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Smart Assistive Hearing Device with Adaptive Sound Profiling

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Abstract: Hearing loss is a growing global health concern that affects millions of people and significantly impacts their ability to communicate and interact with society. Conventional hearing aids primarily amplify all sounds in the environment, including unwanted background noise, which reduces their effectiveness in real-world situations such as classrooms, busy streets, or social gatherings. To overcome these limitations, this project presents the design and development of an AI-powered smart hearing aid system that leverages artificial intelligence (AI) and digital signal processing (DSP) to selectively enhance speech and suppress noise.The proposed system uses a MEMS microphone to capture ambient sound, which is processed by a NodeMCU/ESP32 microcontroller equipped with DSP techniques and lightweight AI algorithms for noise cancellation, speech detection, and adaptive amplification. The processed audio is then wirelessly transmitted to Bluetooth-enabled earbuds, ensuring comfort and ease of use without the need for custom hardware receivers. The system further integrates environment-aware sound profiling, enabling it to automatically adapt to different acoustic environments. Additionally, features such as health monitoring (heart rate and activity tracking) and fall detection with alert notifications are included to enhance safety and usability, particularly for elderly users. By combining low-cost electronic components, wireless communication, and machine learning-based sound enhancement, this project aims to create an affordable, portable, and intelligent alternative to traditional hearing aids. The developed prototype not only addresses the limitations of existing devices but also provides a platform for further innovations in personalized hearing solutions and assistive healthcare technologies.

Index Terms – Smart hearing aid, Artificial intelligence, Digital signal processing, Noise cancellation, Speech enhancement, ESP32, MEMS microphone

I. INTRODUCTION

Hearing impairment is a prevalent global health concern that significantly limits effective communication across diverse acoustic environments. Conventional hearing aids primarily employ uniform amplification of incoming sounds, which often results in the unintended amplification of background noise, reduced speech intelligibility, and listening discomfort in dynamic scenarios such as traffic, crowded public spaces, and indoor social gatherings. These devices generally lack the capability to distinguish between speech and non-speech components of audio signals, making it difficult for users to engage in clear conversations in noisy surroundings [1]. Additionally, frequent manual adjustments are required to cope with changing noise conditions, reducing usability and user convenience. Existing hearing assistance systems also suffer from the absence of intelligent sound classification, environmental awareness, and user-specific adaptation. As a result, users often experience listening fatigue due to prolonged exposure to amplified ambient noise[2].

The lack of learning capability further prevents these devices from adapting to individual preferences and commonly encountered acoustic environments over time. Such limitations highlight the need for an advanced assistive solution that goes beyond basic amplification and incorporates intelligent audio processing mechanisms.Integrating artificial intelligence (AI) and digital signal processing (DSP) techniques into hearing aid systems offers the potential to address these challenges through real-time acoustic scene analysis, adaptive sound profiling, and selective speech enhancement[3]. A smart hearing aid capable of automatic noise suppression, speech prioritization, and environment-aware adjustments can significantly enhance speech clarity, user comfort, and overall communication effectiveness for individuals with mild to moderate hearing loss. By transforming traditional hearing assistance into an intelligent, context-aware, and user-centric solution, such systems can substantially improve the quality of life for users while paving the way for future innovations in assistive auditory technologies. Fig.1 illustrates the block diagram of the proposed Smart Hearing Device, depicting the flow of audio signals from capture through pre-processing, sound classification, noise reduction, beamforming, and adaptive gain control, along with feedback cancellation, user profiling, mobile app connectivity, and optional cloud integration[4].

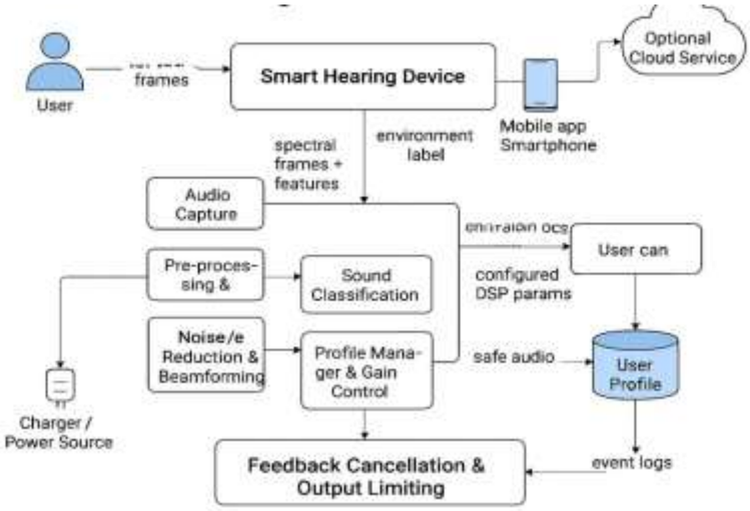

Fig.1 Data Flow Diagram of Smart Hearing Device

II. LITERATURE SURVEY

Research in hearing assistive technology has progressed from simple sound amplification to advanced digital signal processing (DSP) aimed at improving speech clarity in noisy environments. Early hearing aids relied on linear amplification and basic feedback control, which often amplified background noise along with speech.Modern systems incorporate DSP techniques such as adaptive filtering, multiband compression, noise reduction, and beamforming to improve the signal-to-noise ratio [5-4]. Recent studies have explored the use of artificial intelligence (AI) and machine learning for speech enhancement, noise classification, and environment-aware sound adaptation, enabling automatic adjustment of hearing aid parameters without manual intervention.Wireless connectivity and mobile integration have further enhanced usability by allowing remote configuration and real-time monitoring [6-7]. Additionally, the integration of wearable sensors for health monitoring and fall detection reflects the trend toward multifunctional assistive devices [9-10]. These advancements highlight the need for low-cost, embedded AI solutions capable of real-time audio processing for smart hearing aid applications.

III. SMART ASSISTIVE HEARING DEVICE WITH ADAPTIVE SOUND PROFILING

Fig.2 The Smart Hearing Aid Dashboard provides a real-time monitoring and control interface for the device. It displays live ambient noise levels, heart rate, body temperature, and battery status, along with an ECG waveform and current GPS location on a map. The dashboard also shows recent event logs, including speech-to-text outputs, and supports speech translation with replay functionality. Control options such as diagnostics, simulation, and speech testing enable easy system interaction, while Firebase connectivity ensures instant data synchronization between the device and the user interface.

Fig.2 Smart Assistive Hearing Device With Adaptive Sound Profiling Dashboard

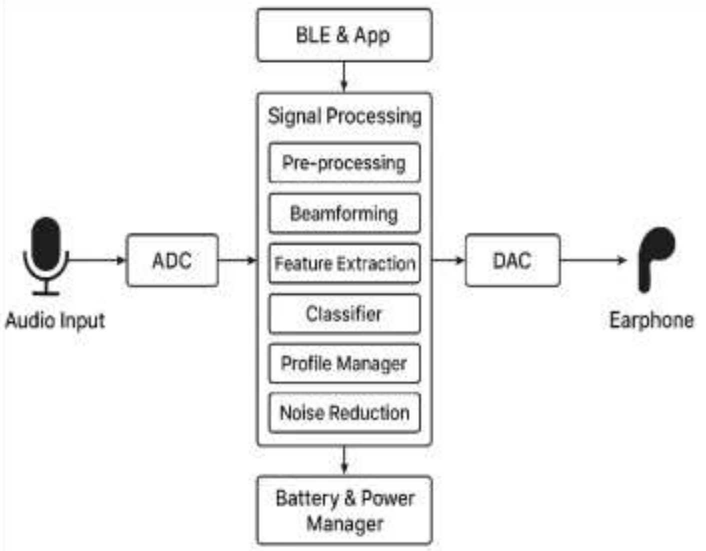

Fig.3 Flow chart for Hearing Aid

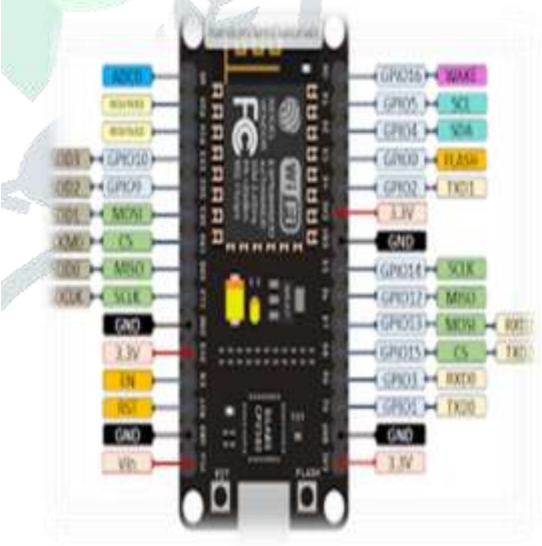

Fig.4 NodeMCU

Fig.3 which shows the flow chart represents the signal processing pipeline of the smart hearing aid, showing how audio is captured, digitized, processed through DSP and AI modules, and converted back to analog sound for output to the earphone, with BLE app control and power management.

Fig.4 shows the NodeMCU is an open-source IoT platform based on the ESP8266 Wi-Fi module. It includes firmware that runs on the ESP8266 and a hardware development kit that allows easy prototyping of IoT applications. It supports the Lua scripting language and can also be programmed using the Arduino IDE, making it beginner-friendly.

IV. RESULTS AND DISCUSSION

Initial testing of the system was conducted using simulated sensor data uploaded to Firebase along with live streaming values from the microcontroller prototype, while both desktop and mobile browsers were used to verify the user interface. The results demonstrated that Firebase listeners synchronized data within milliseconds, ensuring real-time updates. The ECG graph displayed smooth visualization after optimizing the buffer size and refresh rate. Fall detection alerts were triggered instantly on the dashboard, and the location marker accurately updated on the map when new coordinates were received. Additionally, the speech-to-text interface correctly displayed text transmitted from the backend, confirming reliable data communication and visualization across the system.

V. CONCLUSION AND FUTURESCOPE

This paper present the design and development of an AI-powered smart hearing aid system that addresses the limitations of conventional hearing devices by incorporating digital signal processing and lightweight artificial intelligence techniques. The system successfully demonstrated real-time speech enhancement, noise suppression, and environment-aware sound adaptation using an ESP32-based embedded platform and a MEMS microphone. Wireless audio transmission to Bluetooth earbuds improved user comfort and portability, while additional features such as health monitoring, fall detection, and location tracking enhanced user safety and usability. Experimental testing confirmed reliable data synchronization, smooth audio processing, and effective system responsiveness across the hardware and user interface, validating the feasibility of a low-cost, intelligent hearing assistance solution.

The proposed system can be further enhanced by integrating advanced deep learning models for more accurate speech separation and noise classification. Miniaturization of hardware into a compact wearable form factor and optimization for lower power consumption can improve practicality for daily use. Future work may also include personalized hearing profiles based on audiogram data, cloud-assisted model updates, and mobile app-based fine-tuning of audio parameters. Incorporating multi-microphone arrays for improved beamforming and expanding health monitoring capabilities can transform the device into a comprehensive assistive wearable for elderly and hearing-impaired users.

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