Enhanced Auditory Experience for Hard-of-Hearing People in Multi-Speaker Environments through Selective Sound Amplification

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Declaration

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This is to certify that this dissertation is based on the work of,

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under my supervision. The thesis has been prepared according to the format stipulated and is of acceptable standard.

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Abstract

Hearing loss remains a significant global health concern, affecting communication, quality of life, and cognitive function of individuals. Traditional hearing aids, though clinically effective, often remain underutilized due to high cost, limited accessibility, social stigma, and their inadequacy in handling real-world listening environments. These devices typically offer general sound amplification without the ability to distinguish between relevant and irrelevant audio sources. As a result, users frequently experience difficulty engaging in conversations within multi-speaker or noisy settings, leading to frustration and abandonment of assistive technology. Existing mobile applications, although more affordable and accessible, largely replicate this indiscriminate amplification approach and provide only basic noise suppression.

This research addresses these shortcomings by proposing a smartphone-based hearing aid application that integrates selective sound amplification with advanced noise reduction. The system utilizes speaker diarization and identification technologies to isolate and enhance the voice of a desired speaker while suppressing background noise and competing voices. Deep learning-based models for voice activity detection and real-time noise suppression are incorporated to optimize intelligibility and listening comfort. In parallel, a user-centric interface was developed to enable intuitive configuration of amplification preferences, facilitating ease of use among individuals with limited technical experience.

The study employed a Systems Development Research approach, combining empirical investigation with iterative system design and evaluation. The research context focused primarily on university students with mild to moderate hearing impairment, a population chosen for their frequent exposure to challenging auditory environments such as classrooms and lecture halls. Participants were recruited from the Centre for Disability Research, Education and Practice, University of Colombo, and their experiences, challenges, and feedback directly informed system development.

The application was evaluated through acoustic measurements and structured user studies, incorporating quantitative ratings and qualitative interviews to gather comprehensive insights. Results demonstrate substantial improvements in speech clarity, background noise management, and overall satisfaction when compared with existing free applications. By overcoming the limitations of both traditional and smartphone-based hearing solutions, this study introduces a practical and scalable approach to auditory support. The proposed system offers a meaningful contribution to the field of mobile hearing technology by delivering personalized amplification in dynamic, real-world environments. These findings pave the way for further innovation in intelligent hearing support systems that are accessible, adaptable, and capable of enhancing daily communication for the hearing impaired.

Acknowledgement

It is with deep appreciation that we acknowledge those who made this research possible. We owe our deepest thanks to our research supervisor, Dr. T.A.Weerasinghe, Senior Lecturer at the University of Colombo School of Computing, for guiding us from the outset, challenging us to pursue thorough questioning, and providing continuous, insightful feedback. Your expertise and mentorship have been the cornerstone of this project's success. Our sincere gratitude goes to Dr. Nilantha Imbulpitiya, Consultant ENT Surgeon at the Ministry of Health, for generously sharing your clinical expertise and steering us through the medical dimensions of hearing impairment. We are also indebted to Dr.Pathmakumara Jayasingha, Director of the CEDREP at the University of Colombo, and Mr. Buddhika Dissanayake, Manager of CEDREP at University of Colombo for facilitating our connection with the student participants and serving as steadfast supporters of this endeavour. To the students who participated in the design workshop and the final evaluation, we extend our heartfelt appreciation. Your active engagement, thoughtful feedback, and enthusiasm were indispensable to the depth and applicability of our findings. Finally, we wish to thank our families and friends for their unwavering encouragement, belief in our abilities, and constant support throughout this journey. Your patience and understanding sustained us through every challenge.

Table of Contents

List of Figures

List of Tables

List of Acronyms

AI Artificial Intelligence

BTE Behind-The-Ear (Hearing Aid)

CPU Central Processing Unit

DNN Deep Neural Network

DSP Digital Signal Processing

GRU Gated Recurrent Unit

IEEE Institute of Electrical and Electronics Engineers

RNN Recurrent Neural Network

RNNoise Recurrent Neural Noise Suppression Model

SHAA Smartphone-Based Hearing Aid Application

SNR Signal-to-Noise Ratio

UI User Interface

VAD Voice Activity Detection

WHO World Health Organization

Chapter 1 introduces the background and motivation for this research, highlighting the challenges faced by individuals with hearing loss in complex listening environments. It outlines the problem statement, research questions, and objectives, and describes the research approach, scope, and key contributions. This chapter sets the stage for the detailed exploration and solutions presented in the subsequent chapters.

Chapter 1

Introduction

Chapter 1 introduces the background and motivation for this research, highlighting the challenges faced by individuals with hearing loss in complex listening environments. It outlines the problem statement, research questions, and objectives, and describes the research approach, scope, and key contributions. This chapter sets the stage for the detailed exploration and solutions presented in the subsequent chapters.

1.1 Problem Statement

Hearing loss affects over 1.5 billion people globally, with estimates suggesting that this number could rise to 2.5 billion by 2050 [1]. Defined as a reduced hearing threshold below 20 dB, hearing impairment substantially impairs effective communication, thereby influencing educational, social, and occupational functioning. For example, it is reported that university students depend on auditory input for more than 50% of classroom communication time, illustrating the critical role hearing plays in academic performance [2]. Beyond educational contexts, adults with hearing loss are nearly twice as likely to experience unemployment or underemployment compared to individuals with normal hearing [1]. As a widely recommended intervention, hearing aids (HAs) have proven effective in improving auditory perception, social interaction, and quality of life [3, 4]. Nevertheless, global adoption remains low, where only around 17% of individuals who would benefit from hearing aids actually use them [5, 6].

Several barriers hinder the widespread uptake of traditional HAs. Most common among these are prohibitive costs, continuous battery-related expenses, the need for professional fitting and tuning by audiologists, and the stigma often associated with visible, bulky devices [7, 8]. These constraints have given rise to interest in more accessible alternatives, notably smartphone-based hearing aid applications (SHAAs). SHAAs leverage the signal processing capabilities of smartphones and headphones to offer basic amplification functionality, for free or at a subscription cost [9, 10]. Their affordability compared to traditional hearing aids, portability, and ease of access make them an attractive option for populations underserved by traditional hearing health services. However, SHAAs are not without limitations. Advanced features such as noise cancellation, adaptive equalisation, or environment-specific presets are frequently gated behind paid tiers, restricting full functionality to a subset of users [11]. Additionally, many of these applications feature unintuitive interfaces and offer limited customizability, presenting usability challenges for elderly users or individuals with limited digital literacy [12].

Critically, both traditional hearing aids and SHAAs typically operate on the principle of indiscriminate amplification, by enhancing all incoming sounds uniformly, regardless of their source. In the absence of an effective noise reduction feature, SHAAs often amplify not only speech but also background environmental noise, including air conditioners, traffic, construction sounds, and even electrical feedback. This results in an overwhelmingly loud and uncomfortable auditory experience, especially in dynamic acoustic environments. Users are frequently left struggling to distinguish between relevant and irrelevant sounds, leading to listening fatigue, communication breakdowns, and eventual disuse of the technology. Studies have shown that while SHAAs may improve audibility in quiet conditions, their effectiveness diminishes considerably in real-world, noisy settings due to their inability to perform speaker-specific amplification or contextual audio filtering [11, 13].

Despite advances in audio signal processing, voice activity detection, and deep learning-based noise suppression, only few practical software solutions currently exist that combine speaker identification and real-time adaptive noise reduction within a mobile application framework. Most apps enhance or attenuate audio based on volume thresholds or fixed frequency ranges, failing to adapt to nuanced acoustic changes such as speaker shifts or environmental transitions. Moreover, while some recent research has proposed the integration of speaker diarization and intelligent audio routing into hearing solutions, none have been translated into mobile platforms that are both computationally efficient and user-friendly for everyday use.

This research aims to bridge this gap by developing a smartphone-based hearing aid application that addresses these unmet needs. The system will incorporate speaker diarization and identification mechanisms to isolate and prioritise a user-selected speaker in real time. Additionally, it will integrate advanced noise suppression models to minimise environmental noise and competing speech, while providing users with an intuitive interface for personalising amplification settings. Through this approach, the proposed system seeks to deliver a more focused, intelligible, and comfortable auditory experience, particularly in real-world, multi-speaker settings. By addressing both the technological limitations of current SHAAs and the practical barriers of traditional hearing aids, this study endeavours to offer a scalable, cost-effective, and user-friendly alternative for individuals with mild to moderate hearing impairment.

1.2 Research Questions

This study is guided by the need to improve the auditory experience of individuals with hearing impairment, particularly in complex, multi-speaker environments. Traditional hearing aids and existing mobile applications typically amplify all environmental sounds without distinction, often including irrelevant or disruptive noise. This indiscriminate amplification can cause user discomfort, listening fatigue, and reduced speech intelligibility in daily conversations. To address these limitations, the following research questions have been formulated to shape the direction and scope of the study.

Primary Research Question

How can an application be developed to effectively identify and selectively amplify individual sound sources in multi-speaker environments?

The central aim of this research lies in the development of a real-time auditory support system that moves beyond generalised amplification. The solution should be capable of recognising distinct audio sources, especially speech, and selectively amplifying the most relevant signals based on user context. This question encompasses both the technical feasibility and design challenges involved in building such an application, while maintaining accessibility and efficiency on a mobile platform.

Sub-Questions

Q1. What existing technologies and approaches are the most effective for speaker audio classification, selective amplification, and enhanced noise suppression?

This question aims to investigate the current landscape of audio processing techniques that support the classification and separation of sound sources. The focus is on identifying which techniques and algorithms of existing technology such as speech segmentation, noise suppression, or source separation are most suitable for selectively enhancing speech in the presence of background noise or multiple competing voices. It also involves evaluating these methods in terms of practicality, responsiveness, and potential for real-time integration within a smartphone environment.

Q2. How can a hearing aid application with selective sound amplification improve upon the usability of current free applications for the hearing impaired?
Although mobile-based hearing assistance tools are becoming more common, many are plagued by poor usability and minimal customisation options. This question seeks to explore how user experience can be improved by designing a more intuitive and accessible interface. It also involves understanding the limitations of current applications in terms of ease of use, feature accessibility, and interface clarity, especially for users with limited technical skills. The goal is to ensure that technical enhancements are matched by an equally strong focus on user interaction.

Q3. To what extent can an application providing selective amplification deliver a better auditory experience in multi-speaker environments?
The final sub-question addresses the core impact of the proposed solution. It investigates whether selectively amplifying relevant speech sources leads to measurable improvements in users' ability to comprehend conversations and navigate noisy environments. Evaluation will be based on both subjective measures, such as user feedback and perceived benefit, and objective indicators, such as speech clarity and noise suppression effectiveness. This will help determine the real-world value of selective amplification in comparison to existing solutions.

Together, these questions form a comprehensive framework for exploring the technical, practical, and experiential dimensions of hearing support in multi-speaker settings.

1.3 Goal and Objectives

This research aims to develop a mobile-based hearing support system that addresses the shortcomings of existing hearing aid technologies by enabling selective sound amplification and advanced noise suppression in real-world, multi-speaker environments. The study investigates how advanced audio processing and user-centred interface design can be combined to improve speech intelligibility and user experience for individuals with hearing impairments.

Goal

The main goal of this study is to design and propose a software-based solution that improves the clarity of speech in environments with multiple simultaneous speakers by selectively amplifying relevant auditory signals while suppressing unwanted background noise, while also providing a cost-effective and accessible alternative to traditional hearing aids and ensuring ease of use for individuals with varying levels of digital literacy.

This goal is based on addressing the practical challenges encountered by users of both conventional hearing aids and smartphone-based hearing aid applications, particularly in terms of effectiveness, usability, and affordability.

Objectives

To achieve the above goal, the study defines the following specific objectives.

RO1 – To investigate and identify suitable approaches for speaker identification, selective sound amplification, and noise suppression.
This involves conducting a thorough review of relevant techniques and systems that enable the separation and enhancement of individual speech signals from background noise. The outcome of this investigation will guide the technical direction of the system's development phase.

RO2 – To design a user interface that facilitates intuitive configuration and control of selective amplification features.
This objective aims to ensure that the system remains accessible to a wide range of users, including those with minimal experience using digital tools. Special attention will be given to simplicity, clarity, and adaptability of the interface to match the hearing preferences and capabilities of individual users.

RO3 – To evaluate the effectiveness of the proposed solution in improving auditory experiences in dynamic acoustic conditions compared to other existing applications.
This includes testing the system's ability to enhance speech intelligibility and suppress unwanted noise in real-world environments compared to other solutions. Both quantitative metrics and qualitative feedback from hearing-impaired users will be collected to assess overall performance and user satisfaction.

1.4 Research Approach

This study follows the Systems Development Methodology proposed by Nunamaker et al. [10], which is widely recognised in information systems research for combining both system creation and academic inquiry. This methodology supports the development of practical technological artefacts while allowing researchers to analyse and evaluate their impact through iterative design and testing. It is particularly suitable for this research, which involves both the conceptualisation and development of a novel smartphone-based hearing support application. The methodology consists of five interconnected phases, each contributing to specific stages of the system's development and addressing distinct research questions formulated in Section 1.2. The five structured steps are conceptual framework construction, developing a system architecture, analyze and designing the system, build the system, and system evaluation which are discussed in detail in Chapter 4: Methodology.

Through this structured and iterative methodology, the study ensures that both technological and human factors are comprehensively addressed. Each phase builds upon the insights and outputs of the previous one, resulting in a rigorously designed and practically validated solution aimed at improving hearing accessibility in complex, real-world environments.

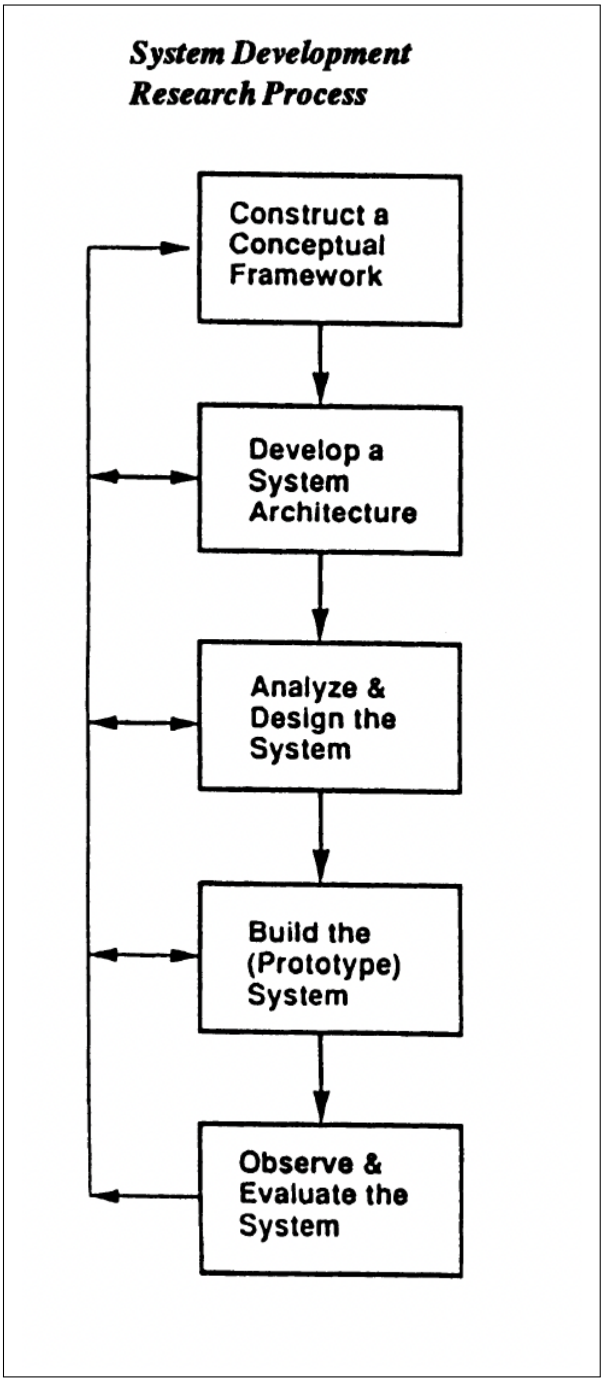


Figure 1.1: Research Approach Overview

1.5 Delimitations, Scope and Assumptions

This section outlines the contextual boundaries and foundational assumptions of the study. It also recognises inherent limitations that may influence the development, evaluation, and generalisability of the proposed hearing aid application.

1.5.1 Delimitations

While the proposed system aims to address key shortcomings in current hearing support technologies, several limitations are acknowledged:

- **Hardware Dependence -** The system is designed to operate on commercially available smartphones using standard wired or wireless earphones. The quality of sound capture and playback may vary depending on the device's hardware specifications, including microphone sensitivity and speaker output capabilities.

- **User Testing Scope -** Evaluation was conducted in a typical environment where the user focused on a lecturer in the presence of background noise. While this scenario represents real-world challenges in educational settings, it may not fully reflect the system's performance in more dynamic or unstructured environments such as outdoor public spaces or social gatherings.

- **Algorithmic Generalisability -** The system leverages an existing deep neural network (DNN)–based algorithm for noise reduction and speaker diarization, selected based on suitability for mobile deployment. However, as these technologies are still evolving, their performance may vary across different conditions, including speaker variability, acoustics, and unseen environmental factors.

1.5.2 Scope

The scope of this study is confined to the design, development, and evaluation of a smartphone-based hearing aid application that provides selective sound amplification in multi-speaker environments. Specifically, the study addresses the following,

- Investigating challenges faced by hearing-impaired individuals in real-world auditory environments.

- Designing a conceptual framework and system architecture tailored to mobile platforms.

- Prototyping a smartphone application that integrates selective amplification and noise reduction using established DNN-based approaches.

- Evaluating usability and performance in structured, simulated environments, particularly classroom-like acoustic settings.

The study does not include long-term clinical trials, integration with medical-grade hearing aids, or development for non-mobile platforms.

1.5.3 Assumptions

This study proceeds with the following assumptions to maintain practical focus during system design and testing:

- Users will have access to a modern smartphone and compatible earphones or headsets.
- The primary user group will consist of individuals with mild to moderate hearing loss. The system is not intended to replace advanced medical-grade hearing aids.
- Testing environments will allow for controlled evaluations with moderately stable background conditions, such as those found in classrooms.
- Participants in user testing will provide honest and reflective feedback, enabling an accurate assessment of usability and performance.
- The selected DNN algorithms will perform adequately under mobile hardware constraints and standard audio input quality.

These assumptions help define the operational boundaries of the project and ensure that system development and evaluation remain feasible and goal-oriented.

1.6 Contributions

This thesis makes several key contributions to the field of hearing assistance technology, specifically in the context of selective sound amplification using mobile platforms. The main research contributions are outlined below.

- A structured literature review on hearing aids, smartphone-based hearing solutions, and audio processing techniques A comprehensive review of existing hearing technologies was conducted to understand their strengths, limitations, and suitability for real-time, selective amplification in multi-speaker environments. This review highlighted the gap in speaker-specific amplification and limitations in noise reduction, forming the foundation of the study.
- A comparative analysis of existing mobile hearing aid applications The study systematically compared cost, usability, amplification strategies, feature availability, and user experience. It identified critical shortcomings such as indiscriminate sound amplification and limited accessibility to advanced features like noise cancellation, even in well-performing applications.

- Development of a conceptual framework for selective amplification in multi-speaker environments Based on the identified gaps, a framework was constructed to guide the development of a mobile application that integrates selective amplification, noise reduction, and user-friendly controls tailored to real-world auditory challenges faced by hearing-impaired users. This framework may also assist future developers integrating emerging algorithms into similar architectures.

- Design and implementation of a mobile-based hearing aid application A working prototype was developed that applies speaker diarization and noise suppression through a DNN-based model. The application allows users to focus on a selected speaker and reduce background noise, offering an accessible and practical alternative to conventional hearing aids.

- Formulation of design guidelines for mobile hearing support applications Based on development challenges and user interactions, the study identified practical design considerations to improve future solutions, including interface simplicity, configurability, and clarity of auditory control.

- Reflections and lessons learned throughout the research process The study presents reflective insights gathered across all stages, from requirement gathering and model selection to interface prototyping and user testing. These include challenges in balancing model performance with device limitations, the importance of inclusive UI design for accessibility, variability in user expectations, and the value of scenario-driven evaluation in generating actionable feedback. These reflections contribute to both methodological development and practical improvements in hearing aid research.

1.7 Thesis Outline

This thesis comprises of seven main chapters and the next chapters are organized as follows. Chapter 2 presents a detailed literature review, analysing prior work related to hearing loss, assistive technologies, smartphone-based hearing applications, and technical methodologies such as speaker diarization and noise suppression. Chapter 3 describes the research methodology, outlining the systems development research approach, the preliminary user studies, and the evaluation framework. Chapter 4 focuses on the design and development process, detailing the construction of the conceptual framework, system architecture, user interface design, and implementation strategies. Chapter 5 presents the results and evaluation, including quantitative and qualitative user feedback and system performance metrics. Chapter 6 discusses the research findings in relation to the objectives and research questions, offering a critical interpretation of the results. Finally, Chapter 7 outlines the recommendations, limitations, and proposed directions for future work based on the study's outcomes.

Chapter 2

Literature Review

This chapter examines existing research and technologies relevant to this study. It begins with the nature and classification of hearing loss and its impact on communication and quality of life. Traditional hearing aids are reviewed, along with their benefits and limitations, followed by an analysis of SHAAs and their current challenges. The chapter also explores advanced audio processing techniques such as noise reduction, speaker diarization, and machine learning, identifying key gaps that inform the design and development strategies in later chapters.

2.1 Overview of Hearing Loss and Assistive Technologies

Hearing loss is one of the most widespread sensory impairments globally, affecting individuals across all age groups and contributing significantly to communication difficulties, reduced quality of life, and cognitive decline. According to the World Health Organization (WHO), more than 1.5 billion people live with some degree of hearing loss, and this number is expected to rise to 2.5 billion by 2050 due to population ageing and increased exposure to risk factors such as occupational noise and untreated ear conditions [1]. Medically, hearing loss is defined as a reduction in hearing sensitivity below 20 decibels (dB), measured through pure-tone audiometry (PTA).

Clinically, hearing loss is categorised into three main types: conductive, sensorineural, and mixed. Conductive hearing loss typically results from obstructions or dysfunction in the outer or middle ear that impede sound transmission. Sensorineural hearing loss, the most prevalent form, is due to damage to the cochlea or auditory nerve and is often permanent. Mixed hearing loss combines elements of both. The severity of hearing loss is classified based on the average hearing threshold across key frequencies (500 Hz, 1000 Hz, 2000 Hz, and 4000 Hz) in the better ear, as summarised in Table 2.1.

Table 2.1: WHO Grades of Hearing Loss (Better Ear) [1]

Grade	**Hearing Threshold (dB)**
Normal	¡ 20 dB
Mild	20–34 dB
Moderate	35–49 dB
Moderately Severe	50–64 dB
Severe	65–79 dB
Profound	80–94 dB
Complete / Deafness	$\geq$ 95 dB

Beyond the pure loudness dimension, hearing loss can also vary across frequency ranges. High-frequency hearing loss, in particular, impairs the perception of consonants such as "s," "f," and "th," which are critical for speech intelligibility [14]. Standard amplification that boosts all frequencies equally may introduce discomfort without effectively restoring intelligibility, leading to the need for frequency-specific amplification strategies [15].

Traditional hearing aids (HAs) have long served as primary tools for managing hearing deficits, particularly among individuals with mild to moderate sensorineural loss. These devices typically amplify environmental sounds through directional microphones, digital signal processors, and compression techniques to enhance speech understanding in different acoustic settings [8, 7]. However, despite their clinical effectiveness, traditional hearing aids remain underutilised due to barriers such as high cost, limited accessibility, social stigma related to device visibility, and their limited performance in complex real-world environments [6, 3, 9].

To address these gaps, Smartphone-Based Hearing Aid Applications (SHAAs) have gained increasing attention. These applications leverage the computational capabilities of modern mobile devices to offer hearing support functionalities, often at a significantly lower cost than conventional aids [2]. Nevertheless, most SHAAs replicate basic amplification approaches without offering true selectivity or advanced noise suppression, thus failing to solve the critical problems faced in noisy and multi-speaker environments.

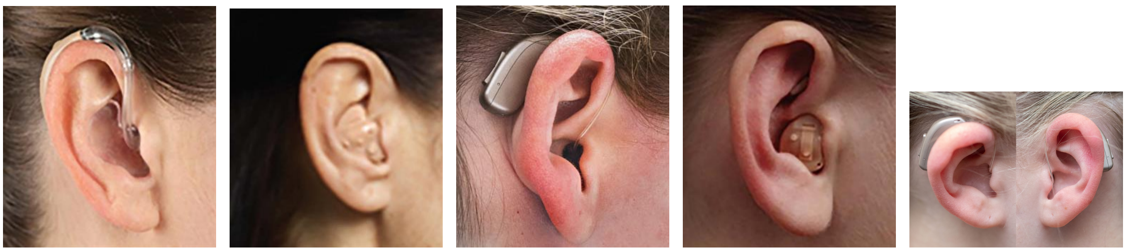
Understanding the complex nature of hearing loss, both in terms of amplitude and frequency dependency, as well as the practical limitations of existing assistive technologies, lays the foundation for designing more effective, intelligent, and accessible mobile hearing solutions.

2.2 Traditional Hearing Aids

Traditional hearing aids have long served as the principal assistive technology for individuals with hearing impairment. These devices aim to restore auditory perception by amplifying environmental sounds, particularly speech, to compensate for reduced hearing sensitivity. Over decades of clinical development, hearing aids have evolved from analogue amplifiers to sophisticated digital systems capable of signal processing, adaptive gain control, and multi-band frequency shaping [16].

A conventional hearing aid consists of four core components: a microphone that captures ambient sound, an amplifier that increases the intensity of the signal, a digital signal processor (DSP) that modifies the signal based on individual hearing profiles, and a receiver (or speaker) that delivers the processed sound into the user's ear. Modern hearing aids may also incorporate advanced features such as noise suppression, directional microphones, automatic scene detection, and wireless connectivity for streaming audio from external devices.

There are several form factors for hearing aids, including behind-the-ear (BTE), in-the-ear (ITE), in-the-canal (ITC), and completely-in-canal (CIC) styles. While functionally similar, the choice among these types depends on the severity of hearing loss, user preference, cosmetic concerns, and physical dexterity. Regardless of the form, most devices are professionally fitted by an audiologist, who programs the device using the user's audiogram and adjusts the frequency gain levels accordingly.



BTE ITE RITE ITC CROSS

Figure 2.1: Different Types of Hearing Aids: BTE, ITE, RITE, ITC, and CROSS

Despite their clinical effectiveness, the adoption of traditional hearing aids remains surprisingly low. According to the World Health Organization, only an estimated 17% of individuals who could benefit from hearing aids actually use them [1]. Several barriers contribute to this underutilisation:

- **Cost**
  Hearing aids are often expensive, with prices ranging from several hundred to several thousand dollars per device. In many countries, they are not covered by insurance or public healthcare schemes.

- **Stigma and visibility**
  The physical visibility of some hearing aids can be associated with ageing or disability, leading to social stigma, especially among younger users.

- **Accessibility and maintenance**
  The requirement for professional fitting, calibration, and periodic maintenance may be burdensome for users living in remote or resource-limited regions. Regular battery replacements and cleaning also add to the maintenance overhead.

- **Performance in complex environments**
  Although advanced models include noise reduction and directional microphones, traditional hearing aids may still struggle in environments with multiple simultaneous speakers or unpredictable background noise, such as classrooms, meetings, or public spaces.

A key limitation of many traditional hearing aids is their default approach to amplification. While they are programmable to apply different gain levels across frequency bands, this programming is usually static and does not respond dynamically to rapid changes in the auditory environment. As a result, many users still experience discomfort or reduced clarity in complex listening situations where speaker location, noise levels, or sound sources fluctuate frequently [17].

These constraints have driven the emergence of alternative hearing support technologies, particularly smartphone-based hearing aid applications (SHAAs). These mobile solutions aim to offer more accessible, adaptable, and user-controlled options for individuals seeking auditory assistance without the high cost or clinic-based requirements of conventional devices. The next section explores these applications in detail and evaluates their potential to bridge the gap between affordability, usability, and functionality.

2.3 Smartphone-Based Hearing Aid Applications (SHAAs)

Modern smartphones possess sufficient computational power, built-in microphones, and signal processing capabilities to serve as viable platforms for hearing assistance. Smartphone-based hearing aid applications (SHAAs) leverage these features to emulate functionalities traditionally offered by medical-grade hearing aids, providing a low-cost, accessible alternative [9]. By utilising devices already owned by users, SHAAs significantly reduce the cost and accessibility barriers associated with conventional devices.

SHAAs can be broadly categorised into three types: audiometry apps, hearing aid control apps, and full-function hearing aid emulation apps. Audiometry apps facilitate basic hearing threshold testing using pure tone audiometry methods. Control apps allow users to adjust amplification levels, gain, and noise filtering for commercial hearing aids via smartphone interfaces. Full-function SHAAs aim to deliver end-to-end hearing support, including environmental noise reduction, gain control, and sometimes frequency shaping. Notable examples in this category include Petralex, Sound Amplifier, and Hearing Clear [18].

These applications are typically designed to work with standard wired or Bluetooth-enabled earphones, eliminating the need for professional fitting. Many SHAAs empower users to personalise their listening experience by manually adjusting amplification and audio profiles, which can be particularly empowering for individuals who prefer self-management over clinical interventions.

One of the major advantages of SHAAs is affordability. Many applications are free or available at minimal cost, with periodic updates delivered through mobile app stores. This makes SHAAs particularly attractive in low-resource settings and for users who are unable or unwilling to invest in traditional hearing aids.

However, SHAAs face several significant challenges. Most amplify sounds indiscriminately, including irrelevant background noise, making it difficult to isolate speech in noisy or multi-speaker environments [11]. Without sophisticated noise reduction algorithms or speaker differentiation capabilities, users may experience listening fatigue, poor speech intelligibility, and discomfort.

Real-time performance is another critical concern. Studies have shown that while Android smartphones offer broader device coverage, iOS devices generally achieve lower audio latency, a key parameter for ensuring synchronisation between auditory and visual cues [18]. Delays exceeding 125 ms can result in noticeable desynchronisation, negatively affecting the user experience.

Furthermore, many advanced features such as adaptive gain control, directional microphone focus, and real-time noise suppression are often gated behind premium versions, leaving free users with only basic amplification. Electroacoustic evaluations have indicated that while SHAAs may perform comparably to entry-level hearing aids in quiet environments, their effectiveness diminishes substantially in complex acoustic settings [19].

Usability also poses a barrier. Many applications have interfaces that are cluttered, overly technical, or inaccessible to individuals with limited digital literacy, a concern particularly pertinent to elderly users.

Despite these limitations, SHAAs hold considerable promise. With the rapid advancement of mobile processors, artificial intelligence (AI), and real-time audio processing algorithms, future SHAAs could offer intelligent, adaptive hearing support capable of rivaling traditional hearing aids. As research on long-term safety, usability, and effectiveness expands, smartphone-based hearing solutions may increasingly become an integral component of accessible hearing healthcare.

2.4 Challenges in Multi-Speaker Environments

Individuals with hearing impairments frequently encounter substantial difficulties in environments with multiple concurrent speakers, such as classrooms or group discussions. These scenarios are characterised by overlapping speech, fluctuating background noise, and limited visual cues, all of which complicate the task of focusing on a specific speaker. Traditional hearing aids and smartphone-based alternatives often apply uniform amplification across all sounds, resulting in listener fatigue, speech distortion, and reduced comprehension.

A review of existing solutions reveals that many smartphone hearing aid applications have been evaluated under controlled or ideal acoustic conditions, with limited focus on noisy, real-world environments [18]. This limits their utility in practical settings, especially where dynamic speaker transitions and environmental noise are present. Moreover, users have reported concerns regarding the lack of speaker separation, insufficient adaptive functionality, and interface complexity, all of which hinder usability in real-time auditory tasks [18]. These challenges underscore the need for hearing assistance systems capable of selective amplification and environmental adaptability.

2.5 Key Concepts in Audio Processing

Addressing these challenges requires the integration of advanced audio processing components. One such technique is **speaker diarization**, which determines "who spoke when" in an audio stream. By identifying individual speakers in multi-speaker scenarios, diarization enables selective amplification of the desired voice stream. This approach is critical in environments where users must shift attention between speakers. Recent work has demonstrated the effectiveness of diarization systems using clustering and embedding-based techniques to isolate dominant speakers [13].

Another key element is **noise suppression**, which aims to filter background noise while preserving speech. Traditional methods such as spectral subtraction and Wiener filtering have been widely used. However, hybrid systems like RNNoise, which combine deep learning with signal processing, offer improved real-time suppression while maintaining speech intelligibility [20].

Voice Activity Detection (VAD) is used to differentiate between speech and non-speech segments, reducing unnecessary processing and improving system responsiveness. Common VAD approaches include minimum tracking and recursive averaging, which are particularly useful in low-SNR or acoustically variable conditions [15].

Finally, platform considerations, especially in mobile applications, play a vital role. Android devices, while widely adopted, typically introduce higher input/output latency compared to iOS, requiring careful optimisation of buffer size, processing overhead, and audio routing paths to maintain real-time performance [13].

2.6 Signal Processing Techniques for Hearing Enhancement

To replicate the sophistication of conventional hearing aids, SHAAs incorporate advanced digital signal processing (DSP) techniques. These include noise suppression, voice activity detection (VAD), frequency compression, and dynamic range control.

Noise suppression is vital for enhancing the clarity of speech in noisy environments. Algorithms such as generalised spectral subtraction and dynamic quantile tracking have demonstrated improvements of up to 6 dB in signal-to-noise ratio (SNR), thereby improving speech intelligibility for users with sensorineural hearing loss [11].

Voice activity detection helps conserve power and optimise processing by identifying segments of speech and filtering out silence or background noise. Coupled with speaker diarization, it allows SHAAs to focus amplification on a selected speaker, suppressing unrelated voices in multi-speaker environments [12, 13].

Frequency compression is employed to shift inaudible high-frequency sounds into the residual hearing range of the user. Multi-band compression and sliding-band dynamic range compression have proven especially effective in compensating for frequency-dependent hearing thresholds [17, 15].

Applications such as Petralex and uSound have implemented some of these techniques with varying success. However, issues such as limited hardware compatibility, user calibration difficulties, and poor optimisation across devices remain key challenges [9, 18].

2.7 Evaluation and Limitations of Existing Smartphone-Based Hearing Aids

Numerous studies have evaluated the feasibility and effectiveness of SHAAs. A multicentre randomised controlled trial conducted in South Korea compared SHAAs with conventional HAs in patients with mild-to-moderate hearing loss. The study concluded that SHAAs provided significant benefits over unaided listening, especially in quiet environments. However, they fell short in noisy situations and at conversational speech levels compared to traditional HAs [5].

Another review indicated that SHAAs on iOS performed better than Android apps due to better electroacoustic characteristics and lower latency [5]. However, the general lack of standardisation in headphone calibration, hardware variance, and inconsistent signal processing quality across devices limits the replicability and user confidence in these tools.

From a usability perspective, studies also found that many SHAAs fail to provide intuitive interfaces or real-time feedback. While users appreciate features such as audio waveform visualisation, environment-specific modes, and Bluetooth connectivity, most SHAAs lack personalisation options such as audiogram-based gain presets or adaptive speaker tracking [9].

Moreover, electroacoustic benchmarks such as the Real Ear Measurement (REM), Word Recognition Score (WRS), and APHAB metrics suggest that while some SHAAs can approach the performance of HAs in controlled environments, they remain inconsistent in practical deployment, especially under dynamic noise conditions [5, 13].

2.8 Real-Time Noise Suppression Using RNNoise

In real-world auditory environments, especially those encountered by hearing-impaired individuals, background noise poses a substantial barrier to clear communication. Traditional noise suppression techniques often involve spectral subtraction, Wiener filtering, or adaptive algorithms, but these methods can introduce artefacts and degrade speech intelligibility. In recent years, deep learning-based approaches have shown superior performance in separating speech from noise with minimal distortion.

RNNoise, developed by Valin [20], presents a hybrid approach that combines conventional digital signal processing (DSP) techniques with a recurrent neural network (RNN) architecture to achieve real-time, full-band speech enhancement. It was specifically designed to be computationally lightweight, enabling its deployment on resource-constrained devices such as smartphones and embedded systems.

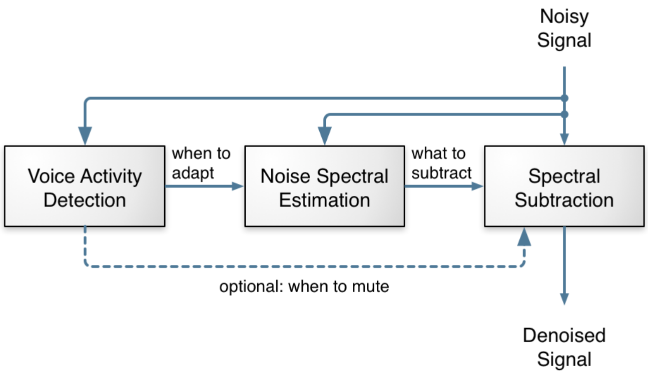


Figure 2.2: Overview of RNNoise Noise Suppression Process

The RNNoise model operates on 20 ms audio frames and uses a gated recurrent unit (GRU) network trained to estimate ideal gain functions for each frequency band. These gains are then applied to the noisy signal to suppress background components while preserving speech content. Unlike purely data-driven models that require extensive computational resources, RNNoise incorporates a traditional DSP front-end for feature extraction, allowing the neural network to focus on learning only the nonlinearities in the noise estimation task.

In the context of hearing aid applications, this efficiency is especially relevant. Unlike models such as DeepMMSE or Conv-TasNet, which often require GPU acceleration, RNNoise can be executed in real time on mobile CPUs, making it ideal for smartphone-based hearing solutions. Valin demonstrated that the model could run on ARM Cortex-A processors at under 10 percent CPU load, confirming its suitability for portable use cases [20].

When integrated into smartphone hearing aid applications, RNNoise significantly improves the signal-to-noise ratio (SNR), particularly in environments with stationary or quasi-stationary noise sources such as fans, traffic, or crowd murmur. It also excels in preserving speech clarity, as it avoids aggressive filtering, a common flaw in many SHAAs that indiscriminately attenuate all high-energy inputs.

In this study, RNNoise was selected to form the core noise suppression component of the audio enhancement pipeline. Its ability to balance noise reduction with low computational overhead makes it a practical and scalable solution for real-time use. Moreover, as shown in comparative evaluations of existing SHAAs like Sound Amplifier and Hearing Clear, the lack of robust adaptive noise suppression has been a primary limitation for users [5, 13].

Therefore, the integration of RNNoise aligns with the system's broader goals to offer an affordable, real-time, and user-centric auditory solution that adapts seamlessly to diverse environmental conditions while maintaining high speech intelligibility.

2.9 Speaker Diarization with Pyannote

One of the critical challenges in developing intelligent hearing aid applications is enabling the system to differentiate and isolate a target speaker in real time, particularly in multi-speaker environments such as classrooms, meetings, or social gatherings. Speaker diarization, the process of partitioning an audio stream into homogeneous segments according to the speaker's identity, has emerged as a promising solution to this challenge.

Among various diarisation toolkits, Pyannote-audio has gained prominence for its robust, end-to-end neural pipeline tailored for speaker diarization tasks. Developed by Bredin et al., Pyannote leverages pre-trained deep learning models to handle voice activity detection, speaker embedding extraction, and clustering, all of which are essential components in accurately attributing speech segments to individual speakers [13].

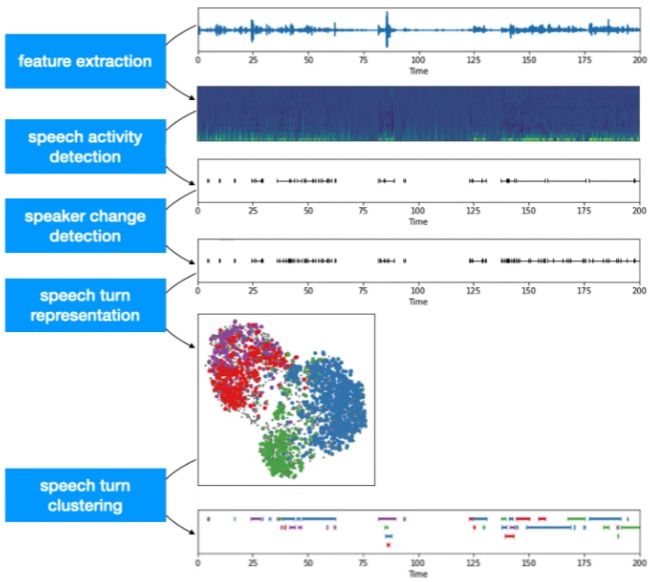


Figure 2.3: Speaker Diarization Pipeline with Pyannote

Pyannote's pipeline begins with detecting segments of active speech using a voice activity detector. These segments are then passed to a speaker embedding model that maps them into a high-dimensional space where utterances from the same speaker are placed closer together. Finally, a clustering algorithm groups these embeddings to identify unique speakers throughout the audio stream. This modular design allows for fine-grained speaker tracking even in overlapping or noisy conditions, which is vital for selective amplification use cases.

The advantages of Pyannote for hearing aid applications are manifold. First, it is open-source and actively maintained, making it an accessible and flexible option for academic and experimental use. Second, the pretrained models are highly generalisable, enabling performance across varied accents, environments, and speech patterns without the need for task-specific training. Most importantly, Pyannote's architecture supports low-latency inference, a crucial requirement for real-time assistive applications such as the one proposed in this research.

Despite its strengths, integration into mobile platforms presents challenges due to computational overhead and the need for real-time processing. However, recent advances in edge AI optimisation and the increasing power of mobile processors make it feasible to implement Pyannote in lightweight settings using quantisation or server-client hybrid architectures.

In the context of this study, Pyannote plays a central role in enabling speaker-specific amplification, allowing users to focus on a particular voice in dynamic group settings while suppressing others. This functionality addresses a core limitation observed in most existing SHAAs, which tend to amplify all sounds indiscriminately and fail to offer real-time speaker control [5, 9].

By integrating Pyannote into the backend audio processing pipeline, the proposed system enhances user experience through selective listening, paving the way for a more natural, personalised, and less cognitively taxing interaction in noisy, multi-speaker environments.

2.10 Summary of the Literature Review and Research Gap

The literature reveals significant advancements in SHAAs, especially in terms of signal processing, accessibility, and cost-effectiveness. Nevertheless, SHAAs still lag behind conventional hearing aids in aspects such as adaptive speaker focus, noise resilience, and latency. This is compounded by a lack of standardisation in headphone calibration and inconsistent performance across Android devices, which dominate global smartphone usage [5, 9].

Although models like Petralex and Sound Amplifier integrate useful functionalities such as amplification presets and equalisation, they fall short in real-time adaptability and speaker-specific amplification. Emerging technologies in speaker diarization [13], deep learning-based noise suppression [20], and frequency personalisation [15] provide an opportunity to close this gap.

The findings suggest a pressing need for a system that incorporates context-aware selective amplification, real-time speaker tracking, and adaptive noise control in an easy-to-use interface. Such a system could bridge the gap between affordability and functional efficacy, enabling hard-of-hearing individuals to communicate more effectively in challenging auditory environments.

This research addresses that need by proposing a smartphone-based hearing aid application that combines intelligent audio processing with user-centric design principles, guided by the strengths and shortcomings observed in existing literature and commercial applications.

Chapter 3

Methodology

This chapter presents the methodological framework employed in the design, development, and evaluation of a smartphone-based hearing aid application tailored for individuals with moderate to profound hearing impairment. The objective of the research is to improve auditory clarity and speaker focus in dynamic, real-world environments, specifically academic settings such as classrooms where traditional hearing aids often fail to deliver sufficient contextual filtering and selective amplification.

Due to the interdisciplinary nature of the problem, which encompasses aspects such as human-centred design and mobile application development, the methodology integrates both exploratory and applied elements. The process was informed by user feedback, literature surveys, and technical feasibility. This duality reflects the study's goal of building a solution that is not only theoretically grounded but also practical, accessible, and scalable.

The research framework adopted in this study is based on the Systems Development Methodology, which supports the iterative construction of systems through a blend of theoretical exploration, prototype development, and empirical evaluation [10]. This methodology was particularly well-suited to the objectives of the current study, which required both the creation of a technical system and the analysis of user-centred challenges in hearing aid use.

The Systems Development Methodology comprises five interrelated stages that were sequentially adapted to suit the goals of this research

3.0.1 Phase 1: Construct a Conceptual Framework

The study began by constructing a comprehensive conceptual understanding of the problem space. This phase involved identifying the research problem, conducting a thorough review of existing literature on hearing loss, assistive technologies, and smartphone-based hearing aid applications [1, 9]. It also included a preliminary user study with individuals affected by hearing impairment to capture real-world challenges and usability barriers. A comparative analysis of existing products was performed to understand their strengths, limitations, and user interface designs.

Key limitations in existing solutions, such as indiscriminate amplification, poor noise handling, and lack of speaker differentiation, were identified during this phase. These findings formed the theoretical underpinning and shaped the problem definition. This phase supported Research Question Q1 by surfacing technological gaps and informed Q2 by highlighting critical user interface shortcomings.

3.0.2 Phase 2: Develop a System Architecture

Upon establishing the conceptual foundations, the system architecture was defined. A high-level design was developed, mapping out the major functional components: real-time audio capture, pre-processing pipeline, selective amplification, noise suppression, speaker diarization, and Bluetooth output modules.

The architectural design emphasized modularity, scalability, and real-time operability on mobile platforms. Special attention was given to integrating lightweight, state-of-the-art techniques such as RNNoise for noise reduction and pyannote.audio for speaker diarization to ensure robust performance under the constraints of mobile hardware. This phase continued addressing Research Question Q1 by ensuring that the system could technically support selective sound amplification in dynamic environments.

3.0.3 Phase 3: Analyse and Design the System

This phase focused on translating conceptual and architectural insights into detailed technical specifications and user interface structures. Available audio processing methods were evaluated for their compatibility with Android smartphone platforms, and detailed wireframes were created for the user interface.

Design decisions prioritised visual simplicity, minimal cognitive load, intuitive control mechanisms, and accessibility for users with varying levels of digital literacy. The feasibility of real-time low-latency streaming and multi-speaker management was analysed, confirming the suitability of proposed backend and frontend components.

This phase directly engaged with Research Question Q2 by addressing usability challenges found in existing SHAAs and refined technical strategies to implement selective amplification effectively.

3.0.4 Phase 4: Build the System (Prototype)

Following the design phase, the system was developed into a functional prototype. The backend was implemented with modular components responsible for real-time audio acquisition, selective amplification based on speaker segmentation, noise suppression using RNNoise, and diarization-driven speaker isolation through pyannote.audio-based models.

Parallelly, the mobile frontend was developed in Java for Android deployment, focusing on intuitive usability, offering users clear control over amplification, speaker switching, and environment-based configuration modes. The application allowed users to start streaming, monitor visual waveforms, toggle noise suppression, and select the dominant speaker among detected streams.

Once individual modules were validated, the backend and frontend were integrated into a cohesive mobile application, preparing the system for comprehensive evaluation. This phase laid the groundwork to answer Research Question Q3 by providing a working application ready for user testing.

3.0.5 Phase 5: Observe and Evaluate the System

The final phase focused on system validation through structured testing and user feedback. The prototype was evaluated in simulated real-world academic environments, where participants used the app during lecture scenarios containing background noise.

User feedback was collected via structured questionnaires and interviews, assessing speech clarity, background noise handling, speaker switching usability, interface simplicity, and overall satisfaction. Additionally, diagnostic outputs such as latency, CPU load, and noise reduction performance were measured.

Observations from this phase directly addressed Research Question Q3 by evaluating the system's real-world effectiveness and Research Question Q2 by validating the usability improvements over conventional SHAAs.

Throughout all phases, development decisions were continuously informed by empirical evidence and technical constraints. This structured framework enabled the study to systematically evolve towards delivering a practical, user-centric, and technically robust hearing support application.

3.1 Constructing the Conceptual Framework

The first phase of the Systems Development Methodology involved constructing a conceptual framework that would inform both the functional and non-functional requirements of the proposed system. This framework was built by integrating insights from three core activities; a preliminary user study, a systematic literature review, and a comparative product analysis. Together, these components provided a multidimensional understanding of the challenges faced by hearing aid users in dynamic environments and the limitations of existing assistive technologies.

Preliminary User Study

As the foundational stage of constructing the conceptual framework, a preliminary user study was conducted to gain insights into the real-world challenges faced by hearing aid users, particularly in academic and multi-speaker environments. This study aimed to identify practical limitations, emotional and physical burdens, and desired improvements that would directly inform the design of the proposed system. The primary objectives of the user study were,

- To evaluate satisfaction levels with traditional hearing aids.
- To identify recurring challenges in noisy and multi-speaker environments.
- To uncover user preferences, frustrations, and feature expectations.
- To assess the emotional and social impact of hearing aid usage in academic contexts.
- To understand any physical or health-related concerns resulting from prolonged device use.

Seven participants were recruited from the Centre for Disabled at the University of Colombo. All were undergraduate students aged 22–25 years, representing the typical use case for the proposed application. They regularly relied on hearing aids in classroom settings, making them ideal subjects for investigating context-specific needs.

Participants Filling Survey

Participant Filling Survey

Figure 3.1: Students Participating in the Preliminary User Survey

- Number of participants – 7
- Age range – 22–25
- Gender – 5 females, 2 males

- Hearing status – 4 mild, 2 moderate, 1 severe
- Device type – Behind-The-Ear (BTE), Receiver-In-Canal (RIC), with one non-user of any device
- Primary use environment – Normal day-to-day environment in University

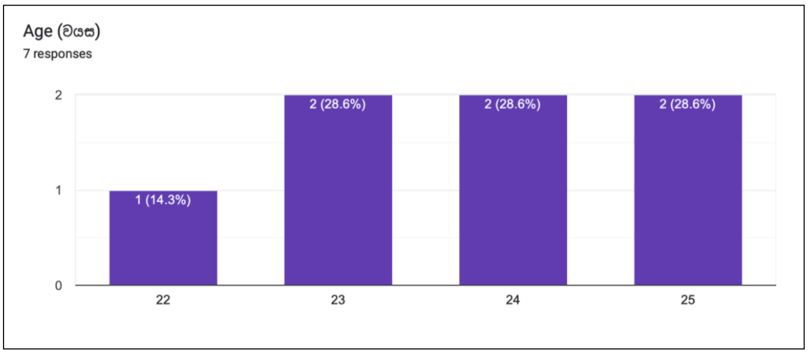


Figure 3.2: Participant Age Demographics

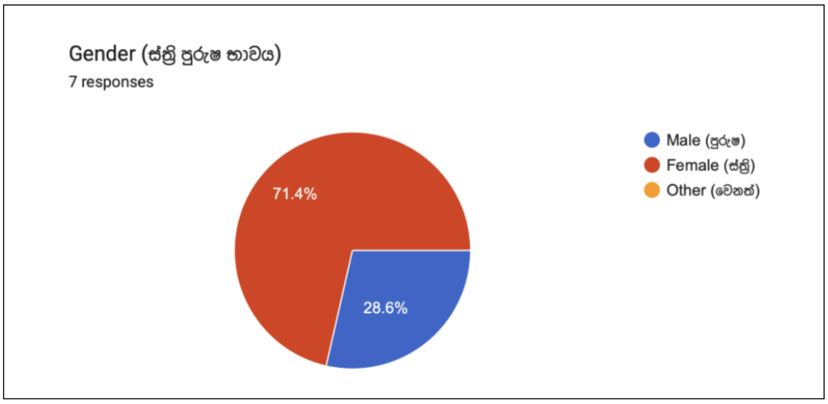


Figure 3.3: Participant Gender Distribution

All participants provided informed consent, and the study was conducted under ethical research practices, ensuring anonymity, voluntariness, and confidentiality.

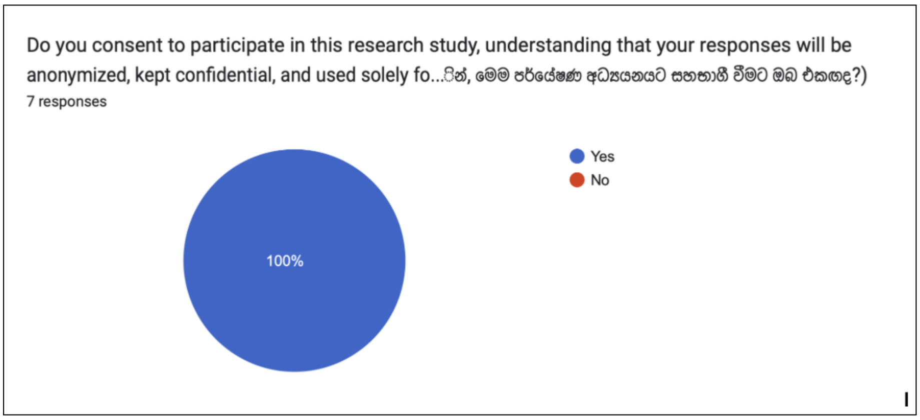


Figure 3.4: Participant Consent

Data Collection Methodology

The study used a mixed-method design comprising both quantitative and qualitative components.

Quantitative Section

Participants rated the questions falling under the following six categories on a 1–5 Likert scale:

- Overall performance of the hearing aid
- Sound quality
- Battery life
- Comfort for long-term use
- Effectiveness in noisy environments
- Contribution to social interaction and overall quality of life

Likert Scale Explanation

- 1 – Very Dissatisfied
- 2 – Dissatisfied
- 3 – Neutral
- 4 – Satisfied
- 5 – Very Satisfied

Qualitative Section

Open-ended questions were used to explore deeper insights:

- What problems do you face with your hearing aid in different environments?
- What features do you like most about your hearing aid?
- What features do you wish your hearing aid had?
- How has better hearing affected your social life?
- Do you experience any health-related issues with prolonged use?

Quantitative Feedback Results of Preliminary Survey

Category Averages

Table 3.1: Average Ratings Across Evaluation Categories

Category	Average Rating
Overall Satisfaction	2.86
Sound Quality	2.71
Battery Life	2.43
Comfort	3.43
Noisy Environment Use	3.29
Social Impact	3.57

Qualitative Findings and Extracted Themes of Preliminary Survey

a) Environmental Challenges

- “Hearing becomes unclear with other noises.”
- “It’s hard to use when it’s raining or near traffic.”
- “Background noise makes it very difficult to follow lectures.”

b) Feature Preferences

- “Volume control helps in certain situations.”
- “Water resistance and Bluetooth features would be ideal.”
- “Rechargeable battery would save a lot of money.”

c) Emotional and Social Impact

- “I feel embarrassed using it in public.”
- “Helps with one-on-one conversations, but not in group work.”
- “I feel disconnected in lectures when the device amplifies everything.”

d) Health Concerns

- “Long usage causes headaches.”
- “Itching and irritation in one ear.”
- “Loud sounds cause mental stress.”

Feature Requests Summary

Table 3.2: Feature Requests Summary from Preliminary User Study

Feature	Mentioned by	% of Participants
Bluetooth Connectivity	6	85%
Custom Amplification Options	5	71%
Noise Reduction	4	57%
Rechargeable Battery	3	43%
Discreet / Smaller Design	3	43%

Interpretation and Implications

This preliminary study confirmed that existing hearing aids often fail to meet the auditory and social demands of university students. The inability to prioritise desired speech sources, the constant amplification of noise, and the lack of adaptive controls were identified as critical pain points. Furthermore, emotional burdens and health discomfort further reduced usage consistency.

These findings provided essential guidance for the development of the proposed mobile hearing solution. The study ensured that user needs rather than only technical ambition remained central to every design decision.

Smartphone-Based Hearing Aid Application Evaluation

As an extension of the preliminary user study, participants were also invited to evaluate two existing smartphone-based hearing aid applications (SHAAs); Google Sound Amplifier and Hearing Clear. This study aimed to examine whether SHAAs address the limitations previously identified in traditional hearing aids and to understand how users interact with them in multi-speaker academic settings. The evaluation was designed to investigate four key dimensions;

- Real-time usability of SHAAs.
- Effectiveness of amplification and speaker clarity.
- User interface intuitiveness and adjustability.
- Comparative user satisfaction between apps and traditional hearing aids.

These insights were intended to directly inform the functional specifications and usability requirements of the proposed mobile solution. Participants were given time to explore both applications under normal environmental conditions with prevalence of background sounds. Support was provided when needed to help them access all features.

Student Testing Sound Amplifier

Student Providing Feedback

Figure 3.5: Students Evaluating Existing SHAAs

The survey captured both quantitative ratings and qualitative responses across the following dimensions.

- Noise Reduction Effectiveness
- User Interface Intuitiveness
- Speaker Clarity
- Ability to Switch Focus Between Speakers
- Customization Options
- Overall Satisfaction

Ratings were collected on a 1–5 Likert scale, where,

- 1 – Very Poor
- 2 – Poor
- 3 – Neutral
- 4 – Good
- 5 – Excellent

Quantitative Results of SHAA Comparison Study

Table 3.3: SHAA Feature Ratings Comparison

Feature	Sound Amplifier (Avg)	Hearing Clear (Avg)
Noise Reduction	2.0	1.8
User Interface Intuitiveness	2.5	2.7
Speaker Clarity	2.0	1.9
Switching Speakers	1.0	1.0

Qualitative Themes and Extracted Comments

User Interface

- "Not intuitive at all. Couldn't find key settings without help."
- "Too many options without guidance."
- "Hearing Clear was slightly easier to use than Sound Amplifier."

Noise Reduction

- "Doesn't cancel construction or traffic noise."
- "Reduces everything, even parts of the speech I need to hear."
- "When someone speaks and the fan's running, I can't focus on the person."

Speaker Focus & Switching

- "Can't shift attention between speakers."
- "No control for switching focus unless I manually adjust volume each time."

Sound Quality & Clarity

- "Voices sound robotic and delayed."
- "Can't differentiate between speakers when two people talk."
- "Helpful in quiet settings, not in class discussions."

Customization Needs

- "I wish I could record the lecture and play it back clearly."
- "A classroom mode would be useful."
- "Option to amplify only one direction is missing."

Interpretation and Implications

The SHAAs tested in this study did not sufficiently address the user needs highlighted during the traditional hearing aid evaluation. Most notably, both applications:

- Lacked selective amplification, leading to cognitive overload.
- Provided inconsistent noise suppression, especially in dynamic settings.
- Offered limited real-time control, which affected focus and responsiveness.
- Contained unintuitive interfaces, especially for users with limited app experience.

Despite slight differences between the two apps, participants consistently rated their experience as inadequate for academic use. These results further validated the research problem and provided empirical evidence to support the design of a more responsive, context-aware mobile solution.

Literature Review

To inform the conceptual framework and ensure that the proposed system addressed both theoretical and practical gaps, a comprehensive literature review was conducted. This review aimed to evaluate current technologies, identify challenges and limitations in hearing assistance solutions, and uncover emerging methods suitable for smartphone-based hearing enhancement in dynamic environments.

The review focused on areas of audiology, mobile health technologies, speech signal processing, and human-computer interaction. Sources were drawn from prominent academic databases such as Google Scholar, IEEE Xplore, and ScienceDirect.

The following keyword combinations were used; "smartphone hearing aids," "hearing loss technology," "selective sound amplification," "noise suppression models," "machine learning in hearing aids," "speaker diarization," and "real-time audio enhancement."

Inclusion criteria required that articles:

- Were published between 2005 and 2024
- Explored technical or user experience aspects of hearing solutions
- Focused on either traditional hearing aids or mobile hearing applications

- Provided empirical evidence or evaluations applicable to assistive device design

An initial pool of over 50 research papers was screened. From this, 12 key papers were shortlisted based on relevance, technical rigour, and applicability to the objectives of this study.

Key Findings and Research Gaps

The reviewed literature showed several limitations across both traditional hearing aids and existing SHAAs.

a) Absence of Context-Aware Selective Amplification

Most conventional hearing aids and mobile apps apply broad amplification to all incoming audio. This leads to difficulties in distinguishing target speech from background noise, particularly in environments like classrooms, restaurants, or group discussions [1, 4, 5]. The lack of speaker-specific focus was identified as a major barrier to user satisfaction and communication clarity.

b) Ineffective and Static Noise Suppression Techniques

Although many SHAAs include basic noise filters, these systems are often static and unresponsive to sudden or gradual changes in background noise. Adaptive filtering, essential for noisy, dynamic environments such as universities, is largely absent [5, 11, 9]. Additionally, traditional filters tend to reduce sound quality or remove portions of speech, leading to confusion or fatigue.

c) Usability and Accessibility Constraints

Applications aimed at hearing support frequently lack user-friendly design. Interface clutter, absence of instructional cues, and reliance on precise manual configuration make them inaccessible to many users, especially those with limited digital literacy [12]. Furthermore, complex controls interrupt real-time interaction and are counterproductive in fast-paced or unpredictable acoustic environments.

d) Underutilisation of Modern Signal Processing Techniques

Emerging technologies such as deep neural networks, speaker diarization models, and real-time speech enhancement have been shown to improve speech separation and clarity in research settings. However, these methods are rarely integrated into consumer-grade SHAAs. Notably, pyannote.audio, an end-to-end diarisation pipeline, provides speaker turn segmentation and classification [13]. RNNoise, a lightweight noise suppression model combining deep learning with traditional DSP, has shown promise for mobile deployment with minimal resource overhead [20]. Despite their technical viability, such tools are underrepresented in current mobile solutions, suggesting a strong opportunity for innovation.

This review provided critical validation for the research direction. The integration of selective amplification, speaker diarization, and real-time neural noise suppression directly addresses the shortcomings highlighted in prior work. Specifically,

- **Pyannote.audio** will be employed to distinguish speakers in multi-speaker environments, enabling speaker-specific amplification.
- **RNNoise** will provide lightweight real-time noise suppression, improving listening comfort without affecting speech intelligibility.
- The proposed system will be built for intuitive use via a mobile interface designed with accessibility principles, such as one-tap controls, presets for common environments (e.g., "lecture," "outdoors"), and support for Bluetooth earphones to ensure discreet use.

The literature also confirmed that few, if any, applications offer these capabilities in a single, integrated, low-cost platform.

Comparative Product Analysis

To support the findings from the literature review and preliminary user studies, a comparative analysis of existing smartphone-based hearing aid applications (SHAAs) was conducted. The primary aim of this analysis was to identify functional limitations and technological gaps in current solutions, especially with regard to real-time use in dynamic, multi-speaker environments such as classrooms.

Eight widely used applications were reviewed; Petralex, Google Sound Amplifier, Hearing Clear, Super Hearing from Distance, Hear from Distance, Ear Spy, Ear Speaker, and Hearing Aid Sound Amplifier. These applications were selected based on their relevance to hearing aid support, user accessibility across platforms, and prevalence in app stores. A detailed feature comparison was conducted to assess capabilities in amplification, speech recognition, noise suppression, personalisation, and platform compatibility.

Table 3.4: Feature Comparison of SHAA Applications (Abbreviated)

Feature	**A1**	**A2**	**A3**	**A4**	**A5**	**A6**	**A7**	**A8**
Hearing Test	Y	N	N	N	N	N	N	N
Amplify (Surround)	Y	Y	Y	Y	Y	Y	Y	Y
Amplify (In Device)	N	Y	N	N	N	N	N	N
Speech Recog.	Y	N	N	N	N	N	N	N
Noise Suppression	Y	Y	N	Y	Y	N	N	Y
Audio Recorder	Y	N	Y	Y	Y	N	Y	Y
Equaliser	Y	Y	Y	Y	Y	Y	Y	Y
L/R Channels	Y	Y	*	Y	*	–	–	–
Speaker Focus	N	N	N	N	N	N	N	N
Upgrade Needed	Y	N	Y	Y	Y	Y	Y	Y

Legend

- A1 = Petralex, A2 = Sound Amplifier, A3 = Hearing Clear, A4 = Super Hearing, A5 = Hear from Distance, A6 = Ear Spy, A7 = Ear Speaker, A8 = Hearing Aid SA
- Y = Yes, N = No, * = Not Specified, – = Not Available

This analysis revealed that while most applications provide basic amplification and equalisation capabilities, they lack essential features required for adaptive and context-sensitive auditory support. Key limitations include the absence of selective speaker amplification, dynamic noise suppression, and audio control, which are features necessary for enabling clearer communication in noisy, multi-speaker settings. For instance, Petralex includes speech recognition and hearing tests but lacks in-device audio handling. Sound Amplifier supports equalisation but excludes recording functionality and audiogram integration.

It was also observed that many applications operate behind a paywall for advanced features, which significantly restricts access for users from low-income or marginalised groups. Additionally, usability issues were apparent in some platforms, particularly regarding non-intuitive user interfaces, limited customisation, and the lack of real-time speaker tracking.

These insights highlight a major gap in the current ecosystem of SHAAs. None of the applications incorporated speaker diarization, dynamic speaker switching, or adaptive enhancement of primary voices. The proposed system aims to bridge this gap by incorporating state-of-the-art, open-source technologies, packaged within a free and accessible mobile application. This ensures that core functionality, such as speaker-focused amplification and real-time clarity enhancement, remains available to all users without financial barriers.

3.2 Develop a System Architecture

Following the construction of the conceptual framework, the development of a robust and modular system architecture was undertaken. The full system architecture, including detailed layer breakdowns and key design considerations, is elaborated in Chapter 4.

3.3 Analyse and Design the System

This phase focused on refining the system's functional and interface specifications based on the user needs and technical feasibility identified in earlier stages. The detailed analysis and design strategies, including environment-specific profiles, selective speaker amplification, and the noise reduction integration, are discussed extensively in Chapter 4.

3.4 Build the System (Prototype)

The construction of the system prototype involved the development and integration of all key functional components outlined during the architectural and design phases. This stage primarily focused on implementing the audio processing pipeline, user interface elements, speaker diarization integration, and noise suppression mechanisms. The detailed design and development process, including system structure, implementation tools, and model integration, are discussed comprehensively in Chapter 4.

3.5 Observe and Evaluate the System

This phase focuses on examining how the developed prototype performs in real-world scenarios. The primary objective is to evaluate the application's ability to enhance the auditory experience for hearing-impaired users, especially in environments where multiple speakers and background noise are present. This includes assessing both the technical performance of the system and the user experience from the perspective of accessibility, clarity, and control.

Observations are guided by structured user testing sessions, where participants interact with the application in typical use environments such as classrooms or public spaces. Key areas of interest include the effectiveness of selective amplification, the clarity of sound output, speaker differentiation, and the overall usability of the interface.

Quantitative feedback is collected using predefined rating scales, while qualitative insights are drawn from open-ended reflections and behavioural observations. Additionally, technical metrics such as latency, responsiveness, and system stability are noted to validate the application's real-time performance.

3.5.1 Evaluation Setup and Methodology

To assess the practical viability and effectiveness of the developed smartphone-based hearing aid application, a structured evaluation was conducted. This stage followed the completion of system implementation and focused on capturing both user perceptions and measurable system performance in realistic auditory conditions. The primary objective was to understand how well the solution functioned in typical daily use, especially in noisy, multi-speaker environments where most conventional aids fall short.

The evaluation was carried out with the same group of participants involved in the earlier preliminary user study. All 8 participants were aged between 22 and 25, identified as having moderate to moderately severe hearing loss, and were affiliated with the University of Colombo's Hearing Aid Centre. They were selected not only due to ease of access and prior engagement but also because their academic context reflected the high-demand listening scenarios the application aimed to support.

Participants were given access to the completed Android application along with a brief guide explaining how to install and use it. The guide included steps for performing the initial hearing test, activating the live audio streaming feature, and adjusting settings such as gain and noise reduction and speaker selection. This ensured consistency across test subjects while still allowing natural exploration of the interface.

Before live usage began, each user completed a hearing test built into the app. This test was used to generate a personalized amplification profile based on their sensitivity to different frequencies. Once the system applied these settings, users were asked to listen to a pre-recorded classroom lecture using another device or a speaker that included real environmental background sounds such as distant conversations, ambient fan noise, and outdoor disturbances. This audio scenario was used to simulate a real-world, multi-speaker academic environment where hearing clarity is critical.

Following this controlled exposure, participants enabled the streaming function, allowing them to hear through the microphone input in real time via Bluetooth or wired headphones. While using the app, users were encouraged to interact with key features, including toggling noise suppression and selecting among different detected speakers when applicable. The behaviours of the users were observed in these sessions to note how participants engaged with the app, any visible points of confusion or delay, and behavioural indicators of user satisfaction or frustration. Participants were also provided a user guide, which will hereafter guide them when using the app.

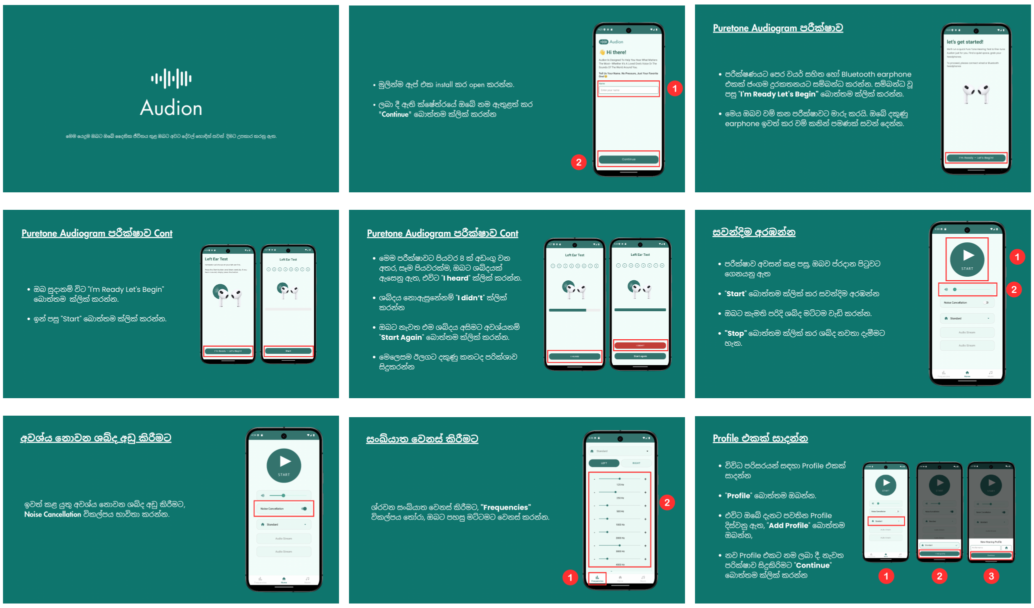


Figure 3.6: User Guide for Application Setup and Usage

After the session, each participant completed a structured questionnaire designed to collect feedback on key experience factors such as amplification, sound clarity, ease of use, and speaker differentiation. These responses were rated on a five-point scale and supplemented with open-ended reflections. Finally, short individual interviews were conducted to allow participants to expand on their responses, share real experiences, and offer recommendations for future improvement.

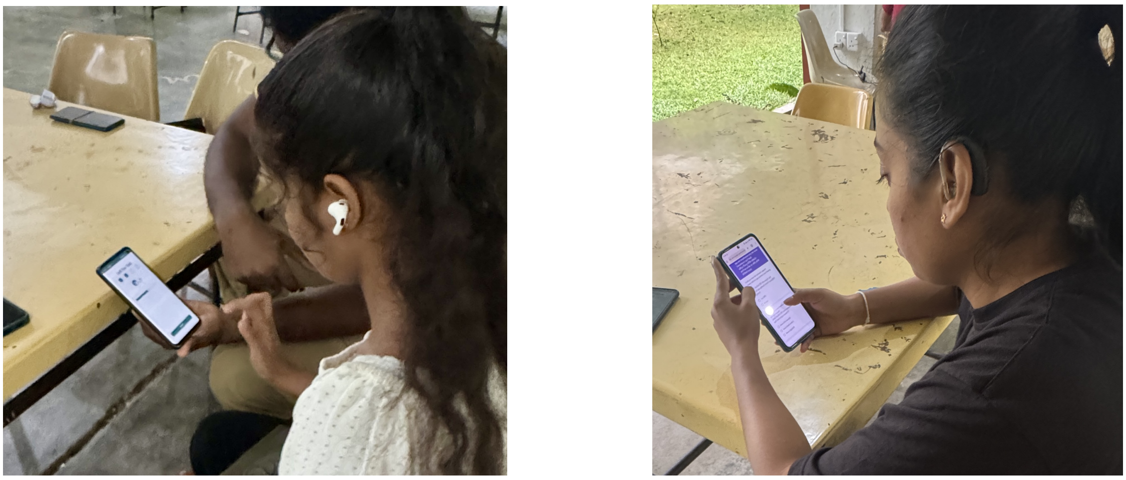


Figure 3.7: System Evaluation Results Overview

In parallel, system-level data was captured through the backend to measure technical metrics such as real-time latency, memory and CPU usage, and noise reduction performance. These measurements were derived from in-app logging functions. The evaluation also included a comparative feature analysis against existing smartphone-based hearing applications like Google Sound Amplifier and Hearing Clear, highlighting the unique offerings and limitations of the proposed solution.

The complete results and findings from this evaluation will be discussed in depth in Chapter 5, *Results and Discussion*, where both user-driven and system-level insights will be analysed to determine the efficacy of the proposed solution.

Chapter 4

Design and Development

Following the identification of user needs, system requirements, and theoretical foundations established in the earlier stages, this chapter presents the detailed design and development process of the proposed smartphone-based hearing aid application. The development followed an iterative approach, where insights from preliminary studies were systematically translated into implementable solutions. The phases described here contributed directly to realising the final working prototype and are organised under distinct stages for clarity.

4.1 Constructed Conceptual Framework

The development process commenced with the construction of a comprehensive conceptual framework. Based on the findings of the preliminary user study, literature review, and comparative product analysis, a framework was developed to guide the system's overall design and implementation. It integrates user experience factors with technical components to address real-world challenges faced by hard-of-hearing individuals.

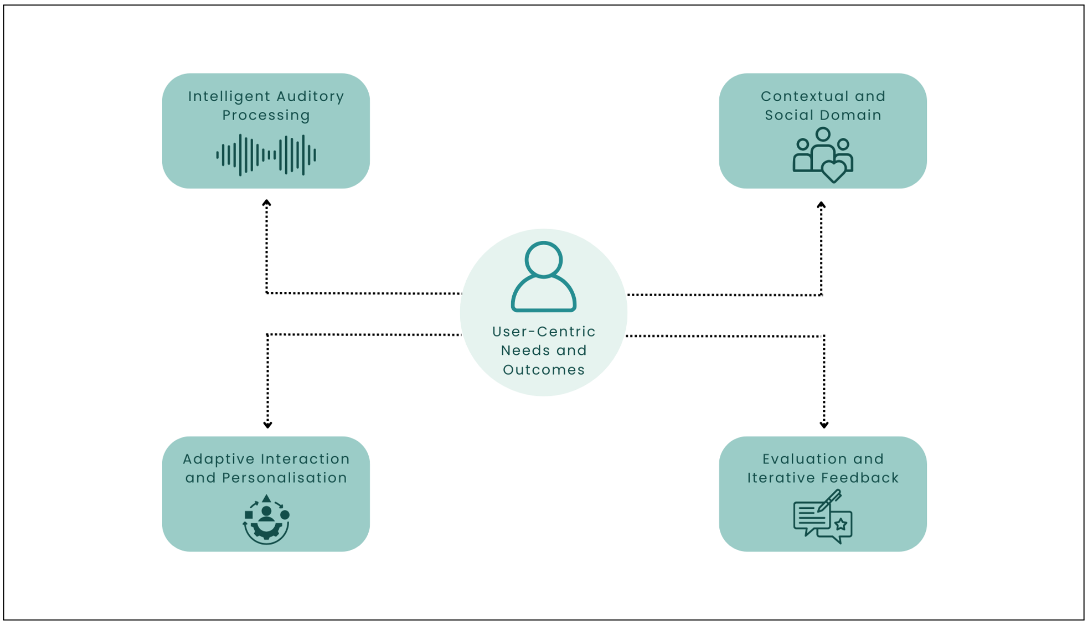


Figure 4.1: Constructed Conceptual Framework for the Hearing Aid Application

The conceptual framework consists of five interconnected domains that collectively form a holistic and dynamic ecosystem with the user's experience at its core:

- **Intelligent Auditory Processing** integrates dynamic speaker identification, adaptive noise suppression, and voice activity detection to achieve enhanced auditory clarity and environmental adaptability.
- **Adaptive Interaction and Personalisation** emphasises a user-centric interface model, providing predefined acoustic scenarios, volume control, and personalised listening profiles with a focus on ease of use and continuous adaptation.
- **Contextual and Social Domain** addresses the situational and ethical factors influencing assistive technology use, ensuring the application remains inclusive, practical, and socially acceptable.
- **Evaluation and Iterative Feedback** establishes a mechanism for continuous refinement through user feedback, quantitative performance metrics, and usability assessments to improve system performance.
- **User-Centric Needs and Outcomes** captures the authentic needs of hearing-impaired individuals, including the need for improved clarity in complex environments, reduced stigma, enhanced social participation, and quality-of-life improvements.

The conceptual framework created a foundation for aligning technological innovation with user-centred design, social factors, and empirical evaluation.

4.2 Development of the System Architecture

Following the conceptual framework, a comprehensive system architecture was developed to translate theoretical considerations into practical, implementable modules. The architecture was designed to ensure real-time responsiveness, modularity, scalability, and accessibility while directly addressing the challenges identified during the analysis phase.

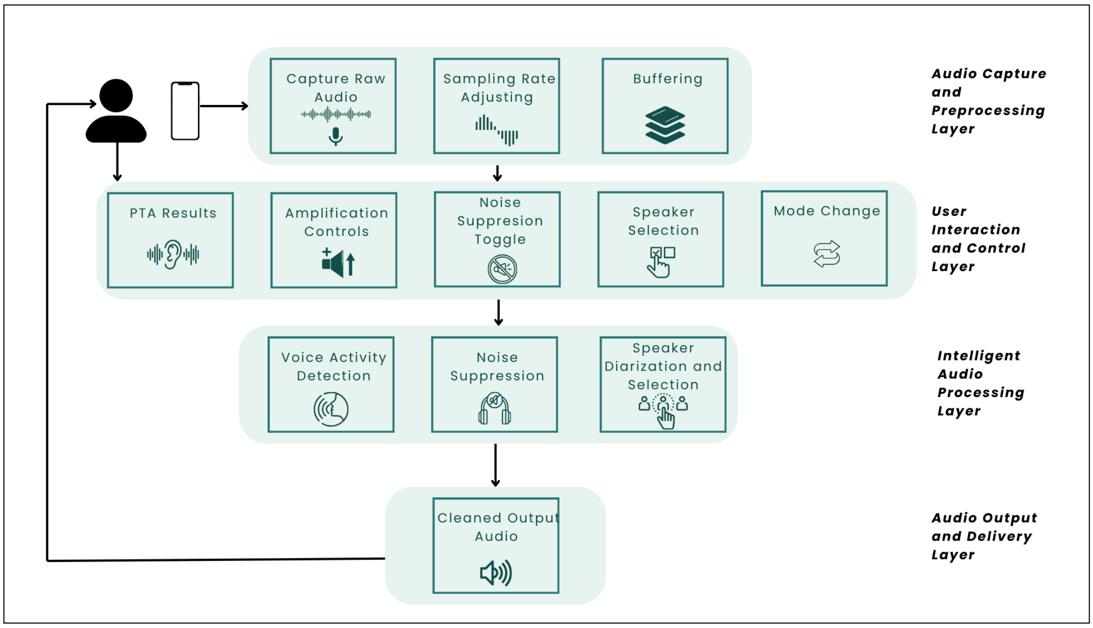


Figure 4.2: System Architecture Overview

The architecture comprises four main layers, each serving distinct functional purposes:

- **Audio Capture and Preprocessing Layer** is responsible for capturing real-time audio from the smartphone microphone, managing tasks such as sampling rate adjustment and preliminary enhancement to prepare the data for processing.
- **User Interaction and Control Layer** provides a user-friendly interface featuring preconfigured modes, volume adjustment, and noise suppression toggling to facilitate intuitive control of the auditory experience.
- **Intelligent Audio Processing Layer** includes modules for speaker diarization, adaptive noise suppression, and voice activity detection, working

together to isolate speech and suppress irrelevant noise while preserving real-time performance.

- **Audio Output and Delivery Layer** ensures that the processed audio is delivered seamlessly through wired or wireless headsets, maintaining discreet and high-quality listening experiences.

The architectural design was guided by several principles, including real-time responsiveness, modularity for easy upgrades, scalability across user contexts, and accessibility through minimal cognitive load design.

4.3 System Design and User Interaction

The design phase involved translating the conceptual and architectural models into a tangible, user-friendly mobile application. Special attention was given to accessibility, minimal complexity, and dynamic adaptability to user-specific hearing profiles and environments.

User-Centric Workflow and Interaction Design

The user interaction begins with a personalised hearing test that defines a custom amplification profile based on the user's sensitivity across frequencies. The main screen features a large "Tap to Start Streaming" button that initiates real-time processing and audio streaming to connected headsets.

Additional features include:

- A slider for manual amplification adjustment
- A toggle control for enabling or disabling real-time noise suppression
- A real-time audio waveform visualiser for visual feedback

Environment-Specific Modes and Retesting

Recognising that hearing needs change with different acoustic environments, users are provided with a separate "Modes" section. This allows users to retest and create environment-specific amplification profiles optimised for contexts such as lecture halls, outdoor gatherings, or social spaces.

Multi-Speaker Management and Speaker Selection

In multi-speaker scenarios, speaker diarization is used to identify and visualise separate speakers. Users can manually select the preferred speaker stream, while the system suppresses others to enhance focus and intelligibility.

Design Priorities

The design placed significant emphasis on usability, ensuring:

- Minimal cognitive load through large, easily recognisable interface elements
- Linear navigation from testing to streaming to fine-tuning
- Optional access to advanced controls for experienced users

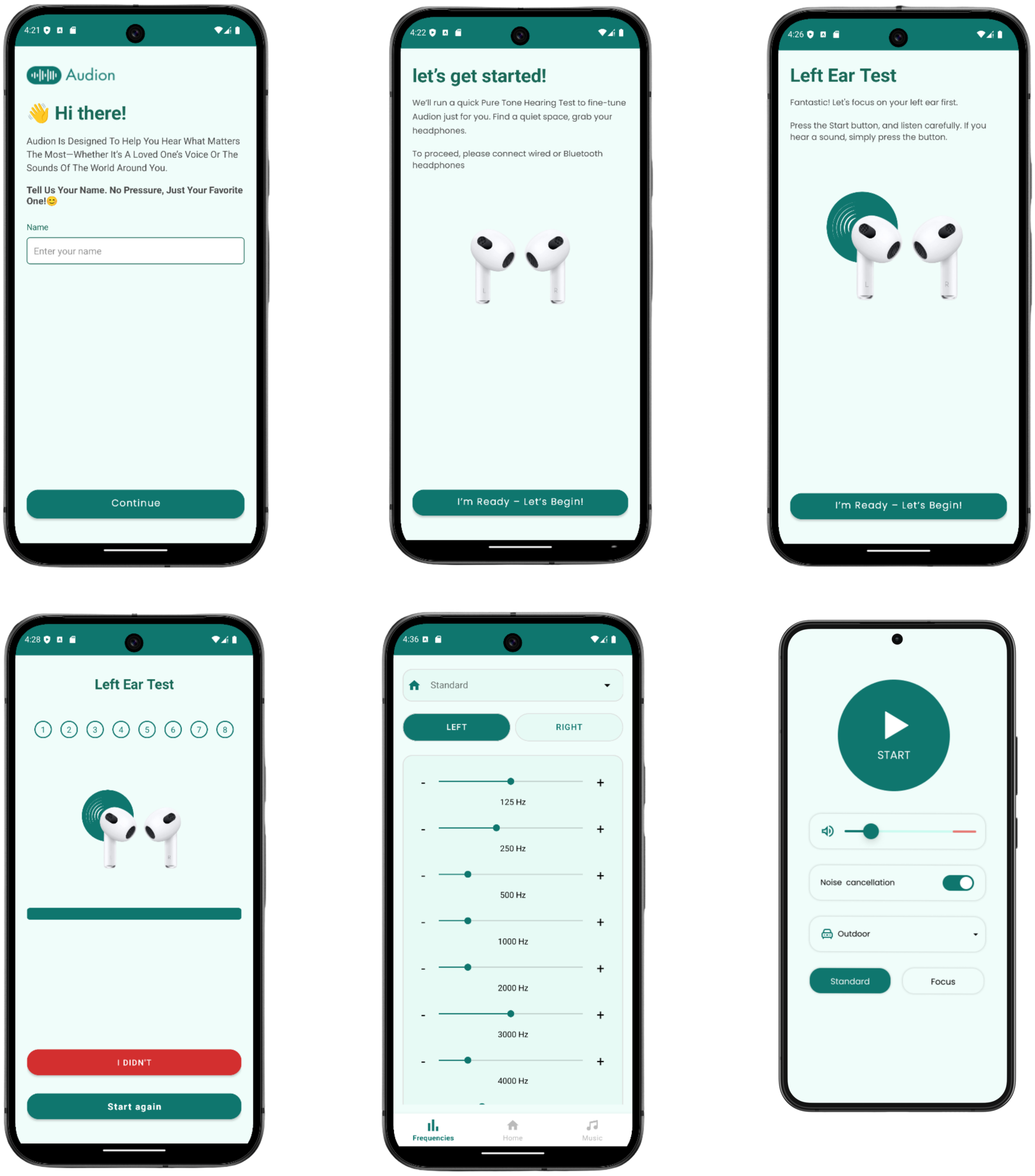


Figure 4.3: User Interface Frames of the Application

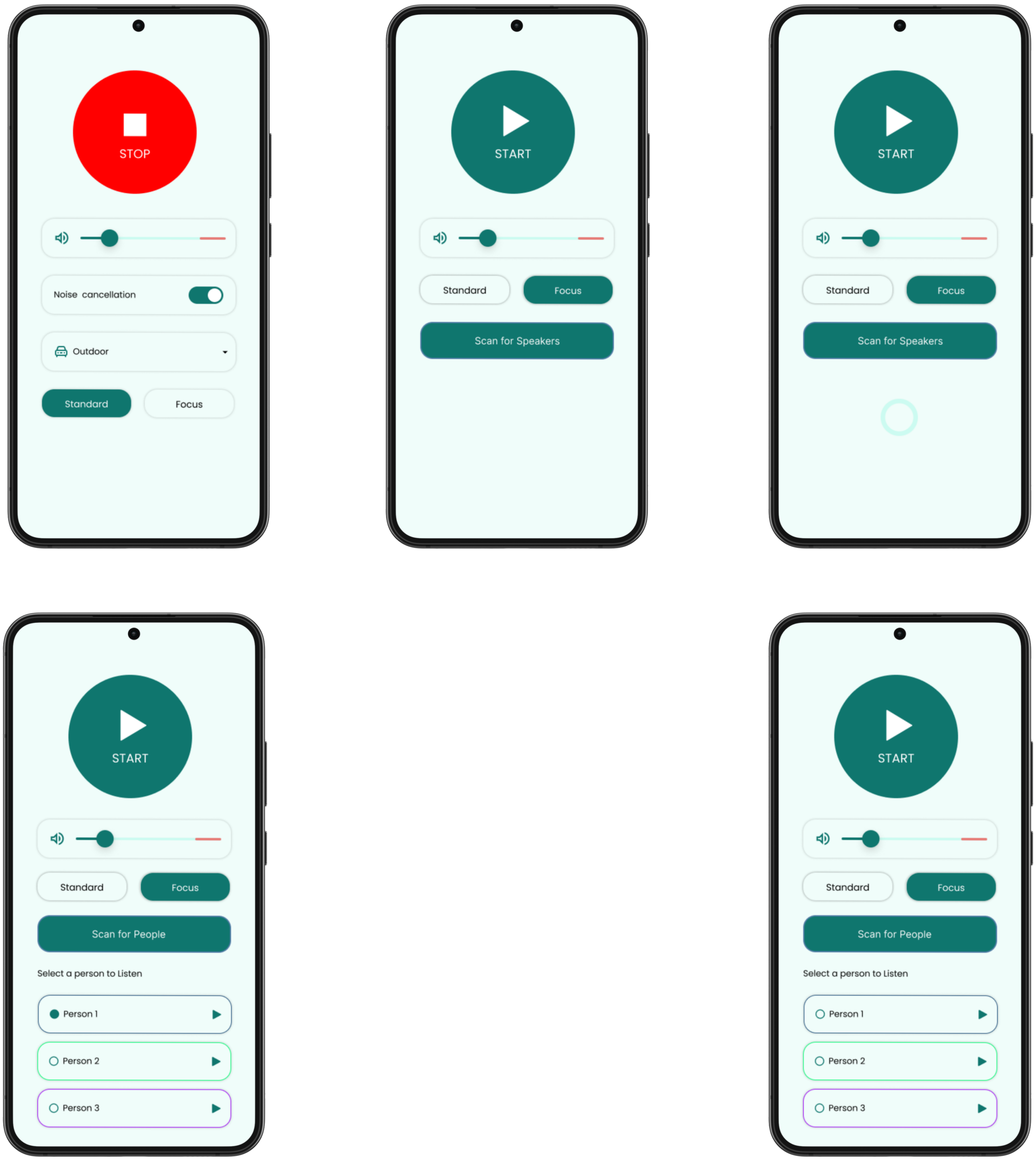


Figure 4.4: User Interface Frames of the Application

4.4 Building the System Prototype

The system prototype was implemented using a modular development strategy that optimised real-time performance and portability on Android devices.

Frontend Development

The mobile user interface and application logic were developed using:

- Java for application control
- XML for defining layout and screen elements

Audio Processing Integration

The backend audio processing was achieved through:

- RNNoise for real-time noise suppression, integrated through C libraries
- Sherpa-ONNX for speaker diarization using ONNX Runtime

Machine Learning Components

Several machine learning models were integrated,

- RNNoise model for combined noise suppression and voice activity detection
- Pyannote segmentation model for speech and non-speech separation
- 3DSpeaker embedding model for speaker identification

Native Code Integration

Native code was employed for audio stream handling and model execution:

- C and C++ for low-latency audio operations
- CMake as the build tool
- JNI to connect Java and C codebases

Asset and File Management

Assets and models were organised as follows:

- ONNX models stored under the assets directory
- Precompiled libraries for different architectures stored in jniLibs (e.g., armeabi-v7a, arm64-v8a)

This modular development process ensured robustness, flexibility, and real-time capabilities necessary to meet the requirements of the target user group.

Chapter 5

Results

This chapter presents the findings of the evaluation conducted on the developed smartphone-based hearing aid application. The aim of the evaluation was to assess the system's effectiveness in enhancing auditory experiences for hard-of-hearing users in real-world, multi-speaker environments. A combination of user-centred testing and system-level performance logging was employed to capture both experiential and technical outcomes. The evaluation included structured testing with the initial user group, observational studies, questionnaires, interviews, and internal system measurements. These results offer insight into how well the system addressed the research objectives and inform further discussion on its usability, functionality, and areas for improvement.

5.1 Quantitative Results

Quantitative findings were obtained from structured questionnaire responses following the evaluation phase. Participants were asked to rate their experience with the application across several dimensions using a 6-point Likert scale, ranging from 1 (Very Bad) to 6 (Very Good). This scale was chosen to avoid neutral bias and encourage participants to express a clear judgement of the app's performance.

The participants experienced a real-world use case where they listened to a lecture under different auditory conditions: with their traditional hearing aid, with the app using only amplification, and then using the app with noise reduction enabled.

A. Speech Clarity

Participants reported noticeable improvements in understanding the lecturer's voice when using the application, particularly with noise reduction enabled. The clarity ratings improved significantly in comparison to traditional hearing aids.

Table 5.1: Speech Clarity Ratings

Metric	Avg. Rating
Clarity with Traditional HA	2.57
Clarity with App (Amplification)	4.16
Clarity with App + Noise Reduction	4.43

Feedback such as "clearer focus on the speaker" and "easier to follow words" suggested that amplification with context-awareness outperformed conventional solutions, particularly in classroom settings.

B. Noise Reduction

Noise suppression capabilities of the application received positive ratings from the users. Many reported that the app effectively filtered out background noise and enabled them to concentrate better on the main speaker's voice.

Table 5.2: Noise Reduction Ratings

Metric	Avg. Rating
Noise Cancellation Effectiveness	4.0
Clarity After Noise Reduction	4.43

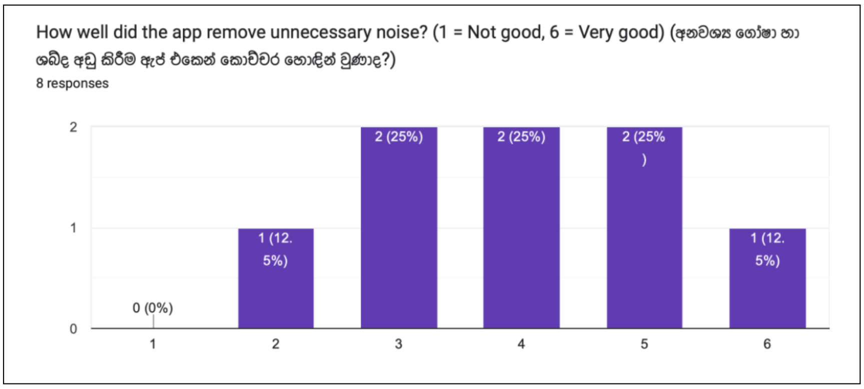


Figure 5.1: Noise Cancellation Effectiveness

Some participants commented that while most background disturbances were effectively reduced, extremely soft voices could be slightly diminished as well. This highlights a potential area for adaptive tuning in future versions.

C. Selective Listening and Speaker Focus

This component of the application allowed users to visualize and focus on a selected speaker when multiple people were speaking. Though tested with fewer participants, this feature still received promising ratings. The diarization-based stream visualization and manual focus option helped reduce cognitive overload in overlapping speech environments.

Table 5.3: Speaker Focus Ratings

Metric	**Avg. Rating**
Ease of Switching Between Speakers	4.0
Clarity of Selected Speaker's Voice	4.5
Overall Usefulness of Speaker Selection	4.3

Comments included phrases such as "I liked choosing who to listen to" and "the selected speaker's voice became clearer," highlighting the advantage of intelligent audio segmentation in dynamic environments.

D. UI Usability

The user interface was rated highly for its simplicity and accessibility. Participants found the layout intuitive and easy to interact with, even without extensive prior instructions.

Table 5.4: UI Usability Ratings

Metric	**Avg. Rating**
Ease of Use	4.4
Design Appeal	4.8

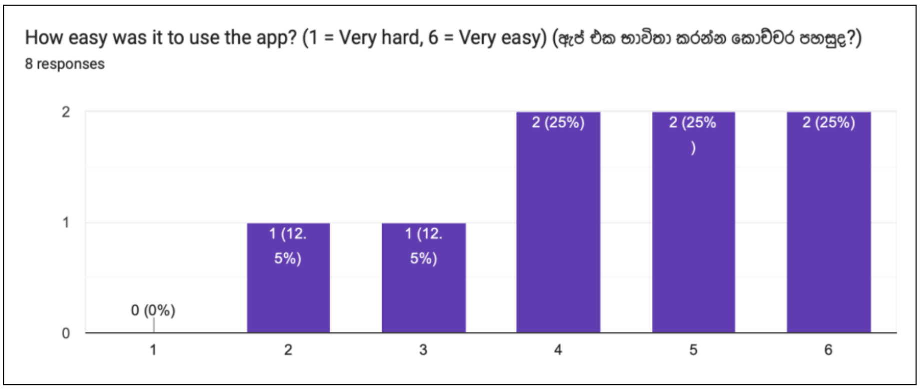


Figure 5.2: Evaluation Results on UI Ease of Use

During the evaluation phase, participants were asked two yes/no questions related to the usability of the application's interface. The first question assessed whether the buttons were easy to press, and the second evaluated whether the text size and colour were easy to read. A total of eight responses were collected for each question.

The results indicate a high level of satisfaction among users, with 87.5% of participants finding the buttons easy to press and 100% of participants confirming that the text size and colour were easy to read. These findings suggest that the user interface design was intuitive, accessible, and appropriately tailored for the target group.

Table 5.5: UI Usability Evaluation

Question	**Yes (%)**	**No (%)**
Were the buttons easy to press?	87.5%	12.5%
Was the text size and colour easy to read?	100%	0%

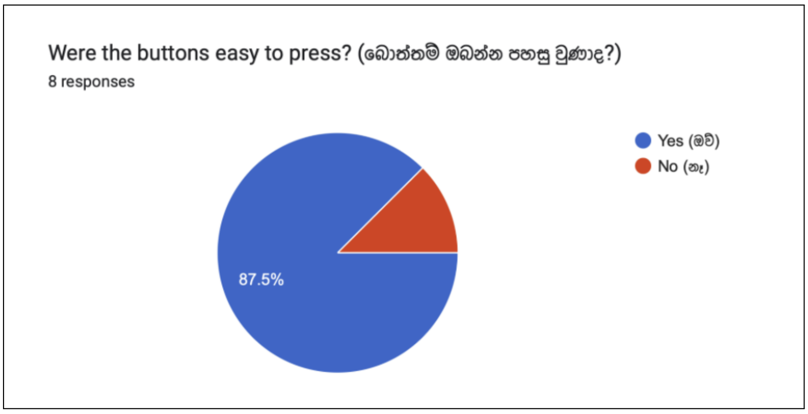


Figure 5.3: Evaluation results on button usability

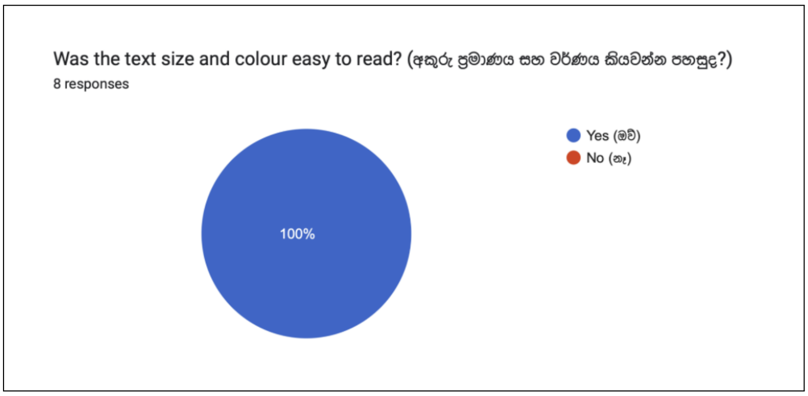


Figure 5.4: Evaluation results on text size and colour readability

Several participants remarked that "it looks like a normal app, not a medical device," which supports the goal of designing an unobtrusive, user-friendly interface.

E. System Comfort and User Preference

Participants were asked whether they would consider replacing or augmenting their current hearing aid with this application. While all users agreed they would use it in classroom environments, two-thirds expressed openness to using it as a full-time alternative, subject to comfort with earphone use.

Table 5.6: User Preference Ratings

Preference Metric	Yes (%)
Would use app in a classroom	100%
Would replace hearing aid with app	~67%

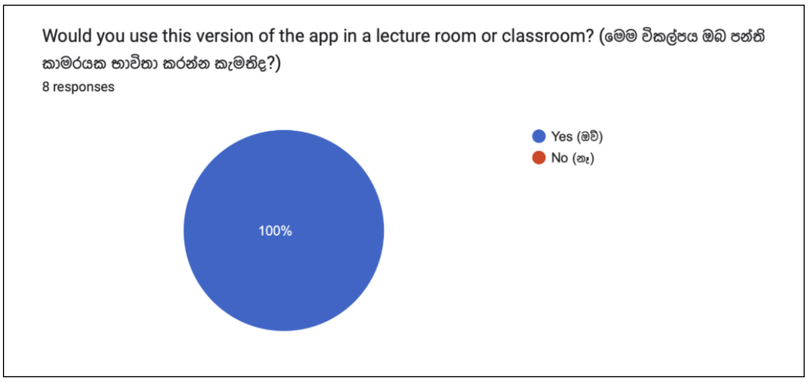


Figure 5.5: Evaluation results on user preference

User reflections highlighted practical benefits such as discreetness, greater control, and socially comfortable usage with common-looking earphones.

The numerical responses indicated strong user satisfaction across most categories, particularly in relation to personalisation and sound quality. Some participants noted challenges in extremely noisy environments, but most agreed that the app provided a better experience than traditional devices or alternative smartphone-based applications.

The next section will present qualitative insights drawn from interviews and written feedback, offering further interpretation of these results.

5.2 Qualitative Analysis

To complement the quantitative findings, a thematic analysis was conducted on open-ended responses and interview data collected from participants. This approach aimed to capture the nuanced experiences and perceptions of users regarding the application's performance in real-world academic settings. The analysis identified several recurring themes that shed light on both the strengths and areas for improvement of the application.

1. Enhanced Speech Clarity and Background Noise Management

Participants frequently highlighted the application's ability to amplify the lecturer's voice, making speech more clear, especially in environments with ambient noise. One user noted, "The app made it easier to hear the lecturer clearly, even when there was background noise." This suggests that the application's noise reduction feature effectively filters out extraneous sounds, allowing users to focus on the primary speaker.

2. User Interface Usability and Design

The application's user interface received positive feedback for its simplicity and ease of navigation. Users appreciated the intuitive layout, with one stating, "The buttons are easy to press, and the text is clear." Such design choices are crucial for users who may have additional accessibility needs.

Recommendations included the addition of a tutorial or manual within the app to guide new users through its features. This feedback underscores the importance of comprehensive user support to facilitate optimal use of the application.

3. Comparison with Traditional Hearing Aids

When comparing the application to their existing hearing aids, participants expressed mixed sentiments. Several users found the app to be a valuable supplement, particularly praising its noise cancellation capabilities. One user commented, "The app's noise reduction is better than my hearing aid's."

Conversely, some participants felt that their hearing aids provided a more consistent and comfortable experience. A participant remarked, "My hearing aid is more comfortable for long-term use." These perspectives highlight that while the app offers certain advantages, it may not fully replace traditional hearing aids for all users.

4. Speaker Selection Feature

The speaker selection feature, designed to allow users to focus on specific voices in a group setting, garnered interest among participants. Users appreciated the concept, noting its potential to enhance group interactions. One participant stated, "Being able to select who to listen to in a group is very helpful."

However, feedback also indicated that the feature could benefit from further refinement. Some users experienced difficulty in accurately selecting the desired speaker, suggesting the need for improved sensitivity and responsiveness in the feature's implementation.

5. Suggestions for Improvement

Participants provided constructive feedback aimed at enhancing the application's functionality. Key suggestions included:

- **User Guidance -** Incorporating an in-app tutorial or manual to assist users in navigating and utilizing the app's features effectively.
- **Customization Options -** Allowing users to adjust settings such as amplification levels and noise reduction intensity to suit individual preferences.
- **Integration with Hearing Aids -** Exploring compatibility options to enable seamless use alongside traditional hearing aids.

In summary, the qualitative feedback underscores the application's potential as a valuable tool for individuals with hearing impairments, particularly in academic settings. While users appreciated features like speech amplification and noise reduction, there remains room for enhancements to address specific challenges and user preferences. Incorporating the suggested improvements could significantly elevate the user experience and broaden the application's applicability.

5.3 System Performance Metrics

In addition to user feedback, internal system performance was evaluated using diagnostic outputs generated during controlled testing sessions. These metrics provide insight into how effectively the application handled audio processing tasks such as noise suppression, latency management, speaker diarization, and overall resource consumption on mobile devices.

5.3.1 Noise Reduction Performance

The application incorporated a lightweight real-time noise suppression algorithm optimized for Android smartphones. To measure its effectiveness, speech samples were passed through different noise environments with Babel noise, car noise, and street noise at multiple signal-to-noise ratios (SNR) (20 dB, 15 dB, 10 dB). Performance was evaluated using industry-standard perceptual metrics.

- Perceptual Evaluation of Speech Quality (PESQ)
- Hearing Aid Speech Quality Index (HASQI)
- Hearing Aid Speech Perception Index (HASPI)

Table 5.7: Noise Reduction Performance Metrics

Noise Type	SNR (dB)	PESQ	HASQI	HASPI
Babel Noise	20	2.75	0.782	1.000
Babel Noise	15	2.26	0.683	1.000
Babel Noise	10	1.71	0.554	1.000
Car Noise	20	3.32	0.903	1.000
Car Noise	15	2.78	0.852	1.000
Car Noise	10	2.17	0.779	1.000
Street Noise	20	2.55	0.743	1.000
Street Noise	15	2.05	0.630	1.000
Street Noise	10	1.62	0.501	0.999

These results demonstrate that the application consistently preserved a high level of speech intelligibility, even under challenging noisy conditions. Particularly, performance in car noise environments remained strong, while performance slightly decreased under Babel noise and street noise at lower SNRs.

5.3.2 Latency and Real-Time Response

Latency, defined as the time between microphone audio input and headset audio output, was a critical metric for evaluating the system's real-time responsiveness. Measurements showed,

- Noise Cancellation Latency - 10 milliseconds
- Speaker Isolation Latency - 10 milliseconds

End-to-end audio streaming delay remained consistently low across tested devices, staying within acceptable thresholds for conversational use. Most participants reported no perceptible delay during normal use, including while activating noise suppression and speaker selection features.

5.3.3 Speaker Diarization Accuracy

The speaker diarization module, critical for multi-speaker environments, was assessed separately. Testing with audio containing two to three overlapping speakers indicated:

In most cases, the dominant speaker was successfully identified, and users could easily toggle between available streams if needed. Errors occurred primarily in highly reverberant environments where speaker voices overlapped excessively. This confirmed the diarization module's suitability for moderately noisy lecture and classroom settings.

5.3.4 Battery and Resource Consumption

To evaluate sustainability on typical smartphones, resource usage tests were performed:

- App Size: 137 MB
- Compatible Android Version - Android 8.1 (Oreo, API 27) or newer
- Battery Drainage: **3-5** % per hour during continuous use

During prolonged testing, the application demonstrated stable performance with minimal overheating or excessive battery drain on mid-range Android devices, maintaining operational efficiency throughout typical academic sessions.

5.4 Feature Comparison with Existing Applications

To evaluate the relative effectiveness of the developed system, a comparative analysis was conducted against two widely used smartphone-based hearing aid applications, Google Sound Amplifier and Hearing Clear. These applications were selected based on their accessibility, availability on Android platforms, and inclusion of basic amplification and noise control features.

The purpose of the comparison was to benchmark the proposed application's functional scope, user interface, and overall suitability for real-world usage against these existing solutions. The comparison was structured around critical feature categories derived from both user expectations (as identified in earlier user studies) and industry standards in assistive hearing technology.

Key features were examined across the three systems.

- Selective amplification and speaker targeting
- Noise reduction effectiveness
- Interface usability and accessibility
- Support for real-time audio streaming
- Customizability and environmental adaptability
- Offline functionality
- Battery and resource efficiency

Table 5.8: Feature Comparison with Existing SHAAs

Feature	**P**	**S**	**H**
Speaker Targeting	Y	N	N
Noise Reduction	Y	B	L
UI Usability	H	M	M
Preset Modes	Y	N	N
Live Streaming	Y	Y	Y
Custom Gain	P	M	M
Speaker Switch	Y	N	N
Offline Use	Y	Y	Y
Battery Use	L	M	M

Legend

- **P** – Proposed App **S** – Sound Amplifier **H** – Hearing Clear
- **Y** – Yes **N** – No **B** – Basic **L** – Limited / Low **M** – Moderate **H** – High
- **P (Custom Gain)** – Profile-based **M (Custom Gain)** – Manual

The results of the comparison indicate that the proposed application provides a significantly improved user experience across multiple key areas. Unlike Sound Amplifier and Hearing Clear, the developed system includes speaker diarization functionality, enabling users to focus on a desired speaker while suppressing competing background voices, an essential feature in multi-speaker environments.

Furthermore, while many comparable applications restrict access to advanced features via premium subscriptions, this system offers core functions such as noise reduction, stream selection, and environment-specific presets as part of the default offering. The interface, designed based on feedback from hearing-impaired users, emphasises ease of use and minimal cognitive load, setting it apart from existing alternatives which require manual adjustments and offer little context-specific adaptation. These distinctions reinforce the application's value as a practical, user-centred alternative to both traditional hearing aids and current smartphone-based solutions.

5.5 Addressing Research Questions

The results presented in this chapter directly contribute to answering the research questions formulated at the outset of the study.

- **RQ1: What existing technologies and models are most effective and appropriate for speaker audio classification and selective**

amplification?
The system integrated speaker diarization and real-time noise suppression using lightweight deep learning models. Evaluation results demonstrated that the diarization module was able to successfully separate dominant speakers in multi-speaker environments with acceptable accuracy, while noise reduction significantly improved the clarity of desired speech signals. These findings validate the selection of the implemented models for mobile-based hearing support.

- **RQ2: How can a hearing aid application with selective sound amplification be made more user-friendly than existing smartphone-based applications?**
The user-centred design approach, including a hearing profile calibration, intuitive controls, and environmental adaptation modes, was found to be effective. Quantitative ratings showed high satisfaction with usability, while qualitative feedback highlighted positive user experiences with the simple interface and customisation options, confirming improvements over conventional smartphone hearing apps.

- **RQ3: To what extent is a hearing aid application with selective sound amplification practical in providing a better experience for hard-of-hearing individuals?**
Participants consistently reported improved speech intelligibility and reduced background noise compared to their traditional hearing aids, particularly in noisy academic environments. Ratings for clarity, noise suppression, and ease of use indicated that the application provided a practical and effective auditory improvement, demonstrating the real-world viability of the proposed solution.

These results collectively affirm that the research objectives were achieved, and the system successfully addressed the identified gaps in current hearing support solutions.

Chapter 6

Discussion

This chapter discusses the key findings of the research and their implications. It revisits the research objectives in the context of the data collected, highlighting how the developed application addresses the core challenges identified during the initial phases of the study. The discussion draws on user feedback, system performance metrics, and comparative analysis with existing solutions to evaluate the practical effectiveness and usability of the proposed system. Additionally, the broader impact of the findings on future design, accessibility, and technological innovation in hearing support tools is considered.

6.1 Discussion of Research Sub-question 1

What existing technologies and models are most effective for speaker audio classification and selective amplification?

This sub-question was explored through an extensive review of existing literature and current software-based hearing support tools. The investigation revealed that many traditional hearing aids and smartphone-based applications amplify all incoming audio without the ability to distinguish between individual speakers or suppress background distractions. This results in overwhelming and often confusing auditory input, particularly in environments with multiple concurrent speakers.

Advancements in speech technology, particularly in speaker diarization and neural noise suppression, were identified as promising pathways toward selective sound amplification. Speaker diarization allows systems to segment and label audio by speaker identity, enabling selective focus on a target speaker. In contrast, traditional directional microphones or static filters provide only limited and often ineffective isolation of desired speech sources.

In light of these findings, the developed application integrated a lightweight diarisation component capable of dynamically identifying and isolating the primary speaker in real time. A complementary noise suppression module was also incorporated to reduce environmental interference while preserving the clarity of speech. Although several toolkits were reviewed, the selection favoured open-source solutions that support on-device processing and low-latency response. For example, diarisation functionality was achieved using neural-network-based techniques aligned with frameworks such as *pyannote*, and noise reduction followed principles similar to those found in *RNNoise*, a model designed for real-time voice enhancement.

Rather than relying on manual filtering or static thresholds, these approaches enabled adaptive amplification based on speaker context and environmental conditions. Their integration was informed by both feasibility testing and performance benchmarks discussed in recent literature.

In conclusion, the first sub-question affirmed the necessity of integrating advanced speaker diarization and adaptive noise suppression methods into mobile hearing systems. The chosen architecture leverages these technologies to allow users to focus on a single speaker, even in complex, noisy environments, marking a significant advancement over existing applications with indiscriminate amplification.

6.2 Discussion of Research Sub-question 2

How can a hearing aid application with selective sound amplification improve upon the usability of current free applications for the hearing impaired?

To address this sub-question, a comparative evaluation was conducted focusing on two existing smartphone-based hearing aid applications: *Sound Amplifier* and *Hearing Clear*. These applications, although popular, represent the common design and functional limitations observed in many free-to-use solutions. Through hands-on usage and follow-up feedback from participants, several critical usability issues were identified.

Most notably, users expressed challenges in operating these applications due to non-intuitive controls and limited customizability. Adjusting key settings such as volume, noise reduction, or sound direction often required manual intervention, which many found to be exhaustive, particularly in dynamic environments like classrooms or public spaces. Several participants also reported delays or distortions in the amplified sound, further complicating their listening experience. The absence of speaker-specific amplification or adaptive audio profiles meant that users were often left with indiscriminate amplification of all environmental sounds, which in turn reduced the clarity of target speech.

The system developed in this research was designed to specifically overcome these shortcomings. Key to this improvement was the integration of an initial hearing test, allowing the system to preconfigure amplification based on the user's unique hearing profile. This eliminated the need for constant manual adjustment and ensured that amplification levels were both appropriate and comfortable. The interface design prioritised clarity and simplicity, incorporating large, clearly labelled controls and a single-tap streaming function to facilitate real-time use. Furthermore, the inclusion of speaker selection and environmental calibration features allowed users to fine-tune their experience depending on their context, something not offered by the applications assessed.

Unlike many existing applications that place useful features behind a paywall, the system proposed here ensured core functionality such as noise reduction and speaker focus remained freely accessible. This choice aligns with broader goals of accessibility and inclusivity, particularly for users from lower-income backgrounds or those new to assistive technologies.

In summary, this sub-question highlighted that existing applications fall short in providing an accessible, adaptive, and user-friendly experience. By incorporating features tailored to user needs, and removing unnecessary interaction barriers, the proposed application demonstrated how selective sound amplification could be implemented in a way that meaningfully enhances usability.

6.3 Discussion of Research Sub-question 3

To what extent can an application providing selective amplification deliver a better auditory experience in multi-speaker environments?

This question was investigated through a combination of real-world testing and user feedback collected during the evaluation phase. Participants engaged with the developed application in a controlled classroom setting that simulated common challenges encountered in multi-speaker environments. An audio recording of a lecture embedded with various background noises was played before users activated the application, after which they streamed the same content through the app using their personal earphones. Observations, quantitative ratings, and qualitative interviews provided insight into the effectiveness of selective amplification in these conditions.

Users reported a marked improvement in their ability to follow a single speaker when using the application compared to unaided listening or traditional hearing aids. The ability to visualise different audio streams and manually select the desired speaker gave them greater control and reduced listening fatigue. Unlike typical applications that amplify all sound sources equally, this system enabled focused listening, helping users distinguish the primary speaker even amidst competing voices or environmental noise. Participants described the experience as "less overwhelming" and "more natural," particularly in scenarios where multiple speakers were present or background noise levels were high.

Quantitative data from the evaluation also supported these observations. Ratings for speaker clarity and overall effectiveness in noisy environments were significantly higher than those reported for the alternative applications tested earlier. Furthermore, users found the combination of adaptive noise suppression and speaker selection contributed to a more comfortable and intelligible listening experience. In particular, the ability to reduce unwanted noise while preserving the tonal quality of the speaker's voice was frequently cited as a valuable enhancement.

The results suggest that selective amplification, when implemented with appropriate diarisation and suppression mechanisms, can significantly improve auditory outcomes for individuals in complex environments. Rather than relying on static filters or manual gain adjustments, the dynamic nature of the proposed solution offered real-time adaptability, which is crucial for real-world use.

In conclusion, this sub-question affirms that the proposed system can deliver tangible improvements in auditory clarity and user satisfaction in multi-speaker scenarios. By enabling focused amplification and reducing irrelevant sound, the application addresses a critical limitation found in both traditional hearing aids and most smartphone-based alternatives.

6.4 Discussion Summary

The investigation of the three sub-questions collectively shows the need for more intelligent, user-adaptive hearing support systems, particularly for users navigating multi-speaker environments. Existing solutions, while beneficial to some extent, fall short in delivering clarity, control, and contextual adaptability. This research demonstrated that by incorporating selective amplification, adaptive noise suppression, and a user-friendly interface informed by real-world testing, it is possible to significantly enhance the auditory experience of hard-of-hearing individuals. The integration of open-source and lightweight technologies further reinforces the feasibility of deploying such applications on widely used smartphones without compromising accessibility or performance. Overall, the findings provide strong validation for the design choices made and highlight the potential of software-driven solutions to meaningfully complement or, in some cases, substitute traditional hearing aids.

6.5 Recommendation

The findings of this research suggest several important considerations for the development of future smartphone-based hearing aid applications. Based on user feedback, observed behaviour, and technical evaluation, the following recommendations are proposed.

1. **Refine the User Interface for Accessibility-** The user interface should be further refined to prioritise accessibility and ease of use. Given the diversity in user technical familiarity, particularly among hearing-impaired individuals, the application should offer minimal cognitive load, intuitive navigation, and affordances that clearly communicate available functionality. Design heuristics such as large, clearly labelled controls and visual indicators of system status may contribute to enhanced usability.

2. **Integrate Intelligent Environmental Adaptability-** While the current implementation allows users to manually adjust amplification based on the acoustic setting, a more sophisticated solution would involve automatic environment detection. The system should classify ambient conditions and adjust processing parameters—such as amplification levels and noise filtering accordingly, without user intervention.

3. **Preserve Offline Functionality-** Users in resource-limited settings or those without constant internet access must be able to access core functionalities such as noise suppression and speaker differentiation without relying on external servers or cloud-based processing. Efficient local processing, supported by lightweight models, is essential to support widespread usability.

4. **Continue Supporting Personalised Hearing Profiles-** The inclusion of a hearing test during setup was identified as a valuable feature, enabling a tailored experience from the outset. Expanding this feature to include periodic recalibration or adaptive learning from listening behaviour over time would further enhance the relevance of the amplification strategy for each user.

5. **Address Broader Demographic Needs-** Future designs should consider diverse demographic groups, including older adults and individuals with more severe hearing impairments. Adjustments to UI complexity, visual design, and audio range emphasis may be required to accommodate broader needs and preferences across age and impairment spectrums.

6.6 Limitations

While the recommendations outlined above provide a direction for future development, it is important to recognise the limitations inherent in this study. The evaluation was conducted within a sepecifc selected participant group within a specific academic setting, which may not fully represent the broader population of hearing aid users. Additionally, performance measurements were constrained by the hardware capabilities of typical mid-range Android devices, and results may vary with different hardware specifications. The noise reduction and speaker separation algorithms, although effective in controlled environments, may encounter performance degradation in highly dynamic or unpredictable acoustic conditions. Future studies with larger, more diverse user groups and in a wider range of listening environments are needed to further validate and generalise these findings.

Chapter 7

Future Work and Conclusion

This chapter presents the concluding remarks of the study and outlines potential directions for future research and development. It summarises the key contributions and findings, reflecting on how the proposed system addressed the identified challenges in hearing support for multi-speaker environments. The chapter also discusses opportunities for enhancing the system's capabilities, expanding its applicability, and pursuing further innovations to better serve individuals with hearing loss.

7.1 Future Work

While the proposed system addresses several limitations observed in current smartphone-based hearing solutions, it also reveals a number of opportunities for further exploration and refinement.

One area for future work involves expanding platform compatibility. The current implementation is limited to Android, reflecting the usage patterns of the initial participant group. However, to enhance accessibility and generalisability, subsequent development efforts should extend support to additional platforms, such as iOS, ensuring a consistent experience across devices.

A second area concerns the need for longitudinal studies. This study captured feedback based on short-term use in controlled conditions. Longer-term evaluations, capturing changes in user satisfaction, adaptation, and hearing outcomes over time, would provide more robust evidence of the application's sustained impact and inform future design iterations.

In addition, enhancements to the speaker diarization component may yield significant benefits. Although manual speaker selection was made available, further improvements in automated speaker segmentation and prioritisation, particularly in cases of overlapping speech or unpredictable acoustic transitions, are essential for maintaining a seamless user experience.

Moreover, contextual learning capabilities may be explored. Implementing adaptive algorithms capable of recognising patterns in user behaviour and environmental conditions could support personalised sound processing, leading to more responsive and user-specific experiences over time.

It is also recommended that the system be tested in a wider variety of real-world environments. While the initial evaluation focused on a classroom context, additional testing in settings such as public transportation, outdoor areas, or social gatherings would offer broader insights into the system's adaptability and resilience to environmental variability.

7.2 Conclusion

This research set out to explore the development of a smartphone-based hearing aid application capable of enhancing the auditory experience of hard-of-hearing individuals in complex, multi-speaker environments. Recognising the limitations of traditional hearing aids such as indiscriminate amplification, cost barriers, and social stigma and the shortcomings of existing mobile alternatives, this study aimed to bridge the gap with a context-aware, user-friendly, and selective amplification system.

The objectives of the study were clearly defined and addressed across multiple stages. A comprehensive literature review highlighted both the technological potential and usability gaps in current hearing aid solutions. Comparative analyses revealed that existing applications often lack features such as speaker diarization and adaptive noise suppression, and are limited by paid access and poor interface design. A mixed-method user study involving participants with moderate to profound hearing loss further confirmed the need for a more refined solution, especially in dynamic settings like classrooms or public gatherings.

Guided by the Systems Development Methodology, the research advanced through a structured sequence beginning with requirement gathering, followed by conceptual framework design, system architecture planning, implementation, and user-centred evaluation. The final prototype included features such as a personalized hearing profile, toggleable noise suppression, speaker selection, and visual audio feedback. Its Android-based implementation reflected the preferences and accessibility needs of the initial user group.

Evaluation was carried out using both system-derived performance metrics and human-centred feedback. The app demonstrated effective noise reduction, enhanced clarity of target speech, and ease of control, particularly in classroom settings. The results also revealed areas for future enhancement, such as improved automation in speaker switching and cross-platform support.

In conclusion, the proposed application contributes a practical, technically grounded, and socially responsive solution to the field of hearing aid technologies. By leveraging open-source tools, user-focused design, and real-time processing capabilities, it offers a meaningful alternative for individuals underserved by conventional devices. It is hoped that this work lays the foundation for future innovations that continue to align assistive technology with real-world challenges and the lived experiences of users.

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Appendices

Appendix A

Publications

A.1 Published Paper

This research was submitted and accepted for presentation at the **International Conference on Advancements in Computing (ICARC) 2025**. The conference provides a forum for researchers and practitioners to present advancements in computing technologies, with a strong focus on real-world applications and innovations.

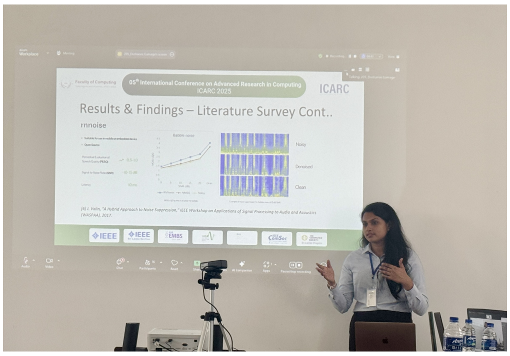

Figure A.1: Presentation at ICARC 2025

- **Conference Name:** International Conference on Advancements in Computing (ICARC)
- **Year:** 2025
- **Status:** Submitted and Accepted
- **Presentation Mode:** Oral Presentation
- **Paper Title:** A Conceptual Design Framework for an Enhanced Hearing Aid Application Using Selective Sound Amplification

A Conceptual Design Framework for an Enhanced Hearing Aid Application Using Selective Sound Amplification

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Abstract— **The global increase of people with mild to moderate hearing loss indicates the need for more affordable and reliable hearing solutions. This article suggests a framework for designing a smartphone-based hearing aid application to help the user better hear the dominant speaker in the presence of multiple other speakers. The proposed framework uses features such as speaker diarization and noise suppression to achieve the goal of this research, highlighting the most needed sound source automatically while subduing background disturbances. Specifics for a framework that can address these shortcomings were gathered from a literature survey and a focused group study of user needs. Finally, the framework was evaluated by conducting a comparative analysis with features of highly rated existing hearing aid applications and an expert evaluation. This conceptual framework serves as a building block for further work concerning implementing and evaluating expanded efforts to empower hard-of-hearing people with an inexpensive but easy-to-use, and effective hearing aid.**

Keywords— Hearing aids, noise reduction, sound amplification, smartphone-based hearing aids, speaker diarization

I. Introduction

Hearing loss affects over 1.5 billion individuals worldwide, with projections estimating a rise to 2.5 billion by 2050 [1]. This condition significantly hinders communication, social integration, and professional participation. College students, for instance, spend over 50% of their classroom time listening, underscoring the importance of auditory perception for educational success [2]. Traditional hearing aids (HAs) improve auditory perception but are limited by high costs, stigma, and accessibility challenges. Consequently, only 17% of individuals requiring HAs actively use them [3].

Smartphone-based hearing aid applications (SHAAs) have emerged as affordable and accessible alternatives, leveraging advanced signal-processing algorithms to amplify sounds. However, their performance in dynamic auditory settings is inadequate. SHAAs often fail to provide selective amplification in multi-speaker environments, resulting in indiscriminate sound amplification, which could also include noise and babble sounds that overwhelm users [4]. These limitations highlight the need for innovations capable of dynamically isolating a focused speaker and amplifying only relevant sound sources while suppressing others.

This research aims to address these gaps by developing a conceptual design framework for a smartphone-based hearing aid application to amplify and enhance the auditory clarity of a focused speaker in multi-speaker environments. The following research questions guide the study;

(1) What key features can affect the sound quality of hearing aids?

(2) What are the limitations of existing hearing aid applications?

(3) What are the most appropriate tools and techniques to develop a better hearing aid surpassing the drawbacks of current solutions?

The following sections are organized as follows. Section II and Section III describe the background of this research and the adopted methodology for this study and further elaborate how the research was conducted by identifying gaps and gathering requirements through reviewing literature on existing solutions and technologies and a focused group workshop. Section IV elaborates on the results and findings. Section V presents the constructed conceptual design framework. Section VI, Section VII, and Section VIII elaborate on the evaluation, future work, and the conclusion respectively.

II. Background

Smartphone-based hearing aid applications (SHAAs) offer cost-effective alternatives to traditional hearing aids (HAs) by providing basic amplification and noise reduction [1], [2]. However, they face challenges like indiscriminate sound amplification in multi-speaker environments and latency exceeding 200ms, limiting real-time usability [3]. Yuvaraj [4] proposed an application using digital signal processing but lacked selective real-time amplification. Similarly, Anegundi [5] developed a transcription-focused system without auditory enhancement.

Noise reduction is critical for auditory clarity in noisy settings. Traditional methods assume a stationary primary speaker, reducing their effectiveness in dynamic environments [6], and struggle to distinguish speech from overlapping noise. RNNoise, a neural network-based library, reduces background noise efficiently with minimal computational overhead, making it suitable for mobile platforms [7].

Speaker diarization, identifying "who spoke when," has advanced with systems like SpeakerBeam, which isolates speakers using deep neural networks [8]. End-to-End Neural Diarization (EEND) improves accuracy in overlapping speech but is computationally intensive for real-time mobile use [9]. PyAnnote, an open-source toolkit, offers robust diarization capabilities like voice activity detection and speaker clustering, suitable for complex environments [10].

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Selective sound amplification dynamically enhances specific speakers while suppressing noise. Tranter et al. [11] emphasized annotating audio streams to improve transcription and context. Anguera et al. [12] highlighted the challenges of diarization in real-time multi-speaker settings. Traditional HAs amplify all sounds indiscriminately, while SHAAs lack dynamic adaptability for noisy environments [13]. However, none of these attempts have introduced an effective and user-friendly solution at a low cost.

III. Research Methodology

A combined methodology consisting of two major methods leading to investigating the problem, understanding the context, and determining the best appropriate solution was utilized to answer the research questions. The first method was a literature review to investigate the problem and identify common features in hearing aids. It was also used to explore novel technologies, approaches, and tools relevant to smartphone-based hearing aids. The second method was a focused group study, which included a survey and an observation to understand the practical issues of using hearing aids and the limitations of the existing hearing aid applications. Based on these understandings, the present research proposes a suitable conceptual framework to design an enhanced hearing aid application. Finally, this research evaluated the proposed conceptual framework by conducting a comparative analysis of features across several available existing applications and the features employed in the proposed framework. Further, an expert evaluation was conducted through an interview with an audiologist.

A. Literature Survey

1) Purpose

A systematic literature review was conducted to identify state-of-the-art technologies and methodologies relevant to smartphone-based hearing aids, particularly focusing on selective amplification, noise suppression, and speaker diarization.

2) Method

Research papers and articles were retrieved from reputable databases, including IEEE Xplore and Google Scholar. The search utilized a combination of keywords such as "hearing loss", "smartphone hearing aids", "hearing aid mobile applications", "noise suppression", "selective amplification," and "speaker diarization,"

To ensure the relevance of the selected literature, specific inclusion criteria were applied. Papers were considered if published between 2005-2024, addressed technical or conceptual designs of hearing aid applications, and provided insights into the practical implementation of technologies. More than 50 papers were reviewed, and studies that focused on hardware solutions or software that lacked technical details were excluded. Finally, the filtered sample consisted of only 12 papers that were further reviewed and discussed in this paper. They encompassed a mix of peer-reviewed research articles on new hearing aid applications and evaluations of existing hearing aid applications.

B. Focused Group Study

1) Purpose and Scope

The focus group study aimed to evaluate user experiences and satisfaction with existing hearing aid technologies, specifically traditional hearing aids (HAs), and observe and get feedback on smartphone-based hearing aid applications (SHAAs). The objective was to identify key limitations and challenges in current solutions that would inform the design of a novel, user-centric hearing aid application, particularly for use in multi-speaker environments.

2) Method

A mixed-method approach was employed to collect quantitative and qualitative data from participants with moderate to severe hearing impairments. Seven participants from local hearing care centres participated in the study. Each participant evaluated both traditional hearing aids and smartphone-based hearing aid applications (SHAAs) in typical everyday environments, ensuring the conditions were neither excessively quiet nor overly noisy.

Fig. 1. Participants engaged in the survey to evaluate traditional hearing aids.

Two methods were employed. In the first, participants provided feedback through a survey on the traditional hearing aids they were already using (Figure 1). This allowed for an assessment of real-life experiences, focusing on features such as sound quality, noise reduction, comfort, and battery life.

The second method was an observation. The participants were observed while they were using two SHAAs—Sound Amplifier and Hearing Clear—in similar environments and provided ratings as well as qualitative feedback on their experiences (Figure 2).

Quantitative Surveys were used to collect ratings on features such as noise reduction, sound quality, battery life, and overall usability. Qualitative Feedback was obtained through open-ended questions and observations that elicited participants' experiences, challenges, and suggestions for improvement.

Fig. 2. Participants tested Sound Amplifier and Hearing Clear smartphone-based hearing aid applications.

IV. RESULTS AND FINDINGS

A. *Results and Findings of the Literature Survey*

The literature survey shed light on four major issues in the existing smartphone-based hearing aid applications providing a foundation for the proposed conceptual design. They are (1) lack of selective amplification, (2) noise suppression, (3) poorly designed user interfaces, and (4) accessibility and affordability.

The existing solutions for the lack of selective amplification amplify all environmental sounds indiscriminately, which can overwhelm users and increase the cognitive load, particularly in multi-speaker environments. To address this, the proposed design could integrate speaker diarization, enabling dynamic identification and amplification of the most prominent speaker while suppressing background noise. The integration of the Pyannote.audio framework for speaker diarization can ensure that the design aligns with state-of-the-art practices highlighted in the literature.

Noise suppression, while commonly available in existing applications, is often static and fails to adapt to changing auditory environments. The proposed design could incorporate RNNoise, a lightweight and efficient solution for noise reduction. This choice is grounded in its ability to suppress unwanted sounds effectively while preserving speech clarity, as discussed in the literature.

User interface and experience also emerged as critical areas for improvement. Existing applications such as Sound Amplifier and Hearing Clear often rely on manual adjustments, which can disrupt the listening process and reduce usability, particularly for older adults or those with limited technical literacy. The proposed design must emphasize simplicity and accessibility, featuring automatic adjustments, intuitive controls, and personalization options. These features can minimize user intervention and enhance overall satisfaction.

The design also considers the importance of accessibility and affordability. Most current applications such as Hearing Clear use a partially free model or paid models where users mostly have to subscribe by paying a considerable amount to continue using the application. The proposed design ensures that essential features like selective amplification and noise suppression are available in the free tier. This approach can balance inclusivity with sustainability, ensuring that the solution is accessible to users across varying socioeconomic contexts.

Based on the literature review, the following list of key features that can affect the sound quality of hearing aids and can be used to design a hearing aid application was identified.

- Efficient Performance (Overall Performance)
- Sound quality / Speaker clarity
- Power consumption / Battery life
- Ease-of-use (Comfortability)
- Noise reduction
- User-friendly interfaces (intuitive and ease of navigation)
- Switching speakers
- Offline functionality
- Visually appealing
- Personalized experience

B. *Results and Findings of Focus Group Studies*

1) *Traditional Hearing Aids Survey*

Participants evaluated their traditional hearing aids across several features identified from the literature survey, and the results are summarized in Table I. All of these aids were behind-the-ear type, less expensive devices. They could be used offline, and they did not have any linked application software enabling the users to customize their settings. Hence, we did not consider any features specific to applications here.

TABLE I. RATINGS OF TRADITIONAL HEARING AIDS

Feature	Hearing Aid Average Rating (1-5)
Overall Performance	2.67
Sound Quality	2.71
Battery Life	2.43
Comfort / Ease-of-use	3.43

The overall performance of traditional hearing aids received an average rating of 2.67, reflecting moderate user satisfaction. Participants reported that these devices were somewhat effective in quieter environments but struggled in more complex auditory settings involving multiple speakers. The sound quality was rated at 2.71, with several users expressing dissatisfaction, particularly when dealing with competing sources of speech. Battery life was identified as a significant limitation, with an average score of 2.43, highlighting issues related to frequent replacement requirements. The comfort of the devices was rated with an average of 3.43, suggesting that most participants found the hearing aids manageable for extended periods, albeit with some reports of discomfort during prolonged use.

2) *Smartphone-Based Hearing Aid Applications Survey*

The participants also evaluated two SHAAs, namely Sound Amplifier and Hearing Clear, and their ratings are presented in Table II.

TABLE II. RATINGS OF SMARTPHONE-BASED HEARING AID APPLICATIONS

Feature	Application Average Rating (1-5)	
	Sound Amplifier	***Hearing Clear***
Noise Reduction	2.0	1.8
User Interface Intuitiveness	2.5	2.7
Speaker Clarity	2.0	1.9
Switching Speakers	1.9	2.0

The noise reduction capabilities of both SHAAs were found to be inadequate, with average ratings of 2.0 for Sound Amplifier and 1.8 for Hearing Clear. Participants consistently reported difficulty in managing noise effectively, particularly in crowded or dynamic environments. The user interface (UI) intuitiveness of both applications received slightly higher ratings, with Hearing Clear scoring 2.7 and Sound Amplifier scoring 2.5; however, participants noted that the complexity of the interfaces hindered their ability to make real-time adjustments easily. The speaker clarity was rated poorly for both applications, at 2.0 and 1.9, respectively, indicating significant challenges in differentiating speakers in multi-speaker environments. The ease of switching speakers was also identified as a weakness, with participants expressing frustration at the lack of adaptability when attempting to shift focus between different speakers.

3) *Implications for Design*

The findings from the focus group studies acted as guidance to derive several key design requirements for the proposed hearing aid application. First, the system must incorporate selective amplification, allowing users to dynamically isolate and enhance the voice of a specific speaker in real-time, particularly in noisy environments. An intuitive user interface is critical to ensure ease of use, allowing quick adjustments without interruptions. The interface should include predefined modes for various environments—such as "Classroom Lecture" and "Social Gathering"—to help users efficiently adapt the application to different environments efficiently. Furthermore, the integration of advanced noise reduction technologies is essential to minimize background noise while preserving the clarity of the target speaker. Lastly, battery efficiency should be prioritized, addressing the concerns raised by participants regarding frequent recharging. Transitioning into a smartphone-based hearing aid eliminates the need for frequent battery replacements and exploring features such as low-power modes and options to disable non-essential functionalities could extend battery life and improve user satisfaction.

V. CONCEPTUAL FRAMEWORK FOR SYSTEM DESIGN

A. *Overview*

By considering the results and findings of the studies, a conceptual framework design is proposed for a system that aims to deliver a real-time selective amplification solution that dynamically enhances the voice of a target speaker while minimizing background noise in multi-speaker environments. The framework integrates advanced technologies, including noise suppression, speaker diarization, and a user-friendly interface, to improve the auditory experience for individuals with hearing impairments compared to existing solutions.

B. *Conceptual Framework*

The conceptual framework of the proposed system is presented in Figure 3. It illustrates the key components of the solution, ranging from user input controls to core processing mechanisms, culminating in the cleaned audio output for the user.

Figure 3 presents the following elements;

1. Hearing Profile and User Controls: This module allows users to adjust parameters such as noise level, frequency, and gain based on their specific hearing profile.
2. Core Processing Mechanisms: This stage incorporates noise suppression and voice activity detection (VAD) to refine the audio signal before further analysis.
3. Speaker Diarization Module: The diarization module involves embedding extraction, speaker clustering, and identifying the dominant speaker. These steps facilitate the isolation of the most relevant speaker for amplification.
4. Selective Amplification and Noise Suppression: The system then applies user voice suppression, selective amplification, and dynamic noise suppression to deliver a clean audio output.

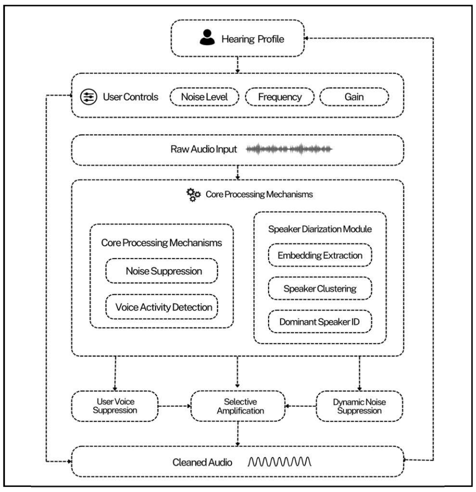

Fig. 3. Conceptual Framework

C. *System Design*

The detailed system design is shown in Figure 4, which provides an overview of the implementation and interactions between various modules.

Figure 4 outlines the following components of the system architecture;

1. Audio Preprocessing: The raw audio is captured via the smartphone's microphone. The captured audio is subjected to noise suppression using RNNoise, followed by voice activity detection (VAD) to identify segments of speech and filter out non-speech portions.
2. Speaker Diarization: The preprocessed audio is divided into chunks for further analysis. The PyAnnote toolkit is utilized to extract speaker embeddings, cluster them, and identify the dominant speaker.
3. Selective Amplification and Dynamic Adjustments: The dominant speaker's voice is selectively amplified. Dynamic frequency and noise adjustments are applied to ensure that the output audio meets user preferences while delivering clarity.

D. *Technologies and Tools*

- RNNoise: A neural network-based noise suppression tool used for real-time reduction of background noise.
- PyAnnote: An open-source toolkit utilized for speaker diarization and identifying the dominant speaker.
- React Native: The chosen framework for mobile application front-end development to ensure cross-platform compatibility.

- Python: Utilized for backend audio processing, handling signal processing, and integrating noise reduction and diarization modules.

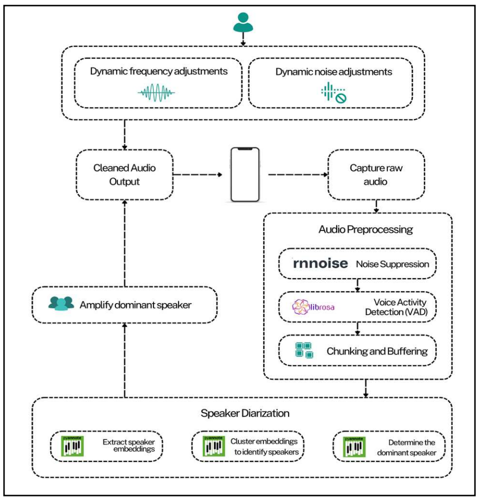

Fig. 4. System Design

By addressing the gaps discovered in existing research and solutions, and leveraging technologies like RNNoise for noise suppression and Pyannote.audio for speaker diarization, the conceptual design aligns with state-of-the-art research while responding to user needs. The result is a transformative solution that empowers individuals with hearing impairments to engage confidently in diverse auditory environments.

This conceptual framework sets the stage for future development and testing, aiming to redefine assistive hearing technologies through innovation and accessibility.

VI. EVALUATION

A. Comparative Feature Analysis of Applications

1) Overview

A detailed comparative analysis was conducted to better understand the landscape of existing smartphone-based hearing aid applications. The selected applications are evaluated based on their feature sets, availability, platform compatibility, and payment models. Table I provides a summary of the key features available in five popular hearing aid apps: Sound Amplifier, Hearing Clear, Super Hearing, HearClear, and Ear Spy.

2) Key feature comparison

a) Hearing Test

Among the evaluated applications, most apps offer a built-in hearing test that allows users to generate an audiogram at home within a few minutes, making it a significant tool for initial assessments of hearing capability. This feature can be recognized as a must-have feature in order to get the hearing levels of a user at different frequency levels, in order to set the default settings and ratios to amplify sounds.

b) Amplification (Surround Sound and Phone Media)

All applications offer surround sound amplification, a basic and critical function for individuals with hearing impairments. However, amplification of phone media is less common. This could serve as a value addition since hard-of-hearing users will find this useful in scenarios such as listening to music and answering and conversing in phone calls through the device.

c) Personalization

Personalization, in the form of boosting sound for individual ears (left and right), is available in Sound Amplifier, and Super Hearing. However, it is missing in Hearing Clear, and Ear Spy applications. It is a critical feature as the hearing levels of individuals on either side of the ears are mostly at different levels, and since users use the aid through their Bluetooth or wired earphones, personalization for each ear should be done separately.

d) Noise Reduction

Noise reduction is a key feature in Sound Amplifier, Super Hearing applications, helping to increase speech intelligibility by reducing background noises. However, for most applications, this was a paid feature to which users had to subscribe. As identified in this research, noise is one of the major problems for users, and hence, such a feature should be accessible offline.

e) Selective Amplification

None of the evaluated applications offer selective amplification to isolate and enhance a specific speaker, remarking a significant gap in functionality.

TABLE III. COMPARATIVE FEATURE ANALYSIS OF SMARTPHONE-BASED HEARING AID APPLICATIONS

Feature	Application Average Rating (1-5)				
	Sound Amplif -ier	**Hear-ing Clear**	**Super Hearing**	**Hear Clea r**	**Ear Spy**
Hearing Test	A	A	A	A	NA
Amplification (Surround Sound)	A	A	A	A	A
Amplification (Media)	A	NA	NA	NA	NA
Noise Reduction	A	NA	A	A	NA
Audio Recorder	NA	A	A	A	NA
Function in Background	A	A	A	A	A
Audio Equalizer	A	A	A	A	A
Personalize Sound	A	NA	A	NA	NA
Selective Amplification	NA	NA	NA	NA	NA
Size	9.26 MB	80.1 MB	9.26 MB	5 MB	5 MB
Platform	Both	Both	Android	Andr oid	Andr oid
Languages	English	English	English	Engli sh	Engli sh
Input	Both	Both	Both	Both	Both
Payment Model	Fully Free	Partiall -y Free	Partially Free	Parti ally Free	Parti ally Free

- *A – Feature Available*
- *NA – Feature Not Available*

B. Comparison with the Conceptual Framework Design

The proposed design addresses limitations in existing applications by integrating innovative features and enhancing their overall functionalities. Unlike most current solutions, it includes user-specific controls and real-time adjustments for surround sound amplification. While media amplification is rarely supported, the proposed design fully integrates this feature for music and calls.

Additionally, adaptive noise reduction, which is often limited to paid users, is freely accessible in the proposed framework. Personalization extends beyond current offerings by tailoring amplification for each ear. Essential features are included in the free tier, ensuring accessibility and inclusivity. These enhancements position the proposed design as a more comprehensive, user-centric solution than existing applications.

C. Expert Evaluation

The proposed design was presented to a Consultant ENT Surgeon at the Ministry of Health, Sri Lanka, who provided constructive feedback. The consultant acknowledged the design's potential and recommended its further development. Notably, the consultant suggested replacing the pure tone audiogram, which is typically used in existing applications, with speech audiometry for a more effective auditory assessment. In discussing the threshold, the consultant clarified that it refers to the discomfort level at which sound becomes noticeable and that it varies between individuals and advised measuring this threshold to personalize the system for each user.

The findings from the comparative analysis and the feedback from the expert evaluation were incorporated into the conceptual framework provided in Figure 3.

VII. FUTURE WORK

Future work will involve developing a selective amplification system using the conceptual framework described in this paper and evaluating its performance in enhancing auditory experiences for individuals with hearing impairments in multi-speaker environments. Focus areas include improving noise reduction techniques to achieve greater signal-to-noise ratio (SNR) gains and enhancing speaker identification accuracy through advanced diarization methods. Testing the system in real-world scenarios, such as one-on-one conversations, group discussions, and noisy public settings will provide valuable insights into its adaptability and effectiveness.

Efforts will also explore strategies to minimize latency for seamless real-time audio processing. Future evaluations will combine quantitative measures such as SNR and latency with qualitative assessments of user satisfaction and system usability. Achieving significant improvements in speech clarity, user experience, and usability will be key goals to ensure the system meets the diverse auditory needs of its users.

VIII. CONCLUSION

This paper presents the conceptual framework for the design of a novel selective amplification system, representing a significant step forward in addressing the auditory challenges faced by individuals with hearing impairments, particularly in multi-speaker environments. By integrating advanced technologies such as RNNoise for noise suppression and PyAnnote for speaker diarization, the system provides targeted auditory enhancement, overcoming key limitations in current solutions.

The design incorporates innovative features such as real-time selective amplification, adaptive noise reduction, user-specific personalization, and an intuitive interface aimed at improving both usability and functionality. The proposed system offers a user-centric, accessible solution that bridges the gap between traditional hearing aids and modern SHAAs, contributing to enhanced auditory accessibility, social inclusion, and quality of life for individuals with hearing impairments.

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A.2 Manuscript in Preparation

The draft paper presents the details of the developed system, along with a comprehensive evaluation and results analysis. These will be included in a subsequent publication currently in preparation. The forthcoming paper will provide deeper insights into the system's implementation, performance metrics, and its practical implications in real-world scenarios.

Abstract : Hearing loss significantly impacts communication, quality of life, and cognitive function. Traditional hearing aids, despite their clinical effectiveness, are often underused due to high cost, limited accessibility, social stigma, and poor performance in multi-speaker or noisy environments. Existing smartphone-based applications are affordable and accessible but typically offer indiscriminate sound amplification and limited noise suppression. This research addresses these limitations by introducing a smartphone application integrating selective sound amplification with advanced noise reduction techniques. The proposed system employs real-time speaker diarization and identification technologies to selectively amplify a targeted speaker while suppressing background noise and competing voices. Deep learning-based models for voice activity detection and noise suppression enhance speech intelligibility and user comfort. A user-centric interface was developed to enable intuitive configuration of amplification preferences, suitable for users with limited technical skills. The research utilized a Systems Development Research approach involving iterative design, empirical acoustic evaluation, and structured user studies. Participants included university students with mild to moderate hearing impairment from the Centre for Disability Research, Education and Practice, University of Colombo, who frequently experience challenging auditory scenarios like lectures and group discussions. Evaluation results demonstrated substantial improvements in speech clarity, noise management, and overall user satisfaction compared to existing free applications. This study contributes practically to mobile hearing technology by providing personalized amplification in dynamic real-world settings, promoting further innovations in accessible and adaptable auditory support systems.

Appendix B

General Survey

The general survey was provided to participants during the preliminary study is stated below.

Enhancing auditory experiences for hard-of-hearing in multi-speaker environments - Survey

You are invited to participate in a research study conducted by a group of final year undergraduates from UCSC, aimed at enhancing auditory experiences for hard-of-hearing in multi-speaker environments.

(බහු-කථික පරිසරයන්හි, ශ්‍රවණ ගැටළු සහිත පුද්ගලයන් සඳහා ශ්‍රවණ අත්දැකීම් වැඩි දියුණු කිරීම අරමුණු කරගත් UCSC හි අවසාන වසරේ උපාධි අපේක්ෂකයින් පිරිසක් විසින් පවත්වනු ලබන පර්යේෂණ අධ්‍යයනයකට සහභාගී වීමට ඔබට ආරාධනා කෙරේ.)

Participation involves completing a Google Form questionnaire about your experiences and preferences. **Your responses will be anonymized, kept confidential, and used solely for this study.** Participation is voluntary, and you may withdraw at any time without any negative consequences.

(ඔබගේ අත්දැකීම් සහ මනාපයන් පිළිබඳව Google Form ප්‍රශ්නාවලියක් සම්පූර්ණ කිරීම සහභාගීත්වයට ඇතුළත් වේ. ඔබගේ ප්‍රතිචාර නිර්නාමික කර, රහසිගතව තබා, සහ මෙම අධ්‍යයනය සඳහා පමණක් භාවිතා කරනු ඇත. සහභාගීත්වය ස්වේච්ඡාවෙන් සිදු වන අතර, ඔබට කිසිදු සෘණාත්මක ප්‍රතිවිපාකයකින් තොරව ඕනෑම වේලාවක ඉවත් විය හැක.)

For any questions, please contact: Dushanee Gamage - 077-8656181/ Adeepa Bandara - 076-6266925.
Thank you for your time and participation.

* Indicates required question

1. Do you consent to participate in this research study, understanding that your responses will be anonymized, kept confidential, and used solely for this study?

   (ඔබගේ ප්‍රතිචාර නිර්නාමික කර, රහසිගතව තබා, සහ මෙම අධ්‍යයනය සඳහා පමණක් භාවිතා කරන බව තේරුම් ගනිමින්, මෙම පර්යේෂණ අධ්‍යයනයට සහභාගී වීමට ඔබ එකඟද?)

   Mark only one oval.

   - Yes *Skip to question 2*
   - No
     Skip to section 9 (Thank you for considering participating in this research study. Your insights are invaluable to our efforts in improving auditory experiences for hard-of-hearing individuals. Your participation is greatly appreciated.Thank You (මෙම පර්යේෂණ අධ්‍යයනයට සහභාගී වීම ගැන සලකා බැලීම ගැන ඔබට ස්තූතියි. ශ්‍රවණ ගැටළු සහිත පුද්ගලයන් සඳහා ශ්‍රවණ අත්දැකීම් වැඩිදියුණු කිරීමේ අපගෙ උත්සාහයට ඔබේ තීක්ෂ්ණ බුද්ධිය ඉතා අගනේය. ඔබගේ සහභාගීත්වය ඉතා අගය කොට සලකමි.ස්තූතියි))

Personal Information (පුද්ගලික තොරතුරු)

2. Name (නම) *

   ____

3. Age (වයස) *

   ____

4. Gender (ස්ත්‍රී පුරුෂ භාවය) *

   Mark only one oval.

   - Male (පුරුෂ)
   - Female (ස්ත්‍රී)
   - Other (වෙනත්)

5. Email Address (ඊ-තැපැල් ලිපිනය) *

___

6. Contact Number (WhatsApp) (දුරකථන අංකය) *

___

Hearing Status (ශ්‍රවණ තත්ත්වය)

7. How would you describe your hearing status (ඔබේ ශ්‍රවණ තත්ත්වය විස්තර කරන්නේ කෙසේද?) *

Mark only one oval.

- Mild hearing loss
- Moderate hearing loss
- Severe hearing loss
- Profound hearing loss
- Not Sure

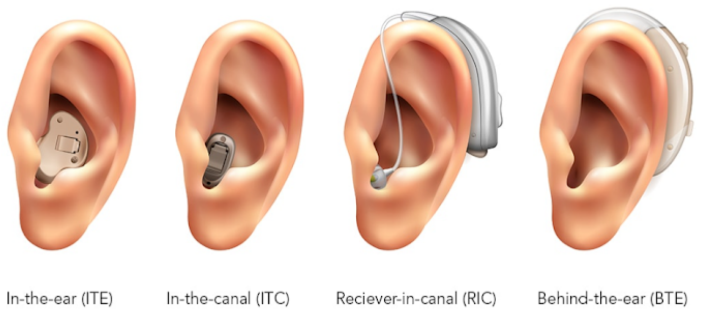
8. Do you currently use a hearing aid (Traditional /Smartphone-based)? (ඔබ දැනට ශ්‍රවණාධාරයක් භාවිතා කරනවාද?)

Mark only one oval.

- Yes *Skip to question 9*
- No *Skip to question 13*

Hearing Aid Usage (ශ්‍රවණාධාර භාවිතය)

9. What type of hearing aid do you use? (ඔබ භාවිතා කරන්නේ කුමන ආකාරයේ ශ්‍රවණාධාරයක්ද?) *



Mark only one oval.

- ◯ Behind the Ear (BTE) *Skip to question 14*
- ◯ In the Ear (ITE) *Skip to question 14*
- ◯ In the Canal (ITC) *Skip to question 14*
- ◯ Completely in Canal (CIC) *Skip to question 14*
- ◯ Receiver-in -Canal (RIC)
- ◯ Smartphone-based hearing aid *Skip to question 21*

10. If you are using a smartphone-based hearing aid, please specify the name. (ඔබ ස්මාර්ට් ජංග
දුරකථනය පදනම් කරගත් ශ්‍රවණාධාරයක් භාවිතා කරන්නේ නම්, කරුණාකර එහි නම සඳහන් කරන්න.)

____

11. Where do you mostly use your hearing aid? (ඔබ වැඩිපුරම ඔබේ ශ්‍රවණාධාර භාවිතා කරන්නේ කොහේද?)
Ex- University ,Home

____

12. How satisfied are you with your hearing aid's overall performance? (Rate 1-5) (ඔබේ ශ්‍රවණාධාරයේ සමස්ත ක්‍රියාකාරිත්වය පිළිබඳව ඔබ කෙතරම් තෘප්තිමත්ද?)

Mark only one oval.

	1	2	3	4	5	
Not	◯	◯	◯	◯	◯	Very Satisfied (ඉතා තෘප්තිමත්)

Reasons for not using hearing aids (ශ්‍රවණාධාර භාවිතා නොකිරීමට හේතු)

13. If you do not use a hearing aid, what is/are the reasons? (ඔබ ශ්‍රවණාධාරයක් භාවිතා නොකරන්නේ නම්, ඊට හේතු මොනවාද?)

Check all that apply.

- [ ] They are too expensive (මිල අධිකයි)
- [ ] They are uncomfortable for the ear (පැළඳීමට අපහසුයි)
- [ ] They do not help me (මට උදව් කරන්නේ නැත)
- [ ] I feel embarrassed to use them (මට ඒවා පාවිච්චි කරන්න ලැජ්ජයි)
- [ ] I do not know much about them (මම ඒවා ගැන වැඩිය දන්නේ නැහැ)
- [ ] Option 6

Experience with Traditional Hearing Aids (සාම්ප්‍රදායික ශ්‍රවණාධාර පිළිබඳ පළපුරුද්ද)

14. How would you rate the sound quality of your traditional hearing aid? (Rate 1-5) ඔබේ සාම්ප්‍රදායික ශ්‍රවණාධාරයේ ශබ්දයේ ගුණාත්මකභාවය ඔබ ඇගයීමට ලක් කරන්නේ කෙසේද?

Mark only one oval.

	1	2	3	4	5	
Very	◯	◯	◯	◯	◯	Very Satisfied (ඉතා තෘප්තිමත්)

15. How satisfied are you with the battery life of your traditional hearing aid? (Rate 1-5) (ඔබේ සාම්ප්‍රදායික ශ්‍රවණාධාරයේ බැටරි ආයු කාලය ගැන ඔබ කෙතරම් තෘප්තිමත්ද?)

Mark only one oval.

	1	2	3	4	5	
Very	◯	◯	◯	◯	◯	Very Satisfied (ඉතා තෘප්තිමත්)

16. How comfortable is your traditional hearing aid for long use? (Rate 1-5) (දිගු භාවිතය සඳහා ඔබේ සාම්ප්‍රදායික ශ්‍රවණාධාරය කොතරම් පහසුද?)

Mark only one oval.

	1	2	3	4	5	
Very	◯	◯	◯	◯	◯	Very Satisfied (ඉතා තෘප්තිමත්)

17. How well does your traditional hearing aid help you hear in places with many people talking? (Rate 1-5) (ඔබේ සම්ප්‍රදායික ශ්‍රවණාධාරය ඔබට බොහෝ අය කතා කරන ස්ථානවල ඇසීමට කොතරම් හොඳින් උපකාර කරයිද?)

Mark only one oval.

- ◯ Very Dissatisfied (ඉතා අතෘප්තිමත්)
- ◯ Very Satisfied (ඉතා තෘප්තිමත්)

18. What problems do you have with your traditional hearing aid in different places? (විවිධ ස්ථානවල භාවිතා කරන විට ඔබේ සාම්ප්‍රදායික ශ්‍රවණාධාර සමඟ ඔබට ඇති ගැටළු මොනවාද?)

19. What features do you like most in your traditional hearing aid? (ඔබේ සාම්ප්‍රදායික ශ්‍රවණාධාරය ඔබ වැඩිපුරම කැමති විශේෂාංග මොනවාද?)

20. Are there any features you wish your traditional hearing aid had? (ඔබේ සාම්ප්‍රදායික ශ්‍රවණාධාරකයේ තිබිය හැකි යැයි ඔබ බලාපොරොත්තු වන විශේෂාංග තිබේද?)

Skip to question 34

Experience with Smartphone-Based Hearing Aids (ස්මාර්ට්ෆෝන් පාදක ශ්‍රවණාධාර සමඟ පළපුරුද්ද)

21. How would you rate the **sound quality** of your smartphone-based hearing aid? (Rate 1-5)
(ඔබගේ ස්මාර්ට් ජංගම දුරකථනය පදනම් කරගත් **ශ්‍රවණාධාරයේ ශබ්දයේ ගුණාත්මකභාවය** ඔබ ඇගයීමට ල
කරන්නේ කෙසේද?)

Mark only one oval.

	1	2	3	4	5	
Very	◯	◯	◯	◯	◯	Very Satisfied (ඉතා තෘප්තිමත්)

22. How satisfied are you with the **battery life** of your smartphone-based hearing aid? (Rate 1-5)
(ඔබගේ ස්මාර්ට් ජංගම දුරකථනය පදනම් කරගත් ශ්‍රවණාධාරයේ **බැටරි ආයු කාලය** පිළිබඳව ඔබ කෙතරම් තෘප්තිමත්ද?)

Mark only one oval.

	1	2	3	4	5	
Very	◯	◯	◯	◯	◯	Very Satisfied (ඉතා තෘප්තිමත්)

23. How comfortable is your smartphone-based hearing aid for **long use?** (Rate 1-5) (**දිගු භාවිතය** සඳහා ඔබගේ ස්මාර්ට් ජංගම දුරකථනය පදනම් කරගත් ශ්‍රවණාධාරය කොතරම් පහසුද?)

Mark only one oval.

	1	2	3	4	5	
Very	◯	◯	◯	◯	◯	Very Satisfied (ඉතා තෘප්තිමත්)

24. How easy is it for you **to use** a smartphone-based hearing aid? (Rate 1-5) (ස්මාර්ට් ජංගම දුරකථනය පදනම් කරගත් ශ්‍රවණාධාරයක් භාවිතා කිරීම ඔබට කොතරම් පහසුද?)

Mark only one oval.

	1	2	3	4	5	
Very	◯	◯	◯	◯	◯	Very Satisfied (ඉතා තෘප්තිමත්)

25. How well does your smartphone-based hearing aid help you hear in places with many people talking? (Rate 1-5) (ඔබගේ ස්මාර්ට් ජංගම දුරකථනය පදනම් කරගත් ශ්‍රවණාධාරය ඔබට බොහෙ පුද්ගලයන් කතා කරන ස්ථානවල ඇසීමට කොතරම් හොඳින් උපකාර කරයිද?)

Mark only one oval.

- ◯ Not Much
- ◯ Very Much

26. What problems do you have with your smartphone-based hearing aid when using in different places? විවිධ ස්ථානවල භාවිතා කරන විට ඔබගේ ස්මාර්ට් ජංගම දුරකථනය පදනම් කරගත් ශ්‍රවණාධාර සමඟ ඔබට ඇති ගැටළු මොනවාද?

27. What features do you like most in your smartphone-based hearing aid? (ඔබගේ ස්මාර්ට් ජංගම දුරකථනය පදනම් කරගත් ශ්‍රවණාධාරයේ ඔබ වැඩිපුරම කැමති විශේෂාංග මොනවාද?)

28. Are there any features you wish your smartphone-based hearing aid had? (ඔබගේ ස්මාර්ට් ජංගම දුරකථනය පදනම් කරගත් ශ්‍රවණාධාරය එයට එක් කිරීමට ඔබ කැමති විශේෂාංග තිබේද?)

29. What help would you need to use a smartphone-based hearing aid better? (ස්මාර්ට්ෆෝන් පදනම් කරගත් ශ්‍රවණාධාරයක් වඩා හොඳින් භාවිතා කිරීමට ඔබට අවශ්‍ය උපකාර මොනවාද?)

30. What features do you like in your current hearing aid or app? (ඔබගේ වත්මන් ශ්‍රවණාධාර හෝ යෙදුමේ ඔබ කැමති විශේෂාංග මොනවාද?)

31. What problems do you have with using hearing aid apps? (ශ්‍රවණාධාර යෙදුම් භාවිත කිරීමේදී ඔබට ඇති ගැටලු මොනවාද?)

32. What do you like best about your hearing aid or app? (Select all that apply) (ඔබේ ශ්‍රවණාධා හෝ යෙදුම ගැන ඔබ වඩාත් කැමති කුමක්ද? (අදාළ සියල්ල තෝරන්න)

Check all that apply.

- [ ] Sound clarity
- [ ] Easy to use
- [ ] Long battery life
- [ ] Customizable settings
- [ ] Good value for money
- [ ] Other (Please specify)

33. What do you dislike most about your hearing aid app? (Select all that apply) (ඔබේ ශ්‍රවණාධාර යෙදුම ගැන ඔබ වැඩිපුරම අකමැති කුමක්ද? (අදාළ සියල්ල තෝරන්න)

Check all that apply.

- [ ] Sound distortion
- [ ] Hard to use
- [ ] Short battery life
- [ ] Missing features
- [ ] Too expensive
- [ ] Other (Please specify)

Skip to question 34

Health and Well-being (සෞඛ්‍යය සහ යහපැවැත්ම)

34. How has "better hearing" helped your social interactions and quality of life? (Rate 1-5) ("වඩා හොඳ ශ්‍රවණය" ඔබේ සමාජ අන්තර්ක්‍රියාවලට සහ ජීවන තත්ත්වයට උපකාර වී ඇත්තේ කෙසේද?)

Mark only one oval.

	1	2	3	4	5	
High	◯	◯	◯	◯	◯	Highly Satisfied

35. What emotional effects have you experienced from using hearing aids? (ශ්‍රවණාධාර භාවිතා කිරීමෙන් ඔබ අත්විඳ ඇති චිත්තවේගීය බලපෑම් මොනවාද?)

36. Do you have any health concerns related to using hearing aids for a long time? (දිගු කලක් ශ්‍රවණාධාර භාවිතා කිරීම සම්බන්ධ සෞඛ්‍ය ගැටළු ඔබට තිබේද?)

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Skip to section 9 (Thank you for considering participating in this research study. Your insights are invaluabl our efforts in improving auditory experiences for hard-of-hearing individuals. Your participation is greatly appreciated.Thank You (මෙම පර්යේෂණ අධ්‍යයනයට සහභාගී වීම ගැන සලකා බැලීම ගැන ඔබට ස්තුතියි. ශ්‍රවණ ගැටළු සහ පුද්ගලයන් සඳහා ශ්‍රවණ අත්දැකීම් වැඩිදියුණු කිරීමේ අපගේ උත්සාහයට ඔබේ තීක්ෂ්ණ බුද්ධිය ඉතා අගනේය. ඔබගේ සහභාගීත්ව ඉතා අගය කොට සලකමි.ස්තුතියි))

Thank you for considering participating in this research study. Your insights are invaluable to our efforts in improving auditory experiences for hard-of-hearing individuals. Your participation is greatly appreciated.Thank You (මෙම පර්යේෂණ අධ්‍යයනයට සහභාගී වීම ගැන සලකා බැලීම ගැන ඔබ ස්තුතියි. ශ්‍රවණ ගැටළු සහිත පුද්ගලයන් සඳහා ශ්‍රවණ අත්දැකීම් වැඩිදියුණු කිරීමේ අපගේ උත්සාහයට ඔබේ තීක්ෂ්ණ බුද්ධිය ඉතා අගනේය. ඔබගේ සහභාගීත්වය ඉතා අගය කොට සලකමි.ස්තුතියි)

Appendix C

Smartphone-Based Hearing Aid Applications (SHAAs) Survey

The smartphone-based hearing aid applications survey conducted during the preliminary study is provided below.

Evaluation of Smartphone-Based HA's

The purpose of this study is to evaluate the effectiveness of existing smartphone-based hearing aids in enhancing auditory experiences for individuals with hearing impairments.

මෙම අධ්‍යයනයේ පරමාර්ථය වන්නේ ශ්‍රවණාබාධ තත්ත්වයන් සහිත පුද්ගලයන් සඳහා ශ්‍රවණ අත්දැකීම් වැඩි දියුණු කිරීම සඳහා පවතින ස්මාර්ට්ෆෝන් පදනම් කරගත් ශ්‍රවණාධාරවල සඵලතාවය ඇගයීමයි.

* Indicates required question

1. Application Name (යෙදුමේ නම) *

Mark only one oval.

- Petralex
- Sound Amplifier
- Hearing Clear

2. How intuitive is the app's interface for adjusting settings like noise reduction, microphone direction, and frequency amplification? (ශබ්දය අඩු කිරීම, මයික්‍රෆෝන දිශාව, සහ සංඛ්‍යාත විස්තාරණ වැනි සැකසීම් සීරුමාරු කිරීම සඳහා යෙදුමේ අතුරු මුහුණත කෙතරම් අවබෝධාත්මකද?)

Mark only one oval.

- Very intuitive (සම්පූර්ණයෙන්ම අවබෝධ කරගත හැකි)
- Intuitive (අවබෝධ කරගත හැකි)
- Neutral (මධ්‍යස්ථ)
- Not very intuitive (තේරුම් ගත නොහැක)
- Not intuitive at all (කිසිසේත්ම තේරුම් ගත නොහැක)

3. How effectively does the app reduce background noise to improve your ability to hear conversations? (ඔබගේ සංවාද ඇසීමේ හැකියාව වැඩි දියුණු කිරීම සඳහා යෙදුම පසුබිම් ශබ්දය කෙතරම් ඵලදායී ලෙස අඩු කරයිද?)

Mark only one oval.

	1	2	3	4	5	
Very	◯	◯	◯	◯	◯	Very Effective (ඉතා ඵලදායී)

4. Do you notice any specific types of noise that the app struggles to cancel out? (යෙදුම අඩු කිරීමට අපොහොසත් වන යම් නිශ්චිත ආකාරයේ ශබ්දයක් ඔබ දකිනවාද?)

Check all that apply.

- [ ] Yes, conversations (ඔව්, සංවාද)
- [ ] Yes, machinery noise (ඔව්, යන්ත්‍රෝපකරණ ශබ්දය)
- [ ] Yes, traffic noise (ඔව්, රථවාහන ශබ්දය)
- [ ] Yes, other (please specify) (ඔව්, වෙනත් (කරුණාකර සඳහන් කරන්න))
- [ ] No, it cancels out all types of noise effectively (නැත, එය සියලු වර්ගවල ශබ්දය ඵලදායී ලෙස අවලංගු කර
- [ ] Other: _______________

5. How useful do you find the directional microphone feature for focusing on specific sounds o voices? (නිශ්චිත ශබ්ද හෝ කටහඬ කෙරෙහි අවධානය යොමු කිරීම සඳහා දිශානුගත මයික්‍රොෆෝන විශේෂාංගය ඔබට කෙතරම් ප්‍රයෝජනවත්ද?)

Mark only one oval.

	1	2	3	4	5	
Not	◯	◯	◯	◯	◯	Very useful (ඉතා ප්‍රයෝජනවත්)

6. In what situations does the directional microphone feature perform best or worst? (දිශානුගත මයික්‍රෆෝන විශේෂාංගය හොඳම හෝ නරක ලෙස ක්‍රියා කරන්නේ කුමන අවස්ථා වලදීද?)

Check all that apply.

- [ ] Best in crowded places (හොඳම, ජනාකීර්ණ ස්ථානවල)
- [ ] Best in quiet places (හොඳම, නිස්කලංක ස්ථානවල)
- [ ] Best in outdoor environments (හොඳම, එළිමහන් පරිසරය තුළ)
- [ ] Worst in crowded places (නරකම, ජනාකීර්ණ ස්ථානවල)
- [ ] Worst in quiet places (නරකම, නිස්කලංක ස්ථානවල)

7. Can you easily adjust the app to amplify specific frequencies that are challenging for you to hear? (ඔබට ඇසීමට අභියෝග කරන නිශ්චිත සංඛ්‍යාත විස්තාරණය කිරීමට යෙදුම පහසුවෙන් සකස් කළ හැකිද?)

Mark only one oval.

- Yes, very easily (ඔව්, ඉතා පහසුවෙන්)
- Yes, somewhat (ඔව්, තරමක්)
- No, with difficulty (නැහැ, අමාරුවෙන්)
- No, not at all (නැහැ, කොහෙත්ම නැහැ)

8. How well does the app amplify higher or lower frequencies based on your hearing needs? (ඔබගේ ශ්‍රවණ අවශ්‍යතා මත පදනම්ව යෙදුම වැඩි හෝ අඩු සංඛ්‍යාත විස්තාරණය කරන්නේ කෙසේද? obagē śravaṇa av)

Mark only one oval.

- Amplifies perfectly (පරිපූර්ණ ලෙස විස්තාරණය කරයි)
- Amplifies well (හොඳින් විස්තාරණය කරයි)
- Neutral (මධ්‍යස්ථ)
- Doesn't amplify enough (ප්‍රමාණවත් තරම් විස්තාරණය නොවේ)
- Amplifies poorly (දුර්වල ලෙස විස්තාරණය කරයි)

9. How would you rate the overall sound quality provided by the app? (යෙදුම මඟින් සපයන සමස් ශබ්ද ගුණය ඔබ ඇගයීමට ලක් කරන්නේ කෙසේද?)

Mark only one oval.

- Excellent (විශිෂ්ටයි)
- Good (හොඳයි)
- Fair (සාමාන්‍ය)
- Poor(පොහොසත් නොවේ)
- Very poor (ඉතා පොහොසත් නොවේ)

10. Are there any distortions or delays in sound transmission that you notice? (ඔබ දකින ශබ්ද සම්ප්‍රේෂණයේ යම් විකෘති කිරීම් හෝ ප්‍රමාදයන් තිබේද?)

Mark only one oval.

- Yes, often (ඔව්, බොහෝ විට)
- Yes, sometimes (ඔව් සමහරවෙලාවට)
- Occasionally (ඉඳහිට)
- Rarely (කලාතුරකින්)
- Never (කවදාවත් නැහැ)

11. Are you able to personalize the app settings to match your specific hearing needs? (ඔබ ඔබේ නිශ්චිත ශ්‍රවණ අවශ්‍යතාවලට ගැළපෙන පරිදි යෙදුම් සැකසීම් පෞද්ගලීකරණය කළ හැකිද?)

Mark only one oval.

- Yes, extensively (ඔව්, පුළුල් ලෙස)
- Yes, somewhat (ඔව්, තරමක්)
- No, limited customization (නැත, සීමිත අභිරුචිකරණය)
- No, not at all (නැහැ, කොහෙත්ම නැහැ)

12. What additional customization options would you find beneficial? (ඔබට ප්‍රයෝජනවත් වන අමත
විශේෂාංග මොනවාද?)

Mark only one oval.

- ( ) More control over specific frequencies (නිශ්චිත සංඛ්‍යාත මත වැඩි පාලනයක්)
- ( ) Different preset profiles
- ( ) Advanced noise settings (උසස් ශබ්ද සැකසුම්)
- ( ) Other (please specify)
- ( ) No additional options needed (වෙනත් (කරුණාකර සඳහන් කරන්න))

13. Compared to traditional hearing aids, how does the app perform in terms of improving you
hearing experience? (සාම්ප්‍රදායික ශ්‍රවණාධාර සමඟ සසඳන විට, ඔබගේ ශ්‍රවණ අත්දැකීම වැඩිදියුණු කි
සම්බන්ධයෙන් යෙදුම ක්‍රියා කරන්නේ කෙසේද?)

Mark only one oval.

- ( ) Better (වඩා හොඳ වේ)
- ( ) About the same (වෙනසක් නැත)
- ( ) Worse (වඩාත් නරක ය)

14. What are the main advantages of using the app over traditional hearing aids? (සාම්ප්‍රදායික ශ්‍රවණාධාරවලට වඩා යෙදුම භාවිතා කිරීමේ ප්‍රධාන වාසි මොනවාද?)

____

15. On a scale of 1 to 5, how satisfied are you with the app's performance overall? (1 සිට 5 දැ
පරිමාණයකින්, සමස්ත යෙදුමේ ක්‍රියාකාරිත්වය පිළිබඳව ඔබ කෙතරම් තෘප්තිමත්ද?)

Mark only one oval.

	1	2	3	4	5	
Very	( )	( )	( )	( )	( )	Very satisfied (ඉතා තෘප්තිමත්)

16. Would you recommend this app to other hard-of-hearing individuals? (ඔබ මෙම යෙදුම වෙන
ශ්‍රවණාබාධ සහිත පුද්ගලයන්ට නිර්දේශ කරනවාද?)

Mark only one oval.

- Definitely yes (අනිවාර්යයෙන්ම ඔව්)
- Yes (ඔව්)
- Neutral (මධ්‍යස්ථ)
- No (නැත)
- Definitely no (අනිවාර්යයෙන්ම නැහැ)

17. Does the app effectively highlight the primary speaker's voice? (යෙදුම ප්‍රාථමික කථිකයාගේ හ
ඵලදායී ලෙස වැඩි කරයිද?)

Mark only one oval.

- Yes, always (ඔව් නිතරම)
- Yes, most of the time (ඔව් ගොඩක් වෙලාවට)
- Sometimes (සමහර වෙලාවට)
- Rarely (කලාතුරකින්)
- Never (කවදාවත් නැහැ)

18. How clear is the speaker's voice when using the app in a noisy environment? (ඝෝෂාකාරී
පරිසරයක යෙදුම භාවිතා කරන විට කථිකයාගේ කටහඬ කෙතරම් පැහැදිලිද?)

Mark only one oval.

- Very clear (ඉතා පැහැදිලිය)
- Clear (පැහැදිලි)
- Neutral (මධ්‍යස්ථ)
- Unclear (අපැහැදිලි)
- Very unclear (ඉතා අපැහැදිලි)

19. Does the app maintain the natural tone and pitch of the speaker's voice? (යෙදුම කථිකයාගේ කටහඬේ ස්වභාවික ස්වරය සහ තාරතාව පවත්වාගෙන යනවාද?)

Mark only one oval.

- Yes, perfectly (ඔව්, පරිපූර්ණයි)
- Yes, mostly (ඔව්, බොහෝ දුරට)
- Neutral (මධ්‍යස්ථ)
- No, somewhat altered (නැත, තරමක් වෙනස් කර ඇත)
- No, significantly altered (නැත, සැලකිය යුතු ලෙස වෙනස් කර ඇත)

20. How does the app's noise cancellation affect your ability to hear the speaker's voice? (යෙදුමේ අනවශ්‍ය ශබ්ද අවලංගු කිරීම, කථිකයාගේ කටහඬ ඇසීමේ ඔබේ හැකියාවට බලපාන්නේ කෙසේද?)

Mark only one oval.

- Improves clarity significantly (පැහැදිලි බව සැලකිය යුතු ලෙස වැඩි දියුණු කරයි)
- Improves clarity somewhat (පැහැදිලි බව තරමක් වැඩි දියුණු කරයි)
- Neutral (මධ්‍යස්ථ)
- Reduces clarity somewhat (පැහැදිලි බව තරමක් අඩු කරයි)
- Reduces clarity significantly (පැහැදිලි බව සැලකිය යුතු ලෙස අඩු කරයි)

21. Does the noise cancellation feature sometimes remove parts of the speaker's voice? (ශබ්ද අවලංගු කිරීමේ විශේෂාංගය සමහර විට කථිකයාගේ කටහඬේ කොටස් ඉවත් කරයිද?)

Mark only one oval.

- Yes, often (ඔව්, බොහෝ විට)
- Yes, sometimes (ඔව් සමහරවෙලාවට)
- Occasionally (ඉඳහිට)
- Rarely (කලාතුරකින්)
- Never (කවදාවත් නැහැ)

22. What level of noise cancellation do you find most effective for hearing the speaker's voic clearly? (කථිකයාගේ කටහඬ පැහැදිලිව ඇසීම සඳහා ඔබ වඩාත් ඵලදායී ලෙස සලකන්නේ කුමන මට්ටමේ ශබ්දය අවලංගු කිරීමද?)

Mark only one oval.

- High (අධි)
- Medium (මධ්‍යම)
- Low (අඩු)
- None (නැත)

23. Do you prefer a balance between noise cancellation and natural background sounds for better speaker identification? (වඩා හොඳ කථිකයන් හඳුනා ගැනීම සඳහා ශබ්දය අවලංගු කිරීම සහ ස්වාභාවික පසුබිම් ශබ්ද අතර සමබරතාවයකට ඔබ කැමතිද?)

Mark only one oval.

- Yes, definitely (ඔව් අනිවාර්යෙන්ම)
- Yes, somewhat (ඔව්, තරමක්)
- Neutral (මධ්‍යස්ථ)
- No, not really (නෑ ඇත්තටම නෑ)
- No, not at all (නැහැ, කොහෙත්ම නැහැ)

24. How well does the app differentiate between multiple speakers? (යෙදුම බහු කථිකයන් අතර කෙතරම් හොඳින් වෙන්කර හඳුනා ගන්නේද?)

Mark only one oval.

- Very well (ඉතා හොඳයි)
- Well (හොඳින්)
- Neutral (මධ්‍යස්ථ)
- Poorly (දුර්වලයි)
- Very poorly (ඉතා දුර්වලයි)

25. Can you easily switch focus between different speakers using the app? (යෙදුම භාවිතා කරන අතරතුර ඔබට විවිධ කථිකයන් අතර අවධානය පහසුවෙන් මාරු කළ හැකිද?)

Mark only one oval.

- Yes, very easily (ඔව්, ඉතා පහසුවෙන්)
- Yes, somewhat easily (ඔව්, තරමක් පහසුවෙන්)
- Neutral (මධ්‍යස්ථ)
- No, with difficulty (නැහැ, අමාරුවෙන්)
- No, not at all (නැහැ, කොහෙත්ම නැහැ)

26. How balanced is the app in reducing background noise while maintaining speaker voice clarity? (හඬ පැහැදිලි බව පවත්වා ගනිමින් පසුබිම් ශබ්දය අඩු කිරීමේදී යෙදුම කෙතරම් සමබරද?)

Mark only one oval.

- Perfectly balanced (ඉතා හොඳින් සමතුලිත)
- Well balanced (හොඳින් සමතුලිත)
- Neutral (මධ්‍යස්ථ)
- Unbalanced (අසමතුලිතයි)
- Poorly balanced (දුර්වලයි)

27. Do you find the app more effective in quieter environments or noisy environments for hearing the speaker's voice? (කථිකයාගේ කටහඬ ඇසීමට යෙදුම වඩා ඵලදායී යැයි ඔබ සිතන්නේ කොහේද? නිස්කලංක පරිසරයකද, නැතිනම් ඝෝෂාකාරී පරිසරයකද?)

Mark only one oval.

- Quieter environments (නිස්කලංක පරිසරයන්)
- Noisy environments (ඝෝෂාකාරී පරිසරයන්)
- Both equally (දෙකම සමානව)
- Neither (කිසිවක් නොවේ)

Appendix D

System Evaluation Survey

The survey used to collect feedback during the system evaluation phase is attached below.

Hearing Aid Mobile Application Evaluation Survey(හියරින් ඒඩ් ඇප් එක පිළිබඳ ඔබේ අදහස්)

This survey is to understand your experience using a mobile hearing aid app. You will test it in differen situations and compare it with your regular hearing aid. Your answers will help us make the app better especially for use in classrooms and lecture halls.
(මෙම විමසුමෙහි අරමුණ වන්නේ ජංගම දුරකථනයක් භාවිතයෙන් ක්‍රියාකරන හියරින් ඒඩ් (hearing aid) යෙදුමක් පිළිබඳව ඔබගේ පරිශීලක අත්දැකීම් සෙවීමයි. ඔබගේ සාමාන්‍ය හියරින් ඒඩ් උපකරණය සහ මෙම යෙදුම වෙන්ව භාවිතයෙන් පරීක්ෂා කළ පසු එවැනි අත්දැකීම් අපට ලබාදීම ඉල්ලා සිටී. මෙම පිළිතුරු, විශේෂයෙන්ම පන්තිකාමර සහ දේශන ශාලාවන්වල යෙදුම භාවිතයට ගත හැකිද යන්න තක්සේරු කිරීමට හා යෙදුම තවදුරටත් වැඩිදියුණු කිරීමට උපකාරී වේ. විශේෂයෙන්ම, කථාවේ ශබ්දය පැහැදිලිව ඇසෙන්නෙද සහ අනවශ්‍ය ඝෝෂා හා ශබ්ද අවම කරන්නට හැකිද යන්න පිළිබඳ ඔබගේ අදහස අපි සොයයි.)

1. Name (නම)

Traditional Hearing Aid Test(ඔබේ සාමාන්‍ය හියරින් ඒඩ් එක භාවිතා කිරීම)

Step 1: Get Ready to Test Your Normal Hearing Aid Device
To begin, please **play the test YouTube video** on a device **other than the one with this app**.
You can use your **laptop**, **another phone**, or **tablet** for this.

Video - https://www.youtube.com/watch?v=Mlpx_9MhMIU

👉 Place that device about **5 meters away** from you.
👉 **Keep wearing your usual hearing aid**.
👉 **Do not use this app yet**.

Now, **listen carefully** to the audio playing and check if you can hear it clearly.
After this step, you'll be asked to give your **feedback** on how well you heard it

📢 පියවර 1: ඔබේ ඇසීම පරීක්ෂා කිරීමට සූදානම් වන්න

පරීක්ෂණය ආරම්භ කිරීමට, කරුණාකර **යූ ටියුබ් වීඩියෝව** ඔබේ ඇප් එක තියෙන දුරකථනයක් **වෙතින් වෙනත් උපාංගයක්** මත play කරන්න.
ඔබට භාවිතා කළ හැක්කේ ඔබේ **ලැප්ටොප් එක, වෙනත් ජංගම දුරකථනයක්,** හෝ **ටැබ් එකක්.**

👉 ඒ උපාංගය ඔබෙන් **මීටර් 5 ක්** දුරකින් තැබිය යුතුය.

👉 ඔබේ **සාමාන්‍ය හෙයරින් ඒඩ් එක** පළඳගෙන සිටින්න.

👉 තවමත් **ඇප් එක භාවිත නොකර** කරන්න.

දැන්, **ශබ්දය නියමව ඇසෙයිදැයි** අවධානයෙන් සවන් දෙන්න.
මෙම අදියරෙන් පසු, ඔබට **ඇසීම පිළිබඳ අදහසක්** ලබාදීමට හැකියාව ලැබේ.

Test Youtube Video

http://youtube.com/watch?v=Mlpx_9MhMIU

2. Could you hear the lecturer’s speech clearly with your hearing aid?
(ඔබේ හියරින් ඒඩ් එකෙන් ගුරුතුමාගේ කතාව පැහැදිලිව ඇහුනද?)

Mark only one oval.

- Yes (ඔව්)
- No (නෑ)

3. How clear was the lecturer’s speech with your hearing aid? (1 = Not clear at all, 6 = Very clear)
(ඔබේ හියරින් ඒඩ් එකෙන් ගුරුතුමාගේ කතාව කොච්චර පැහැදිලිව ඇහුනද?)

Mark only one oval.

	1	2	3	4	5	6	
Not	◯	◯	◯	◯	◯	◯	Very clear (බොහොම පැහැදිලි)

4. What problems did you face while using your hearing aid?
(ඔබේ හියරින් ඒඩ් එක භාවිතා කරනකොට මොන වගේ ගැටලු තිබුණද?)

____
____
____
____
____

5. Did you hear any background noise or unclear sounds?
(අනවශ්‍ය ගෝෂා හා ශබ්ද, හෝ පැහැදිලි නොවන ශබ්ද ඇසුණාද?)

Mark only one oval.

- Yes (ඔව්)
- No (නෑ)

App with Amplification Only (No Noise Cancellation) (ඇප් එකේ ශබ්දය විශාල කිරීම පමණයි – අනවශ
ගෝෂා හා ශබ්ද අවම කිරීමක් නැහැ)

📢 Step 2: Test with the App
Now, make sure the **video is still playing** in the background.
👉 **Remove your regular hearing aids**
👉 **Connect your earphones to your phone**
👉 Open the app and tap the big **green "Start" button**

After that, you'll be asked to **give your feedback** based on what you hear using the app.

📢 පියවර 2: ඇප් එක සමඟ පරීක්ෂණය කරන්න

දැන්, **අදාල වීඩියෝව තවමත් play වෙලා තියෙන්න** ඕනේ.
👉 ඔබේ **සාමාන්‍ය හෙයරින් ඒඩ් එක ඉවත් කරන්න**
👉 **ඔබේ දුරකථනයට earphone සම්බන්ධ කරන්න**
👉 දැන්, අපේ ඇප් එක **විවෘත කරලා** එහි තියෙන **හරිත "Start" බොත්තම** ඔබන්න

ඉන්පසු, ඔබට **අලුතින් ඇසුණු අන්දම පිළිබඳ අදහසක්** ලබාදෙන්න.

6. Could you hear the lecturer's speech clearly with the app (without your hearing aid)?
(ඔබේ හියරින් ඒඩ් එක නැතුව ඇප් එකෙන් ගුරුතුමාගේ කතාව පැහැදිලිව ඇහුනද?)

Mark only one oval.

- Yes (ඔව්)
- No (නෑ)

7. Compared to your hearing aid, how was the app's sound?
(ඔබේ හියරින් ඒඩ් එකට සසඳනකොට, ඇප් එකේ සද්දය කෙසේද?)

Mark only one oval.

- Better (වඩා හොඳයි)
- Same (එකම තරමට)
- Worse (අඩුවෙන්)

8. How well did the app make the lecturer's voice louder? (1 = Not good, 6 = Very good)
(ඇප් එක ගුරුතුමාගේ කතා ශබ්දය වැඩි කරන හැටි කොපමණ හොඳද?)

Mark only one oval.

	1	2	3	4	5	6	
Not	◯	◯	◯	◯	◯	◯	Very good ඉතා හොඳයි

9. Did you hear any unnecessary noise or unclear sounds?
(අනවශ්‍ය ගෝෂා හා ශබ්ද, හෝ පැහැදිලි නොවන ශබ්ද ඇසුණාද?)

Mark only one oval.

◯ Yes (ඔව්)
◯ No (නෑ)

10. What did you like about the app?
(ඇප් එක ගැන ඔබට කැමති වුණ දේවල් මොනවද?)

11. What problems did you face?
(භාවිතා කරනකොට මොන වගේ ගැටලු තිබුණද?)

App with Amplification + Noise Cancellation(ඇප් එකෙන් ශබ්දය වැඩි කිරීම සහ අනවශ්‍ය ගෝෂා හා ශබ්ද අඩු කිරීම)

📢 Step 3: App with Amplification + Noise Cancellation

(ඇප් එකෙන් ශබ්දය වැඩි කිරීම සහ අනවශ්‍ය ගෝෂා හා ශබ්ද අඩු කිරීම)

Now the sound is being amplified using the app.
👉 To reduce background noise, **click on the "Noise Reduction" button** in the app.

This will help you focus more clearly on the main sound.
Then, you can **give feedback** on whether it improved your hearing experience.
📢 පියවර 3: ඇප් එකෙන් ශබ්දය වැඩි කිරීම + ශබ්ද අඩු කිරීම

දැන් ඔබගේ ඇසීම **ඇප් එක හරහා වැඩි කරමින්** ක්‍රියාත්මක වේ.
👉 දැන්, අනවශ්‍ය ගෝෂා ශබ්ද අඩු කිරීමට, **"Noise Reduction" බොත්තම** ඔබන්න.

මෙය ඔබට **ප්‍රධාන ශබ්දය අවධානයෙන් ඇසීමට** උදව් කරයි.
ඊට පසුව, **ඇසීමේ පිළිබඳ අදහසක්** ලබාදෙන්න.

12. With noise cancellation ON, could you hear the lecturer's speech more clearly?
(අනවශ්‍ය ගෝෂා හා ශබ්ද අඩු කිරීම ON කරාම ගුරුතුමාගේ කතාව පැහැදිලිව ඇහුනද?)

Mark only one oval.

- Yes (ඔව්)
- No (නෑ)

13. Did the unnecessary noise reduce a lot?
(අනවශ්‍ය ගෝෂා හා ශබ්ද බහුලව අඩු වුණාද?)

Mark only one oval.

- Yes (ඔව්)
- No (නෑ)

14. Was the lecturer's speech still clear after the noise was removed?
(අනවශ්‍ය ගෝෂා හා ශබ්ද අඩු කළ පසුවත් ගුරුතුමාගේ කථාව පැහැදිලිව ඇසුණාද?)

Mark only one oval.

- Yes (ඔව්)
- No (නෑ)

15. pared to your hearing aid in noisy places, how was the app?
(අනවශ්‍ය ශබ්ද සහිත තැනක ඔබේ හියරින් ඒඩ් එකට වඩා ඇප් එක කොපමණ හොඳද??)

Mark only one oval.

- Better (හොඳයි)
- Same (එකම තරමට)
- Worse (අඩුවෙන්)

16. How well did the app remove unnecessary noise? (1 = Not good, 6 = Very good)
(අනවශ්‍ය ගෝෂා හා ශබ්ද අඩු කිරීම ඇප් එකෙන් කොච්චර හොඳින් වුණාද?)

Mark only one oval.

	1	2	3	4	5	6	
Not	◯	◯	◯	◯	◯	◯	Very good ඉතා හොඳයි

17. Would you use this version of the app in a lecture room or classroom?
(මෙම විකල්පය ඔබ පන්ති කාමරයක භාවිතා කරන්න කැමතිද?)

Mark only one oval.

- Yes (ඔව්)
- No (නෑ)

18. Would you stop using your hearing aid and use only this app?
(ඔබේ හියරින් ඒඩ් එක භාවිතය නවතා දාලා මේ ඇප් එක පමණක් භාවිතා කරන්න කැමතිද?)

Mark only one oval.

- Yes (ඔව්)
- No (නෑ)
- Maybe

19. If you selected No or Maybe, what are the reasons?

Mark only one oval.

- App is not clear enough (ඇප් එක පැහැදිලි නෑ)
- Sound has issues (සද්දේ ගැටලු තියෙනවා)
- Noise cancellation is not strong (අනවශ්‍ය ශබ්ද හොඳට අඩු වෙන්නේ නෑ)
- Hearing aid is more comfortable (හියරින් ඒඩ් එක වඩා හොඳයි)
- App is hard to use (ඇප් එක අමාරුයි)
- Other: ____________________

20. What did you like about the app?
(ඇප් එක ගැන මොනවද ඔබ කැමති වුණේ?)

21. What problems did you face when using the app?
(ඇප් එක භාවිතා කරනකොට මොනවද ගැටලු වුණේ?)

22. What can we improve to make the app better than your hearing aid?
(අපිට මොනවද වැඩිදියුණු කරන්න පුළුවන්?)

User Interface (UI) and Ease of Use. පරිශීලක අතුරුමුහුණත් (UI) සහ භාවිතයේ පහසුව

23. How easy was it to use the app? (1 = Very hard, 6 = Very easy)
(ඇප් එක භාවිතා කරන්න කොච්චර පහසුද?)

Mark only one oval.

	1	2	3	4	5	6	
Very	◯	◯	◯	◯	◯	◯	Very easy ඉතා පහසුයි

24. Were the buttons easy to press?
(බොත්තම් ඔබන්න පහසු වුණාද?)

Mark only one oval.

- Yes (ඔව්)
- No (නෑ)

25. Was the text size and colour easy to read?
(අකුරු ප්‍රමාණය සහ වර්ණය කියවන්න පහසුද?)

Mark only one oval.

- Yes (ඔව්)
- No (නෑ)

26. How good was the app's design? (1 = Very bad, 6 = Very good)
ඇප් එකේ නිමාව (design) කොපමණ හොඳද? (1 = ඉතා නරකයි, 6 = ඉතා හොඳයි)

Mark only one oval.

	1	2	3	4	5	6	
Very							Very good ඉතා හොඳයි

27. Do you want to share anything else that can help us improve the app?
(තවත් මොනවහරි කියන්න කැමතිද?)