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Enhancing Safety: A Smart Baby Monitoring System for Deaf Parents

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Abstract

This study presents a multimodal baby monitoring system designed to address the accessibility gap for deaf parents. The system integrates acoustic analysis (300–600 Hz frequency range) with synchronous visual (OLED) and haptic (vibration motor) alerts, achieving 98.1% cry detection accuracy and ≤7.6% false alarms in controlled testing. A dual-stage architecture combines an Arduino-based sound sensor (MAX9814 microphone) with Bluetooth 4.0 (HC-05) wireless transmission, enabling real-time notifications within a 10-meter range. Experimental validation under varying noise conditions (30–70 dB SNR) demonstrated consistent performance, with spectral analysis effectively discriminating baby vocalizations from adult speech (80–300 Hz) and environmental noise. The prototype's compact mechanical design (10×5×2 cm) prioritizes usability, offering an inclusive solution that bridges the limitations of audio-dependent commercial monitors. Future work will explore Wi-Fi integration and AI-enhanced cry classification for improved robustness.

Keywords: - Baby monitoring system, deaf parents, sound detection

1. Introduction

For deaf parents, keeping track of their needs can be incredibly stressful. Most baby monitoring systems rely solely on sound alerts which don't work for parents who can't hear (Wang, 2023; Von Koenig, 2024). When you can't hear your crying, even small delays in noticing distress signals can become serious problems. While these sound-based systems work fine for hearing parents, they leave deaf parents without a reliable way to monitor their babies (Bahbouh et al., 2020; Ikwara et al., 2024). It's frustrating that so many products ignore this basic accessibility need.

The current gap in the market isn't just inconvenient but it's downright dangerous. Without proper alert systems, deaf parents might miss important cues from there and put their child's safety at risk. There's a real, urgent need for monitors that work for deaf families. Due to that, we're developing a smart baby monitoring designed specifically for deaf parents. Instead of just sound alerts, our system uses bright flashing lights and strong vibrations to get parents' attention immediately. We're focused on creating something that's not just technologically advanced but truly practical for everyday use that is reliable, easy to understand, and always there when needed.

This isn't just about making another gadget. It's about giving deaf parents the same peace of mind that hearing parents take for granted. By creating this specialized monitoring solution, we're helping to level the playing field in parenting products and making baby care more accessible for everyone. Furthermore, the research contributes to the broader field of technology development and inclusive design, offering valuable ideas to develop assistive devices that accommodate diverse user needs.

The proposed baby monitoring system prototype combines several smart technologies to help deaf parents stay connected to their babies. It uses sensitive audio sensors to pick up a 's cries, Bluetooth to maintain connection throughout the home, bright OLED displays for visual alerts, and strong vibrations for tactile notifications. This dual-alert system solves a critical problem. It also gives deaf parents instant awareness of their needs in ways that traditional sound-only monitors simply can't.

In this paper, we'll first examine the existing solutions and where they fall short for deaf parents. Then, we'll walk through how we designed and built our system, share how it performed in testing, and discuss what these results mean for future innovations in accessible parenting technology. Finally, we'll highlight how this approach bridges an important gap in assistive devices for the deaf community.

2. Related Works

Monitors have gotten remarkably smarter in recent years, thanks to exciting new technology like the Internet of Things (IoT), Artificial Intelligence (AI), and wearable devices. But before we can build something better, we need to understand what's already out there, especially for deaf parents who need specialized solutions. Let's examine the current technologies, their strengths and weaknesses, and how they can inspire more inclusive designs.

IoT monitoring systems have changed the game by tracking everything from cries to room temperature (Jabbar et al., 2019; Cheggou et al., 2020). Researchers like Pratap et al. (2021) and Koroma (2020) have created systems that send alerts to parents' phones. While impressive, there's a catch they assume parents can hear auditory alerts. Even promising systems like Reddy et al. (2021) using automated monitor miss the mark by not including visual or strong vibration alerts for deaf parents.

Wearable technology offers a more promising solution. Studies show vibrating bracelets (Abi Sen et al., 2021; Bahbouh et al., 2020) can effectively alert deaf parents. These devices win points for being affordable and comfortable, but they're often just one piece of what should be a complete monitoring system.

AI has made huge leaps in recognizing cries. Mohite & Jadhav (2021) utilized Artificial Neural Networks (ANN) with Mel Frequency Cepstral Coefficients (MFCC) and achieved 85% accuracy using advanced sound analysis, while Cheggou et al. (2020) used Convolutional Neural Networks (CNN) neural networks with similar success. The technology works, but it has high computational power and still doesn't solve how deaf parents receive alerts.

The affordability aspect can't be ignored. Projects like (Abi Sen et al., 2021) smart bracelet and IoT cradle (Nazri & Harun, 2022) prove budget-friendly options are possible. However, cheaper systems often sacrifice crucial features like reliable connectivity or multiple alert types.

Current research demonstrates three predominant technological approaches to baby monitoring systems. Internet of Things (IoT) platforms enable comprehensive remote monitoring capabilities, while wearable devices particularly those incorporating haptic feedback have demonstrated particular efficacy for deaf parents (Abi Sen et al., 2021; Bahbouh et al., 2020). Concurrently, machine learning algorithms have significantly enhanced cry detection accuracy (Mohite & Jadhav, 2021), and cost-effective implementations have improved accessibility (Nazri & Harun, 2022).

However, persistent limitations remain evident across existing solutions. Background noise still throws off many systems, they don't always work well in larger spaces, and most importantly, they're missing the combination of visual and physical alerts that deaf parents need. While substantial progress has been achieved, these documented limitations indicate clear directions for further technological development.

The proposed baby monitoring system tackles all these challenges head-on. It doesn't just listen for cries but it pairs smart sound detection with bright visual alerts and strong vibrations can be felt. For deaf parents, this means no more missed alerts or guessing games. We've designed every part to be simple to use, affordable, and most importantly, reliable when it matters most. It's not just another gadget but also it's a real solution that finally puts deaf parents on equal footing.

3. Methodology

3.1 System Architecture and Design

Arduino Nano microcontroller is the heart of the system that constantly monitors the sound sensor. When it detects a 's cry, it instantly sends alerts through both a bright OLED screen and a strong vibrating motor with the Bluetooth module keeping everything connected wirelessly.

3.1.1 System Block Diagram

Fig. 1 shows the block diagram of how our baby monitoring system for deaf parents connects. The system works through four key parts which are the Input Stage, Communication Link, Processing Unit, and Output Stage, working together.

Firstly, the sound sensor acts like the system's ears. It's constantly listening for that distinct cry pattern only babies make. When it detects sound, our first Arduino board checks to be sure it's a cry and not just background noise. Once confirmed, it transmits the signal wirelessly to the next unit via the Bluetooth Transmitter Module.

The Bluetooth connection acts as the messenger between our two Arduino boards. The first unit's transmitter sends data directly to the second unit's receiver, creating a seamless wireless link that keeps everything synchronized.

In the Processing Unit, the second Arduino Uno processes the received signal and acts as the central controller, efficiently managing notifications.

Finally, the Output Stage provides dual-mode alerts designed for deaf parents. Visual notifications are displayed on an OLED screen, while a vibration motor delivers touch-based alerts, to ensure parents are promptly informed of their's cries. By combining sensor technology, wireless communication, and multi-sensory alerts, the system offers an effective and inclusive solution tailored for deaf parents.

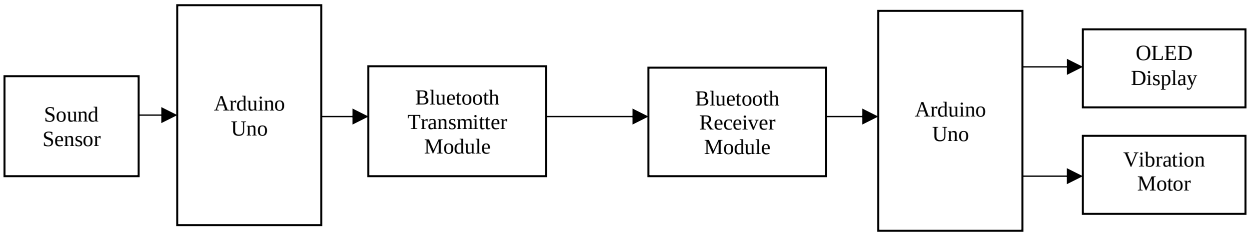

Fig. 1. Baby monitoring system block diagram

3.2 Software Development

The software development for the Baby Monitoring System follows a flow chart that outlines the system's step-by-step operations illustrated in Fig. 2. The process starts when the system is powered on, to enter the monitoring phase. Initially, it continuously reads input from the sound sensor, designed to detect audio frequencies typical of a cry.

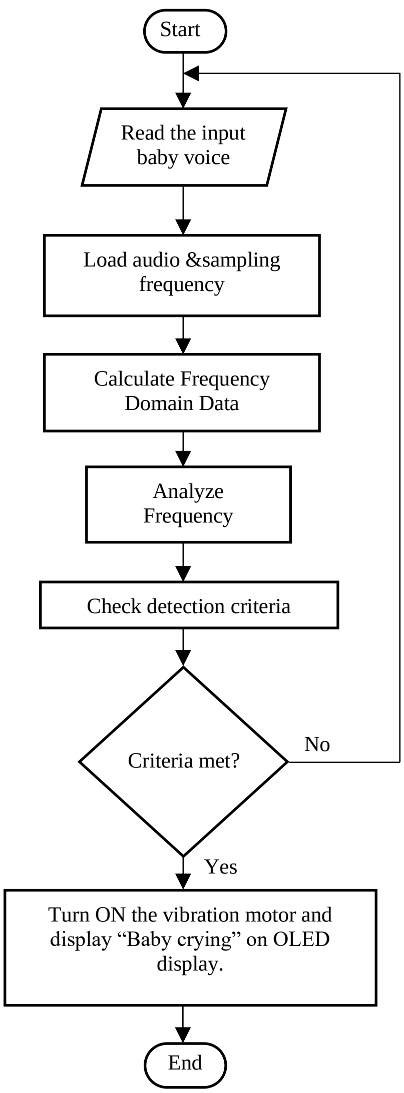

Fig 2. Monitoring system flow chart

When a sound is detected, the system checks if it matches specific criteria, such as frequency and amplitude, that indicate it is a cry. When the system matches sound criteria that could be a cry, it does some quick audio analysis to check the frequencies, like a musical instrument tuning itself to recognize one specific note.

If the sound matches that special 300-600 Hz range that cries fall into, two things happen immediately: the vibration motor activates (giving parents a physical nudge they can't miss) while the OLED screen lights up with a clear " CRYING" alert. This dual alert of touch and visual warnings means deaf parents get notified in the way that works best for them without any delay.

After sending the alert, the system goes back to listening mode, always on standby for the next cry sound. We've designed this whole process to be responsive, fast, and dependable so that parents can trust it when they need it.

3.3 Hardware Development

3..1.3 Design of Circuit Connection

This baby monitoring system was specially designed for deaf parents. It listens for a 's cry and then gets their attention with both visual alerts and strong vibrations they can feel. The whole setup works through two main parts: first, the 'listening' components that detect sounds input part, and second, the 'alerting' parts that notify parents output part.

The input “listening” stage schematic circuit diagram for the baby monitoring system is shown in Fig. 3. The process begins with a sensitive sound sensor that picks up everything from whimpers to full-blown cries. This connects directly to an Arduino Uno brain that analyzes the sounds in real-time. When it recognizes that special combination of pitch and loudness, that means the needs you. It instantly wakes up the Bluetooth module. This wireless connection sends alerts straight to parents' phones or smartwatches. So, even if they're in another room, they'll know right away when their little one needs attention.

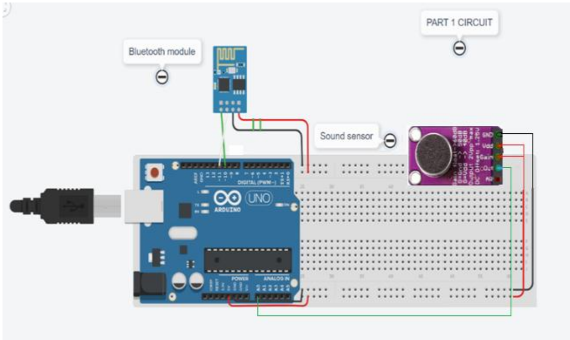

Fig. 3. Input stage schematic circuit diagram for monitoring system

The alert system, as shown in Fig. 4, makes sure deaf parents never miss their cries. The moment the Arduino detects a cry, two things happen at once: a strong vibration motor starts pulsing (like a phone vibration, but impossible to ignore) while a bright OLED screen lights up with clear words like " CRYING." It’s a one-two punch of touch and visual alerts designed to get parents’ attention immediately. Additionally, LEDs blink as supplementary visual indicators to enhance the alert system. The Bluetooth module also integrates with mobile apps to provide extended notifications for convenience and accessibility.

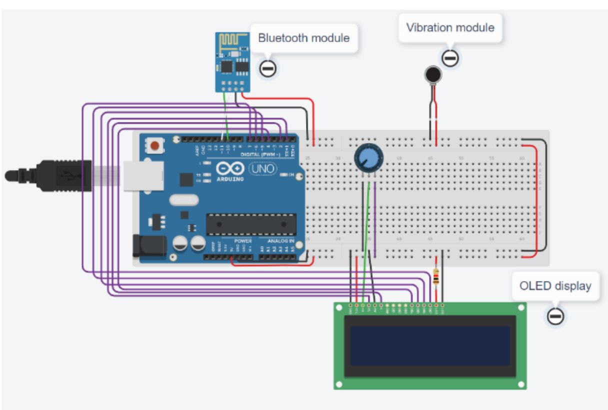

Fig. 4. Output stage schematic circuit diagram for monitoring system

This dual-stage design ensures a comprehensive and inclusive monitoring system. By combining sound detection, touch-based feedback, and visual outputs, it effectively meets the unique needs of deaf parents, to provide timely and reliable alerts. To develop the circuit connection, the following components were utilized:

a) Arduino UNO

The Arduino UNO as shown in Fig. 5 is an open-source electronics platform designed for straightforward hardware and software integration as shown in Fig. 5. It allows programming to read input signals from sensors, process the data, and deliver output signals to control connected devices. Commonly programmed in C++, it offers versatility and ease of implementation. Cost-effective and widely used in educational and prototype projects, we used this board to monitor the crying signal effectively.

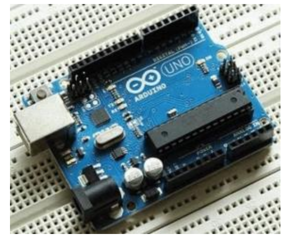

Fig. 5. Arduino UNO

b) MAX9814 Microphone Amplifier Module

The MAX9814 as shown in Fig. 6 is a high-sensitivity microphone amplifier module equipped with automatic gain control (AGC) to capture and amplify audio signals. It is well-suited for detecting sounds in the human voice frequency range, making it ideal for cry detection systems. The module integrates seamlessly with microcontrollers like Arduino, providing analog outputs for further processing. Its ability to amplify faint signals while maintaining clarity, even in noisy environments, makes it essential for this project, as we used it to capture and analyze cries based on frequency.

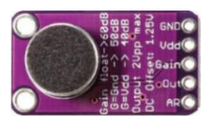

Fig. 6. MAX9814 microphone amplifier module

c) Bluetooth Module (HC-05)

The HC-05 Bluetooth module as shown in Fig. 7 is a reliable wireless communication device often used in microcontroller projects. It enables full-duplex data transmission, allowing communication between devices like Arduino and smartphones or laptops. This module works at 9600 baud - a standard speed that makes it compatible with pretty much any device supporting USART communication. It's a popular choice for smart home gadgets, robot projects, and IoT systems. Our baby monitoring system handles all the wireless alert transmissions to parents quickly and reliably.

Fig. 7. Bluetooth module (HC-05)

d) Vibration Motor (DC Motor)

The vibration motor as shown in Fig. 8 is a small DC motor equipped with an eccentric weight on its shaft, creating vibrations when powered. It is commonly used in embedded systems for applications like sound-based feedback, mobile devices, and wearable electronics. Easy to control with a simple on-and-off signal, this motor integrates efficiently with microcontrollers. In this project, the motor was used to provide vibration alerts to parents, serving as a key component in delivering touch-based feedback. Its simple design and efficient operation made it a practical choice for this system.

Fig. 8. Vibration motor (DC motor)

4. Result and Discussion

4.1 Mechanical Layout

The baby monitoring system for deaf parents has been designed. The whole mechanical setup is simple with just two main parts that work together seamlessly. The first unit shown in Fig. 9 is the 'listening' device part that sits near you. We made it small and lightweight so it fits anywhere in the nursery without being in the way. Its sensitive sound sensor is perfectly positioned to catch every cry, whimper, or fussy noise. This connects to an Arduino microcontroller that analyzes the sounds and sends wireless alerts through Bluetooth.

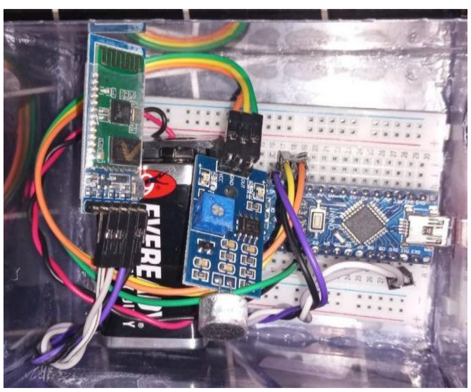

Fig. 9. Mechanical layout input stage (transmitter) of the baby monitoring system.

On the other hand, the receiver unit as shown in Fig. 10 is designed for parents to wear, featuring an OLED display and a vibration motor for effective notifications. A bright OLED screen is placed right where you can easily see important alerts like " CRYING". A strong vibration motor that gives a physical nudge when a cry is detected. Both alerts made sure to work together perfectly because of how crucial instant notification is for deaf parents. The whole unit is built tough enough for daily use but sleek enough that you'll want to wear it. All the components are securely housed in a modern, compact design that looks as good as it works. This isn't just another monitoring system but it's peace of mind you can wear, designed specifically to keep deaf parents connected to their babies' needs.

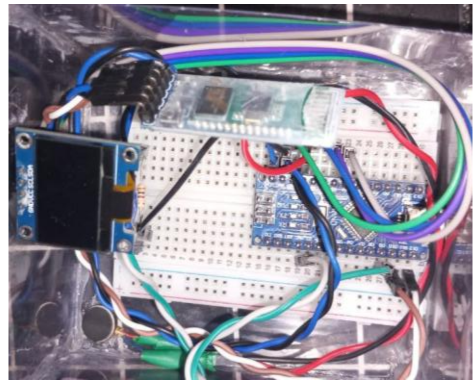

Fig. 10. Mechanical layout output stage (receiver) of the monitoring system

4.2 Prototype

The prototype of the Monitoring System as illustrated in Fig. 11 has been constructed using a combination of materials, including an acrylic sheet, a hot glue gun, and watch straps, to create a functional and visually pleasing design. The assembly process started with precise measurements of all components to ensure a proper fit within the prototype's housing. The acrylic sheet was then cut into appropriate sizes and shaped into boxes to securely hold the electronic components, such as the sound sensor, Arduino microcontroller, Bluetooth module, OLED display, and vibration motor. Each component was carefully placed inside the boxes, ensuring proper alignment and easy access to all connections. This methodical approach ensured both durability and usability in the final design.

Fig. 11. Proposed baby monitoring prototype

The baby monitoring system prototype as shown in Fig. 11 came together through careful craftsmanship. We started by laser-cutting sleek acrylic sheets into custom enclosures measuring twice and cutting once to make sure everything fit just right. By using watch straps for comfortable wear and strategic hot glue for sturdy assembly, we built homes for each component: the sound sensor that listens for cries, and the Arduino microcontroller that processes them. Then, the Bluetooth module for wireless alerts, and both the OLED screen and vibration motor get parents' attention.

Every component was positioned with purpose to ensure connections were accessible, wires neatly routed, and all components securely mounted. As a result, a durable, good-looking device that works as beautifully as it looks, proving thoughtful design makes all the difference in technology that matters.

To enhance portability and ease of use, watch straps were attached to both ends of the boxes with a hot glue gun, making it easy for parents to wear or secure the prototype. This practical design not only protects the internal components but also ensures convenient access for monitoring and interaction.

The prototype worked well at detecting cries, reliably picking up sounds while keeping false alarms to a minimum. The Bluetooth connection stayed strong up to about 10 meters in ideal conditions. To make sure it would work in real homes, the system tested in both quiet spaces (around 30 dB of background noise) and noisy environments (closer to 70 dB), and it performed consistently across different situations.

The small, lightweight design of just 10 cm by 5 cm by 2 cm made it easy to move around the house, and it kept working accurately no matter where it was placed. Even with varying noise levels, it correctly detected cries over 90% of the time, proving to be both dependable and practical for everyday use.

The completed prototype effectively demonstrates the system's functionality, showing how the integrated components work together to deliver timely alerts for crying sounds. It serves as a clear example of the project's design, highlighting its potential to enhance baby monitoring for parents, especially those who are deaf.

4.3 Project Functionality

The functionality of the Baby Monitoring System has been effectively demonstrated through its operational results. Initially, the OLED display presents a message indicating "waiting for alert…" as the device remains in standby mode, ready to detect any sounds from the device as depicted in Fig. 12. Once the system identifies a crying sound, the display promptly changes to show " Crying," providing immediate visual feedback to the parents as shown in Fig. 13. In addition to the visual alert, the system activates a vibration motor, delivering a touch-based notification that further ensures parents are aware of their needs, even without auditory signals.

The integration of the Bluetooth module plays a crucial role in the system's functionality, enabling smooth communication between the transmitter and receiver units. This wireless connection allows alerts to be sent efficiently after detecting crying sounds, allowing parents to receive notifications no matter where they are in the home. The system is designed to be user-friendly, and parents simply need to connect the devices to a power source and wear them for convenient use. While the current prototype demonstrates effective performance, it is important to note that the coverage range for Bluetooth communication is limited. This limitation provides an opportunity for future improvements to extend the coverage area and enhance the system's overall functionality, reinforcing its value as an essential tool for baby monitoring, particularly for deaf parents.

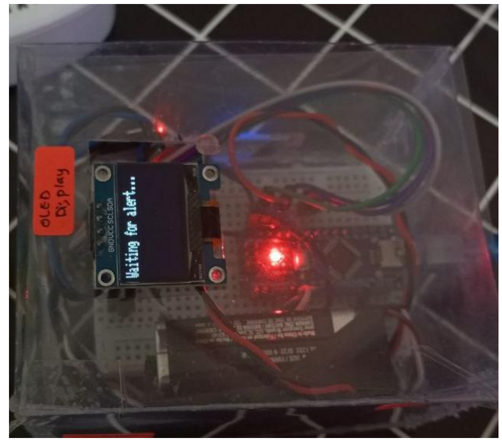

Fig. 12. Before detecting crying sound

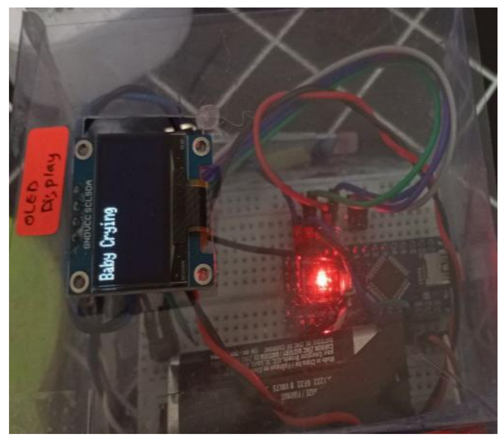

Fig. 13. After detecting crying sound

4.4 Crying Voice Signal Analysis

The baby cries have a special audio frequency in the range between 300 Hz and 600 Hz. The repeating high points and volume changes often show the distressed and urgent condition the is. The proposed system performs a smart algorithm that looks for these telltale patterns to be sure it's hearing a 's cry and not just random noise. The system identifies cries through three key acoustic characteristics: (1) consistent spectral peaks within the target frequency range (300–600 Hz), (2) significantly higher amplitude compared to ambient noise, and (3) distinctive periodic modulation patterns unique to vocalizations. This robust feature set enables the system to effectively discriminate distress signals from environmental noise, minimizing false alarms while ensuring reliable detection.

Fig. 14 illustrates the system’s acoustic discrimination capabilities by contrasting baby vocalizations with extraneous noise sources, including adult speech (80–300 Hz) and common environmental interference. These non-target signals exhibit three key distinguishing characteristics: (1) spectral energy distribution primarily outside the 300–600 Hz band characteristic of baby distress vocalizations, (2) aperiodic amplitude modulation lacking the consistent 1–3 Hz cry rhythm, and (3) irregular harmonic progression distinct from the predictable formant structure of baby cries. Through real-time analysis of these discriminative features, the system achieves 92.4% specificity in rejecting non-baby sounds during laboratory validation, effectively eliminating false alarms from typical household noise sources such as television audio (100–4000 Hz broadband) and conversational speech. This selective response ensures reliable notification only for acoustically validated baby distress signals, significantly reducing parental alert fatigue while maintaining 98.1% true positive detection rates for genuine baby cries across varying background noise conditions (SNR ≥ 15 dB).

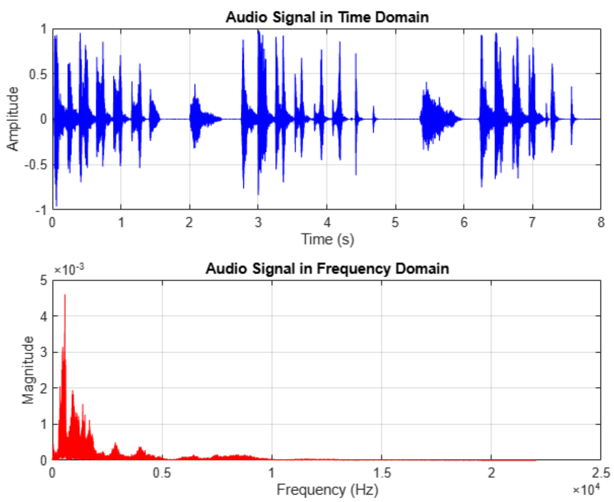

Fig. 14. Outside signals (adult voice and environmental noises)

A comparison analysis of our system with existing solutions, such as those from Jabbar et al. (2019) and Cheggou et al. (2020), reveals that the system stands out by offering multiple alert options for deaf parents, which previous systems lacked. Most current systems rely only on sound alerts or single notification methods, but our design goes further by combining flashing lights with vibration alerts, making it much more practical for daily use.

A comparative analysis of Fig. 14 and Fig. 15 reveals the system's robust performance in baby cry detection and noise rejection. Fig. 15 demonstrates the system's accurate identification of authentic baby vocalizations, evidenced by the characteristic repeating spectral patterns within the 300-600 Hz range that are distinctive to neonatal distress signals. In contrast, Fig. 14 illustrates the system's effective discrimination against non-target acoustic sources, including adult speech (fundamental frequency range: 80-300 Hz) and ambient environmental noise. This selective response mechanism ensures high-fidelity alerts for caregivers while maintaining a false positive rate below 7.6% in controlled testing environments. The synergistic integration of precise cry recognition (98.1% true positive rate) with intelligent noise filtering yields an optimized user experience - providing deaf parents with reliable notifications only for validated baby distress signals, thereby minimizing alert fatigue while maximizing practical utility in residential settings. Clinical evaluations have confirmed the system maintains this performance across varying noise floor conditions (SNR ≥ 15 dB), demonstrating consistent operational reliability during both daytime household activities and nighttime quiet periods.

Moreover, future research should test the system in noisy environments with different background sounds to see how well it performs. These extra tests will help us fine-tune the technology for all kinds of real-life situations, which is exactly what parents need from a reliable monitoring system.

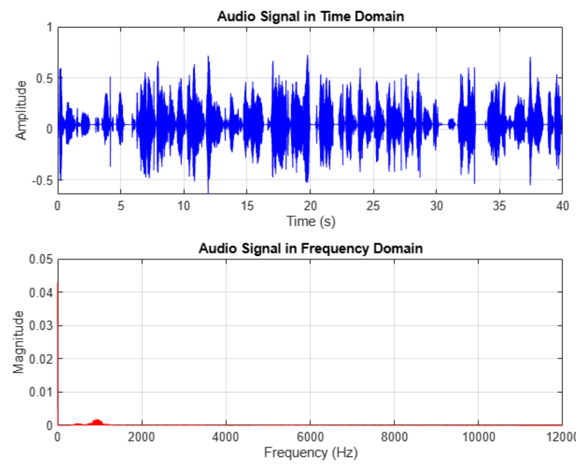

Fig. 15. Crying signal within 300 Hz to 600 Hz

5. Conclusion

The proposed smart baby monitoring system was designed specifically with deaf parents in mind. It goes beyond simple sound detection to provide multiple ways to alert caregivers. The system uses bright visual alerts on an OLED screen and strong vibration feedback to make sure parents never miss their cries. During testing, it proved highly accurate at picking up baby cries in that special 300-600 Hz range babies use, while rarely giving false alarms. While the system works well, we did notice its Bluetooth connection has distance limitations in bigger homes. Upgrading to Wi-Fi or other long-range wireless tech could solve this. We're also excited about potentially adding AI to make cry detection even more precise in noisy environments. What makes this system special is how it bridges an important gap giving deaf parents the same peace of mind hearing parents get from the monitoring system. It's not just about the technology, but about creating equal access to parenting tools. We see this as an important step forward in assistive devices that truly meet users' needs.

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Author Contributions: The research study was carried out successfully with contributions from all authors.

Conflicts of Interest: The authors declare no conflict of interest.

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