Machine Learning–Based Wearable Assistive Device for Hearing-Impaired

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Abstract - *Hearing-impaired people may find it challenging to receive the alert from the doorbell and other important sounds within the home environment. This paper proposes a Machine Learning-based IoT Doorbell with a wearable text and vibration alert system. When the person rings the bell, the ESP32 microcontroller will be activated to capture the sound using a Microphone. The sound will be converted to text using a Speech-to-Text module, which will be wirelessly transmitted to the wearable device to display the text message and vibration feedback. The proposed system will also include Machine Learning-based sound classification to detect other important sounds such as baby crying and cooker/kettle whistle. Keywords: ESP32, IoT, Machine Learning, Speech-to-Text, Wearable Device*

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1. INTRODUCTION

The hearing-impaired are significantly affected in terms of communication and awareness of events in the surrounding environment. The traditional method of using doorbells and alerts is not feasible for hearing-impaired people. Failure to receive important sounds, such as conversations from visitors, baby cries, and cooker beeps, often causes inconvenience. With the development of IoT and ML technologies, it is possible to convert sounds into visual and tactile alerts. The proposed system integrates speech recognition and ML-based sound recognition with a wearable alert system. This will enable hearing-impaired people to lead independent lives.

2. LITERATURE REVIEW

1. Yaganoglu and Köse (2018):

proposed a wearable device for hearing-impaired individuals to recognize critical sounds in the environment. The proposed system utilized a Raspberry Pi device, a microphone, and a vibration motor to classify various sounds like doorbell sounds, alarm sounds, phone ring sounds, honk sounds, dog barking sounds, and human speaking sounds. Audio fingerprinting, MFCC, and ZCR feature extraction methods have been utilized for sound classification in the proposed system. The proposed system achieved high accuracy in sound classification. For instance, the proposed system achieved 99% accuracy in alarm sound classification, 98% accuracy in doorbell sound classification, and 94% accuracy in overall sound classification. However, the proposed system performance is affected in noisy environments and in the presence of multiple sound sources. In addition, the proposed research does not incorporate IoT-based wireless communication technology. Hence, there is a need to design an efficient wearable system with high accuracy in sound classification in noisy environments.

2. Sharma and Kumar (2019):

Sharma and Kumar (2019): Proposed a smart doorbell using the Internet of Things (IoT) technology for the hearing-impaired population. The proposed system can notify the hearing-impaired people using the IoT technology. The proposed system proved the efficient usage of IoT technology for the hearing-impaired population in a smart home environment. The proposed system is limited to providing the functionality of a doorbell and sending the notification to the people using their smartphones. The proposed system does not consider the detection of other sounds, such as alarms and crying kids. This indicates the need for a wearable device to efficiently detect sounds and notify the people in real time.

3. Saeed, M., Hussain, A., Khan, N., & Rehman, S. (2020):

Proposed an assistive system for the deaf and hearing-impaired people through the use of IoT technology in smart homes. The proposed system utilizes sensors and LED indicators to alert the users regarding the events occurring in the smart homes. This increases the awareness of the users regarding the events occurring in the smart homes. The proposed system can be used in fixed indoor environments where the users can easily observe the visual indicators. However, the proposed system is not portable, and the users are not provided with the facility of vibration alert through wearable devices. It can also not be used when the user is away from the source of the alert.

4. Kaur, J. & Singh, M. (2021):

Proposed a wearable assistive device for hearing-impaired people, which can transform sound into vibration. The proposed system can transform sound into vibration using a microcontroller, sound sensor, and vibration motor. The proposed research demonstrated the efficiency of the proposed system, which is portable and convenient for use while increasing awareness of sound. However, the proposed system does not have IoT connectivity and intelligent sound classification. It is difficult to monitor the proposed system since it does not have IoT connectivity. This demonstrates the significance of integrating IoT and intelligent sound classification methods to enhance the overall efficiency of the proposed system.

5. Paidi, Haliza, Zain, and Othman (2022):

Proposed a wearable doorbell notification system using nRF24L01 wireless modules in the communication between the doorbell transmitter and the wearable receiver device. In this proposed research study, the authors proposed using Arduino Nano boards, a push button, vibration motor, LED, and Nokia 5110 LCD as wearable devices to send and receive information to and from the doorbell and wearable devices. In this proposed research study, the authors proposed testing the performance of the proposed wearable doorbell notification system using different data rates of 250 Kbps, 1 Mbps, and 2 Mbps in a residential house environment. In this proposed research study, the authors proposed using 250 Kbps as the most stable data rate with a response time of 0.8 ms and indoor range of up to 22 meters. However, this proposed research study does not include sound recognition, speech-to-text recognition, and IoT devices, which is a limitation of this proposed research study.

6. Jayasudha and Aadhav (2024):

Proposed an IoT-based vibrating doorbell system for hearing-impaired people using Arduino Nano and a coin vibration motor. In this proposed system, the coin vibration motor will be activated when the doorbell button is pressed. This proposed system is simple, cost-effective, compact, and easy to implement in home environments. In the proposed study, it was shown that the proposed vibration-based assistive technology can be used to increase accessibility among deaf people. However, this proposed system can only support doorbell alerting function and does not support wireless communication and environmental sound detection. This implies that there is a need to develop an advanced system that can detect different environmental sound signals and send wireless wearable device notifications.

3. SYSTEM OVERVIEW

The proposed system is a Machine Learning–Based IoT Doorbell integrated with a wearable alert device designed for hearing-impaired individuals. The system converts audio signals into readable text and vibration alerts to ensure effective communication and safety inside a home environment.

The overall system is divided into two main units:

- Doorbell Unit
- Wearable Alert Unit

Both units communicate wirelessly using Wi-Fi through ESP32 microcontrollers.

3.1 BLOCK DIAGRAM DESCRIPTION

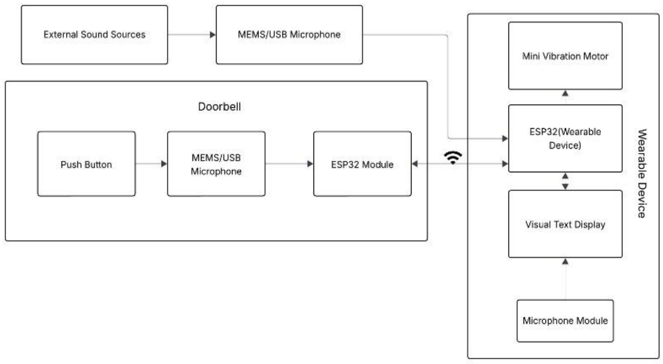

Fig 1: *Block Diagram*

The doorbell unit consists of a push button, ESP32 microcontroller, and a microphone. The push button acts as the trigger mechanism when a visitor arrives. The microphone captures speech and environmental sounds. The ESP32 performs audio processing, speech-to-text conversion, machine learning classification, and wireless data transmission.

The wearable unit consists of another ESP32, an OLED/TFT display, and a vibration motor. This unit receives processed data from the doorbell unit and generates visual and haptic alerts for the user.

The wireless communication between the two units ensures flexibility and portability without physical wiring constraints.

3.2 OPERATIONAL METHODOLOGY

The proposed system operates in two primary modes: visitor speech detection and household sound monitoring. When a visitor presses the push button on the doorbell unit, the ESP32 microcontroller is activated. The connected microphone captures the visitor's speech. The captured audio is processed and converted to text using a speech-to-text module. The generated text message is then transmitted wirelessly via Wi-Fi to the wearable unit. Upon receiving the message, the wearable device displays the converted text in real time on the OLED/TFT screen. At the same time, the vibration motor is activated to provide haptic feedback, ensuring that the user receives immediate notification even without visual attention.

In addition to visitor speech detection, the system continuously monitors household sounds. The microphone captures ambient audio signals, which are processed using feature extraction techniques such as Mel Frequency Cepstral Coefficients (MFCC). These extracted features are fed into a trained Machine Learning classifier to identify predefined sound categories, such as baby crying or a cooker/kettle whistle. When a match is detected, the system generates a corresponding alert message and transmits it to the wearable unit. The wearable device then displays the alert message and activates vibration feedback to notify the user. This dual-mode operation enhances both communication and safety for hearing-impaired individuals.

4. SOFTWARE INTERFACE

The software interface plays an important role in the implementation of the proposed system. It manages the interaction between the audio input, machine learning model, and the hardware components of the system. The software is responsible for creating and processing the audio dataset, extracting relevant sound features, running the trained neural network model, and generating alerts when important environmental sounds are detected. This interface ensures smooth communication between the sound detection system and the wearable alert device.

4.1 DATASET CREATION

For the development of the sound classification system, an audio dataset containing critical household sounds was created. The dataset includes sounds such as baby crying, kettle (cooker) whistle, and background noise. These audio samples were collected from publicly available audio datasets and additional recordings when required.
All audio files were standardized to a fixed duration and sampling rate to maintain uniformity across the dataset. Low-quality or noisy recordings were filtered out to ensure better model performance. Before feature extraction, the audio signals were normalized and converted into a consistent format. This preprocessing step helps reduce variations caused by different recording environments and improves the reliability of the machine learning model during training and testing.

4.2 SOFTWARE IMPLEMENTATION AND MODEL INTEGRATION

The software interface of the proposed system is responsible for processing audio signals, executing the trained machine learning model, and communicating the detected sound events to the wearable device. The system is implemented using Python, which provides powerful libraries for audio processing and machine learning.
Audio signals captured through the microphone are processed using the Librosa library, which is used for loading audio files, preprocessing signals, and extracting Mel-Frequency Cepstral Coefficient (MFCC) features. These features represent the spectral characteristics of sound and are used as inputs to the neural network model. The classification model is developed using TensorFlow and Keras, which provide tools for building and deploying neural networks. During real-time operation, the system continuously captures audio frames from the microphone, performs MFCC feature extraction, and feeds the extracted features into the trained model for prediction.
If the model detects a critical sound such as baby crying or kettle whistle, the software interface triggers an alert mechanism. The detected event is transmitted to the wearable device, which notifies the user through vibration and text-based alerts, thereby assisting hearing-impaired individuals in recognizing important environmental sounds.

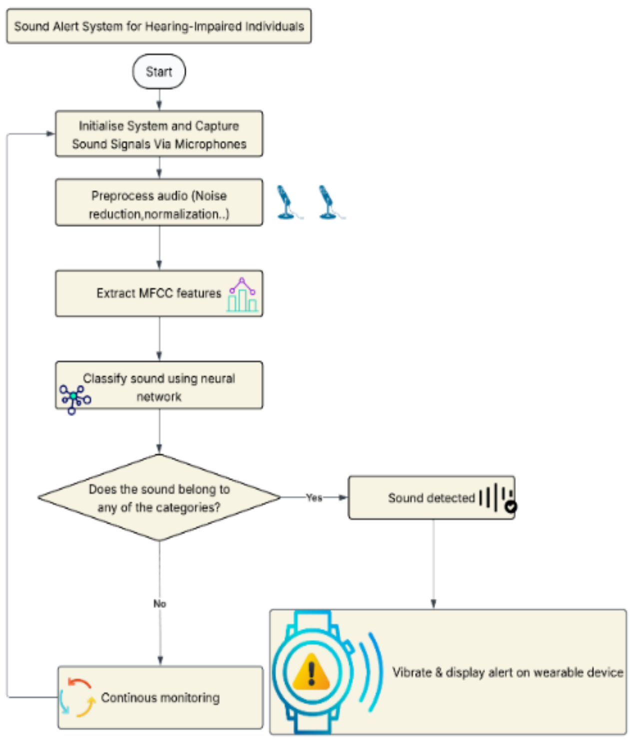

Fig 2: *Flow chart*

5. DESIGN AND IMPLEMENTATION SETUP

5.1 ESP32 Dev Board (Controller) :

- Dual-core 32-bit processor, up to 240 MHz
- 3.3V operating voltage
- 4MB Flash (typical)
- Built-in WiFi & Bluetooth

- ADC, DAC, PWM, I2C, SPI, UART support

Fig 3: *ESP32 Dev Board (Controller)*

5.2 MAX Microphone Module:

- Operating voltage: 3.3V–5V
- Analog sound output
- Adjustable gain
- High sensitivity audio detection

Fig 4: *MAX Microphone Module*

5.3 Push Buttons (Input):

- Operating voltage: 3.3V–5V
- Momentary tactile switch
- Digital input to ESP32

Fig 5: *Push Buttons (Input)*

5.4 Vibration Motor:

- Coin / ERM (Eccentric Rotating Mass) vibration motor
- Operating Voltage: 3V – 5V DC
- Current Consumption: ~70–100 mA
- Provides haptic (vibration) alert for sound detection or notifications

Fig 6*: Vibration Motor*

6. Operation of the System

The proposed system is designed as a two-part wearable solution for individuals with hearing impairments. It consists of a doorbell unit and a wearable unit, both connected through Wi-Fi, allowing wireless communication between them.

The doorbell unit includes a push button, an ESP32 microcontroller, and a MAX9814 microphone. The push button acts as a trigger when a visitor arrives. Once activated, the microphone captures the visitor's voice, and the ESP32 processes this audio through several steps. First, the signal is cleaned using noise reduction techniques to improve clarity. Then, it is converted into text using a speech-to-text method. After that, machine learning is applied to classify the input data. The processed information is then sent to the wearable unit via Wi-Fi.

The wearable unit is built using an ESP32, an OLED display, a vibration motor, an INMP441 microphone, and a user control button. It receives the data from the doorbell unit and provides alerts in two forms: visual messages on the display and vibration feedback. This combination ensures that the user can notice alerts easily.

The INMP441 microphone also allows the system to capture conversations, helping the user understand interactions more clearly. The user has control over enabling or disabling this feature as required.

In addition, the system can detect important household sounds such as a baby crying or a kettle whistle. When such sounds are identified, the device notifies the user through both text display and vibration. This makes the system useful for improving safety and awareness in daily life.

6.1 Prototype

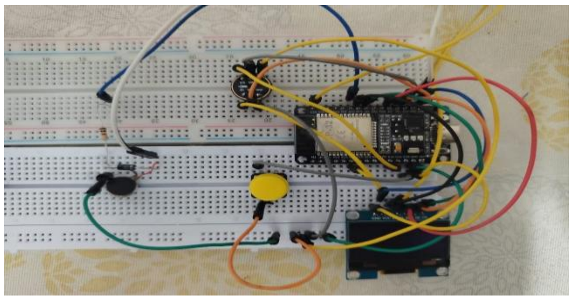

Fig 7: *Wearable Unit*

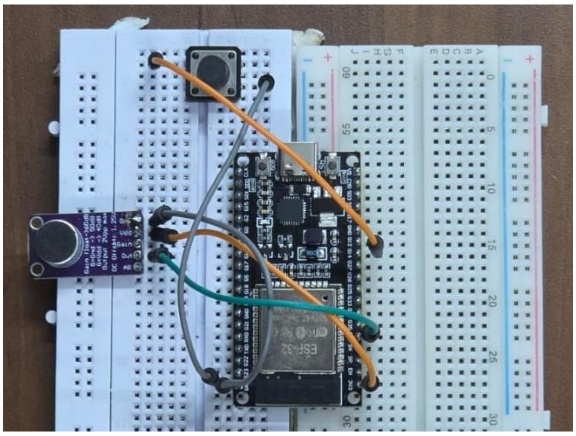

***Fig 8**: Doorbell unit*

7. RESULTS

The developed system consists of a Doorbell unit and a Wearable unit.
The system was tested in real life situations to check how well it can identify and capture important sounds such as baby crying and Cooker/kettle Whistle. While testing, the system was able to identify the sounds with accuracy.

The developed system was tested in different real-life situations to check how well it can detect and respond to important sound events. During testing, the system was able to successfully identify sounds like a baby crying, and a kettle whistle with good accuracy.

The ESP32 processed the audio signals efficiently, and the machine learning model helped in identifying the sounds in real time. Once a sound was detected, the system immediately alerts the user in two ways: by displaying a message on the OLED screen and by providing vibration feedback.

The wireless connection between the doorbell unit and the wearable device worked using Wi-Fi. The system responded quickly enough to be useful in real-time situations.

Overall, the system performed reliably and showed that it can effectively assist people with hearing impairments by notifying them of important sound events in their surroundings

8. CONCLUSIONS

This project shows a simple system that can detect important sounds like a baby crying or a kettle whistle. When these sounds are detected, it gives alerts using light and vibration. This is very helpful for people who cannot hear properly, as it helps them stay safe and aware. The project also shows how machine learning can be used with electronics to create useful real-life solutions. Overall, this system can make daily life easier and safer.

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BIOGRAPHIES

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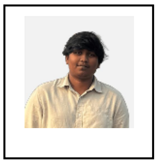

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Anuja, k completed her B tech in Electronics and Instrumentation under Cochin University of science and Technology. Completed her master's in Power Electronics and drives under Anna University Chennai. Pursuing PhD in control systems from National Institute of technology Calicut. Her research interest includes model predictive controller, assertive devices neural network..