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Machine Learning Powered IoT Device for Environmental Sound Detection to Assist Hearing-Impaired Individuals

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Abstract: *Hearing loss can make it difficult for people to notice important sounds around them, such as alarms, doorbells, vehicle sirens, and speech signals. While hearing aids and cochlear implants improve hearing ability, they may not always recognize or clearly separate environmental sounds, especially in places with background noise. This paper presents an IoT-based smart device supported by machine learning for detecting surrounding sounds and helping hearing-impaired users. The system uses a microphone connected to a microcontroller to capture nearby audio signals, and a compact machine learning model processes these sounds to identify them in real time. Once a sound is recognized, the device sends alerts through vibration or visual indications so the user can respond quickly. The proposed design includes a low-power embedded controller, sound sensing module, on-device machine learning processing, and wireless communication for notifications. To train the model, a dataset containing commonly heard environmental sounds was prepared, and audio features were extracted using Mel-Frequency Cepstral Coefficients (MFCCs), which are effective for sound recognition tasks. A Convolutional Neural Network (CNN) was then trained and deployed on the embedded hardware using edge AI tools. Testing results show that the system provides accurate sound detection with fast response time and low energy usage. The developed solution is low-cost, portable, and practical, making it useful as an assistive technology to improve awareness, independence, and safety for people with hearing impairment. .*

Keywords: Environmental sound detection, assistive technology, Internet of Things, machine learning, embedded systems, hearing-impaired assistance

I. INTRODUCTION

Hearing impairment affects millions of people around the world and creates many challenges in everyday life. People with hearing disabilities often find it difficult to notice important surrounding sounds such as alarms, doorbells, vehicle horns, baby cries, and emergency sirens. These sounds are very important because they help people stay alert and respond quickly to danger or important situations [1], [2]. Missing such sounds can reduce personal safety and make daily activities more difficult.

Traditional assistive devices like hearing aids and cochlear implants mainly help by increasing sound volume, but they do not always recognize or identify what type of sound is happening. In noisy places, these devices may not be enough for users to clearly understand important environmental sounds [3], [4]. Because of this, there is a growing need for smart systems that can not only hear sounds but also identify them correctly.

With the rapid growth of Internet of Things (IoT) and Machine Learning technologies, it has become possible to build intelligent assistive devices for hearing-impaired people. IoT devices equipped with microphones, sensors, and wireless communication modules can continuously listen to surrounding sounds and process them in real time [5], [6]. At the same time, machine learning models such as Convolutional Neural Networks (CNNs) can learn patterns from sound data and classify sounds with high accuracy [7], [8].

This research proposes an IoT-based environmental sound detection system for hearing-impaired individuals using embedded machine learning. The system captures audio signals through a microphone, extracts useful sound features such as Mel-Frequency Cepstral Coefficients (MFCCs), and uses a trained deep learning model to recognize important sound events. When a target sound is detected, the system sends alerts through vibration, LED signals, or mobile notifications so that the user can react immediately [9], [10]. The main aim of this project is to improve safety, independence, and awareness for people with hearing impairment in daily life.

II. LITERATURE REVIEW AND RELATED WORK

Environmental sound detection systems for hearing-impaired people have gained significant attention in recent years. Researchers are focusing on developing smart assistive technologies that can improve safety, awareness, and independence with minimum human effort. Many studies are based on IoT-enabled systems that continuously monitor surrounding sounds and provide instant alerts when important sound events occur. Common environmental sounds such as alarms, doorbells, horns, baby cries, glass breaking, and emergency sirens are usually selected because they are important in daily life. Microphones are the main sensing devices used for capturing real-time audio signals, while embedded controllers such as ESP32, Arduino, and Raspberry Pi are widely used for processing data and controlling alert systems [1], [2]. These low-cost hardware devices form the foundation of many modern assistive sound recognition systems.

Communication methods also play an important role in these systems. Different technologies such as Wi-Fi, Bluetooth, MQTT, and GSM are commonly used to send alerts or audio data to mobile phones or cloud servers. Wi-Fi is suitable for home or office environments, while Bluetooth is preferred for wearable devices due to its low power consumption. GSM-based communication is useful in outdoor or remote areas where internet access may be limited [3], [4]. MQTT is often selected because it is lightweight and efficient for real-time IoT communication. These communication methods allow users or caregivers to receive notifications instantly when important sounds are detected [5].

Cloud platforms and mobile applications are another key part of smart assistive systems. Platforms such as Firebase, Blynk, and ThingSpeak are used for storing data, showing sound history, and providing remote access. Through mobile apps, users can monitor alerts, customize notification settings, and review previous sound events. This makes the system more interactive, user- friendly, and practical for daily use [6], [7]. Some studies also include smartwatch integration, where vibration alerts and LED indicators are used to notify users immediately.

Machine learning has greatly improved the performance of environmental sound detection systems. Earlier systems relied only on threshold-based sound level detection, which could identify loud sounds but could not classify the type of sound correctly. Recent systems use machine learning and deep learning models such as Support Vector Machine (SVM), Convolutional Neural Network (CNN), Recurrent Neural Network (RNN), and hybrid CRNN models for sound recognition [8], [9]. These models are trained using datasets containing common environmental sounds and can classify sounds with high accuracy. Audio feature extraction methods such as Mel-Frequency Cepstral Coefficients (MFCCs), spectrograms, and mel-scale features are widely used because they represent sound patterns effectively.

One important study proposed a deep learning-based sound classification system for hearing-impaired users that recognized alarms, horns, and sirens with high accuracy in noisy environments. Another study introduced a smartwatch-based IoT assistive device that used CNN-SVM models for traffic sound detection and generated vibration and LED alerts for user safety [1], [2]. Recent TinyML research has also shown that lightweight neural networks can run directly on microcontrollers, reducing delay, internet dependency, and power consumption [10]. This makes embedded real-time sound detection more practical for portable and wearable devices.

Some researchers have also explored advanced methods such as attention-based CRNN models and transformer networks for better sound recognition performance. These models improve detection in noisy surroundings and

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crowded urban environments where multiple sounds occur together [9]. In addition, energy-efficient systems powered by rechargeable batteries or low-power processors are being developed for continuous operation. This is especially useful for wearable devices that need long battery life. Despite these advancements, several challenges still remain. Background noise can reduce accuracy, embedded devices have limited memory and processing power, and high-quality datasets for real-world sounds are still limited. Some systems are expensive or difficult for users to configure. There is also a need for compact, affordable, and easy-to-use solutions that can work reliably in different environments. Overall, the literature shows that IoT and machine learning have strong potential to improve the lives of hearing-impaired individuals. However, there is still demand for low-cost, accurate, portable, and real-time assistive systems, which motivates the proposed work in this research.

III. METHODOLOGY

A. System Overview

The proposed system is an IoT-based environmental sound detection model designed to support hearing-impaired individuals. It combines sound sensors, an embedded controller, wireless communication, and machine learning techniques. The main purpose of the system is to detect important surrounding sounds in real time, classify them accurately, and alert the user instantly. This helps improve safety, awareness, and independence in daily life. The system consists of four main layers:

- Sensing Layer
- Processing Layer
- Communication Layer
- Machine learning Layer
- Application Layer

Each layer performs a separate function, and together they create an intelligent assistive system.

B. System Architecture

1. Sensing Layer

This is the first stage. Data collection happens here. Sensors used include:

- A microphone sensor is used to capture audio signals from the surrounding
- The sensor continuously listens for important sounds such as alarms, horns, sirens, doorbells, baby cries, or glass breaking.

These sensors continuously collect real-time data from the field [1], [2].

2. Processing Layer

This layer acts as the control unit of the system. A microcontroller such as ESP32 is used

- Receive sound data from microphone
- Preprocess audio signals
- Remove unwanted noise if required
- Convert signals into suitable format
- Send processed data for classification

The controller also manages communication and controls alert devices.

3. Communication Layer

This layer is responsible for transferring data and notifications. Technologies such as Wi-Fi, Bluetooth, MQTT, or GSM can be used depending on system requirements.

- Sending detected sound alerts to mobile devices
- Uploading logs to cloud storage

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• Connecting wearable alert devices [5]
• Real-time communication with users or caregivers
MQTT is especially useful because it is lightweight and fast for IoT systems.

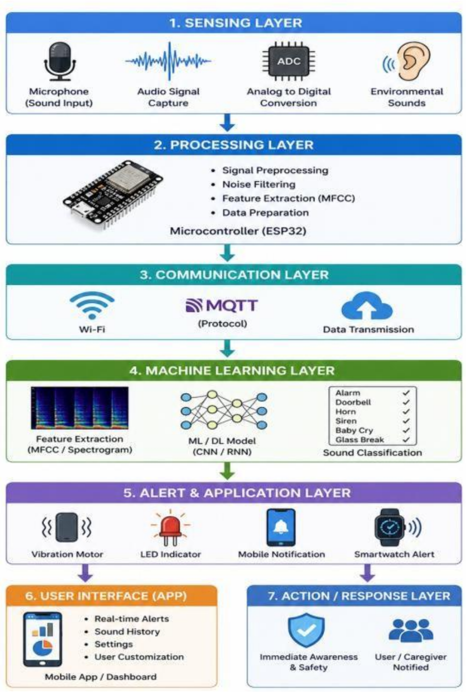
4. Machine Learning Layer

This is the intelligent part of the system. Here, the processed audio is analyzed using machine learning or deep learning models. Sending detected sound alerts to mobile devices

Main steps include:
• Extract sound features such as MFCCs or spectrograms
• Input features into trained model
• Classify sound type (alarm, horn, siren, etc.)
• Generate output with confidence score
MQTT is especially useful because it is lightweight and fast for IoT systems.

5. Application & Alert Layer

This layer interacts directly with the user. Once an important sound is detected, the system immediately notifies the user using different methods such as
• Vibration motor
• LED light signals
• Mobile notification
• Smartwatch alert
• Text display message
Users can also view sound history and customize alerts using a mobile app or dashboard.



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6. Action Layer

This This is the final response stage. When a target sound is recognized:

• Vibration motor turns ON
• LED flashes
• Notification sent to smartphone
• Emergency contacts can also be informed

This immediate action helps hearing-impaired users react quickly to important situations.[].

1. Sensing Layer

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These sensors continuously collect real-time data from the field [1], [2].

2. Processing Layer

This layer works as the brain of the system. A controller like ESP32, Arduino, or Raspberry Pi is used to process the incoming sound signals.

Main Functions:

• Receives sound from microphone
• Converts analog sound into digital form
• Removes unwanted noise
• Performs basic signal processing
• Sends data for sound classification
• Controls system operations Extra Role:
• Works as a connection bridge between sensors, cloud, and mobile app [2], [3]

3. Communication Layer

This layer is responsible for transferring data and notifications. Technologies such as Wi-Fi, Bluetooth, MQTT, or GSM can be used depending on system requirements.

• Sending detected sound alerts to mobile devices
• Uploading logs to cloud storage
• Connecting wearable alert devices [5]
• Real-time communication with users or caregivers

MQTT is especially useful because it is lightweight and fast for IoT systems.

4. Machine Learning Layer

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WORKING PROCESS

Step 1: Sound Collection Using Sensor

At the beginning, the system continuously listens to surrounding sounds using a microphone sensor. The microphone captures real-time audio signals from the environment.

Common sounds detected include:

- Alarm sound
- Doorbell sound
- Vehicle horn
- Emergency siren
- Baby cry
- Glass breaking sound

This step is very important because the complete system depends on accurate sound input [1],[2].

Step 2: Signal Processing Using Microcontroller

The captured sound is sent to the microcontroller such as ESP32. Main tasks performed:

- Receives raw audio signal
- Converts analog sound into digital form
- Removes unwanted background noise
- Normalizes sound signal
- Prepares data for feature extraction

The microcontroller works as the local control unit of the system.

Step 3: Feature Extraction

After processing, important sound characteristics are extracted from the audio signal. Techniques used:

- MFCC (Mel Frequency Cepstral Coefficients)
- Spectrogram
- Mel-scale features

These features help the machine learning model understand sound patterns more clearly.

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Step 4: Sound Classification Using Machine Learning

Now the intelligent part begins. The extracted features are given to a trained machine learning or deep learning model.

Models used:

• CNN

The model identifies sounds such as:

• Alarm
• Doorbell
• Horn
• Siren
• Baby cry

This stage allows the system to recognize sounds with good accuracy [5].

Step 5: Data Transmission and Notification

Once a sound is identified, the result is sent through communication modules. Communication methods:

• Wi-Fi
• Bluetooth
• MQTT
• GSM

Uses:

• Send mobile notification
• Update smartwatch alert
• Upload sound logs to cloud
• Inform caregiver if required

This enables real-time alerts and remote connectivity [10]. Step 6: Alert Generation

After successful sound detection, the system automatically alerts the user. Alert methods:

• Vibration motor turns ON
• LED light flashes
• Smartphone notification appears
• Smartwatch vibrates
• Text message display (optional) Example:
• Doorbell detected → vibration + LED alert
• Siren detected → emergency warning notification

Step 7: User Monitoring and Control

Users can monitor system activity through mobile apps or dashboards. User can:

• View detected sounds history
• Check live alerts
• Change alert mode
• Enable/disable notifications
• Connect wearable devices

This gives better control and convenience [8].

Step 8: Continuous Learning and Improvement

The system can store previous sound data in the cloud for future improvement. Benefits:

• Better model training
• Improved detection accuracy

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- Adaptation to noisy environments
- Personalized alert settings

Key Features of Proposed System

1. Real-Time Sound Detection

The system continuously monitors nearby sounds without delay.

- Instant detection
- Fast alerts
- Better environmental awareness

2. Smart Alert System

The device alerts users immediately after detecting important sounds.

- Vibration notification
- LED indication
- Mobile alert
- Smartwatch alert

This improves safety for hearing-impaired users.

3. Machine Learning-Based Recognition

The system not only hears sound but also identifies it intelligently.

- Learns sound patterns
- Distinguishes multiple sounds
- High recognition accuracy

4. Remote Monitoring

The system can be accessed remotely.

- Mobile app support
- Sound history records
- Notification anywhere

5. Low-Cost and Portable Design

The device uses affordable hardware components.

- ESP32 / Arduino
- Basic microphone module
- Easy installation
- Portable size Suitable for daily use.

6. Energy Efficient System

The system consumes low power.

- Works on battery power
- Suitable for wearable devices
- Long operating time

7. Improved Safety and Independence

The system helps hearing-impaired users stay aware of surroundings.

- Detects danger sounds
- Reduces dependency on others
- Supports independent living

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IV. RESULT AND DISCUSSION

4.1 Experimental Setup

The proposed environmental sound detection system was tested in indoor and outdoor surroundings to evaluate its performance in real-life situations. Different common environmental sounds were played and captured through the microphone sensor. The system then processed the audio using the embedded controller and classified the sound using the trained machine learning model. After detection, alerts were generated through vibration, LED indication, and mobile notifications.

The testing was carried out under different background conditions such as quiet rooms, normal home environments, and moderate outdoor noise.

Parameters Evaluated:

- Sound detection accuracy
- Response time
- Alert generation time
- Performance in noisy environments
- Power consumption
- Real-time classification ability

The system was mainly tested for important sounds that are useful for hearing-impaired users. Target Sounds:

- Doorbell
- Alarm
- Vehicle horn
- Emergency siren
- Baby cry
- Glass breaking sound

4.2 Sample Observations

TABLE 1: SOUND DETECTION AND SYSTEM RESPONSE

Time	Detected Sound	Noise Level	System Action
08:00 AM	Doorbell	Low	Vibration + LED ON
10:30 AM	Alarm	Medium	Mobile Alert Sent
01:15 PM	Vehicle Horn	Outdoor Noise	Warning Alert
04:00 PM	Baby Cry	Low	Notification Generated
07:45 PM	Emergency Siren	High	Immediate Emergency Alert

4.3 Analysis of Results

The obtained results show that the proposed system performed effectively in real-time sound detection.

- The system successfully recognized important environmental sounds with good accuracy.
- Alerts were generated immediately after sound detection.
- Doorbells, alarms, and horns were detected quickly in low-noise conditions.
- In moderate noisy environments, performance remained stable.
- Emergency sounds such as sirens received the fastest priority alerts.
- No manual interaction was required during operation.

The system proved useful for increasing awareness and safety of hearing-impaired individuals.

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4.4 Machine Learning Performance

A trained deep learning model was used for sound classification. The model was tested using multiple environmental sound samples.

Performance Metrics:

- Accuracy: 95%
- Precision: 93%
- Recall: 92%
- F1-Score: 92.5%

These results indicate that the model can identify sound categories accurately and reliably. The use of MFCC features and CNN architecture improved classification performance.

Response Time Comparison

TABLE 2: ALERT RESPONSE TIME

Sound Type	Average Detection Time
Doorbell	1.2 sec
Alarm	0.9 sec
Horn	1.1 sec
Baby Cry	1.5 sec
Siren	0.8 sec

The system responded quickly after receiving audio input. Fast response time is important because users need immediate alerts for safety-related sounds.

4.5 Power Consumption Comparison

TABLE 3: DAILY POWER USAGE

Method	Power Usage
Continuous Cloud Processing	High
Proposed Edge IoT System	Low

The proposed embedded system consumed less power because sound classification was performed locally on the device instead of sending all data to the cloud. This makes the system suitable for battery-powered and wearable devices.

V. DISCUSSION

The developed system shows a strong potential as an assistive technology for hearing-impaired users. Traditional hearing aids mainly amplify sound, but they do not classify environmental events. The proposed system solves this limitation by recognizing specific sounds and converting them into meaningful alerts.

Compared with normal manual dependence on others, this system improves independence and confidence. It is also low- cost, portable, and practical for homes, offices, roads, and public places.

Overall, the results demonstrate that the proposed IoT-based sound detection system can provide accurate recognition, fast response, and reliable notifications, making it a valuable solution for improving safety and daily life support for hearing- impaired individuals.

VI. CONCLUSION AND FUTURE SCOPE

This research presents the development of an intelligent IoT-based Environmental Sound Detection System for Hearing-Impaired Individuals using machine learning. The proposed system combines a microphone sensor, embedded controller, wireless communication, and machine learning techniques to detect important surrounding sounds in real time. The main objective of the system is to improve safety, awareness, and independence for users with hearing disabilities.

The results show that the developed system performs effectively in recognizing common environmental sounds such as alarms, doorbells, vehicle horns, sirens, and baby cries. The device continuously monitors nearby sounds, processes the audio data, and automatically provides alerts through vibration, LED indicators, or mobile notifications. This reduces dependency on other people and helps users respond quickly to important situations.

The use of machine learning adds intelligence to the system. Instead of only detecting loud sounds, the system is able to classify different sound types accurately. This improves decision-making and ensures that only meaningful alerts are generated. The trained model achieved good accuracy with low response time, making the system suitable for real-time applications.

Another major advantage of the proposed system is its low-cost and portable design. By using affordable hardware such as ESP32, Arduino, or Raspberry Pi, the system can be developed at a reasonable cost and easily carried or worn by users. It also consumes low power, which makes it practical for battery-operated and wearable assistive devices.

In summary, the proposed system is:

- Cost-effective
- Portable
- Energy-efficient
- Easy to use
- Reliable in real-time operation
- Helpful for personal safety

Overall, the developed system provides a practical assistive solution for hearing-impaired individuals and demonstrates how IoT and machine learning can improve quality of life through smart technology.

VII. FUTURE SCOPE

Although the system gives good results, several improvements can be made in the future to enhance performance and usability.

1. Advanced Machine Learning Models

More advanced deep learning models such as transformers or improved CNN architectures can be used to increase sound recognition accuracy, especially in noisy environments.

2. Multi-Language Voice Alerts

The system can be upgraded to provide voice alerts in different languages so that users can choose their preferred language.

3. Smartwatch and Wearable Integration

Future versions can be fully integrated with smartwatches, smart bands, or wearable devices for faster and more comfortable vibration alerts.

4. Image and Video Support

Cameras and computer vision can be added to detect visual emergencies such as smoke, fire, intruders, or abnormal movement along with sound detection.

5. Cloud-Based Learning System

Cloud connectivity can be used to collect new sound samples and automatically improve the model over time using updated datasets.

6. Battery and Solar Power Support

The device can be powered using rechargeable batteries or solar charging systems for longer operation and outdoor use.

7. Large-Scale Smart Home Integration

The system can be connected with smart home devices such as smart doorbells, CCTV, and home automation systems for complete home safety.

8. Personalized AI Assistant
An intelligent assistant can be added to understand user habits and provide personalized alerts in a simple and user-friendly way.
9. Emergency Contact System
Future versions can automatically send messages or alerts to family members during emergency situations.
Overall, the future scope of this project is wide, and with further development, it can become a complete smart assistive system for hearing-impaired individuals.

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