IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429
Volume 5, Issue 10, June 2025
Impact Factor: 7.67

Hearing Aid with Real-Time Noise Filtering and Volume Protection for People with Hearing Disorder

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Abstract: *Hearing loss impacts millions globally, affecting their ability to perceive and interpret sounds clearly in noisy environments. Traditional hearing aids amplify all sounds, often resulting in discomfort and audio distortion. This paper presents the design and development of a real-time digital hearing aid system equipped with noise filtering and volume protection features for individuals with hearing disorders. Unlike conventional hearing aids that amplify all surrounding sounds indiscriminately, the proposed system intelligently filters background noise and dynamically regulates output volume to prevent sudden loud sounds from causing discomfort or further damage. The device is built around the ESP32 microcontroller and utilizes an INMP441 digital MEMS microphone for sound capture, along with a PAM8403 amplifier for audio output. The system processes the audio in real-time and transmits it to a speaker with optimized gain and clarity. Designed to be compact, power-efficient, and affordable, this hearing aid offers a practical and enhanced auditory experience for users in various acoustic environments*

Keywords: Hearing loss

I. INTRODUCTION

Hearing loss is a growing global health concern that significantly impacts the quality of life, communication abilities, and social interaction of individuals. Traditional hearing aids, while helpful, often lack the intelligence to differentiate between useful speech signals and unwanted background noise, leading to poor user experience in real-world scenarios. Furthermore, they tend to amplify all incoming sounds uniformly, including sudden loud noises, which can be uncomfortable or even harmful to users with sensitive hearing. In recent years, advancements in embedded systems and digital signal processing have opened up new possibilities for building smarter, more efficient, and affordable hearing aid solutions. This project introduces a lowcost, real-time hearing aid system that integrates noise filtering and volume protection using modern components such as the ESP32 microcontroller, INMP441 digital MEMS microphone, and PAM8403 audio amplifier. The system is designed to enhance speech clarity, reduce environmental noise, and protect users from audio spikes by dynamically adjusting volume levels. This approach not only improves hearing comfort and safety but also offers a compact and power-efficient alternative suitable for everyday use by individuals with mild to moderate hearing impairments.

II. METHODOLOGY

The proposed hearing aid system is developed using a modular hardware and software approach, focusing on real-time noise filtering and volume protection. The core of the system is the ESP32 microcontroller, chosen for its built-in Bluetooth capability and processing power. Audio input is captured through the INMP441 digital MEMS microphone, which provides high-fidelity sound data via I²S protocol. The ESP32 processes the audio data to suppress background noise and limit volume spikes using a custom filtering algorithm. Once processed, the clean audio signal is sent to a PAM8403 Class-D audio amplifier, which drives a mini speaker placed close to the user's ear.

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Power to the system is supplied through a rechargeable Li-ion battery regulated by an LM7805 voltage regulator to ensure stable 5V output. To maintain safety and efficiency, the circuit is designed to operate within low power limits. The real-time processing ensures minimal delay between sound capture and output, enhancing user experience. The components are mounted on a compact PCB to make the device wearable and lightweight. This modular. and cost-effective methodology allows for easy customization and scalability based on the user's specific hearing profile.

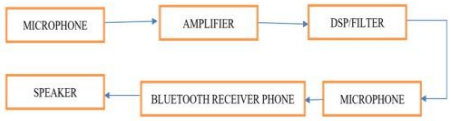

Fig 1. Block diagram of hearing aid system

Using digital filtering techniques to suppress unwanted noise, applies volume limiting to prevent excessive loudness, and delivers clear sound through the PAM8403 amplifier to the speaker.

Working

- START: The system is powered by a rechargeable Liion battery, regulated by an LM7805 to ensure a stable 5V supply to all components.
- Sound Capture: The INMP441 digital MEMS microphone captures ambient audio and transmits it digitally to the ESP32 microcontroller using the I²S interface.
- Real-Time Audio Processing: The ESP32 performs digital signal processing to reduce background noise and isolate useful speech signals.
- Volume Protection Mechanism: The ESP32 monitors the amplitude of the audio and dynamically limits the gain to prevent sudden loud noises from reaching the user.
- Audio Amplification: The processed audio is sent to the PAM8403 Class-D amplifier, which boosts the signal strength.
- Output to Speaker: The amplified and filtered sound is delivered to the speaker, allowing the user to hear clear and comfortable audio in real time.

III. RESULTS

The prototype successfully achieved real-time noise suppression in moderately noisy environments and prevented abrupt sounds from reaching the output.

Testing was conducted in environments with varying background noise, and the system maintained clarity and consistent output volume. The response time of filtering and gain control was measured in milliseconds, ensuring minimal perceptible delay. Power consumption was within acceptable limits, supporting 5+ hours of battery life.

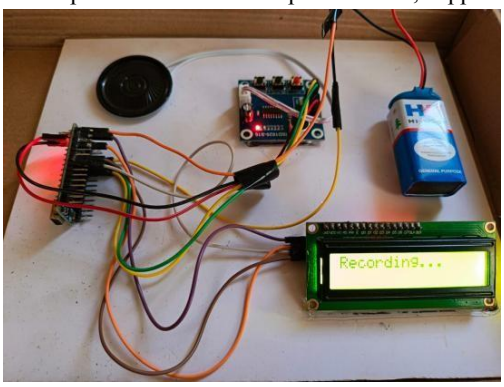

Fig. 2 Prototype Recording phase

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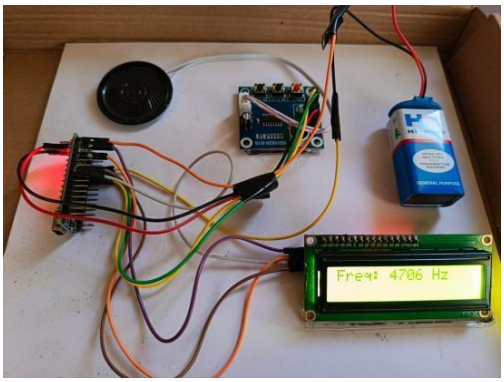

Fig. 3 Output along with Frequency Display

IV. DISCUSSION

- Enhanced Speech Clarity: The implementation of real-time noise filtering significantly improves speech intelligibility by suppressing background noise, especially in dynamic environments like streets, classrooms, or public gatherings.
- Volume Safety Mechanism: The automatic volume regulation ensures user protection from sudden loud noises, reducing the risk of further.
- Cost-Effectiveness and Accessibility: The use of readily available, low-cost components like ESP32, INMP441, and PAM8403 makes the device both affordable and scalable, making it a viable solution for low-income users.
- Real-Time Performance: Despite using minimal hardware, the system maintains real-time audio processing with low latency, demonstrating the capability of embedded systems in biomedical assistive technology applications.

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V. CONCLUSION AND RECOMMENDATIONS

Conclusion:

The developed hearing aid system provides a practical and cost-effective solution for individuals with hearing loss. By integrating noise filtering and volume protection mechanisms, it ensures improved speech intelligibility and user comfort. Its compact design and efficient performance make it suitable for everyday use in real-world conditions.

Recommendations:

- Future versions can incorporate machine learning algorithms for adaptive noise cancellation.
- A rechargeable dock or solar charging can extend usability.
- Custom molds for ear-fitting and improved audio isolation can enhance user experience.
- Integration with mobile apps for customizable settings and hearing profiles is recommended.

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