THE APPLICATION OF ARTIFICIAL INTELLIGENCE TO ASSIST PEOPLE WITH HEARING IMPAIRMENTS: AN OVERVIEW OF EXISTING SOLUTIONS

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Abstract:

Hearing impairment is a very serious problem, because it negatively affects communication between people and it also impacts their overall quality of life. Therefore, it is crucial to develop methods to help people with this problem. Although there are many hearing aids with advanced features, many analyses show that more than half of users are not satisfied. The application of Artificial Intelligence (AI) and especially Deep Learning (DL) are increasingly being mentioned as a solution. These methodologies are of recent date. Therefore, this paper provides an overview of the most important methods that use AI approaches to enable personalization and individualization of hearing aids. This primarily refers to Automatic Speech Recognition (ASR) methods, Sign Language Recognition methods (SLR), Intelligent methods for personalized hearing aids, Artificial intelligence methods in bone conduction hearing systems and Methods based on the Internet of Things (IoT). We have demonstrated the existing methods capabilities and challenges, but directions of future development are also particularly emphasized.

Keywords:

Hearing Aid Methods, Artificial Intelligence, ASR, Sign Language Recognition, IoT.

INTRODUCTION

Many studies show that almost half a billion people worldwide have some kind of hearing problem. People with hearing impairments face various problems that affect their social integration, their educational and professional opportunities and therefore it can affect their personal and work life. This is the reason why the hearing aid industry is currently in rapid progress, so millions of dollars are spent annually on hearing aid research.

Traditional hearing aids provide a certain level of support, but they have some limitations in complex acoustic environments, because a lot of people cannot understand speech in situations with background noise. Artificial Intelligence (AI) opens up new opportunities for creating personalized solutions that overcome these challenges transforming hearing aids to become smarter, more personalized, and able to adapt to different environments, offering a new level of hearing assistance that was unimaginable in previous years.

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AI provides innovative tools that can contribute to overcoming most challenges through technologies such as: Automatic speech recognition (ASR) and its transformation into text, speech translation into sign language using Deep Learning (DL), the development of smart hearing aids with AI functions, personalized assistive technologies to improve access to audio information, etc. With AI capabilities, hearing aids have become intelligent systems capable of analysing and adapting to different sound scenarios. AI enables not only better speech perception, but also interaction with modern technologies. This is primarily about smartphones, IoT (Internet of Things) devices and virtual assistants. This paper is related to the current state of AI hearing assistance, but it should also identify challenges and propose guidelines for further progress.

In the past, hearing aids did not have any signal processing, but their role was only to amplify the signal. But digital signal processor (DSP) expansion in the 1980s and 1990s leads to their improvement and it was the initial step toward more sophisticated hearing aids. To enhance further noise reduction in various acoustic situations, Machine Learning (ML) algorithms were introduced in the early 2000s. This was the beginning of AI in hearing aid solutions. Today, AI and DL have greatly improved real-time processing, but also the hearing aids customization.

Advanced solutions offer much more than the initial solutions and provide hearing impaired people relaxed conversations with relatives, friends or colleagues. This is enabled by the great progress of technology in recent years, especially in smaller and faster processor production, as well as in the field of multi-core and multi-processor processing. In this paper, we will focus on a few of the most important AI solutions.

A significant step is enabled by using AI in ASR technology. The main goal is to enable hearing aids to recognize, analyse and interpret speech in real time, to significantly improve sound quality, and to adapt in different environments [1] [2].

People who have very severe hearing loss still cannot communicate in the classical way. They have to use sign language to be able to communicate at all. In that case, AI is the logical choice [3] [4].

Many authors deal with intelligent methods using deep learning-based algorithms for personalized hearing aids, as presented in [5] [6] [7]. These methods selectively suppress noise while maintaining speech signals. The DL is used to provide speech intelligibility improvements. For now, at most commercially available hearing aids, the beamforming (spatial selectivity) is often used to suppress a noise.

It is important to notice that AI also enables Bone Conduction technology to become more precise, adaptive and intelligent for different users enabling them have an easier life resulting in advanced possibilities of their interacting with the environment [8] [9]. The advancement of this technology is of particular importance.

AI methods with the IoT enable the significant improvement. We can connect different devices and sensors in a network and we can analyse and adjust settings in real time, enabling better recognition of sound signals, improved security and greater autonomy [10] [11] [12].

The paper is divided into several parts. The main principles of hearing assistance are presented in Section 2. Section 3 is the main part, where we analyse the most important existing methodologies to assist people with hearing impairments. In Section 4, the effectiveness of the existing methods and the direction of future development are shown. Section 5 is related to conclusions.

2. HEARING ASSIST FUNDAMENTALS

There are several levels of hearing loss. We can say that the hearing threshold of 20 dB is actually the limit that indicates that a person has hearing problems. These problems can be mild or moderate, but they can also be very serious (severe or profound). It is also important to emphasize that the problems can exist in both ears, but they can also be asymmetrical, where they exist in only one ear. All these problems are analysed and solved depending on the specific situation, but in recent years they have begun to be methodologically solved at a significantly higher level. Figure 1 shows typical hearing thresholds.

Even mild hearing loss people need help and some kind of assistance is necessary. They can still use spoken language, but aids, cochlear implants, and other assistive devices are required. If hearing is still profoundly impaired, people often use sign language for communication. Hearing aids can reduce environmental and enhance speech by using intelligent AI algorithms. Hearing problems can be classified into several categories.

- Difficulty understanding speech
- Misunderstanding information
- Reduced ability to participate in conversations

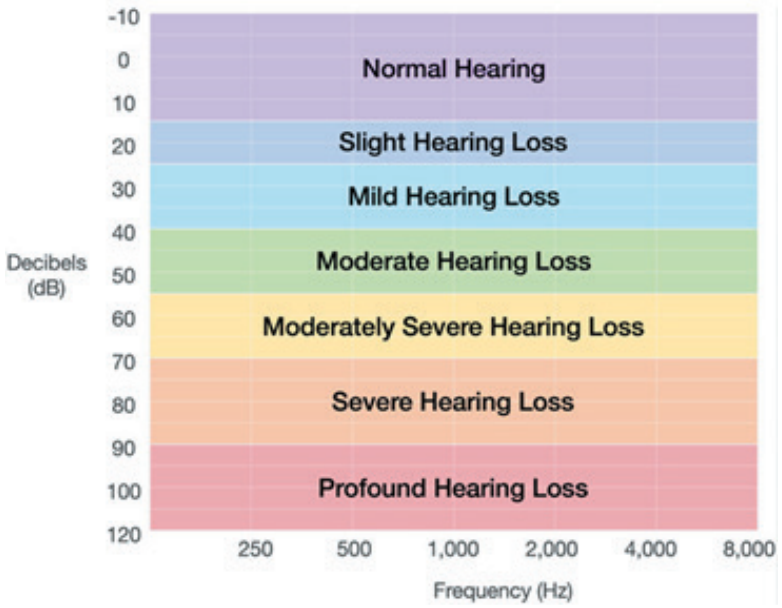

Figure 1. Hearing threshold typical values [13]

Assistive listening devices, which include hearing aids and hearing aid accessories are used, so that people can fully engage in communication, even if their hearing is severely impaired. The sound in amplified and, at the same time, the noise is suppressed, so the communication is much easier.

AI and ML are used in the Internet of Things (IoT) applications, and they are also applicable in hearing aid purposes. This paper is related to the systematic review of existing AI methods in hearing aids. We present the most significant challenges, as well as the things that pose a challenge in the future. AI model can learn user preferences and behaviours. If the user frequently changes settings in certain situations, the device can automatically apply those changes and can adapt to it, by analysing how the user reacts to different sounds.

3. THE METHODOLOGIES TO ASSIST PEOPLE WITH HEARING IMPAIRMENTS

AI hearing aids are based on complex technology, intelligent algorithms and sophisticated signal processing. It is necessary to highlight three core components of such systems to provide a more personalized and hassle-free hearing experience, as presented in Figure 2:

- **Artificial intelligence (AI)** is the most important part because it represents computer technology in order to make some devices do human intelligence things. Here, for example, it is image recognition or language understanding.
- **Machine learning (ML)** enables various algorithms to improve themselves from the user experience. These algorithms process large amounts of information and find patterns that help them make predictions or decisions.
- **A Deep Neural Network (DNN)** tries to work like the human brain. It is a kind of machine learning algorithm consisting of many layers that work together to solve complex problems, like recognizing faces or translating languages.

The merging of AI technologies and hearing aids represents an advanced solution to solve many hearing problems for the millions that live with hearing impairment around the world. The main goal is to enhance real-time listening using AI engines, helping people to personalize their sound experience. In this section, several of the most important existing solutions are described. Figure 2 shows AI and ML description model.

Figure 2. AI and ML description model

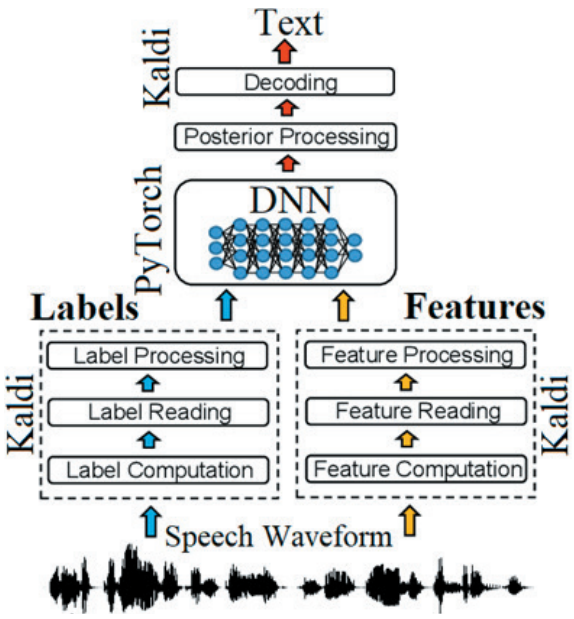

Figure 3. Automatic Speech Recognition (ASR) description model

3.1. AUTOMATIC SPEECH RECOGNITION (ASR) METHODS

ASR is a methodology based on AI and ML, according to which human speech is converted into text by using different algorithms for its recognizing and processing. ASR depends on various components such as preprocessing, speech classification, various feature "extraction" techniques, classification, databases, and system performance. From the technology perspective, speech recognition has benefited from advances in DL and big data. The advances are evidenced not only by a lot of published scientific papers, but more importantly by the worldwide industry adoption of a variety of deep learning methods. In recent years, there has been rapid development, with popular applications for real-time captions (TikTok and Instagram), for podcast transcriptions (Spotify), for meeting transcriptions (Zoom), YouTube and more. Figure 3 shows typical ASR description model.

Also, one of the basic components of AI speech processing is a technique known as Natural Language Processing (NLP). People and the AI system are in the most natural human form interaction. In that way, it enables to extract language characteristics based on a sound recording. The synthesis and analysis of human speech is performed by training neural networks, i.e. DNN with a large amount of data.

The YouTube application uses automatic speech recognition to generate translations of videos. We can turn on Subtitle/CC option in the settings and video clip is processed in real-time in order to have a translation. The ASR enables people with partial hearing loss not only to communicate digitally, but also to communicate in real life, because with the advent of portable devices, these possibilities are always available to them.

There are plenty of toolkits that allow for easy speech recondition using different programming languages. Some of the most important open-source tools can be seen in Table 1.

Table 1. The most important open-source speech recognition tools

Tool	Programming languages	Trained models
CMU Sphinx	C, Python, Java, others	English and 10 other languages
Kaldi	C++, Python	English
Julius	C, Python	Japanese
ISIP	C++	Digits only

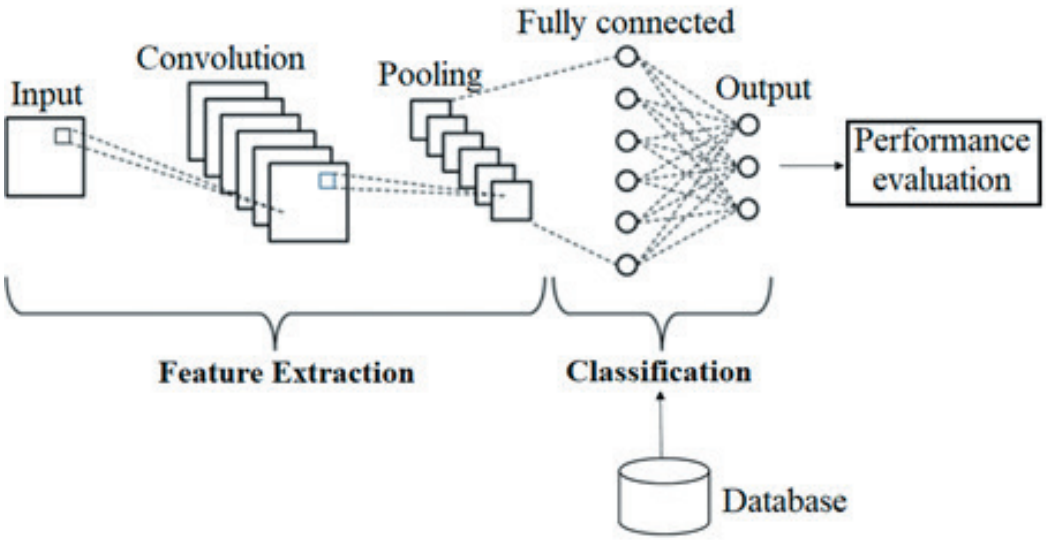

Figure 4. Sign language recognition model using AI

3.2. SIGN LANGUAGE RECOGNITION METHODS

People who have severe hearing problems can use sign language as a way of communication. Recently, the field of computer vision and DL has been developing a lot. As a result, vision-based programs are being developed that also enable the translation of sign language to text. It is necessary to take video sequences and extract temporal and spatial features from them. Then Inception process starts using CNN (Convolutional Neural Network) for recognizing spatial features. Finally, RNN (Recurrent Neural Network) is used to train on temporal features. The dataset used is Sign Language Dataset that corresponds to some speak language. Figure 4 shows a sign language recognition model using AI.

Mobile and desktop applications use AI to translate speech into text format. But real-time translation to sign language is also possible. Sign language translation systems are based on computer vision and DNN, so that hand gestures and facial expressions can be recognized. The combination of different sensor inputs can significantly increase the accuracy and efficiency of the system.

The speech translation into sign language consists of:

- Speech recognition where speech is recognized using the ASR
- Motion analysis where cameras and sensors track hand gestures and facial expressions.
- Translation into sign language where DNN map recognized speech elements to sign language.

Sign language translation applications can be integrated with smartphones, computers and devices for easier communication. Therefore, sign language people can communicate with people who speak verbally through mobile applications that enable mutual communication in real time, often by using Cloud-based services.

3.3. INTELLIGENT METHODS FOR PERSONALIZED HEARING AIDS

Even when using hearing aids, people may have understanding problems in public places, such as stadiums, cafes, etc. In that case, it is also necessary to use some

advanced algorithms to suppress unwanted environmental noise. AI can analyse sound and automatically adjust the hearing aid to focus on important sounds, improving speech recognition and the personalization of the experience is also enabled. AI enables hearing aids to become a much smarter, more adaptive, improving user's ability to communicate and enjoy everyday activities. Table 2 shows key components of AI hearing aids, while Figure 5 shows the display of a typical AI hearing aid and one example of a hearing aid application.

3.4. AI IN BONE CONDUCTION HEARING SYSTEMS

Bone Conduction (BC) technology thar uses vibrations to transmit sound directly through the bones of the skull to the inner ear, bypassing the middle and outer ear.

Sound is converted into vibrations that are transmitted by special BC devices through the temporal bone to the cochlea (inner ear). This technology enables listening even for people with middle ear damage or a complete lack of the external ear. AI in these devices enables the adaptation of sound vibrations according to the user's frequency needs. For example, AI algorithms can adjust the intensity of vibrations to optimize sound reception without causing discomfort. AI in BC technology is used to improve sound quality, filter noise and adapt to user needs. Intelligent noise filtering and speech enhancement are enabled in that case and AI algorithms analyse the vibrations transmitted through the skull and distinguish useful sounds (speech) from unwanted noise. Figure 6 shows an example of the BC hearing system.

Table 2. Key hardware and software components of AI hearing aids

Component type	Component role
Microphones	Input for capture sound from the environment and to form o audio signal
Processors	Use different AI algorithms to analyse and process input audio signal
Receivers	They are used to send processed audio signal to user's ear
Connectivity module	It is used to communicate with other devices, such as tablets, smartphones, smartwatches, etc.
Software	It is used to execute AI algorithms and to start user interfaces, often via different mobile applications

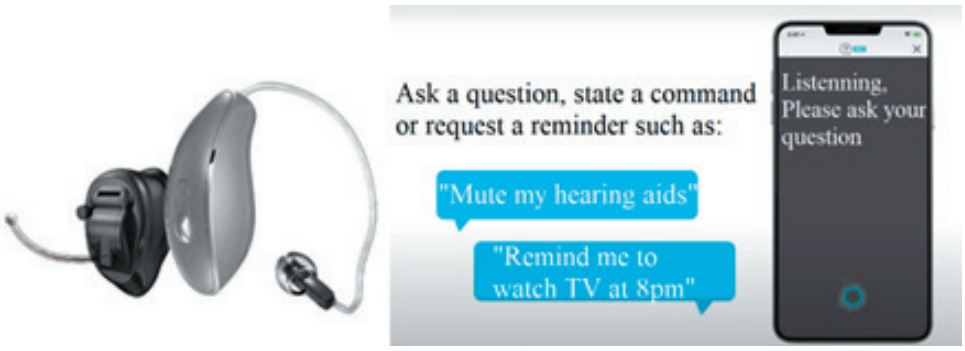

Figure 5. (a) AI hearing aids (b) An example of hearing aid Application

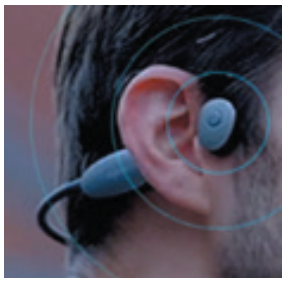

Figure 6. An example of the BC hearing system

3.5. METHODS BASED ON THE INTEGRATION WITH THE INTERNET OF THINGS

Interaction with other devices and technologies is possible by connecting with smartphones, computers or other devices. AI enables hearing aids to recognize and integrate different forms of sound, such as phone calls, music, sound signals from the TV, and to process and adapt them accordingly. Also, they can be synchronized with speech recognition applications improving the user experience in everyday interactions. One of the advantages of AI and IoT integration is better safety because IoT devices can recognize warning and sound signals (alarms, sirens) and notify the user in a visual or vibrational way. Figure 7 shows the IoT hearing aid system.

4. THE EFFECTIVENESS OF THE EXISTING METHODS AND THE DIRECTION OF FUTURE DEVELOPMENT

Personalisation and device setting adjustment is of crucial importance. Personalization is influenced by multiple factors, and it is important that the manipulation is not too complex, regardless of the user's level of education or skill. Psychosocial and cultural factors also play an important role. A key metric used in many studies is the acceptance rate of the proposed solutions. The overall acceptance rate for all proposed solutions was more than 80% in the last 20 years. This growing acceptance shows that the AI-enabled hearing aid applications are successfully accepted solutions and have progressively improved performance over time.

So, the conclusion is that the future of AI and hearing aids is bright. Context-aware personalization is another future direction, with advanced solutions that automatically identify a user's operating audio environment and adjust settings accordingly. Effective feedback mechanisms, such as surveys and continuous feedback loops, will be useful for refining personalization solutions based on a user's experiences. Integration with portable devices is also one of the most important tasks in order to ensure further personalization enhancement. The ultimate goal of AI hearing aid technology is to improve audibility, speech perception, and comfort in listening.

5. CONCLUSION

The latest generations of hearing aids will focus on lowering costs to make devices more accessible to more users around the world. The revolution with AI capabilities in real-world scenarios, unlike traditional methods, opens the way for personalized experiences in noisy and dynamic environments. In this paper, we have shown that there are several hearing aid solutions that provide high-quality audio to the users, making them comfortable. It is evident that AI-enabled hearing aid applications have begun more personalized, efficient, and satisfying for users. Also, by using the advantages of wireless communication, hearing aids have become almost invisible and look like a piece of jewellery. The proposed solutions are user-oriented because only newer and more advanced solutions provide a satisfactory experience to users, because their living standards and expectations have also improved in recent years.

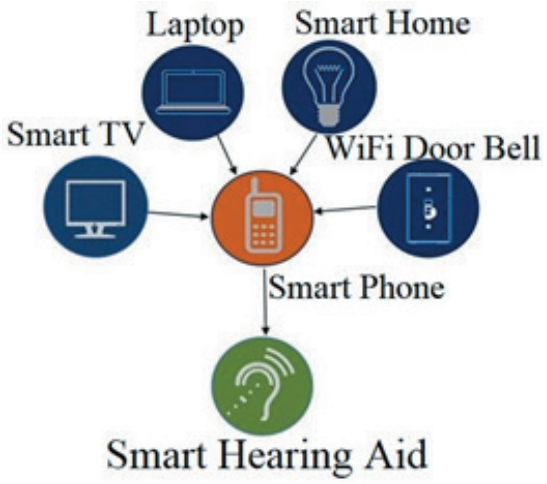

Figure 7. IoT and smart AI hearing aid interaction

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