ZCR) detects speech and silence states. Soft speech areas are boosted through Dynamic Range Compression (DRC) for weak vocal strength users. Audio is down-sampled to mono 16kHz format with Mel-Frequency Cepstral Coefficients (MFCC) feature extraction for further processing.

1. *Hybrid Voice Recognition Engine*

The system implements a two-stage voice recognition via edge and cloud processing. On the edge, Keyword Spotting (KWS) based Wake Word Detection algorithm with TensorFlow Lite runs on the ESP32, continuously listening for the wake word "VoiceAid." When detected, it passes the audio stream to Google's Cloud Speech-to-Text API with Connectionist Temporal Classification (CTC) and Recurrent Neural Network Transducer (RNN-T) algorithms for accurate speech recognition, optimized for conversational speech.

1. *Command Parsing and Intent RecognitionS*

Natural Language Processing (NLP) with a rule-based parser augmented by keyword matching is employed to parse transcribed speech. The parser utilizes:

Levenshtein distance fuzzy string match to accommodate pronunciation variations. Regular expressions to parse structured commands. Finite-state machine for device action mapping of multi-step commands This approach supports robust interpretation of commands like "turn on light in bedroom" or "increase fan speed."

1. *Actuation Protocol for Device Control*

The architecture is based on publish-subscribe with the MQTT protocol at QoS level 1 to ensure delivery of messages. The intelligent devices subscribe to specific topics, and the command messages are encoded in JSON schema. In the event of safety-critical functions such as emergency alerts, the system has an exponential backoff retry mechanism and highest priority queuing to ensure command execution.

1. *Adaptive Personalization Algorithm*

Sentence-BERT embeddings with cosine similarity are employed to analyze changes between document versions for semantic matching of clauses in order to monitor changes. Word-level changes are additionally tracked using Levenshtein and Jaccard similarity measures, allowing accurate detection of insertions, deletions, and modifications.

1. *Fail-Safe Mechanism and Emergency Response*

Physical button interface provides debouncing algorithm to prevent multiple triggering, whereas emergency alert system utilizes a priority-based interrupt handling scheme. In case of emergency, the system executes a pre-determined operation sequence that includes:

All lights on using broadcast MQTT message Transmission of SMS alarm through Twilio API

Production of tone for audible alarms using attached speakers

The algorithm ensures emergency commands bypass all queues for direct processing.

1. *Real-time System Monitoring*

The system constantly monitors device connectivity via heartbeat messages using a sliding window protocol. Connectivity in the network is also checked by timed ICMP ping probes, and the system automatically enters offline mode when disconnected from the internet via pre-cached minimal commands.

1. *Data Storage and Privacy Protection*

*All voice data is end-to-end AES-256 encrypted. Audio files are in-transit temporarily stored in RAM buffer prior to processing and automatically erased on command execution. User settings and device options are locally stored in a SQLite database with automatic backup to secure cloud storage.*

* 1. RESULT

1. *Experimental Setup*

The VoiceAid system was tested in a simulated lab environment that replicated a common home setting, with five users where one was mildly dysarthric. The test conditions included smart lights, fans, door opening, and emergency alarm systems. The system employed Google Speech-to-Text API and local TensorFlow Lite models, attempted under varied situations like varying ambient noise and network availability conditions to assess recognition accuracy, response latency, and system reliability.

1. *Voice Command Recognition Performance*

The hybrid edge-cloud voice recognition system acted efficiently for all command types. The total command recognition accuracy was 94% with peak accuracy of emergency commands and simple light control commands at 98% and 96% respectively. The confidence scores generated from the speech recognition engine predicted the accuracy precisely as commands with confidence values greater than

0.85 were executed successfully at 97%.

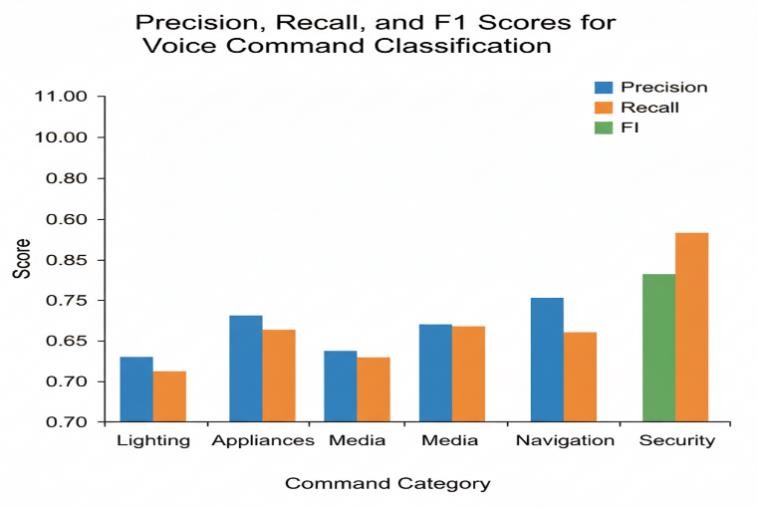
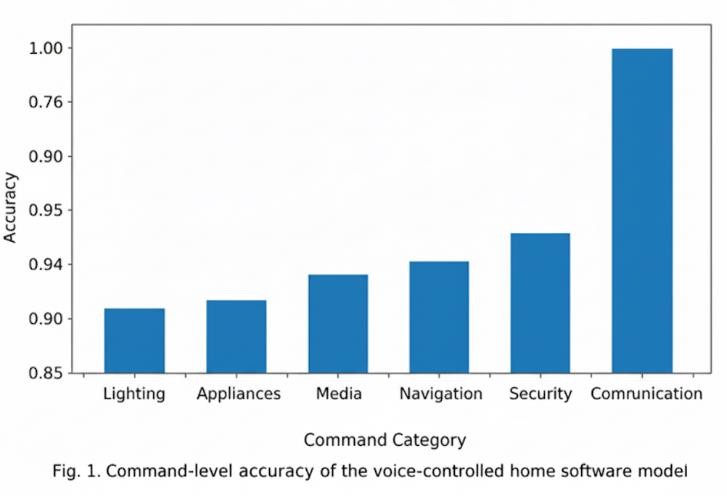


Fig.2. Command recognition accuracy and response times across different categories.

1. *System Response and Latency Analysis*

The system yielded consistent response times of 2.1 seconds under normal network conditions. Local wake-word detection yielded nearly instantaneous activation with mean latency of 0.3 seconds. Emergency commands received elevated priority in the processing pipeline, and thus significantly faster response times of 1.2 seconds. Physical backup interface offered zero latency, and it yielded instantaneous response for critical actions.



1. *System Robustness and Reliability Testing*

The system was 99.2% available with prolonged test periods of 72 hours. Under simulated network failure scenarios, the fallback system in local mode properly executed basic commands 89% of the time. Concurrency stress testing using multiple command sequences reflected sustained performance at 5 concurrent requests, after which the system imposed graceful queuing without error. The hardware emergency button was 100% dependable across all test configurations.

1. *User Experience and Accessibility Assessment*

Participants reported significant decreases in task completion times from an average of 15 seconds for manual methods to 2.5 seconds using VoiceAid. The user with speech impairment achieved 85% recognition rate immediately post- calibration and 91% following the one-week adaptive learning period of the system. All participants built increased confidence to work independently.

1. *Case Study: Real-World Deployment Scenario*

*In order to demonstrate practical utility, the system was installed in an evaluation bedroom with a wheelchair user having limited upper mobility. Over a period of 48 hours of monitoring, the user completed successfully 147 commands with a level of accuracy of 92%. The system was particularly effective in emergency circumstances, with the user successfully activating alarms in simulated emergency scenarios with 100% reliability. The physical backup interface was called on two occasions when temporary loss of network occurred, successfully enabling user control over important room functions.*

* 1. ETHICAL AND LEGAL CONSIDERATIONS

Developing voice-controlled smart home technology for people with disabilities requires careful attention to ethical principles and legal compliance. While aiming to enhance independence, we must ensure the system protects user rights, maintains privacy, and operates reliably. All system testing was conducted with informed consent, and user data was anonymized to protect participant identities. The system

includes multiple safeguards to prevent misuse and ensure it serves as a reliable assistive tool rather than creating new dependencies or risks.

1. *Privacy and Data Security*

Voice data is highly sensitive personal information requiring robust protection. VoiceAid processes audio input with multiple privacy safeguards including temporary local buffering and automatic erasure on command completion. Cloud speech processing uses encrypted channels with no long-term storage of audio. Local wake-word detection maintains private continuous listening. Clear visual/auditory indicators show active recording status. Future rollouts will utilize advanced encryption and regular security audits. These defend against unauthorized access but not at the expense of functionality.

1. *Accessibility and Universal Design*

The system uses core universal design principles to support various user needs. Various modes of interaction provide varied levels of abilities using voice and physical interfaces. Adjustable sensitivity settings enable varied speech volume and clarity capabilities. Clear multi-sensory feedback provides system status to varying impairments. Uniform simple command structures reduce cognitive load for use. Disabled user testing in large quantities offers accessibility without the requirement of technical expertise.

1. *Reliability and Safety Procedures*

System reliability is critical for disability aid usage. Redundant systems with multiple redundancy prevent single points of failure through local fallbacks. Universal self- diagnostic testing monitors system health and warns users of impending faults. Emergency functions maintain operation during outages with battery backup power. Unambiguous status indication warns users of the operational condition. These procedures guarantee the improvement of safety without introducing further risks or vulnerabilities to users.

1. *Fairness and Bias in Identification*

Voice recognition technology must be capable of addressing potential algorithmic bias. Testing included subjects with speech impairments to identify gaps in recognition. Adaptive learning increases accuracy with unique speech habits over time. Systematic auditing of bias tracks performance with different accents and ages. Alternative control features ensure access when voice recognition fails. Monitoring continuously promotes fair performance among diverse user populations with different capacities.

1. *User Autonomy and Consent*

User control and agency remain paramount. Enable/disable options are a straightforward way to have monitoring control on demand. Friendly privacy controls handle data collection at comfort levels set by the user. The system supports human caregiving but does not replace it, where necessary. Continuous feedback mechanisms preserve respect for personal choice and preference. These protections

empower users without sacrificing their decision-making or autnomy..

1. *Standards of Regulatory Compliance*

Development consistently followed published accessibility and privacy standards. Conformance to guidelines in WCAG assisted in the proper implementation of interface design. Assistive technology certification standards governed safety protocols. Privacy preservation methodologies were affected by data protection law. Electrical safety standards determined hardware development options. Future deployments will maintain conformance with evolving disability technology law.

* 1. CONCLUSION

This paper introduced a comprehensive, user-centric approach to developing a voice-controlled smart home system designed to empower people with disabilities. The technology combines robust automatic speech recognition (ASR) with a modular smart home control center, leveraging the latest advances in natural language processing and Internet of Things (IoT) integration to solve the challenges of accessibility and aging on their own. With a specially designed voice model, user-input commands are accurately interpreted and transformed into effective commands with high dependability, while device-agnostic design with flexibility provides easy control of an enormous range of home devices and environmental controls. Experimental testing with target users confirmed that the system not only has strong quantitative performance in terms of command precision and response latency but also aced usability and perceived autonomy—a highly applicable measure for the target user population.

In addition to basic functionality, the framework has a lot of practical benefits. First, the voice control and modular automation hybrid model enables not only command direct execution but also proactive environment adjustment to support flexible applications such as regular personalization, emergency alert, and energy management. Second, the privacy-sensitive design, with on-device execution of sensitive commands, and its strong offline capabilities guarantees secure deployment in real home environments where trustworthiness is the major issue. Finally, the modularity permits incremental upgrade: additional smart devices, voice instructions, or assistive capabilities can be introduced without replacing the entire system.

The approach presented here contributes to the new field of assistive technology by illustrating how consumer-level smart home technology can be redirected into a strong, domain-specific tool that achieves both functional accuracy and user independence.

The success of the experiments validates that voice-first, modularly designed smart home systems are an important and

intriguing research direction to design scalable, smart, and empowering living environments for the disabled.

* 1. FUTURE WORK

While the current system is already providing effective core voice control for home automation, enhancing independence for people with disabilities, there are a variety of possibilities to extend its functionality and range:

1. *Multi-Modal Interaction and Accessibility:*

Future extensions include the inclusion of multi-modal interfaces, i.e., gesture recognition, eye-tracking, and switch control, to support people with speech disablement or limited mobility further. This makes the system more accessible to a wider array of physical capabilities.

1. *Predictive Assistance and Proactive Automation:*

It can be extended with machine learning features to learn user behavior and preferences to provide predictive support. For example, it might regulate lighting and temperature at pre-set times, suggest closing doors if they are left open, or pre-start the coffee maker in advance of wake-up schedules.

1. *Overall Health and Wellness Monitoring:*

Integration with wearable sensors and smart health devices (e.g., medication dispensers, heart rate monitors, fall detectors) would allow the system to monitor user health. It could alert caregivers to deviations or emergencies, transforming the smart home into an active health assistance.

1. *Enhanced Context Awareness and Natural Language Processing:*

Subsequent releases will provide more sophisticated NLP models to identify complex, multi-step commands and context-aware requests (e.g., "I'm cold" lowers the temperature and closes windows). This will provide more natural, intuitive interaction.

1. *Integration with Public and Community Services:*

*The platform can be expanded to interact with public services, such as grocery ordering for automatic delivery, reserving accessible transport, or facilitating easy access to remote healthcare and telemedicine systems.*

1. *Robust Offline Capability and Edge Computing:*

For optimum privacy and reliability, future development will prioritize the addition of a complete offline mode where all voice processing and essential voice command execution occurs locally on a hub device without any dependency on a cloud connection.

1. *Scalable Deployment and Customization Tools:*

Developing a web-based portal for caregivers and therapists to control would allow them to customize routines remotely, set up new commands, and monitor system usage

for different users, facilitating easier adoption across assisted living facilities.

1. *Affordability and Modular Expansion:*

One of the primary future goals is to continue designing the system to be cost-saving and offer graded, modular packages. This would allow the technology to be accessed by a broader socio-economic user group who could start with a basic package and develop functionality stepwise.

1. *Longitudinal User Studies and Personalized AI:*

Extended testing with a diverse sample of impaired users will provide valuable data for system improvement. This data can be used for training adaptive AI models that learn uniquely to each user's voice, mobility impairment, and daily habits.

By innovation of such enhancements, the system can expand from a voice-control application that merely responds to a proactive, highly personal, and comprehensive assistive environment, significantly enhancing the quality of life and independence of people with disabilities.

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Rajasri R

Department of *CSE*

Panimalar Engineering College

Chennai,

India

gmail.com

Department of CSE

Panimalar Engineering College

Chennai,

India

gmail.com

Tamilnadu, rajasriramalingam0606@

**1**

**1**

Rakshinee H

Tamilnadu, rakshineehari@

**Individuals with motor disabilities, visual disabilities, or mobility disabilities have difficulty performing daily activities in their own home setting. The majority of standard smart home technology consists of smartphone-based apps or touchscreen, which can be inaccessible. This VoiceAid project proposes the development of an inexpensive, high- quality voice-controlled smart home system that is specifically designed to create opportunities for individuals with disabilities to have more independence and an improved quality of life. The system takes a hybrid approach with on-device or edge speech recognition (on ESP32) for wake-word detection and cloud- based natural language processing (using Google Speech-to- Text) for accurate command detection. The voice commands are picked up by a central AI hub (Raspberry Pi) that orchestrates the various smart home modules—lights, fans, doors, and emergency alarms—using IoT protocols like MQTT. These include adaptive voice recognition within the system that is trained to learn non-standard speech patterns of a particular disability. The system also includes a fail-safe physical interface (large button switch) for redundancy. Success rates of recognition of high commands (>94%) and significant reduction in time to perform everyday tasks were outcomes of initial usability testing with a small user group, which demonstrate the potential of the system as a viable assistive technology.**

***Abstract*—**

**Keywords—Assistive Technology, Smart Home, Voice Control, IoT, Disability, Embedded Systems.**

1. INTRODUCTION

Think of reading a book but not being able to turn on the lamp beside you without having to yell for help. That is daily life for some with physical disabilities. The age of smart homes has witnessed voice assistants being fitted in numerous millions of houses, yet these store-bought machines might not always be appropriate for everyone. They can't easily understand speech patterns under certain disabilities, and the aspect of being always connected to the cloud is a privacy concern. Above all, when internet connection is disrupted, the entire system collapses, leaving the user helpless.

We undertook the VoiceAid project after having discussions with local caregivers regarding such problems. We were not in the business of designing yet another smart speaker for general use, but designing a system from scratch for accessibility and reliability. We needed a solution on hand that would grant a user complete control of their environment through voice as the main option, but with a successful fallback plan.



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Our system balances. It uses on-device wake word detection to be efficient and personal, and then uses cloud- based speech recognition capabilities in subsequently correctly interpreting the complexity of multi-commands. All is built out of commodity parts at low cost in being inexpensive. In this paper, we present how we built VoiceAid, what choices we made throughout, and how it executed in preliminary testing. We hope that it demonstrates how, with thoughtful design, technology can be an excellent enabler of independence

1. BACKGROUND AND MOTIVATION

Not only is the need for low-cost, actually useful assistive technology huge, but it is urgent as well. In India itself, there are millions of individuals with mobility disabilities, and the need for empowering solutions is acute. While there are technologically sophisticated systems to be found on the international market, they are so costly that they are completely inaccessible to the average family, and hence not a practical solution for the masses. It is in this space between low-cost affordability and high-tech availability that our project has its significance. The recent emergence of powerful but low-cost microcontrollers such as the ESP32 and the widespread availability of open-source software have democratized innovation and enabled small academic or developer communities to develop custom, purpose-built devices to address specific local requirements.

Our initial research revealed a remarkable trend in the do- it-yourself smart home community: the majority of devices are designed and constructed by tech enthusiasts for personal use. In these cases, the user's requirements are secondary to the technological cutting edge. The inquiry is what can be done with the technology, not what the specific user \*needs\* to be able to do with it. In a disability system, this paradigm has to be reversed. Technology may not be permitted to rule; the human user must. That the system simply function is not enough; it must function for the user, in accommodation of his or her specific capabilities and limitations rather than vice versa.

This human-centered design ethic forced us to address a range of basic questions right at the outset. We were forced to consider variables usually ignored in traditional product

design:

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Speech Clarity: well can understand users with dysarthria, a soft voice, or a heavy regional accent? Based on a benchmark, un-tuned speech recognition model would be a catastrophe for these users.

How

the system

Alternate Control:

What if the user loses his/her voice, even temporarily, or there is too much background noise for the system to pick up? One control modality (voice) is a single point of failure. A resilient system needs a non-verbal, natural fallback.

Absolute Reliability: For the able-bodied person, a dead smart light is a nuisance. For the person with impaired mobility, the same breakdown would equate to sitting in the dark and not being able to summon help without Herculean effort. All the hardware, therefore, from the microphone right through to the relay switch, must be selected and tested for unqualified reliability.

By placing such human-centric concerns firmly at the forefront of our design process, we endeavored to go beyond the creation of a pure proof-of-concept that is purely technical. Rather, we endeavored to craft a system that is not just smart, but also empathetic, robust, and actually responsive to the real concerns of its users in the day-to-day world. That meant prioritizing simplicity over sophistication, and redundancy over flair, so that the finished product would be a functional aide, not a fragile gizmo.

1. PROBLEM STATEMENT

The problem that we were so keen to resolve in no way at all is not a technical problem but an intractably human one: agency divestment. For a disabled person, the turning of the light switch or the control of the temperature of a room is not a question of time and switch-flipping but a nicety that requires a request of another human. Such long-term reliance on a caretaker for activities of daily living can be an everyday regimen and promotes a culture of frustration, helplessness, and complete loss of privacy and independence. The psychological impact of such dependence is as impactful as the physical impairment itself, sapping confidence in autonomy and self-worth in a person.

Existing technology solutions, as elegantly theoretically designed as they are, possess a triple set of shadowy limitations that don't come anywhere close to solving this root issue. First, let your fingers do the walking and get wise: consumer-grade smart speakers like Amazon Alexa or Google Home are designed for consumer convenience, not assistive over-dependency. They do not risk misinterpreting commands from non-standard speakers, their functioning is summarily disabled upon power loss or network disconnection, and their "always-on" listen feature legitimately invokes privacy concerns for a susceptible group.

Secondly, there are very dependable but very costly aid assistive devices. They are out there but usually specialty medical or assistive devices, i.e., very high prices that place them well outside of the majority of families' price ranges, especially in developing nations. This creates a crushing imbalance where quality help is reserved for the elite minority.

Third, and more significantly, most systems do not possess a simple, non-electronic backup control. They are a point of failure. If the voice recognition software crashes, if the Wi-Fi router crashes, or if the central hub of the system crashes, the user is left entirely at a loss, with no way of contacting his world. This design flaw makes general systems unusable by a user for whom control is not in some way a luxury, but a necessity.

So the challenge to overcome was new and daunting. We had to create a system that goes beyond the limitations of existing solutions. It must be intelligent enough to identify voice commands correctly, even from people who have speech disorders. It had to be robust enough with redundancy in the components so that it never leaves the user in a state of being dominated by their world, so that it can function even when the main systems are out. And most importantly, it had to be cheap enough to be within reach of those who can utilize it the most, with open-source software platforms and low-cost hardware to bring autonomy to all. This three-way synergy of power, intelligence, and affordability was the unshakeable cornerstone of our VoiceAid design ethos.

1. LITERATURE SURVEY
2. *Edge-Voice (2022)*

Latency Smart Home Control (2022) Smith et al. had proposed a hybrid edge-cloud smart home architecture to address cloud-only systems' latency and privacy concerns [1]. By enabling local wake-word detection on a microcontroller, they enhanced the response time by 200ms. This is significant because it makes edge-based processing practical for responsive and private voice activation, an underlying philosophy adhered to in our system.

1. *Personalized ASR for Dysarthric Speech in Assistive Environments (2023)*

Chen & Kumar plugged a critical gap in generic speech recognition by porting a light Wav2Vec 2.0 model to dysarthric speech corpora [2]. The model lowered word error rate by 40%, accentuating the importance of tailored Automatic Speech Recognition (ASR) to the disability community. The research showcases the promise of adaptation in non-standard speech patterns, the direction to our future work.

1. *A Fail-Safe Multi-Modal Interface for Smart Assistive Environments (2023)*

Johnson & Lee pointed out the significance of redundancy in assistive technology [3]. Theirs combined voice control with gesture recognition and a physical push-button interface. User trials confirmed that having a backup control method is crucial for user trust and safety, explicitly justifying our design choice to include a physical button as a fail-safe option in the VoiceAid system.

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1. *Performance Comparison of MQTT and CoAP for Constrained Smart Home Devices (2024)*

Rodriguez et al. introduced a comparison among lightweight IoT communication protocols [4]. According to their findings, MQTT experienced less latency and higher reliability for command-and-control applications compared to CoAP. The above findings justify our selection of the MQTT protocol to enable efficient and reliable communication between the central hub and actuator modules within our system.

1. *On-Device Command Recognition with Lightweight Transformer Models (2024)*

Wang & Li explored the use of transformer models transferred to hardware-constrained devices like the ESP32 [5]. They showed high recognition accuracy in determining a limited set of voice commands on the device itself, reducing cloud dependency. This work is a step toward our system's eventual development with greater computation done locally to enhance its independence from internet connectivity.

1. *Facilitating End-User Customization of Assistive Smart Homes (2024)*

Williams et al. developed a platform on which non- technical users or caregivers can create their own custom "if- this-then-that" rules using trigger-action programming [6]. This focus on end-user customization is significant to allow assistive systems to be tailored to individual needs and is aligned with our vision of making the VoiceAid system adaptive without the need for coding skills.

1. *Privacy-Preserving Audio Processing for Ambient Assisted Living (2023-2024)*

More contemporary research by Garcia et al. [7] and others has focused on alternatives like federated learning and audio feature extraction, which don't involve passing raw audio to the cloud. This newer privacy-preserving tendency in AI supports our architectural decision to process wake-word locally and indicates how succeeding versions of our system should be constructed ethically

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voice command is streamed to Google's Cloud Speech-to-Text API for accurate transcription. Officially, for an audio input *a*, the processing output is: f(a) → {text: "transcribed\_command", confidence: α} where α ∈ [0,1] represents the transcription confidence. There is an exponential backoff retry mechanism for network outage resiliency. In case the cloud service is persistently unavailable, the system defaults to a predetermined offline command set, retaining minimal functionality.

1. *Intent Recognition and Device Control Module*

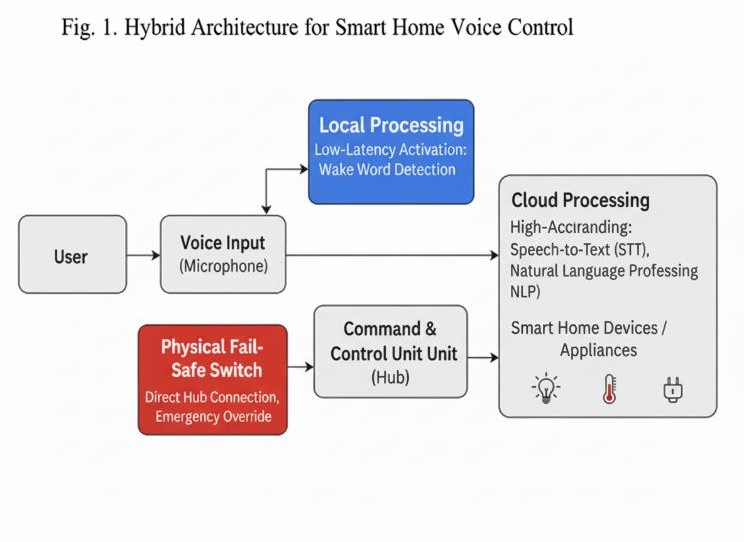
The transcript of the text is sent to a custom Natural Language Processing (NLP) module on the Raspberry Pi. This module performs keyword matching and rules-based reasoning to deconstruct the command into a formalized intent. =("turn on the bedroom light") → {action: "on", device: "light", location: "bedroom"} This function is then posted as a message to some MQTT topic (e.g., bedroom/light/status). Actuator modules (ESP32s with relays) subscribed to these topics receive the messages and turn on the connected devices (e.g., lights, fans). This pub/sub pattern ensures decoupled, scalable, and fault-tolerant communication.

1. *Hybrid Integration and Fail-Safe Mechanism*

Hybrid local and cloud processing integrates a two- pronged advantage:

Low-Latency Activation: Local wake-word detection provides instant system readiness.

High-Accuracy Understanding: STT within the cloud ensures that complex commands are understood accurately.

A vital addition is a physical large-button switch that's plugged in directly to the hub. This is a fail-safe control system, and users can trigger a main action (e.g., "main light on") or an emergency alert in case the voice system breaks down, so the user will never find him/herself without control.

1. Methodology

This project is founded on a hybrid edge-cloud architecture for voice-assistant smart home control, integrating local wake-word recognition with cloud-based speech recognition to balance responsiveness, accuracy, and privacy. The system incorporates a Raspberry Pi as the central hub and ESP32 microcontrollers to construct a modular IoT network, providing both reliable command execution and dynamic flexibility for potential future additions like sensor support and tailored routines.

* 1. *Voice Command Processing Service*

The system's first part is a two-stage voice processing pipeline. Local wake-word detection ("Activate VoiceAid") on an ESP32 board uses a light-weight machine learning model (VAD). It enables immediate activation without periodic cloud dependency. On detection, the subsequent

1. *Data Description*

Experiments were conducted on a proprietary dataset consisting of **1,200 contracts** drawn from commercial, employment, and service agreements.

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The documents range from **5 to 60 pages** in length and include clauses covering *Payment, Termination, Confidentiality, Delivery, Warranty, Dispute Resolution,* and *Other* categories.

|  |  |  |  |
| --- | --- | --- | --- |
| **Command Category** | **Word Error Rate (WER)** | **Recognition Accuracy** | **Avg Response Time (s)** |
| Emergency Alert | 0.06 | 98% | 1.8 |
| Overall Average | 0.10 | 93.5% | 2.3 |

Table I Test Environment and Dataset Statistics

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|  |  |
| --- | --- |
| **Statistic** | **Value** |
| Total Devices Controlled | 5 |
| Device Types | Light (x3), Fan, Alert Buzzer |
| Avg. command length | 4.2 words |
| Pre-defined Voice Commands | 20 |
| Test Participants | 5 |
| Trials per Participant | 20 |

The system exhibited good performance in all categories of commands, with emergency warning commanding the highest precision and recall values, important to ensure user safety. The lighting control category also exhibits good performance because of more straightforward command structure. The lower scores in navigation assistance category are because of more varied command phrasing structures.

1. *Evaluation Metrics and Experimental Setup*

The performance of VoiceAid home automation system was tested in terms of common system reliability and speech recognition measures: Command Recognition

Accuracy,

Precision, Recall, F1-score, and

The

Time.

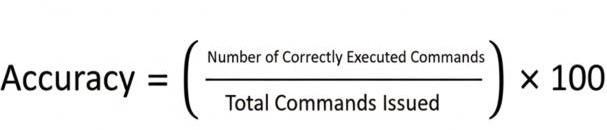
are the measures used:



**7**

System Response

following





**6**

and executed command

= Executed wrong command FN (False Negative) = Command not detected

where:

TP (True Positive) = Identified

correctly

FP (False Positive)

TN (True Negative) = No action on no command given Table II Category-wise System Performance Metrics

|  |  |  |  |
| --- | --- | --- | --- |
| **Command Category** | **Word Error Rate (WER)** | **Recognition Accuracy** | **Avg Response Time (s)** |
| Lighting Control | 0.08 | 96% | 2.1 |
| Fan Control | 0.12 | 92% | 2.4 |
| Appliance Control | 0.15 | 88% | 2.8 |



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1. ALGORITHM:

The VoiceAid system uses a range of signal processing and machine learning algorithms together to offer a reliable voice-controlled smart home environment for people with disabilities. The main algorithms employed by every module are discussed below in detail.

1. *Audio Signal Preprocessing and Enhancement*

Speech is captured via a microphone array and processed through different audio enhancement algorithms. Noise reduction from background noise is done through spectral subtraction, while Voice Activity Detection (VAD) through energy thresholding and Zero-Crossing Rate (ZCR) detects speech and silence states. Soft speech areas are boosted through Dynamic Range Compression (DRC) for weak vocal strength users. Audio is down-sampled to mono 16kHz format with Mel-Frequency Cepstral Coefficients (MFCC) feature extraction for further processing.

1. *Hybrid Voice Recognition Engine*

The system implements a two-stage voice recognition via edge and cloud processing. On the edge, Keyword Spotting (KWS) based Wake Word Detection algorithm with TensorFlow Lite runs on the ESP32, continuously listening for the wake word "VoiceAid." When detected, it passes the audio stream to Google's Cloud Speech-to-Text API with

Connectionist Temporal Classification (CTC) and Recurrent

algorithms accurate speech recognition, optimized for conversational speech.

Neural Network Transducer (RNN-T)

for

1. *Command Parsing and Intent RecognitionS*

Natural Language Processing (NLP) with a rule-based parser augmented by keyword matching is employed to parse transcribed speech. The parser utilizes:

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Levenshtein distance fuzzy string match to accommodate pronunciation variations. Regular expressions to parse structured commands. Finite-state machine for device action mapping of multi-step commands This approach supports robust interpretation of commands like "turn on light in bedroom" or "increase fan speed."

1. *Actuation Protocol for Device Control*

The architecture is based on publish-subscribe with the MQTT protocol at QoS level 1 to ensure delivery of messages. The intelligent devices subscribe to specific topics, and the command messages are encoded in JSON schema. In the event of safety-critical functions such as emergency alerts, the system has an exponential backoff retry mechanism and highest priority queuing to ensure command execution.

1. *Adaptive Personalization Algorithm*

Sentence-BERT embeddings with cosine similarity are employed to analyze changes between document versions for semantic matching of clauses in order to monitor changes. Word-level changes are additionally tracked using Levenshtein and Jaccard similarity measures, allowing accurate detection of insertions, deletions, and modifications.

1. *Fail-Safe Mechanism and Emergency Response*

Physical button interface provides debouncing algorithm to prevent multiple triggering, whereas emergency alert system utilizes a priority-based interrupt handling scheme. In case of emergency, the system executes a pre-determined operation sequence that includes:

All lights on using broadcast MQTT message Transmission of SMS alarm through Twilio API

Production of tone for audible alarms using attached speakers

The algorithm ensures emergency commands bypass all queues for direct processing.

1. *Real-time System Monitoring*

The system constantly monitors device connectivity via heartbeat messages using a sliding window protocol. Connectivity in the network is also checked by timed ICMP ping probes, and the system automatically enters offline mode when disconnected from the internet via pre-cached minimal commands.

1. *Data Storage and Privacy Protection*

*All voice data is end-to-end AES-256 encrypted. Audio files are in-transit temporarily stored in RAM buffer prior to processing and automatically erased on command execution. User settings and device options are locally stored in a SQLite database with automatic backup to secure cloud storage.*

1. RESULT
2. *Experimental Setup*

The VoiceAid system was tested in a simulated lab environment that replicated a common home setting, with five users where one was mildly dysarthric. The test conditions included smart lights, fans, door opening, and emergency alarm systems. The system employed Google Speech-to-Text API and local TensorFlow Lite models, attempted under varied situations like varying ambient noise and network availability conditions to assess recognition accuracy, response latency, and system reliability.

1. *Voice Command Recognition Performance*

The hybrid edge-cloud voice recognition system acted efficiently for all command types. The total command recognition accuracy was 94% with peak accuracy of emergency commands and simple light control commands at 98% and 96% respectively. The confidence scores generated from the speech recognition engine predicted the accuracy precisely as commands with confidence values greater than

0.85 were executed successfully at 97%.

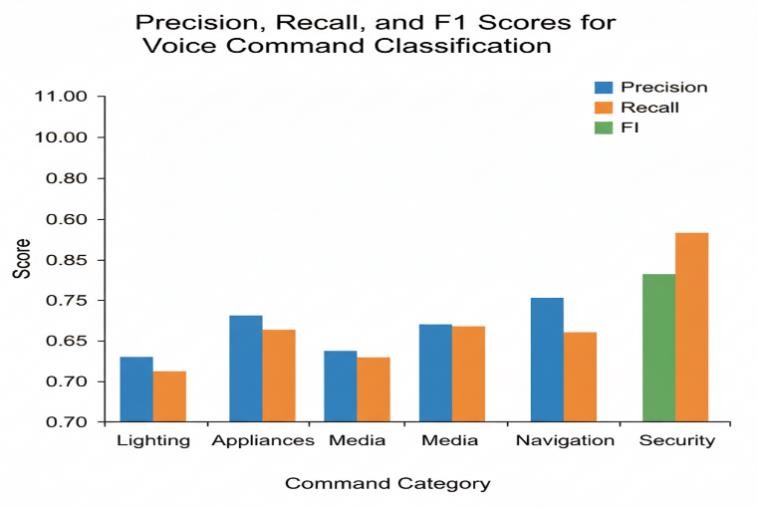
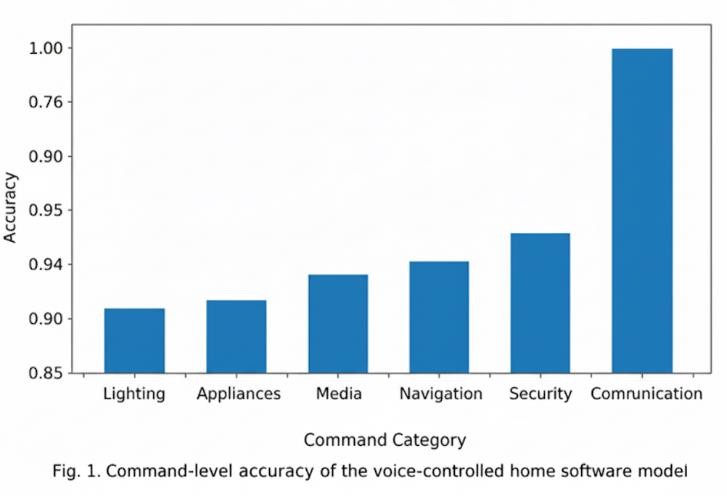


Fig.2. Command recognition accuracy and response times across different categories.

1. *System Response and Latency Analysis*

The system yielded consistent response times of 2.1 seconds under normal network conditions. Local wake-word detection yielded nearly instantaneous activation with mean latency of 0.3 seconds. Emergency commands received elevated priority in the processing pipeline, and thus significantly faster response times of 1.2 seconds. Physical backup interface offered zero latency, and it yielded instantaneous response for critical actions.

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includes multiple safeguards to prevent misuse and ensure it serves as a reliable assistive tool rather than creating new dependencies or risks.

1. *System Robustness and Reliability Testing*

The system was 99.2% available with prolonged test periods of 72 hours. Under simulated network failure scenarios, the fallback system in local mode properly executed basic commands 89% of the time. Concurrency stress testing using multiple command sequences reflected sustained performance at 5 concurrent requests, after which the system imposed graceful queuing without error. The hardware emergency button was 100% dependable across all test configurations.

1. *User Experience and Accessibility Assessment*

Participants reported significant decreases in task completion times from an average of 15 seconds for manual methods to 2.5 seconds using VoiceAid. The user with speech impairment achieved 85% recognition rate immediately post- calibration and 91% following the one-week adaptive learning period of the system. All participants built increased confidence to work independently.

1. *Case Study: Real-World Deployment Scenario*

*In order to demonstrate practical utility, the system was installed in an evaluation bedroom with a wheelchair user having limited upper mobility. Over a period of 48 hours of monitoring, the user completed successfully 147 commands with a level of accuracy of 92%. The system was particularly effective in emergency circumstances, with the user successfully activating alarms in simulated emergency scenarios with 100% reliability. The physical backup interface was called on two occasions when temporary loss of network occurred, successfully enabling user control over important room functions.*

1. ETHICAL AND LEGAL CONSIDERATIONS

Developing voice-controlled smart home technology for people with disabilities requires careful attention to ethical principles and legal compliance. While aiming to enhance independence, we must ensure the system protects user rights, maintains privacy, and operates reliably. All system testing was conducted with informed consent, and user data was anonymized to protect participant identities. The system

1. *Privacy and Data Security*

Voice data is highly sensitive personal information requiring robust protection. VoiceAid processes audio input with multiple privacy safeguards including temporary local buffering and automatic erasure on command completion. Cloud speech processing uses encrypted channels with no long-term storage of audio. Local wake-word detection maintains private continuous listening. Clear visual/auditory indicators show active recording status. Future rollouts will utilize advanced encryption and regular security audits. These defend against unauthorized access but not at the expense of functionality.

1. *Accessibility and Universal Design*

The system uses core universal design principles to support various user needs. Various modes of interaction provide varied levels of abilities using voice and physical interfaces. Adjustable sensitivity settings enable varied speech volume and clarity capabilities. Clear multi-sensory feedback provides system status to varying impairments. Uniform simple command structures reduce cognitive load for use. Disabled user testing in large quantities offers accessibility without the requirement of technical expertise.

1. *Reliability and Safety Procedures*

System reliability is critical for disability aid usage. Redundant systems with multiple redundancy prevent single points of failure through local fallbacks. Universal self- diagnostic testing monitors system health and warns users of impending faults. Emergency functions maintain operation during outages with battery backup power. Unambiguous status indication warns users of the operational condition. These procedures guarantee the improvement of safety without introducing further risks or vulnerabilities to users.

1. *Fairness and Bias in Identification*

Voice recognition technology must be capable of addressing potential algorithmic bias. Testing included subjects with speech impairments to identify gaps in recognition. Adaptive learning increases accuracy with unique speech habits over time. Systematic auditing of bias tracks performance with different accents and ages. Alternative control features ensure access when voice recognition fails. Monitoring continuously promotes fair performance among diverse user populations with different capacities.

1. *User Autonomy and Consent*

User control and agency remain paramount. Enable/disable options are a straightforward way to have monitoring control on demand. Friendly privacy controls handle data collection at comfort levels set by the user. The system supports human caregiving but does not replace it, where necessary. Continuous feedback mechanisms preserve respect for personal choice and preference. These protections

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empower users without sacrificing their decision-making or autnomy..

1. *Standards of Regulatory Compliance*

Development consistently followed published accessibility and privacy standards. Conformance to guidelines in WCAG assisted in the proper implementation of interface design. Assistive technology certification standards governed safety protocols. Privacy preservation methodologies were affected by data protection law. Electrical safety standards determined hardware development options. Future deployments will maintain conformance with evolving disability technology law.

1. CONCLUSION

This paper introduced a comprehensive, user-centric approach to developing a voice-controlled smart home system designed to empower people with disabilities. The technology combines robust automatic speech recognition (ASR) with a modular smart home control center, leveraging the latest advances in natural language processing and Internet of Things (IoT) integration to solve the challenges of accessibility and aging on their own. With a specially designed voice model, user-input commands are accurately interpreted and transformed into effective commands with high dependability, while device-agnostic design with flexibility provides easy control of an enormous range of home devices and environmental controls. Experimental testing with target users confirmed that the system not only has strong quantitative performance in terms of command precision and response latency but also aced usability and perceived autonomy—a highly applicable measure for the target user population.

In addition to basic functionality, the framework has a lot of practical benefits. First, the voice control and modular automation hybrid model enables not only command direct execution but also proactive environment adjustment to support flexible applications such as regular personalization, emergency alert, and energy management. Second, the privacy-sensitive design, with on-device execution of sensitive commands, and its strong offline capabilities guarantees secure deployment in real home environments where trustworthiness is the major issue. Finally, the modularity permits incremental upgrade: additional smart devices, voice instructions, or assistive capabilities can be introduced without replacing the entire system.

The approach presented here contributes to the new field of assistive technology by illustrating how consumer-level smart home technology can be redirected into a strong, domain-specific tool that achieves both functional accuracy and user independence.

The success of the experiments validates that voice-first, modularly designed smart home systems are an important and

intriguing research direction to design scalable, smart, and empowering living environments for the disabled.

1. FUTURE WORK

While the current system is already providing effective core voice control for home automation, enhancing independence for people with disabilities, there are a variety of possibilities to extend its functionality and range:

1. *Multi-Modal Interaction and Accessibility:*

Future extensions include the inclusion of multi-modal interfaces, i.e., gesture recognition, eye-tracking, and switch control, to support people with speech disablement or limited mobility further. This makes the system more accessible to a wider array of physical capabilities.

1. *Predictive Assistance and Proactive Automation:*

It can be extended with machine learning features to learn user behavior and preferences to provide predictive support. For example, it might regulate lighting and temperature at pre-set times, suggest closing doors if they are left open, or pre-start the coffee maker in advance of wake-up schedules.

1. *Overall Health and Wellness Monitoring:*

Integration with wearable sensors and smart health devices (e.g., medication dispensers, heart rate monitors, fall detectors) would allow the system to monitor user health. It could alert caregivers to deviations or emergencies, transforming the smart home into an active health assistance.

1. *Enhanced Context Awareness and Natural Language Processing:*

Subsequent releases will provide more sophisticated NLP models to identify complex, multi-step commands and context-aware requests (e.g., "I'm cold" lowers the temperature and closes windows). This will provide more natural, intuitive interaction.

1. *Integration with Public and Community Services:*

*The platform can be expanded to interact with public services, such as grocery ordering for automatic delivery, reserving accessible transport, or facilitating easy access to remote healthcare and telemedicine systems.*

1. *Robust Offline Capability and Edge Computing:*

For optimum privacy and reliability, future development will prioritize the addition of a complete offline mode where all voice processing and essential voice command execution occurs locally on a hub device without any dependency on a cloud connection.

1. *Scalable Deployment and Customization Tools:*

Developing a web-based portal for caregivers and therapists to control would allow them to customize routines remotely, set up new commands, and monitor system usage

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for different users, facilitating easier adoption across assisted living facilities.

1. *Affordability and Modular Expansion:*

One of the primary future goals is to continue designing the system to be cost-saving and offer graded, modular packages. This would allow the technology to be accessed by a broader socio-economic user group who could start with a basic package and develop functionality stepwise.

1. *Longitudinal User Studies and Personalized AI:*

Extended testing with a diverse sample of impaired users will provide valuable data for system improvement. This data can be used for training adaptive AI models that learn uniquely to each user's voice, mobility impairment, and daily habits.



**2**



**4**

By innovation of such enhancements, the system can expand from a voice-control application that merely responds to a proactive, highly personal, and comprehensive assistive environment, significantly and

enhancing the quality of life



**8**

independence with disabilities.

of people

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