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IoT-based Assistive Hearing Companion for Deaf

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***Abstract*—Hearing impairment prevents many individuals from detecting vital environmental sounds like fire alarms, car horns, doorbells, emergency signals, babies' cries, and voices of human beings. Not detecting such sounds may cause safety, communication, and response issues. This paper introduces an AI based assistance system, Assistive Hearing Companion for Deaf, to enhance environmental awareness of deaf and hearing impaired people. In this proposed system, the continuous collection of surrounding sound by the use of microphone, pre-processing of the collected sound, extraction of Mel Frequency Cepstral Coefficients (MFCCs), and classification of sound using Convolutional Neural Network (CNN) takes place. Upon classification of the sound, immediate notification of the sound will be conveyed to the individual using vibration, visual, or mobile notifications.**

The paper also discusses some recent advancements in the area of environmental sound recognition and assistive devices, analyzes various approaches, their limitations, and emphasizes the need for a smart and accurate system for environmental sound recognition in real time. The purpose of this research is to provide greater accessibility and enhance safety of deaf and hard-of-hearing people.

***Keywords*— Artificial Intelligence, Environmental Sound Recognition, Convolutional Neural Network (CNN), Mel Frequency Cepstral Coefficients (MFCC), Assistive Technology, Hearing Impairment, Machine Learning, Real-Time Alert System, Accessibility.**

I. Introduction

The development of assistive devices has become an important area for enhancing the life of people with disabilities. Within these, assistive devices for deaf and hearing impaired users are targeted at enabling communication, interaction with the environment and the completion of everyday tasks by users. Even though there has been an immense progress in the hearing aids, these devices have limitations in terms of being unable to detect important events in the environment. This is why many hearing impaired people encounter problems with detecting fire alarms, ambulance siren, car horn, doorbell, crying babies and human voice.

Modern breakthroughs in Artificial Intelligence (AI), Machine Learning (ML), and audio signal processing have opened up new possibilities for the development of intelligent assistive systems that can recognize environmental sounds automatically.

In contrast to regular hearing aids, AI-based systems are capable of analyzing ambient sounds, differentiation between sound events, and alerting the user about any activity around them. This is how people with hearing impairment can get timely alerts without using their remaining hearing capacity.

The field of Environmental Sound Recognition (ESR) has been a growing area of research in recent times. Contemporary ESR systems record audio information using microphones, preprocess the audio information, extract relevant acoustic features, and classify the different types of sounds using machine learning or deep learning algorithms. In the different methods of feature extraction, one of the most common techniques that have been utilized is Mel-Frequency Cepstral Coefficients (MFCC). This technique effectively captures the frequency information of environmental sounds while keeping the computational cost low. Similarly, Convolutional Neural Networks (CNNs) have shown excellent results in recognizing complex sound patterns.

Several scholars have presented the concept of intelligent assistive systems using the technique of sound recognition coupled with wearables, vibration units, visual feedback, mobile applications, and Internet of Things (IoT). While some systems emphasize the recognition of indoor sounds like doorbells and alarm, there are others that consider sound localization, communication, or wearables as a means of notification. Despite their success, most of the current techniques exhibit poor performance in terms of limited sound recognition coverage, degraded performance in noisy conditions, expensive hardware, delayed processing, and personalization.

In this paper, we introduce the Assistive Hearing Companion for Deaf Using AI-Based Environmental Sound Recognition. This intelligent assistive tool aims to increase environmental awareness in deaf and hard of hearing users. In the developed tool, the continuous capture of environmental sounds will be done by utilizing a microphone, while appropriate audio preprocessing will be performed to enhance the quality of the captured audio signal. MFCC features will be extracted from the preprocessed audio data. Then, the environmental sounds recognition will be accomplished by means of CNN. In particular, various sounds such as alarms, horns, knocks on doors, baby cries, whistles, emergency sirens, and human voice will be recognized by the system.

This paper highlights the recent literature on AI-enabled technologies, sound recognition in the environment, compares the various methods used, highlights the current research gaps as well as the necessity of having an intelligent, real-time and affordable assistive technology. The proposed solution combines sound classification with user notifications for improved safety and independence.

II. Literature Survey

The importance of assistive technologies has increased in providing accessibility and independence to Deaf and Hard-of-Hearing (D/HoH) people. While auditory perception may not necessarily help the user identify crucial environmental sounds in some cases, there have been efforts to develop alternative ways of converting auditory data into visual and/or tactile information. Environmental sounds, such as the sirens of emergency vehicles, fire alarm systems, car horns, and any other types of warnings can convey important information about the surrounding environment of an individual.

Various researches in recent times have focused on the use of artificial intelligence and machine learning techniques for identifying environmental sounds and alerting D/HoH people to such sounds. Such methods involve the use of different methods which include traditional machine learning methods, deep learning methods, pre-trained audio classification methods, and embedded computing devices. The features that help identify various environmental sounds are obtained using audio feature extraction techniques such as Mel Frequency Cepstral Coefficients (MFCC). Various machine learning models like Convolutional Neural Network (CNN), SVM, KNN, Random Forest, and YAMNet have been studied for classifying sounds. Different modes of feedback have been studied to make such sounds perceptible to the user.

Previous research has shown that AI technology can help in environmental awareness and provide safety for the deaf and hard-of-hearing population. On the other hand, some difficulties that arise in the field include the lack of sound categories, presence of background noise, environmental variability, computational needs, and the provision of timely and clear alerts. While some researchers have been focused on classifying the sounds in the environment, others have considered only emergency sirens or wearable devices. The following researches are thus analyzed to learn about the existing technologies, their results, and limitations.

The Alhaqbani et al. [1] study explored the application of artificial intelligence for the recognition of environmental sounds and the production of alerts for people who are either deaf or hard-of-hearing.

The main objective of the study was the recognition of five important environmental sounds, including fire alarms, sirens, gunfire, car honking, and dog barking. The CRISP-DM model of data mining was applied by the researchers for the purposes of modelling, evaluation, and deployment.

Audio samples were gathered from online sources as well as manual recordings, and exploratory analysis was conducted to detect problems with data quality and class imbalance. The audios were converted to WAV format with a sampling rate of 16kHz and mono channel. Data augmentation was done using pitch shifting, time shifting, and adding noise, while synthetic minority oversampling technique (SMOTE) was implemented to balance classes, resulting in 300 samples per class.

Extraction of Mel-Frequency Cepstral Coefficients (MFCC) was done using the preprocessed speech audio signal for classification purposes. SVM, KNN, RF, and one-dimensional CNN were the algorithms used in this work. In the testing evaluation, SVM, RF, KNN, and CNN obtained accuracies of 98.41%, 100%, 97.98%, and 99.55%, respectively.

But after evaluating various parameters such as precision, recall, F1-score, cross-validation, and AUC, the 1D-CNN gave the best trade-off. The 1D-CNN had a validation accuracy of 95.8% and an AUC up to 0.97. The model trained was then used to build an application in which the environmental sound captured by the mobile phone microphone was processed in real-time and classified. The application displays the recognized sound, confidence level, and priority visually with vibratory alert in addition to giving the history of sounds recognized earlier.

The research proves that an effective use of both environmental sound recognition technology and alert systems that are easily available could benefit safety and independence of people who are deaf or have hearing problems. Nevertheless, researchers found it necessary to increase the number of sound classes, test the system in noisy conditions, and explore light-weight models for mobile devices.

In their research work, Buhat et al. [2] presented a study on the use of an advanced wearable technology system for classifying and localizing sound to aid DHH people in recognizing the sound that is significant within the environment. The AICanHear sound system was developed in two models, which included the headband and wristwatch models. The system is not only used in sound classification but also sound localization.

The researchers selected various sounds, from those with high priority (sirens), medium priority (car horns, dog barking, and water flowing), to low priority (door knocks, alarm clock, baby crying, and broken glass).

The primary processing unit of the headset was the Raspberry Pi 3B development board, whereas the Electret microphones served to capture the sound data.

The wristwatch was designed using the NodeMCU ESP8266 microcontroller, LCD screen, Surface Mount Device (SMD) RGB LEDs, and a thin vibration motor to convey information to the user. For sound event classification, the YAMNet deep learning classifier that employs MobileNetV1 architecture and uses Google AudioSet for training was used. The classification was performed through TensorFlow Lite, whereas NodeMCU was used to convey information about sound classification and localization to the wristwatch. Different signals were provided depending on the priority and direction of sound.

The results indicated that the classification of the sounds had an average accuracy rate of 70.48% inside and 63.33% outside. Sirens were the simplest sound events to classify, whereas baby crying was one of the hardest sounds to identify. Sound localization from four different sides was also tested by the researchers – front, back, left, and right. The average accuracy rate for the localization of the sounds was higher from front and right sides compared to back and left sides.

However, the experiment revealed that factors such as environmental noise, sound reflections, microphone position, and outdoor conditions influenced the effectiveness of classification and localization. Improvements in future were suggested, including offline mode, smaller device, increased battery life, custom haptic feedback, and history storage of sound events.

Yasu et al. [3] have studied the perception of ambulance siren sounds by Deaf and Hard-of-Hearing (D/HoH) people and whether the modification of the acoustical properties of the ambulance sirens would facilitate the perception of the sirens. This study was prompted by the challenges faced by many D/HoH people in perceiving ambulance sirens despite the use of hearing aids and cochlear implants. First of all, a preliminary survey was done using 41 D/HoH students to study the perception of ambulance siren sounds.

The questionnaire was made taking into account various aspects including the hearing characteristics of the respondents, hearing aids and cochlear implants, overall perception of sirens, the nuisance from the sirens, situations in which the sirens were heard, the frequency of hearing the sirens, and their effect on activities like communication and sleeping. It was found out that 37 participants have sensorineural hearing loss and about 70% respondents wear hearing aids and/or cochlear implants. It was also revealed from the survey that there were differences in the situations in which the respondents with and without hearing impairment have troubles with sirens.

During the main experiment, fourteen D/HoH volunteers rated ambulance sirens, fire sirens, and police sirens. The scientists manipulated the tempo and pitch of sounds. The tempo was altered to −50%, +25%, and +50%, while the shift of pitch ranged from −2 to +2 octaves. The volunteers evaluated sounds on five dimensions: audibility, urgency, loudness, intrusiveness, and preference.

A recognition test was used in addition to assess the participants' ability to recognize the type of emergency vehicle. The findings revealed that the increase in tempo by 25% enhanced the audibility and urgency perception of the sirens irrespective of the emergency vehicle type. In contrast, increasing the pitch, especially by an octave or two, increased the loudness and nuisance perception of the sirens.

Recognition accuracy was found to be maximum for the sound of ambulance sirens and minimum for fire-truck sirens. The statistical analysis using Kruskal-Wallis test revealed significant differences in the preferences and sense of urgency according to variations in pitch and tempo of the siren sounds. It can be said that the experiment recommended keeping the original pitch of the sirens intact and increasing their tempo.

However, the study was conducted under fairly controlled listening situations, and the authors suggested the need for further studies on the influence of environmental noise, comparisons of hearing participants, and the connection between audiometric properties and perceptual evaluation.

III. Comparative Analysis

Literature analyzed in this study reveals that Artificial Intelligence (AI), Machine Learning (ML) and Deep Learning (DL) greatly enhanced the creation of assistive technologies for people who are either deaf or hard of hearing. Various methods were suggested which rely on such factors as environmental sound recognition, wearable technologies, computer vision, Natural Language Processing (NLP), Internet of Things (IoT) and sound localization. Although these methods proved to be efficient, they still solve only certain parts of the problem and have their limitations.

Table I provides comparative analysis of the literature under consideration in terms of the main methodology, contribution and limitation.

It is possible to conclude that there is much valuable information in literature but it is necessary to create something more universal.

A. Research Gap

From the literature review, there is an indication that there has been significant progress in terms of coming up with smart assistive technologies for people with hearing impairment.

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There have been suggestions for systems that make use of artificial intelligence, deep learning, internet of things, computer vision, wearable technology, and even mobile applications. However, despite all these innovations, there are some research gaps.

1) Limited Integration of Several Technologies

Currently, most available assistive systems are built to accomplish only one particular task. While some are made specifically for sound recognition, others are concerned about communication, recognition of gestures, or even object recognition with computer vision. There is very little research available on the combination of sound recognition, wearables notification system, and intelligent alert system in an assistive device.

2) Decreased Performance in Real Environment

Many existing systems show high recognition rates when tested in laboratory settings. On the other hand, real-life environments have background noises, overlapping sounds, traffic, conversations, and varying acoustic conditions, which have a negative impact on the system performance. Robustness in noisy and dynamic environments is one of the biggest challenges faced in environmental sound recognition.

3) High Hardware Cost

Several existing assistive technologies require special hardware, including smart glasses, wearable cameras, multiple microphones, or high-end embedded systems. While offering various additional features, the total cost of these systems makes them inaccessible to many people. There is an increasing demand for inexpensive systems which can effectively work on regular devices, including mobile phones, wearable vibro-tactile units, or embedded systems.

4) Computational Complexity and Real-Time Operation

Although CNNs and other deep learning systems have enhanced the recognition accuracy, they have been seen to require high computation requirements. This is why many systems suffer from increased processing times and energy consumption while operating continuously. With environmental warnings being of critical importance for the safety, the development of algorithms for decreased latency with increased classification accuracy becomes an important issue.

5) Absence of Personalized Environmental Awareness

The majority of the current assistive solutions learn predefined sound sets and can recognize only a limited number of environmental sounds. Nevertheless, people experience varying sound environments at home, office, and other places.

The lack of personal sound learning and recognition, including personal doorbells, household equipment, or personal warning signals is one of the major limitations.

6) Narrow Range of Environmental Sound Identification

Some of the solutions available at present can identify a very few sound events such as those of alarm or horns of vehicles. Critical sounds such as that of babies crying, whistling, breaking of glasses, human voices, whistles of pressure cookers, siren calls, and many others are usually not identified simultaneously. Wider identification of environmental sounds will help to increase the user safety levels.

7) Requirement of Lighter Edge Implementation

Most of the deep learning models are created to work on either desktops or cloud environments. Deployment of deep learning models on lightweight embedded devices having low memory and processing power still remains a challenge. Future research may try to optimize the environmental sound recognition models for low-power wearable devices.

The proposed Assistive Hearing Companion for Deaf Using AI-Based Environmental Sound Recognition aims at bridging all these research gaps.

TABLE I. Comparative Analysis

#	Method	Key Result	Limitation
[1]	KNN with vibration alerts	Fast indoor sound detection	Limited sound categories
[2]	YAMNet-based sound recognition	Accurate environmental sound recognition	High hardware cost
[3]	IoT-based alerting	Provides real-time notifications	Network dependent
[4]	Wearable IoT device	Improves accessibility	Connectivity issues
[6]	Assistive technology survey	Reviews existing solutions	No implementation
[7]	Natural language processing	Improves communication	Language limitations
[9]	3D-CNN model	High recognition accuracy	High computational cost
[11]	Haptic glove	Provides tactile feedback	Requires wearable device
[14]	MFCC with KNN	Accurate visual alerts	Higher hardware cost
[15]	Gesture and sound recognition	Supports communication and safety	Multiple input devices
[16]	Smart wristband	Portable vibration alerts	Limited battery life

B. Summary of Literature Survey

The literature review reveals that Artificial Intelligence has now emerged as a significant driving factor in the development of modern assistive technology for deaf and hard-of-hearing people. Modern studies have used environmental sound recognition, wearable notifications, communication assistive technology, computer vision, natural language processing, sound localization, and Internet of Things-enabled assistive technology in order to enhance user safety and accessibility. The use of deep learning models like Convolutional Neural Networks, feature extraction technique like MFCC, and pre-trained models like YAMNet has greatly increased the precision of environmental sound recognition.

The studies described above have proven that wearables and apps can serve as practical tools to notify users using vibrations and visual warnings. Additionally, the use of computer vision and sound localization helps to increase situational awareness as they can recognize the surrounding objects and determine the direction of the sounds. However, despite all of the improvements mentioned above, most of the existing systems are still aimed at single functionality and not at a complete assistive solution to recognize environmental sounds and to notify immediately.

The survey also indicates some of the limitations that still hinder the practical application of the concept, such as computational complexity, coverage of sounds, cost of hardware used, degradation of results due to noise, and lack of personalization in the learning process. It is clear from the results above that there is a need for an intelligent and real-time assistance system that has good sound recognition and user notification.

The suggested Assistive Hearing Companion for Deaf Using AI-Based Environmental Sound Recognition is a solution for overcoming these challenges by incorporating AI-based environmental sound recognition with wearable and visual notification systems. This system uses efficient feature extraction and deep learning algorithms for classifying sounds and notifying users about them.

IV. Conclusion

Assistive technologies have become more crucial in ensuring the safety, accessibility, and independence of deaf or hard-of-hearing people. This paper has summarized some of the recent research papers concerning environmental sound recognition systems based on artificial intelligence, wearable assistive technologies, communication assistive technologies, sound localization, and intelligent notification systems.

From the literature review, it is evident that there have been major improvements in recognizing key environmental sounds and giving alerts using machine learning and deep learning algorithms.

The literature further proves that feature extraction methods like Mel-Frequency Cepstral Coefficients (MFCC) and deep learning algorithms like CNN have been widely used due to their capacity to classify complex sounds found in the environment. In the same way, wearable technology, Internet of Things (IoT)-enabled devices, and computer vision have increased the capability of assistive tools through better and context-aware notifications for the user. Such developments have helped in achieving environmental awareness and independence of hearing impaired people.

Nevertheless, there are a number of limitations that still exist in the implementation of the existing systems. For instance, most of the existing systems can only detect a few environmental sounds, are expensive to implement and suffer from poor performance in a noisy environment. Moreover, other problems include high computational complexity, higher processing time, less personalization and no presence of assistive platforms. It is evident that most of the existing systems concentrate on functionality but not on providing an all-in-one solution.

In order to overcome the above-mentioned difficulties, the paper suggests the development of an Assistive Hearing Companion for Deaf using AI-based Environmental Sound Recognition System. The suggested solution involves using the combination of feature extraction based on the MFCC algorithm and sound classification based on the CNN approach in order to recognize such important sounds as alarms, vehicle horn, siren, crying babies, knocking on the door, whistles, and human voice. After the sound is recognized, the system provides vibration, visual and mobile notifications for fast reactions to the surroundings.

Potential future research in this area could include increasing the number of environmental sounds which can be recognized, achieving better results in noisey environments, lowering complexity to allow processing on resource constrained devices, and personalizing the model through machine learning to the specific individual and their environment. Combining sound recognition with computer vision and intelligent wearable devices can further improve environmental awareness.

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