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Impact of Intelligent Automation on Hearing Aid Development

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Abstract
Hearing problem is common nowadays and it doesn't have a positive impact on human interaction and livelihood. hearing aids have elevated the treatment of hearing impairment. Audio signals are processed in a way that human audiogram is able to pick them. Conventional approaches in developing hearing aids usually find it difficult to meet user's specific requirements in noisy environments. Recent developments of hearing aids using artificial intelligence have cracked ice on new possibility of improving the hearing aid functionalities. Data driven approaches positively results in achieving user specific needs in very noisy environments. Elevation in artificial intelligence are globally changing every part of the environment we are in now. As it is growing and advancing artificial intelligence has now elevated the hearing aid technology in life changing ways. Current hearing aids are being armed with very intelligent attributes like machine learning algorithms, automated sound adjustment and activity tracking. This review paper collects together most of the work done by integrating artificial intelligence into improving the hearing aid itself. This is achieved by looking at how intelligence is combined with hearing aid design, taking note of different models, their capabilities and how everyday hearing is improved.

Keywords — **hearing aid, deep neural networks, speech signal, digital signal processing**

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Introduction

World Health Organization report [1] states that, "Over 5% of the world's population has disabling hearing loss, including both adults and children. According to [2], a person will not pick sound signals that fall below a minimum level also known as hearing threshold. A hearing impaired person cannot hear well as others with hearing threshold of twenty decibels or better in both ears [3]. Hearing impairment is not a one size fits all type of situation, it is in different forms [4]. Three main types are sensoneurial, conductive and hybrid hearing loss [4]. The figure 1 gives an illustration of the sages of hearing loss and the hearing threshold in decibels. For mild hearing loss one will be facing difficulty in understanding normal speech. For hearing threshold of forty to seventy decibels there will be difficulty in understanding loud speech

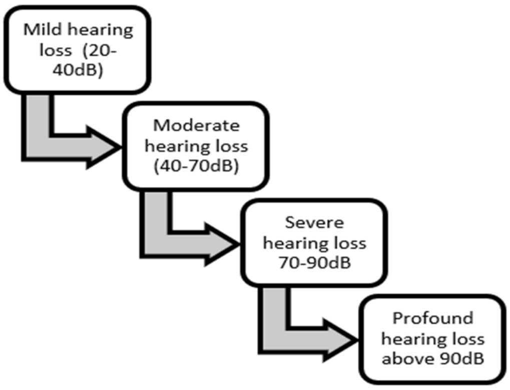

Fig 1. illustration showing loss of hearing and hearing thresholds

Severe hearing loss is when one only understands amplified speech. Above ninety decibels this hearing thresholds shows challenges in understanding amplified speech and this is profound hearing loss. Hearing impairment can be on one ear and both ears. The patients also are exposed to rising hearing threshold, limited frequency bandwidth, reduced frequency quality audibility and limited depth of sensitivity. Hearing aid electronic devices have a huge ability for patients with mild to profound hearing impairment to be able to communicate again in an enhanced etiquette. The electronic device makes up for the dying cue of human ear and thereby elevating quality to understand sound signals of patients. Clear speech audibility is notably elevated when sound signals are sent at appropriate volumes. In the same way hearing aids are designed to intensify and process input audio signals to match with human audiogram thereby helping to eliminate challenges caused by hearing impairment. Information published by World Intellectual Property Organization (WIPO) gives an insight that the propagating research and inventions is aiming at compensating hearing for unfortunate patients as shown by figure 2 [5]. The Major causes of hearing loss are genetics, toxic substance that affects the ear, too much noise and aging. World Health Organization made a prediction that by the year two thousand and fifty about seven hundred million people could be suffering from hearing loss. Most children with severe hearing impairment barely access education in developing countries. Hearing aid devices greatly rescues deaf patients.

Unfortunately, these electronic devices are highly accessible to those in industrialized countries. If hearing loss remains untreated it can possibly lead to Alzheimer or even develop Dementia, according to a report by Johns Hoprkins these three are connected [6].

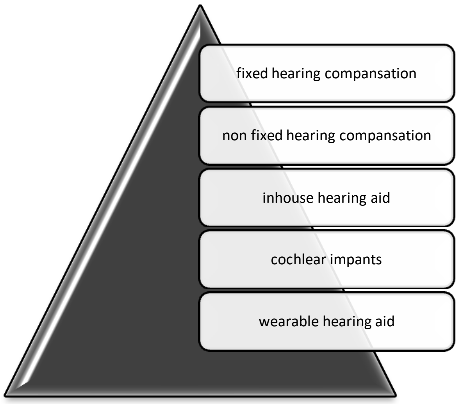

Fig 2. illustration of the development of various hearing aid

In the process of advancing digital signal processing, present day hearing aids are becoming more versatile, smaller in size and widely used by the use of artificial intelligence. Hearing aid devices can separately intensify audio signals to match the users specific hearing capabilities, serving as a delicate aid for those with hearing impairment. At the core of this progress is the design part that modifies and determines how sound is operated logically a delivered to the user. Filters in hearing aid devices, perform multiple tasks such as enhancing speech audibility, surrounding noise reduction and articulate frequency responses to match the users audiogram. Design of these filters are bound to consider power efficiency, group delay, performance and hardware size. If delay goes past twenty milliseconds lip reading is affected hence no user satisfaction on using hearing aid [7]. The massive increase in the number of individuals with hearing loss and difficult situations they meet pin points a case of emergency to advance and improve hearing aid technology. Out there those who should be having hearing aids are moving without them because the existing hearing devices possess some characteristics and limitations. To truly rectify this problem there is need to use emerging technology which is infusing artificial intelligence and the use of wireless network to hearing aids.

I. Methodology

Using Research4life, Google scholar, Science direct and other internet sources, research for articles and other materials was done for analysis and performance argumentation. When researching the fundamental words used were hearing aid filters, filter design methods which base on artificial intelligence and other design techniques to make sure that qualifying characteristics of the hearing aid filter are thoroughly reviewed. Validation and comparison of all captured design methods was considered. The study's exclusion criteria included research articles published before 2010 and those that were not subjected to peer review. Based on their titles, one hundred and eighty papers were taken from the internet. Thirty clone papers were eliminated in the initial screening of these papers. Ninety-five of the remaining one hundred and fifty articles were eliminated after their abstract relevance evaluation. Looking at the overall content in the articles twenty five were eliminated, hence this paper is a product of thirty journal papers. Evaluation of intelligent automation design techniques was done in terms of characteristics offered by digital filter when processing audio signals.

II. Intelligent Automation and the hearing aid system

A. *Part played by hearing aid in reducing hearing impairment*

Sensorineural Hearing Loss (SNHL) is the most popular type of hearing loss, where tiny hair cells in the cochlea of the inner ear no longer have the strength to pick up specific sound frequencies as they should. Normally people with sensorineural hearing loss often find it challenging to pick up sounds clearly in noisy environments. Hearing aids comes in to rescue by intensifying specific sound signals that match the human hearing system. Figure below shows the outlay of the hearing aid. The hearing aid internal structure is illustrated below, the figure shows amplification, conversion, filtering and output of the audio signals via a hearing aid.

Fig 1. internal part of the hearing aid system

A hearing aid has a makeup which allows it to capture hearable signals by utilizing a microphone. The microphone transforms weak audio signals into stronger ones. The stronger signals are delivered to the ear via the speaker. Digital hearing aids are there to make interaction clearer and comfortable. Signal processing algorithms are behind the sound enhancement of speech, which is essential in our day today. Hearing aid consists of an amplifier where by small quiet sounds are intensified so as to make them loud and comfortable. The heart of a hearing aid is filter bank, where background chattering is filtered out so that speech outshines noise. Amplitude shaping, shifting frequency and compression of the audio signal for smooth and a more natural output is done by hearing aid [11]. Most important characteristic in hearing aid device is noise cancellation. This attribute enables users to pick sounds that matter.

Types of hearing aids

a) Post auricular hearing aid
It is designed in a way that it can be attached to the outside ear with a tube that directs signal waves into the canal of the human ear
b) Internal hearing aid device
These are worn inside canal it has to fit the user comfortably

B. Some of the problems faced by engineers in designing hearing aid

- Minimum size of integrated circuit of hearing aid
- Reduced wattage use
- Upgrade in tonal balance and bass feedback [12]
- Being able to handle high peak power consumption since hearing aids are adopting wireless transitions
- Avoiding overlapping frequency bands
- Reducing background noise in sensitive components like filters
- Achieving a transition width that is narrow
- Achieving less logic computation operations

C. Artificial intelligence and the hearing aid system

i. Artificial intelligence explained:

deep learning is a sub type of machine learning suitable for self training algorithms and extraction of features. Machine learning algorithms are the ones designed to predict future results. Artificial intelligence is the wider formula of intelligence demonstrated by machines whilst mimicking humans. The figure below shows an illustration of the relationship between the three terms. When performing a computation, the set of instructions that makes machines to do a specific task and make decisions are called artificial intelligent algorithms. As time moves machines powered by artificial intelligence are able to adapt to responses because they learn from data and will no longer need frequency coding on them.

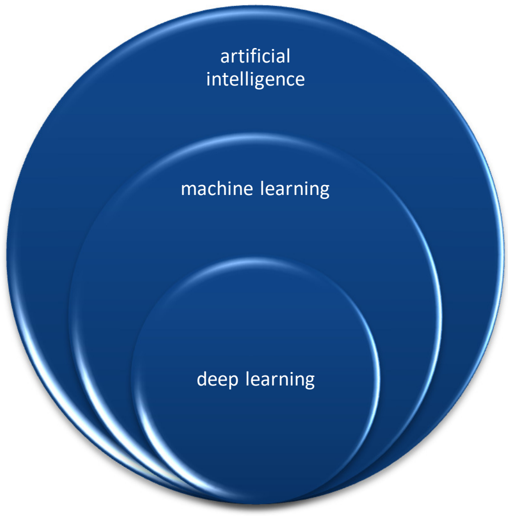

Fig 2. relationship of artificial intelligence, deep neural networks and machine learning

ii. Role played by artificial intelligence in hearing aid development

a) Enhancing Hearing Aid performance for smarter use and better sound quality

Intelligent automation is changing current hearing aids by sharpening sound quality and boosting speech clarity. This makes user to experience clear listening without background noise effects. The latest models of hearing aids using artificial intelligence are Oticon, Phonak, Starkey, Widex and Signia [13]. According to Achin Bhowmik [14], in these past many years hearing aids have been using machine learning to distinguish sound which we still use but in a different methods. Bhowmik also explains how hearing aids have two general listening scenarios which are music and chatting environment modes. In place of using a set programming code, machine learning allows the hearing devices to take note of the trillion sound signals one listens to everyday. This will enable the aid to make tuning adjustments in real time. Giving credit to the artificial intelligent technologies because hearing aids are able to stream audio directly from television making hearing more reliable and defined [12].

b) Advancement in processing speech and clarity

Recent searches elaborate that machine learning powered speech enhancement algorithms can make speech clearer even in noisy places. This is achieved by

- **Auditory Background Classification**

Auditory Background Classification uses a smart technology to imitate how a human ear and brain classify different sounds. Hearing aid devices understand and respond to real world listening environments more reliably [13]. Innovated hearing devices use auditory background classification to identify different types of listening situations such as quiet places, music and background noise. As soon as the environment is recognized the hearing aid automatically activates sound features such as directional microphones, feedback control to match the setting and microphones.

- **Edge mode**

This edge mode was developed to solve the limitations of traditional auditory background classification systems. The difference is that the user is in control of the artificial intelligence key buttons. With a simple tap on the hearing aid the use activates intelligent sound processing in noisy environments. Behind the scene the hearing aid customize parameters across various sound categories.

iii. Different technologies utilized in hearing aids

a) Deep neural networks

The use of deep neural networks technology in hearing aids is to mimic how the human brain functions when responding to audio signals without plus programming done. The neural networks allow the hearing aid to imitate how a person's brain would pick and classify audio signal as if one has no hearing loss. Put in other words neural networks improves signal to noise ratio, listening comfort, speech understanding and elevates quality of sound

b) Machine learning

This technology is under artificial intelligence and makes use of algorithms to separate vast amount of processed information so as to make predictions and decisions. It looks mainly at consistent learning and continuous solution bringing to problems abilities. When used in hearing aid devices, this technology takes note of the user's adjustments in a particular space. A conventional hearing aid is set to use a coded program which may find it uneasy to differentiate between speech and background noise. An artificial intelligent hearing device can make you tailor the listening environmental to ones needs. The algorithm will adapt to picking up and fore fronting audio signals that are important to user. It will also work on filtering out the environmental noise.

Table 1 showing hearing electronic devices that use artificial intelligence

Manufacturer of hearing aid	Year of launch	Artificial intelligent chip type	Overall hearing aid lab score in %	Overall score for hearing tracker performance in %	Reference
Signia Pure C and G ix	2023	integrated	92	84	[14]
Oticon real	2023	integrated	94	86	[14]
Oticon intent	2024	integrated	98	88	[14]
Resound vivia	2025	dual	82	84	[14]
Phonak lumity	2022	integrated	92	86	[14]
Phonak sphere infinio	2024	Dual	84	90	[14]
Starkey genesis	2023	Integrated	90	82	[14]
Starkey edge artifial intelligence	2024	integrated	90	84	[14]

Analyzing the table above deep neural networks can be utilized as one chip responsible for the neural networking processing and two chips with a plus one also dedicated to the deep neural network. Though all hearing aids in the table show very good performance, manufacturers who use dual chip [13] say that the extra chip enables them to fold in more watts for processing power. Manufactures who use integrated chip claim their aids processing speed is better, smaller size and consume less power. Though tangible evidence has not yet been published.

IV. Advantages of hearing aids which utilize artificial intelligence

- Simply hands free meaning patients doesn't have to manually switch to programs or settings, it like the hearing device automatically adapts
- Professionals spend lesser time teaching complicated instructions and spend more time providing personalized care.
- Hearing aids are enhancing into multipurpose tools that goes beyond just filtering and amplification.

- More satisfactory hearing aids are manufactured which leads to greater acceptance by the users

D. Artificial intelligence in Hearing aid filter bank design

The challenges faced by researchers gives an eye opening that the hearing electronic devices should be tailor made so that it fits the different hearing needs of the user. The device should pose instinctive and more human like. Filter bank is a team of same specifics filters arranged and working together sequentially to process audio signals. Audio signal processes are done in the heart of the wearable device, which is the filter bank. Down sampling of input audio signals into smaller frequency band is done in the filter bank. It divides available sound into different frequency band. Decimation is the other name of the process. Each band receives a certain amount of selective amplification in order to match with human audiogram, following further decomposition to several bands. Hearing aid filter bank help to pick unique sound characteristics that vary between patients. This ensures that each user receives tailored auditory compensation, improving hearing experience. One hundred and twenty five hertz to eight kilohertz are considered to be average normal hearing and mostly the whole frequency range is divided into eight kilohertz [15].
Enhanced efficiency of hearing aid massively rests on selecting the correct variety of filter bank. Varieties of filters are described below according to their attributes and assessed following their compatibility for hearing aid utilization**.** Below is the general diagram for filter bank. The aim being on providing same hearing services as of a human ear the hearing aid should be adjustable to the frequency with low hearing sensitivity. This is a stepping ladder to making a customized hearing aid to meet customers' needs rather than generalizing them. The general diagram of filter bank is shown below in figure 4.

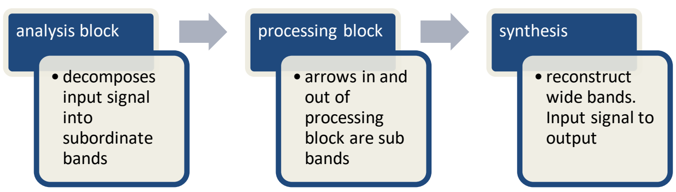

Fig. 3 general diagram for filter bank

iv. Performance parameter for filter design and evaluation

Matching error: this is the discrepancy between an individual's hearing loss threshold across different frequencies and the optimal threshold in their audiogram. This is essential when assessing how well the hearing aid filter design is working. A smaller matching error means better support for the user hearing needs. This is achieved by tuning the hearing aid based on one's specific hearing profile, usually matching error of up to 3dB is tolerable [23].
Adaptability: greater adaptability is necessary for more precise fitting in order to enhance user flexibility.
Wattage use: a wearable medical gadget is crucial to keep its power consumption low. If it uses too much power, it can heat up and becomes uncomfortable to the wearer. This also drains the battery life faster. By keeping power use down, we can help the battery last longer and ensure a safer experience for the user.
Hardware complexity: to lower power dissipation, it is important to keep hardware complexity simple. By reducing the number of multipliers used simplicity is achieved and hence minimize power consumption.
Computational complexity: it is crucial to maintain the smallest number of computations in order to control wattage use. Filtering algorithms can be energy intensive and demanding.
Size: since hearing aids are wearable appearance is quite important. Many people worry about the stigma that comes with using them. If the size is smaller with a compact fitting hence user feels comfortable too.
Delay: for closed fitting group delay should not be more than twenty milliseconds, for open fitting it should not be more than ten milliseconds. Latency exceeding these values affect lip reading
Higher stop band attenuation: stop band attenuation should be higher than sixty dB or more is required for the filter channels [23]. A higher stop band can provide more gain before start of feedback and may give improved magnitude response programmability [15].

v. Impact of digital filter design deep neural techniques in improving filter performance

According to [35] the authors introduced an intelligent way to design digital filter bank for hearing aids by the use of deep neural networks. The network was trained on a fifty three order finite impulse response filter to help correct hearing impairment. The filter response is a result of networks learned weights. This neural network method resulted in in accurate outcomes and speed for processing was much improved that traditional methods

III. Conclusion and future perspective

Hearing technology has come from a long way and efficiently getting smarter day by day. Automated intelligence application on hearing aids does not only amplify sounds but makes it clearer. Today's hearing devices can actually adjust themselves to suit the environment of the user. features like edge mode allows users to have more control and auditory environmental classification help the devices understand their surroundings just like normal humans do. As this technology continue to evolve, hearing aids can connect with other smart technologies which opens doors to functions like direct streaming and internet based application integration.

Acknowledgement
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