GE-International Journal of Engineering Research
Vol. 3, Issue 12, Dec 2015 IF- 4.007 ISSN: (2321-1717)
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Website: www.aarf.asia Email : editor@aarf.asia , editoraarf@gmail.com

HISTORICAL ADVANCEMENTS OF HEARING AID TECHNOLOGY- A REVIEW

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ABSTRACT

This paper overview the history of hearing aids, types of hearing loss and advancements in the technology of hearing aid till date. The paper also covers the analog and digital processing approaches of technology of hearing aids. The hearing aid technology nowadays is entirely focused on consumer needs and is dependent on the type of hearing loss which the patient is suffering from. There have been great advancements in the technology of hearing aids since 19th century due to increasing use of digital technology. This have caused the drastic changes in the size, shape and various advancements are observed for feedback and noise cancellation mechanism of hearing aids due to rapid innovations.

Keywords: Hearing aid, hearing loss, ear, impairments, digital, analog, digital signal processing, connectivity.

I. INTRODUCTION

Ear plays a vital role in communication and it is very necessary to listen everything correctly and in a proper manner to understand the views of another person and to relate our own thoughts with them.

Two third of the world's population is suffering from hearing loss and the number is going to increase according to present trends. Hearing loss affects both our personal and professional aspects of life and therefore increases stress in life. To correct the hearing loss and impairments the device called hearing aid came into the picture as mentioned by Athanasius Kircher from Rome in his work "Neue Hall und Thonkunst" in 1650 about fans, tubes and horns [1]. During that time trumpets or horns were the only remedy for improving hearing loss and were used to amplify the sounds [2]. But now due to technical advancements hearing aid can be referred to as a device that is battery operated and manipulates the sound according to the need of a patient and help in improvised communication.

Hearing aid is basically comprised of three key components:

1. Microphone: Receives sound from surroundings.

2. Amplifier: Amplifies the sound received by microphone.

3. Loudspeaker: Delivers the amplified sound to ear directly.

II. HEARING MECHANISM

Hearing mechanism follows the series of events that change sound waves to electrical impulses which are carried to brain by auditory nerve. Ear is divided into three major parts, described as outer, middle and inner ear.

Following are the events that take place for receiving a particular sound:

- Sound waves enter the outer ear (pinna) that serves as a collecting point of sound waves. After that wave travels into the narrow tube also known as ear canal that leads to tympanic membrane inside the ear and commonly called as eardrum.
- This point is the beginning of middle ear and primarily consists of three tiny bones. As the wave reaches eardrum, it starts vibrating and transmits these vibrations to these tiny bones and cause them to vibrate as well. These bones are called ossicles and are named as Malleus, Incus and Stapes. These bones help in amplification of sound and transfer it to the entrance of inner ear.
- The entrance of inner ear is an oval window and opens into a fluid filled organ called cochlea. Hence the fluid present inside this organ is called cochlear fluid. The vibrations received by the cochlea cause ripples in the cochlear fluid and bend the projections from tiny hair cells present in it. Thus it causes electrical impulses to transfer into brain through auditory nerve, which is also called eighth cranial nerve.
- And at last brain interprets the impulses and converts them to sounds what are collected initially.

The various parts of ear described above are shown in figure 1. The type of hearing loss is dependent on specific part of ear that is damaged. The type of hearing loss along with other audiological issues determines which hearing aid is more suitable to each patient.

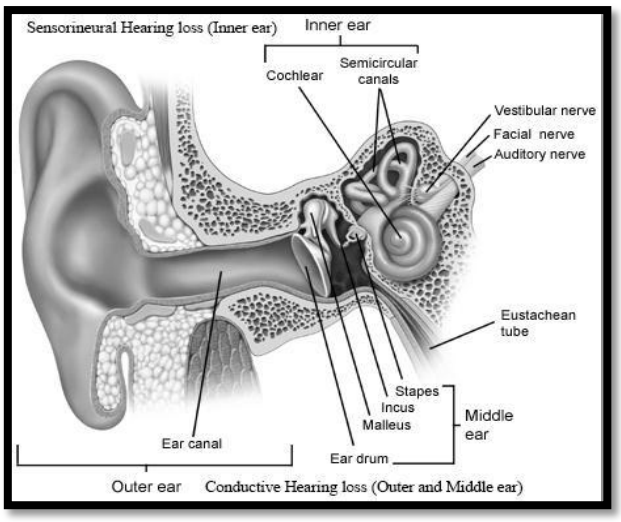

Figure 1 Description of ear [3]

III. TYPES OF HEARING LOSS

There are three different types of hearing loss which are as follows:

A. Conductive loss: This type of loss occurs when sound waves are obstructed to pass through the inner ear due to variety of problems like earwax buildup (cerumen), infection, fluid in middle ear and punctured eardrum [4]. This kind of hearing loss can be treated medically or surgically.

B. Sensorineural loss: This type of hearing loss occurs when auditory nerve or hair cells in the inner ear are damaged. The main causes can be aging, noise, illness, injury, infection, head trauma, toxic medications, or an inherited condition [5]. Nearly 90% of people have this kind of hearing loss. [6]

C. Mixed loss: this type of hearing loss is a combination of both conductive and sensorineural hearing loss.

IV. HISTORY OF HEARING AIDS

The history of hearing aids starts with the research of Athanasius Kircher from Rome who described about fans, tubes and horns in his work "Neue Hall und Thonkunst" in 1650 .

Further past and research along with innovations has been discussed in Table I below:

Table I

ADVANCEMENTS OF HEARING AID

Year	Advancements	Companies and Person/s Invnolved in advancements.
About 1800	First company was established to manufacture hearing aids, most of which were tubes and trumpets on commercial basis.	F.C.Rein.
1892	The first patent for an electrical hearing aid was filed.	Mr. Alonzo E. Miltimore.
1900	"Akoulallion" was the first commercially manufactured hearing aid that was made of carbon dust and was later renamed as "Akouphone" and was manufactured by Akouphone Co. of Alabama in the US.	Akouphone Company.
1902	To increase the quality and reliability of electrical hearing aids carbon ball was invented and was first tested on English Queen Alexandra for her coronation.	Hutchison and Kelley.
1907	The triode vacuum tube or valve was invented for radio applications in hearing aid.	Lee DeForest.
1921	The patent for first vaccum hearing aid was filed with single triode and manufactured by company Globe and took all credits of Lee DeForest.	Earl C. Hanson.
1933	The first bone conductor (BC) was invented to resolve almost all types of hearing losses and was placed on cranium. This acts as vibrator which transmits the sound directly to the inner ear.	Hugo Lieber.
About 1930's	The first battery operated vacuum tube hearing aid was designed by two manufacturing companies located in England named, Amplivox and Multitone primarily consisting four elements: a microphone, earphone/receiver, amplifier and two batteries.	Amplivox and Multitone companies.
About 1930's	Beltone company introduced the first one piece vacuum tube hearing aid due to rapid changes in size of batteries and in technology of hearing aid and sooner it became the standard of hearing aids.	Beltone company.
December 1947	The size of the body type hearing aids was strategically reduced due to the invention of transistor. The device became small, cheap, effective and of low power consumption.	Bell Laboratories.
1952 and 1953	This was the beginning of the era of transistorized hearing aid. After the invention of junction transistor by Raytheon Manufacturing Corp., companies like Microtone, Maico, Unex and Radioear introduced their first transistorized hearing aids. The body type hearing aid devices were now replaced by Behind the Ear (BTE) type hearing aid.	Raytheon Manufacturing Corp., Microtone, Maico, Unex and Radioear companies.
1954	A US-based company, Ontarion introduced haering aid built in spectacles and named it "The Listener".	Ontarion company
June 1955	A US based company, Dahlberg introduced the Miracle Ear, which was their first In the Ear (ITE) type hearing aid instrument.	Dahlberg company
1969	A German based company Wilco manufactured the first built in directional microphone type hearing aid and received a patent for the same.	Oho Hassler of Willco company.
About 1980's	With the invention of IC technology analog type sound processing hearing aids came into existence. Many noise cancelling circuits were building and most popular were the "Zeta Noise Blocker", introduced by Linear Technology.	Linear Technology
1983	Successful wearable digital hearing aids were made, soon after analog technology and were capable of sound processing technology and were developed in company Audiotone.	Nunley, Staab, Steadman, Wechsler and Spencer
About 1990	A report for complete-in the-canal (CIC) type hearing aid was submitted in USA.	Mead Killion

V. CLASSIFICATION OF HEARING AIDS

With vast innovations and inventions hearing aids has been constantly evolving in the thirst of rapid technological advancements. Several types of hearing aids are now available for the patients. Each category has its own advantage depending on amplification, size, noise cancellation and feedback reduction.

A. Classifications on the basis of wearing: Hearing aids are often classified on the basis of wearing in four basic styles and all are used for treating sensorineural loss. Following are different styles in the order of their decreasing size.

1. Body aids: Body aids were the first electronic aids that were used by people with profound sensorineural loss. The aid is either kept in pocket or fastens on belt and is connected to ear through wire. Due to its big size, it has various signal processing options. These are generally used when other types of aids cannot be used.

2. Behind-the-ear (BTE): These aids are worn behind the ear and are connected in plastic earmold to be fitted outside the ear. The components and circuitry are present inside the slim plastic earmold box. These are used for mild to profound sensorineural hearing loss. A whistling sound is generally observed by the BTE aid either due to improper fitting or because of wax builds up inside the ear.

3. In-the-ear (ITE): These aids completely fit in the outer ear and the components are present in the hard plastic box which is of exact shape as our ear. The technological advancement in ITE is added technology for telecoil. A telecoil is a small magnetic coil inside it that improves the sound transmission during telephone calls. But due to its placement inside the ear, they are constantly at high risk of damage due to ear wax or ear leakage. These are generally not recommended for small children as casing needs to be change with age.

4. Canal aids: Canal aids are generally same as ITE except the difference of their comparative small size. These are fitted into the ear canal or completely in the canal (CIC). But due to their small size it is difficult to have telecoil technology in them and they also get damaged due to ear wax and ear leakage. Sometimes patients find them not as comfortable as they are hard to remove from the canal.

B. Classification on the basis of technology: In the predigital era, hearing aids were just used as a mode of amplification of sound but now with evolving digital technology, amplification is combined with complex and advanced forms of signal processing. Now hearing aid comes with speech enhancement, noise reduction, self adapting directional inputs, feedback cancellation, data monitoring and as well as the mode of connection to other multimedia devices [7]. Therefore we have analogue, digital programmable and digital hearing aids.

A traditional analogue hearing aid converts the sound signal to an electrical signal with a voltage analogous to sound pressure and transfer it to ear directly through the speaker of the hearing aid [8]. There is also an intermediate device known as digital programmable hearing aid device. This is an analogue device that has been programmed with different amplification presets. Therefore this provides some of the limited features of complete digital hearing aid that includes, improved sound localization, increased range of amplification and better amplification in presence of background noise [8].

A digital signal processing (DSP) has been a great advancement to analogue hearing aids and these are called as digital hearing aids. A digital hearing aid incorporates both analog to digital converter (ADC) and digital to analog converter (DAC) along with noise reduction filters. The driving force for the development of DSP was the need of developing and evaluating efficient methods of complex speech transmission systems [7]. The main difference in the working of digital hearing aids as compared to analogue aids is that, in digital aids, the audio signal is sampled digitally at high rates and then amplification technique is tailored corresponding to the need of the patient and finally is converted to analog signal.

VI. DEVELOPMENT OF DIGITAL HEARING AIDS

The introduction of DSP in hearing aids in 1996 allowed various signal processing algorithms to be implemented. But the innovative idea of making the sound digitalized arouse due to the need of developing the secure telephonic link between Washington and London during World War II [9]. The idea was clearly to ensure that speech signals can be encrypted securely and can be received loud and clear. This is what was implemented in offline DSP technique for the first time in hearing aid.

The sequence of events took place in Bell laboratories for earliest experiments for offline DSP over hearing aids in 1960's. The first step for offline DSP was analog recording of the unprocessed sound signal and then feeding it to ADC and preparing a digitized tape of

unprocessed digital signal. The tape was sent to the computer for processing and the digital signal was sent to the DAC where again analog recording was prepared. The process was repeated several times until a noise free recording was obtained [9]. This all was time consuming and tedious way to remove noise and then it was considered to be not practical. Engineers than thought of a hybrid model and worked over real time programming of analogue hearing aid in 1970's. Both the use of offline DSP and computer controlled hybrid device provided substantial tools for developing improved methods of signal processing. But to implement these techniques in digital hearing aid it was necessary to develop real time methods for processing digital signals.

By the late 1970s digital computers were able to perform computation simultaneously and were developed for array processing. The array processors were able to process sound signals in real time. Thus digital hearing aids slowly started coming into existence and first fully working software for real time operation was developed till summer 1982 [9]. The array processor was thus used for testing the power of DSP. The studies of this instrument provided a vital insight as to what could be achieved later in future. Gradually with time high speed DSPs were made for wearable hearing aid.

VII. ADVANTAGES OF DSP IN DIGITAL HEARING AID

Digital signal processing (DSP) offers several actual and potential advantages over analogue hearing aids in digital sound processing hearing aids. Although the digital technology does not change the basic configuration that much but DSP adds on the number of advantages for a patient residing in a remote area [10]. Some of the advantages of DSP are described below:

A. Wide range dynamic compression: This feature of digital hearing aid allows the reduction in the discrete frequencies which are not suitable for listener's hearing spectrum and causes discomfort. Patients residing in urban areas are more prone to high levels of environment noise and the compression feature plays a vital role in such cases [11].

B. Noise Reduction: along with compression feature there is a provision of noise reduction. This can be achieved through various noise reduction algorithms with the help of DSP. DSP helps in monitoring high number of frequency band for noise and hence more effective control, particularly if the noise is constant [10]. Studies show that these noise reduction algorithms provide improved ease of listening in adverse acoustic environment [12]. Directional hearing aids were developed to listen in noisy environment and DSP allows the provision of automatic directional and unidirectional microphone usage [13].

C. Feedback reduction: Digital hearing aids embedded with DSP provide the solution of the most common problem of hearing aids, which is of feedback. DSP constantly monitors the acoustic feedback arising due to several reasons and when this occurs, it produces a counter phase signal that has noise cancelling effects [14]. Feedback reduction technology allows the successful and better fitting of custom earmolds that are completely occluding where quality is important [15].

D. Self adjustable or trainable: This is the most advanced feature of present day hearing aids. In these DSP enables digital hearing aids, once the amplification parameters are set, the instrument can be adjusted by the patient to his own choice of listening levels. Gradually with the time, the instrument learn the patient's preferred gain and frequency response for everyday acoustic range and optimizes itself for the same [16] .

VIII. CONCLUSION

Hearing aids today have many automatic and semi automatic features like: noise reduction, direction control, feedback control, accessibility to define user's environment (traffic, school, restaurant, and noise-free office). These technological advancements will continue to evolve and learning technology will also be added, making them more intelligent. We should expect the emergence of fuzzy logics, neural networks and genetic modulations in the area of hearing aid technology.

As the technology grew olds it becomes more complex to innovate and invent something new in the same field. But the new era of hearing aid and the changes in current technology can be seen soon. Concepts of connectivity and individuality will be the driving force for new innovations. As the DSP chips undergo more technological changes and get more advanced in terms of capability, patient's satisfaction will also do the needful job of improvement in algorithms. Hence digital technology has proven better over analogue technology and will lead the advancements to a much higher level.

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