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Development of an Intelligent-Based Elevator System

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Abstract

Elevator systems are central to modern smart buildings, and recent innovations aim to make them more intuitive, safe, and inclusive. Traditional models that rely on manual control panels often limit accessibility for users with physical or visual impairments while also presenting safety concerns in crowded or high-traffic environments. To overcome these challenges, this study developed an intelligent elevator system that combines voice recognition for hands-free operation with ultrasonic sensing for obstacle detection at the doors. A prototype was designed and tested under varying ambient noise conditions and distances to assess recognition accuracy, wake-up responsiveness, and door safety performance. Results indicated strong system reliability, achieving up to 97 percent recognition accuracy at 1m in quiet conditions and maintaining effective responsiveness across stationary and babble noise environments, while ultrasonic sensors consistently detected human presence to prevent accidental entrapment. These outcomes confirm that the integration of voice and sensor technologies not only enhances convenience but also strengthens safety and accessibility. In conclusion, the project demonstrates that an intelligent voice-controlled elevator with sensor-assisted doors is both practical and reliable, making it a valuable solution for high-rise residential, commercial, and institutional buildings seeking to align with the principles of smart, inclusive, and safe infrastructure.

Keywords: *Accessibility, embedded system, speech recognition, ultrasonic sensor, vertical transportation.*

1.0 Introduction

The rapid advancement of elevator technologies has profoundly shaped the landscape of modern computer engineering, especially in the domain of embedded control systems and smart automation. Elevators, once simple mechanical hoists, have evolved into sophisticated, intelligent systems that rely on microcontrollers, programmable logic controllers (PLCs), and sensor networks to ensure efficient, safe, and adaptive vertical transportation. In high-rise environments such as commercial complexes, residential towers, and healthcare facilities, elevator systems have become indispensable to the functional integrity of buildings.

In recent years, elevator research has increasingly explored the use of voice recognition and real-time sensing to improve accessibility, hygiene, and user experience. A notable example is the work of [1], [2], and [3], who developed a speech-controlled elevator prototype using a Raspberry Pi. The study highlighted the practicality of creating low-cost, voice-responsive platforms for modern elevator systems, showing how such innovations can make vertical transportation more inclusive and user-friendly. Similarly, [4], [5], and [6] validated the feasibility of voice-activated elevator control systems with high command accuracy, paving the way for more inclusive automation.

Motivated by the global health crisis, [7] proposed a touchless smart lift that employs voice recognition to minimize contact-based transmission risks. The system underlines the relevance of such innovations not only for convenience but also for public health. In related efforts, [11] designed a system for reducing virus contact in elevators using image recognition while Padilla, Ramos, and Garcia designed a voice-activated elevator interface specifically for visually impaired users, using auditory feedback to improve accessibility and reduce dependency on physical interfaces.

Beyond control, system security and robustness have also been key areas of concern. [1], as well as [2], [4], and [5], examined the vulnerabilities of voice-command systems and proposed continuous authentication techniques to safeguard against spoofing and inactivation [5], [6]. These findings highlight the critical need to balance usability with secure implementation in voice-activated elevators.

In addition to voice control, researchers such as [8] and [3] have contributed to the development of sensor-based safety enhancements. Their work focuses on infrared and image-recognition mechanisms for intelligent door operation and contactless interface design [7], [8]. Complementing these contributions, [8] explored the use of Arduino Pi to control DC motor lift systems, reflecting growing interest in microcontroller-based vertical mobility systems for embedded control education and prototyping [9].

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Chen and Huang further extended these innovations by incorporating Field Programmable Gate Arrays (FPGAs) and GPRS modules, enabling real-time remote monitoring of voice-controlled elevators a critical step towards full smart building integration [10].

Given Nigeria's ongoing urbanization and the corresponding demand for smart, inclusive, and contactless infrastructure, the adoption of voice-activated elevator systems with intelligent sensing is both timely and strategic. This study, therefore, presents a robust, cost-effective voice-controlled elevator system augmented with ultrasonic door sensors, specifically designed to enhance safety, accessibility, and operational convenience within intelligent building environments.

The integration of voice recognition and sensor technologies into elevator systems has attracted increasing academic and industrial attention in recent years, particularly in the domains of accessibility enhancement, contactless control, and smart infrastructure deployment. Several researchers have undertaken significant studies in this domain, proposing various architectural models and control strategies for speech-operated and sensor-enhanced elevator systems.

[1] implemented a voice-recognizing elevator system using a Raspberry Pi, demonstrating a low-cost yet efficient design capable of accurately interpreting floor-selection commands [2]. Their approach utilized an embedded microphone, speech recognition engine, and basic motor control logic to simulate elevator movement, showing high precision in command execution within a lab-controlled environment.

In a similar study, [3] designed a speech-controlled elevator prototype where a Raspberry Pi was used as the primary processing unit. Their system architecture included a microphone, speech recognition module, and a control unit interfaced with the elevator simulation panel [1]. The prototype demonstrated high command recognition accuracy and improved user interaction through an audio feedback module, making it suitable for budget-constrained smart building applications.

2.0 Materials and Methods

This section presents the methodological framework employed in the development and evaluation of the intelligent voice-controlled elevator system with sensor-integrated door automation. The approach encompasses both the mechanical and electronic hardware components as well as the embedded software implementation that governs the overall system behavior.

2.1 Hardware Implementation

The hardware implementation of the intelligent elevator system combines both the mechanical structure and the electronic control units as shown in Figure 1 and Figure 2. The chassis was designed in SolidWorks 2023 using a 15 mm thick acrylic cube to simulate a compact elevator shaft. Vertical movement is achieved through a belt and pulley arrangement supported by a slider mechanism. The system is powered by a 5v stepper motor connected through a ULN2003A driver, which translates programmed angular displacements into precise floor positioning. The motor rotates 900 degrees for the first floor, 1800 degrees for the second, 2700 degrees for the third, and 3600 degrees for the fourth, ensuring accurate and repeatable movement of the cab. A four-by-four keypad and a microphone serve as the main input units, allowing passengers to either press a key or issue voice commands. The ESP32 microcontroller, which operates at 3.3 volts with built-in Wi Fi and Bluetooth, coordinates these inputs and directs the actuation of the elevator.

To enhance safety and user interaction, an HC SR04 ultrasonic sensor was installed near the door section. This sensor operates on a five volts supply and measures distance using ultrasonic waves at 40 kilohertz, enabling it to detect obstacles or human presence and prevent accidental entrapment. Door control is managed by an SG90 servo motor rated at 1.8kilogram centimeter torque, which provides sufficient force for reliable small scale door operations. The system runs on a rechargeable lithium-ion battery rated 3.7 volts and 1800 milliampere hour, stepped up where necessary to power the sensors, microcontroller, and motors. Figure 1 illustrates how these components are connected in the circuit design, while Figure 2 shows the physical prototype that demonstrates their interaction in real time.

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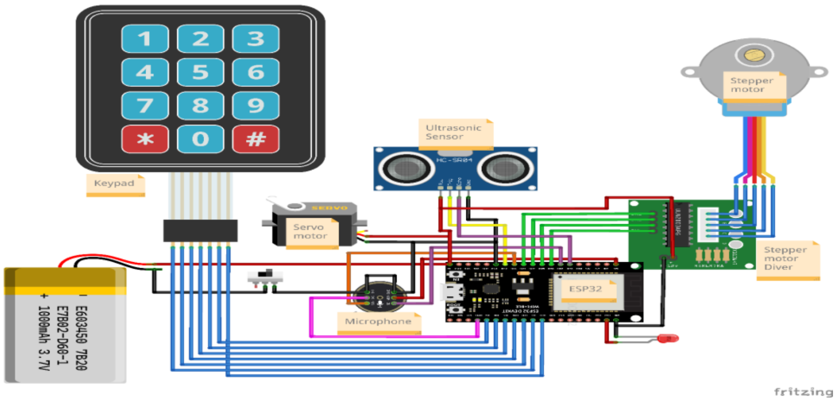

Figure 1: Circuit diagram of the system


Figure 2: Hardware prototype of the system

2.2 Software Implementation

The software architecture is centered on Espressif's MultiNet speech command recognition model, which is optimized for deployment on embedded microcontrollers, particularly the ESP32 platform. MultiNet allows for offline, multilingual command recognition without requiring retraining for new commands, making it a flexible and scalable solution for embedded speech-controlled systems.

The system begins with real-time audio capture using the INMP441 digital microphone, which transmits audio signals to the ESP32 module. The captured audio is preprocessed to extract feature vectors commonly Mel-Frequency Cepstral Coefficients (MFCCs)—suitable for neural network processing. The MultiNet model architecture combines convolutional layers for feature extraction and recurrent layers (e.g., LSTM) to model temporal dependencies in spoken language. In some configurations, attention mechanisms are included to enhance focus on relevant input segments.

The speech recognition model is trained using 500 dataset of labeled audio commands,the data is divided into 70% for training the system, and 30% for testing the system, with Connectionist Temporal Classification (CTC) employed as the loss function. CTC is particularly suited for this task because speech inputs vary in length and may not align neatly with the target labels. By allowing the model to learn the most likely alignment between input frames and output sequences, CTC enables accurate recognition without requiring pre-segmented data. To ensure operability on a resource-constrained device such as the ESP32, model quantization techniques are applied, which significantly reduce memory usage while maintaining reliable inference accuracy.To ensure operability on a resource-constrained device like the ESP32, model quantization techniques are applied, significantly reducing the memory footprint while preserving inference accuracy.

Upon deployment, the optimized model is embedded within the ESP32 firmware using the TensorFlow Lite for Microcontrollers library. When activated, the ESP32 processes microphone input in real time, with recognized commands interpreted and translated into elevator control signals. The system can be extended to include user feedback mechanisms such as OLED displays or voice output modules to enhance interactivity and system transparency.

The software development lifecycle included iterative testing and fine-tuning, particularly focusing on command misrecognition and latency under various acoustic conditions. The real-time responsiveness and robustness of the system were validated in both controlled and semi-structured environments.

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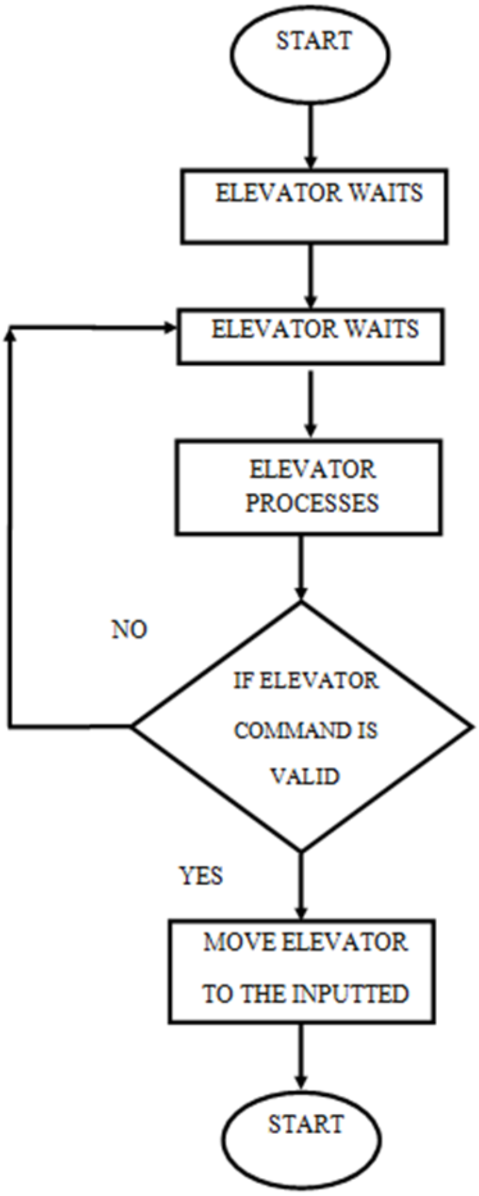

Figure 3: System Design Flowchart

3.0 Results and Discussion

To evaluate the environmental performance of the speech recognition system, experiments were conducted under different ambient noise levels and at varying distances from the microphone. The key metrics measured were recognition accuracy and wake-up responsiveness in quiet, stationary noise, and babble noise conditions, including Acoustic Echo Cancellation (AEC) tests. The results are summarized in Table 1.

Table 1: Device environmental performance

Distance	Quiet Environment (%)	Stationary noise Environment (%)	Babble Noise (%)	AEC Wake Up (%)
1m	97	90	88	89
3m	95	85	75	73
6m	90	75	70	65
10m	80	70	60	54

The data shows that recognition accuracy is highest in quiet environments, reaching 97 percent at 1 meter, but gradually decreases with distance and higher noise levels. For example, at 10 meters, performance drops to 80 percent in a quiet setting and as low as 54 percent under babble noise with AEC. This trend highlights the sensitivity of the system to both distance and background noise, which is consistent with typical challenges in speech-based interfaces. Nevertheless, the system still maintains acceptable responsiveness within a practical range of 1 to 3 meters, which is suitable for elevator usage scenarios where passengers are generally close to the microphone. The inclusion of AEC also proved useful in mitigating the impact of echoes, though further improvements could enhance robustness in highly noisy environments.

Beyond recognition accuracy, deployment on the ESP32 was carefully evaluated to ensure real-time operability. Thanks to model quantization, inference times averaged under 200 milliseconds per command, with negligible lag perceived by users. This level of responsiveness ensures smooth interaction, where commands are executed almost instantly after being spoken. While performance declined slightly in noisy conditions, the overall system remained reliable, validating the feasibility of running a compact yet efficient speech recognition model directly on a resource-constrained microcontroller.

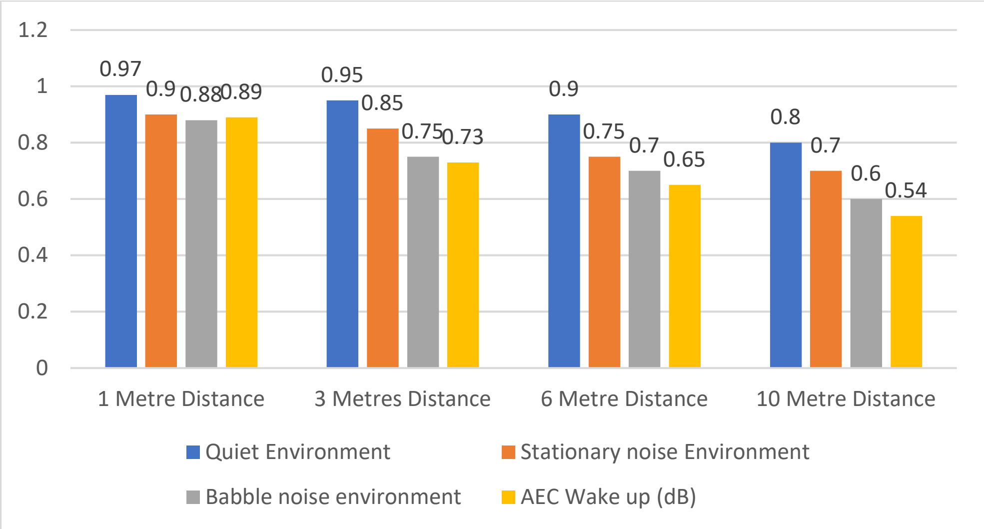

Figure 4: Device environmental performance

4.0 Conclusion and Recommendations

4.1 Conclusion

The development of a voice-controlled elevator system integrated with a sensor-based door mechanism represents a significant step forward in the design of intelligent vertical transportation systems. The successful implementation of this project has demonstrated the practical feasibility and functional reliability of using voice recognition and ultrasonic sensing technologies in modern elevator systems. The system provides an accessible interface that eliminates the need for physical contact with control buttons, making it particularly suitable for individuals with disabilities and for applications in public or health-sensitive environments.

Furthermore, the inclusion of ultrasonic sensors ensures safe door operation by detecting human presence and preventing accidental entrapments. Experimental testing of the prototype confirmed its responsiveness, accuracy, and user-friendliness, validating its potential for real-world deployment in high-rise residential, commercial, and institutional buildings. The project contributes to ongoing efforts to enhance safety, convenience, and inclusiveness in smart building design.

4.2 Recommendations

1. **Integration of Multilingual Support**: Future versions of this system will incorporate multilingual speech recognition to cater to diverse user populations, particularly in multilingual societies.
2. **Enhanced Noise Filtering**: To improve command recognition in noisy environments, advanced digital signal processing and noise-cancellation algorithms should be integrated into the speech recognition pipeline.
3. **Wireless Connectivity**: Incorporating wireless communication modules (e.g., Wi-Fi or Bluetooth) will enable remote system diagnostics, usage monitoring, and software updates.
4. **Touchscreen Backup Interface**: While voice control is the primary mode of interaction, a secondary touchscreen or tactile interface is recommended for redundancy in case of system failure.
5. **Battery Backup**: An uninterruptible power supply (UPS) system should be included to maintain functionality during power outages, enhancing reliability and safety.

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