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An Appraisal of the Advancement of Emerging Technologies in Hearing Aids

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Abstract

Background/Objectives: To shed light on the history of development of hearing aid, along with the various pros and cons of each developed technological solution. **Methods/Statistical Analysis:** A historical survey has been conducted, which highlights some of the more renowned and widely deployed hearing aids within the market. The different types of hearing losses and the varying degree of assistance provided by the different technological solutions have been discussed. Over the years, the overall accuracy as well as practicality of the hearing aids have improved, ranging from cumbersome and heavy hearing aids in the early 1960-1970s to the portable and wearable ones available in the market at present. **Findings:** Technological innovation is spearheading massive improvement within the hearing aids. Some of the key features causing these changes include wireless technology, frequency lowering, directional microphones and digital noise reduction algorithms. Although DSP has provided significant changes in the hearing technology, limitations still exist, which require re-search contributions from different fields like clinical audiology, psychoacoustics and signal processing. **Application/Improvements:** Most of the portable and reliable hearing aid devices are very expensive. Therefore, there is a need to develop affordable pieces of equipment that is able to cater to basic hearing functionalities.

Keywords: Digital Signal Processing (DSP), Directional Microphones, Digital Noise Reduction, Ear Trumpets, Frequency Lowering, Hearing Aid

1. Introduction

According to a WHO report, approximately 360 million people are having deafness worldwide[1]. It causes negative effects on the development and learning abilities of children, and creates problems in daily activities of adults. Overall, it affects personal and professional relationships[2]. Significant improvements in hearing aids came in parallel with the developing technology. With the development of digital technology, complete digital hearing aids came into market at the end of the 20th century. DSP chips not only have improved the existing features, but also have given many new features to a modern hearing aid. A directional microphone, noise reduction algorithms and wireless technology has increased Signal to Noise Ratio (SNR) and Speech recognition in modern listening devices. This article reviews the history of hearing aids and presents an overview of the recent developments and future trends.

2. Background of Hearing Aids

Till 1947, hearing aids were heavy in weight and body worn only, but the invention of transistor brought a great change in the hearing aidsbecause of cost effective, smaller in size and low power consumption[3] thus resulting in reduced size of hearing aids. The struggle was started to improve listening comforts by reducing noise. In 1969, the built-in directional microphone was manufactured[4] and in 1970s, integrated circuits for non-linear

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compression were made for hearing aids, which could reduce the environmental noise from speech[5]. The era of digital hearing aids was begun in 1996[6] and a first 100% digital B.T.E hearing aid device was made on the bases of Adaptive speech alignment, which uses two different processes for consonant and vowel sounds and divide sound into seven bands[7].

From the start of the 21st century, manufacturers introduced different features and technologies in the hearing aids which made them more comfortable and reliable for the users. The computer technology has brought a remarkable change in performance of hearing aids, sizes are made smaller and smarter and have the ability to adjust to different listening conditions but there is still a space for improvement especially with the background noise.

3. Hearing Loss and it Types

WHO defines it as "Disabling hearing loss" in the adults is greater than 40 dB and in children, it is greater than 30 dB in better hearing ear. It causes negative effects on the life of children and adults, such as isolation, depression, reduced social interaction and impaired cognitive function[8]. Three types of hearing loss are discussed as under

3.1 Conductive Hearing Loss

It is due to impairment such as blockage of auditory canal of the middle or external ear. No sound waves can pass through it in the result of that defect. Conductive hearing loss can also be caused by any accident, suchas punctured eardrum, trauma, or disorder such as oteosclerosis, neoplasms, severe otitis media, birth defects, congenital, blockage by wax or atresia of the ear canal. In this type of loss a patient has an equal loss for all frequencies from the audible range of 20 to 20 kHz. It can be treated through surgical or medical methods[9].

3.2 Sensorineural Hearing Loss

About 90% of the hearing losses are sensorineural. Most of them directly effects cochlea and eighth cranial nerve and it is due to dysfunctioning of the inner ear receptors. The causes of this impairment can be prenatal, congenital, aging, birth related disorders, bacterial infections, ototoxic drugs, trauma, intense noisy environment, Meniere's disease, fractures of the temporal bone, cochlear otosclerosis and congenital malformation[9,10].

3.3 Mixed Hearing Loss

This type of loss is the combination of both upper two types of losses[11]. Other hearing losses or decreased sensitivity can be due to the environmental factors such as recreational noise, occupational noise, loud music or other intense sounds and aging[9,12].

4. Hearing Aid Technology

It is an electroacoustic device and converts acoustic power into electrical power, amplify it electronically and convert it back to sound. It amplifies sound for a hearing impaired person so that he/she can listen and participate well in daily activities. It helps the user in hearing more both in qui-et and noisy situations[13,14]. It consists of a microphone, an amplifier, a speaker and a battery. The microphone picks a sound signal which is converted to electrical signal and amplified. After the desired processing, it is con-verted back to sound signals by speaker[2,10].

Block diagram of digital hearing aid is as shown in figure 1; it contains the digital signal processing portion which makes it more flexible and easily programmable than that of analog hearing aid. In the last couple of years, much of the innovation occurred in hearing aids. Recent innovations consist of open ear hearing aids, smaller light weight hearing aids and wireless hearing aids that provide connectivity to the household electrical devices, powerful behind the ear hearing aids and noise reduction algorithms[15]. However further improvements can be made to the hearing aid by improving DSP chips, increasing the number of channels in the hearing aid, improved intelligibility, wire-less technology and algorithms for background noise reduction[2].

4.1 Analog Hearing Aid

Analog hearing aids amplify both the speech and noise signals equally, some of them are programmable having

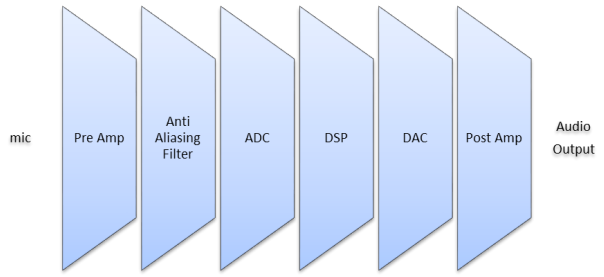

Figure 1. Block diagram of modern hearing aid[16].

a microchip through which the device is set to different listening environments like in a silent place or in a noisy area. For various environments, analog hearing aids can store multiple programs. A push button on the aid is used to set the device for different listening environments. Analog aids are less expensive[13,14] but are becoming less common due to more flexibility in digital hearing aids.

4.2 Digital Hearing Aid

This device convert the sound wave into binary codes of a computer and at the output; they pro-duce the exact sound signals. The sound amplification process of a digital aid is much more complex, which allows it to perform well, especially in noisy situations. Due to feature of programming, digital aid provides a greater flexibility and fulfils the sound requirement of a user or specific pattern[13,14]. Some common features are built in most hearing aids that helps the users in different situations. A few of these features include T-coil[14,17], DAI (Direct Audio Input), Directional microphones, noise reduction algorithms, frequency lowering techniques and bluetooth technology etc, which are further explained in section 6.

5. Types of Hearing Aid

They are classified into two main groups; an implantable and external devices, as shown in the figure 2.

5.1 Implanted Hearing Aids

This group is further divided into destructive and non-destructive types.

Cochlear implant comes in destructive type and is for the patients who are profoundly deaf[13,18]. It consist of a microphone, a signal processor, transmitter, receiver and electrode array that placed inside the cochlea. Speech Signals are transmitted to array through skin, bones and cartilage using FM.

Non-destructive are those implantable aids which utilize direct and conventional bone conduction. In former one, an exciter is attached to the mastoid area of the temporal bone which is pressed with constant pressure and transmit signals, but the soft skin attenuates it and hence the transmitted signal fidelity is poor[18]. Possibly the exciter is a source of problem like headache, eczema, pain and skin irritation[19]. A further development to it is the BAHA (Bone Conduction Hearing Aid)[20].

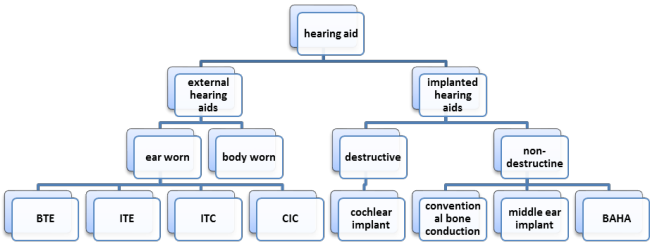

Figure 2. Types of hearing aids.

In BAHA direct bone conduction of a signal occurs and it bypasses the external ear[18,21]. It consists of abutment, sound processor and titanium screw. The titanium screw is implanted behind the ear in the skull and sound processor, after osseointegration, transmits the vibration directly through the bone to the cochlea fluid[21,22]. In this way the signal fidelity increases as compared to the conventional bone conduction method, user feels comfortable and this procedure is surgically reversible.

Implantable hearing aids have no occlusion effects as they don't need ear molds, further they do not have feedback problem and they are especially for the patients having external or middle ear malformation and suffering from chronic otitis[18].

5.2 External Hearing Aids

External devices are subdivided into body worn and ear worn instruments. A body worn hearing aid consists of a speaker and a separate case which contains an amplifier, battery and a control circuitry. The case is connected to an ear mold (speaker) through a cord and the size of the case is that of a playing card's pack and is carried in a pocket[18]. Ear Worn Hearing Aids are the basic hearing aids and differ by their size, placement (inside or on the ear) and sound amplification level[13], Sometimes they are also called air-conducted (AC) hearing aids. The four types of AC hearing aids are as shown in figure 3.

Behind-the-Ear (BTE) aid consists of two parts, the case and the earmold. The case contains the electronic circuitry and is placed behind the ear (pinna) while earmold is fitted inside the ear. The earmold is connected with case via tube which carries sound signal to an ear.

Mini BTE aid is a very small aid and it fits behind the ear. A very small, almost invisible tube is placed in the canal which is connected to the aid and carries sound[13,14]. It reduces occlusion, feedback, increase comfort and has

Figure 3. Types of ear worn hearing aid (courtesy of NIDCD/NIH).

good cosmetic concern. This type of aid is less damaged by earwax like substance, so it is the best choice for the users having problem of earwax.

In-the-Ear (ITE) aid's circuitry (case) is placed outside of the ear. It is larger as compared to ITC and CIC[13,14] and smaller than BTE[18]. As the ear grows its case is replaced so it is not suitable for children or younger.

In-the-Canal (ITC) aid is partially fitted into the ear canal. It is made according to the user's ear canal shape and size, and is used for mild to moderately severe hearing loss. Due to its smaller size, it is made a bit more discrete with respect to ITE.

Completely-in-the-Canal (CIC) aid is deeply placed in the canal so it is most conspicuous of all aids[18]. The case of CIC is completely fitted in the canal. It is almost hidden in the canal and is used for mild to moderately severe hearing loss.

Both the ITC and CIC are very small, so their adjustment is very difficult. Due to their space availability they have limited features. They are not used for severe to profound hearing loss be-cause their small size of battery limits the power and volume of the device also they are not much suitable for children, they have some listening and cosmetic advantages[13,14].

6. Technological Advancement

Since the introduction of digital signal processing to hearing aids in 1996[15], much advancement occurred in the hearing aids. In modern hearing aids DSP chips have improved the features very much, but still limitations exist and some users have complained regarding the speech recognition in noise.

6.1 Wireless and Bluetooth Technology

Wireless technology is not new in hearing aids. It dates back to 1930 when t-coils or induction coils were used in hearing aids[17]. Wireless communication in hearing aids has improved with time as soon as some progress occurred in wireless communication technology.

Bluetooth is FM based wireless technology and provides wireless connectivity between different devices like MP3 players, mobiles phones, computers etc. It is a short range communication mode of almost 30-300 ft transmission range which depends on the class of Bluetooth being used[23-25].

The Bluetooth development in the hearing aids increased the connectivity between the patients and technology i.e. Today wireless technology has many features in hearing aids i.e. wireless technology can be used for the command code (add-to-aid), audio signal streaming (add-to-aid), remote control, streaming and companion microphones[26].

6.2 Frequency Lowering

Frequency lowering option is utilized in case of severe to profound hearing loss. The concept of frequency lowering is that the high frequencies are shifted toward the lower frequencies where it is easy for patient to listen[23].

Frequency transposition and Frequency compression are two major approaches for frequency lowering technique implementation. In the frequency compression approach the whole band of frequency is compressed to a narrow bandwidth, i.e. if the patient inaudible range is above 4000 Hz and compression ratio of 2 is used, then after the frequency compression, the signal at 8 kHz will now appear at 4 kHz and a signal previously at 4 kHz will now appear at 2 kHz. The overall band-width would become 0-4 kHz, which now contains the frequencies previously inaudible[27]. How-ever in frequency transposition higher frequencies are shifted towards the lower frequencies such that they are superimposed. i.e. a patient with an inaudible range of above 4 kHz, and if one octave transposition target is used, then the signal at 8 kHz will be shifted to 4 kHz and the signal at 4 kHz will be shifted to 2 kHz. But the original 4 kHz, 2 kHz and 1 kHz (and

so forth) signals will remain in their original positions and will thus be mixed with the frequencies above 4 kHz. This approach has a main advantage of keeping the temporal structure of original signal preserved, although it causes initial confusion and masking of the original signal[27]. Audibility extender allows to set it as a primary or secondary listening mode in different listening situations. The Phonak Naida model uses the frequency compression and it uses the cutoff frequency as a limit for stopping amplification and start higher frequency shifting towards lower frequencies[23].

6.3 Directional Microphone

Directional microphones in the hearing aids have been improved very much since the last fifteen years[28]. Different algorithms were made for directional microphones using digital signal processing[29] and they might be explained instep-by-step[28].

Directional microphones were developed in hearing aids in order to increase the SNR[23]. There are two sound ports in fixed directional microphones, signals entering at the back port are acoustically delayed and then are subtracted from those which enters from the front of microphone[30]. Many researchers have shown advantages of it but its performance reduces when there is a uniform noise of moderate level[31]. The next advancement in directional microphone technology is Multi-channel automatic adaptive directional microphone. This kind of directional microphone contains different polar designs in frequency channels of hearing aids and switches automatically between the directional and omnidirectional modes[23]. The step-by-step progress in directionality is directional microphones, automatic directional microphones, adaptive directionality, Band-split directionality, manual and auto beam width adjustment, manual and auto both steering of pattern, asymmetric directionality, narrowing beam-width and multiple microphone array[28].

6.4 Noise Reduction

Like other algorithms, noise reduction has also been much improved with digital signal processing. In early analog devices, algorithms were intended to reduce the gain of low frequencies and hence filter out noise[23]. It prevented the analog compression circuitry to be activated by a strong low frequency signal. The limitation of analog algorithm is that the algorithm was implemented in one channel only and gain reduction was based on the input signal level[32].

In the presence of both speech and noise, many DNR algorithms don't change the signals significantly and preserve or maintain the speech audibility[33]. The goal of DNR is to reduce noise effect and improve speech, as the DSP technology improves the more complicated and newer algorithms may be applied to improve voice quality in noise.

7. Conclusion

As soon as the technology progressed, hearing aids have also been improved with it. Early in the 17th century ear trumpets were used. Later on electronic hearing aids were introduced and with the invention of transistors, their sizes were reduced and fitted to wear on or behind the ear. At the end of the 20th century, digital hearing aids became available in the market. Hearing aid technology has been much improved with Digital Signal Processing (DSP). The advancement and increased processing speed has provided many features in the hearing aid technology and has served those patients who could not take benefit of hearing aid devices previously. This article overviews the history and advancement in those hearing aid features that assist the users to listen in different noisy situations. Although DSP has provided significant changes in the hearing technology, limitations still exist, which require research contributions from different fields like clinical audiology, psycho-acoustics and signal processing.

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