Signal processing and neural network techniques used in Cochlear Implant for different types of noises

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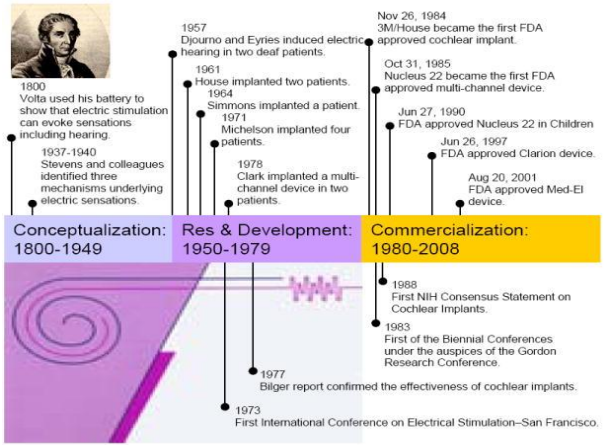
Abstract -Cochlear Implant (CI) is the technology, which provides solutions for different types of hearing loss. There is different challenges face by the designers of Cochlear implant in developing signal processing techniques so that can provide the voice which function like normal cochlea of inner ear. This paper discusses various signal processing and neural network techniques used for processing speech data in CI in chronological order of development. The paper also reviews the existing CI devices, their development and techniques used for speech processing in existing CI devices. Wavelet analysis, PET, fMRI are a few techniques used for feature extractions, ambient noise removal and spectral estimation. There are also various other techniques which we will be discussing here. We will also be discussing the development of some environment-specific noise suppression algorithms. Even though there have been some developments in the field of cochlear implant this is an area that is seeing rapid growth. This is the zone of our further discussion.

Keywords-Cochlear Implant (CI), Positron emission tomography (PET), Bionic wavelet transform (BWT).

Introduction-Hearing loss is a common problem in people everywhere and there are various reasons why this happens like by noise, aging, disease, and heredity. To use the Cochlear implants (CI) there are some criteria. If there are some damage in the hair cells of the inner ear or in the auditory nerves only then it is used otherwise cannot use [1, 2].



How much electric stimulation is useful in feasible manner can see in conceptualization phases while electrical stimulation how much safe can see in research and development phase gives the utility and safety of electric stimulation and commercialization phase tells how can treat sensorineural hearing loss with wide spread use of electric stimulation [3]. There are various CI techniques available with the help of various areas in which we are focusing on some techniques based on signal processing and neural network in chronological order.

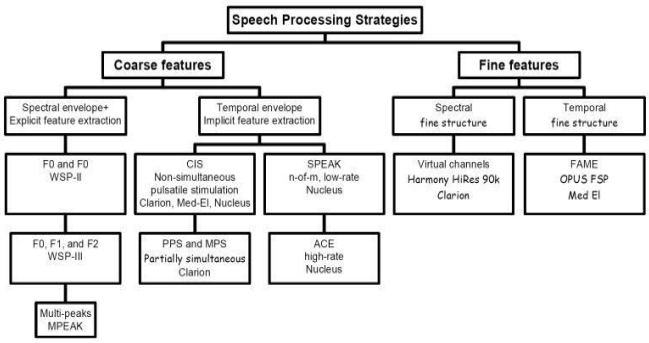
Fig-1 Architecture of three phases in the development of cochlear implant

Cochlear Implant Noise Removal Techniques

Various Cochlear implant noise removal techniques available developed by different researchers and scientists, and here discussion based on the most important research work related to Cochlear implant noise removal techniques which can be seen in the tabular from.

Signal processing Technique	Neural Network Technique	Hybrid Technique
Wavelet analysis	Positron emission tomography	Environment specific noise suppression
Bionic wavelet transform	PET imaging with 15O-labeled water	Noise Reduction Strategy Based on Fractional Derivatives
Pitch estimation	Neurons coding	Hearing the Song in Noise
Stochastic resonance	Aging brain with fMRI	Identifying positive roles for endogenous stochastic noise during computation in neural systems
Suprathreshold stochastic resonance to cochlear implant coding	Neural Coding of Interaural Time Differences with Bilateral Cochlear Implants	
Cochlear Implant Subjects using Time-Frequency Masking based Noise Reduction		
Effects of Adaptation Rate and Noise Suppression on the Intelligibility of Compressed-Envelope Based Speech		

Table 1 Summary of division of techniques according to category



How signal processing function in cochlear implant with its technologies can be seen by the figure 2.

Fig-2 Classifications of signal processing strategies in cochlear implants

A. Wavelet analysis

The wavelet analysis helps to extract feature, noise removal of ambient type and did spectral estimation by using the selected frequency-localised functions [4].

In October 2011 with the wavelet functioning the Gaussian white noise in periodic signals and in audio signals has been reduced, and cross-correlation has been used for the determination purpose of the best fit between an original signal and the processed one [6].

In 2014 for noise suppression in robust speaker recognition, adaptive wavelet shrinkage method is used. Wavelet sub-band coefficients thresholds can automatically computed by this and are proportional to the noise contamination [5].

B. Positron emission tomography

With the help of neural network work has been done in speech perception that links frontal and temporoparietal language regions where used mechanism is cortical mechanism by which identification of speech and non-speech can be done. From the study of language processing it is identified that left inferior frontal cortex and posterior temporal cortex, regions are showed as speech/language centres [7].

In October 2014 there was a review of PET related to cochlear implantation speech restoration which describes functionality of brain networks. After doing analysis of neuroimaging it indicates that auditory recovery also depends on visual cues after cochlear implantation [8].

In 2014 more work was done on PET in which evaluate the relationship between duration of cochlear implant and result of PET in temporal lobe while user was listening to speech and to determine whether any correlation exists between cortical activation and speech therapy results. The tendency towards increasing level of activation in areas of primary and secondary cortex on the left side of brain was observed [9].

C. PET imaging with 15O-labeled water

The PET method is used in terms of identification of brain areas that are activated in Quiet, Speech, Noise, SPIN listening conditions irrespective of gender and ear effects and also tells about the activation of complex neural network in these conditions. Speech in quiet condition requires least demand because then CI users were able to hear clearly the last word in the sentence with 100% accuracy while in other conditions usersrequire great processing for identification of words. The difficulty in listening is reflected in terms of size of activation areas[10].

D. Bionic wavelet transform (BWT)

Comparison of WT and BWT based upon three criteria namely recognition rate, tolerance of noise and no. of required channels. In neural network each had a different no. of hidden nodes. Vowels and consonants were processed by WT, BWT respectively for the detection purpose of saturation recognition rate. Because recognition rate which is obtained by CI users can be attributed to other reasons instead of signal processing. These can include surviving ganglion cells, electrodeinsertion depth, and the status of the subjects, etc. The no. of speech frames of signals processed by BWT is also smaller than the WT, thisshow that higher time resolutionis achieved by BWT thus leading to areduction inthe stimulation duration of the electrodes. Thus BWT required a less no. of channels as compared to WT but could alleviate the contradiction between fine frequency coding and spread of excitation. BWT has more noise tolerance than WT which indicates improvement in recognition rate increase for non-speech frames [11].

E. Neurons coding

The sound code is based on neural firing rate, after a certain sound level neurons no longer respond if sound level increases. Neurons do not fire in a regular way while phase locking occurs for frequencies up to 4-5 kHz approx but is lost if it occurs above this. It is observed by Heinz that vibration of different phase is depends on the different places of the BM.

There are several reasons why coding in CI is poorer, may be mismapping in allocation of frequency bands for electrodes, electrodes could not convey detailed information related to formant frequencies, phase change across electrode is not normal and there can be regions where neurons are missing in cochlea.

There are several benefits of having two ears like normal user like the intensity and the time of arrival of sound gives cues which help in sound localization. But these benefits can not be possible with CI in two ears because electrode array could not be inserted at the same depth in both ears but it can give relief from Head-shadow effect and also give higher signal-to-background ratio. The spectral cues cannot be used by CI users which is given by pinna because they work mainly at high frequencies above 6kHz [12].

F. Pitch estimation

For pitch estimation there are two approaches one is spectrum and another is waveform. Spectrum is based upon Fourier analysis. With the help of Fourier analysis many peaks may be detected in the spectrum. In waveform also there is a need to find out peaks and the interval between them by measuring its periods [13].

In March 2007 research initially assumed that high rate electrical stimulation evokes a pitch sensation corresponding to electrodes and stimulation rate by the cochlear implant electrode. But it was later discovered that some other factors also effect electric pitch sensation. In contrast late pitch sensation shows no correlation with speech perception [14].

In February 2014 it was discovered that Contemporary cochlear implants with multiple electrode stimulation can produce poor music perception but good speech perception [15].

In October 2014 permission was granted to insert deep flexible long straight electrodes reaching the apical region with little or no insertion trauma and the potential benefits of deep insertion were gained by using pitch-locked temporal stimulation patterns [16].

G. Aging brain with fMRI

In older people fMRI gives increase in memory which is currently working and attention related cortical areas but reduced activation in auditory cortex. Auditory signals do acoustic analysis means providing the signal in the form of phonemes. The bilateral superior temporal regions show decreased activation while region around prefrontal cortex and precuneus shows increase activity in older people compare to younger people [17].

In December 2009 some study indicated that the how CI user are catching the accurate signal depends upon the neural plasticity and correct placement of the electrode array because on that basis user can learn a new language in the form of electrical stimulation [20].

In March 2015 further research carried on in Hearing loss presbycusis which shows that older people have common sensory declines. If do comparison between Elderly and younger groups then Elder showed greater activation in response to acoustical stimuli in the temporal lobes. [18].

H. Environment specific noise suppression

Based on the SNR measurement, target-dominated envelopes are taken at SNR>=0db, while masker-dominated envelopes are removed at SNR<0db. By using these criteria it is clear that the because of SNR channel selection criterion can restore the language recognition in noise for CI users, and that's why, it is denoted as optimal ACE (opACE) [19].

There are some other noise reduction algorithms have been proposed by Hochberg in 1992 [24]; Weiss, in 1993 [28]; Yang and Fu, in 2005 [23]; Loizou in., 2005[26]; Kasturi and Loizou,in 2007[22]; Hu in 2007[25] for unilateral CI users.

Later on a different algorithm was also introduced which wasthen used tosimulatedifferent environmental acoustic conditions [27].

In the same way there are other various techniques which are available for the purpose of enhancement of CI users listening capability namely I. Stochastic resonance, [30] J. Neural Coding of Interaural Time Differences with Bilateral Cochlear Implants, [31] K. Suprathreshold stochastic resonance to cochlear implant coding, [32] L. Cochlear Implant Subjects using Time-Frequency Masking based Noise Reduction, [33]M. Noise Reduction Strategy Based on Fractional Derivatives [34], N. Hearing the Song in Noise

[35], O. Identifying positive roles for endogenous stochastic noise during computation in neural systems [36], P. Effects of Adaptation Rate and Noise Suppression on the Intelligibility of Compressed-Envelope Based Speech [37].

Commercial Use of CI-

The company names which are related to CI in markets are Cochlear Limited (Australia), MED-EL (Austria), Sonova (Switzerland), William Demant Holding A/S (Denmark) [21]. Food and Drug Administration (FDA) give approval for cochlear implant systems only to Clarion, Nucleus and MED-EL and all three have many similar features.

1. Multichannel stimulation functionality is provided in all cochlear implant systems.
2. For the communication purpose between the externally worn hardware and the implanted electronic components use the transcutaneous communication which is used by all systems.
3. After the CI implantation there is a need to check the integrity of the electrode and this comes under technology telemetry and all incorporate this technology.
4. By these technologies there is different range of options for speech processing of cochlear implant.
5. For setting purpose of intra-cochlear electrodes there is need to set threshold for stimulation purpose and for this there is need of programming for the speech processor of the cochlear implant.

Technologies used by devices-

1. The devices offer two additional speech coding strategies namely **The Nucleus 24 and the Nucleus 24 Contour**. The first known as ACE (Advanced Combined Encoder), Second speech processing strategy is Continuous Interleaved Sampling (CIS).
2. **Clarion** used CIS processing to implant in 1991. Compressed Analog stimulation (CA) is the second available strategy but refined to as Simultaneous Analog Stimulation (SAS) and while the variation on these two was introduced in 1999.
3. **MED-EL** system also provides same strategy like Clarion initially while in current CIS+ which uses a Hilbert transform for envelope detection is the first sequential stimulation processing strategies and another one is strategy provided by MED-EL speech processors is n-of-m processing which is somewhat similar to ACE processing with the Nucleus device [29].

Conclusion- Cochlear implantation is a miracle for the hearing impaired persons. This paper focuses on signal and neural networks technique used for speech signal processing and its commercial use in different available CI devices. These techniques are mainly used to enhance speech quality and not considering speech intelligibility. Speech intelligibility is the area which is still missing or least explored in Cochlear Implant while it should be given more preference.

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