An Auditory-Model-Based Electrical Stimulation Strategy Incorporating Tonal Information for Cochlear Implant

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Types of Hearing Loss

Hearing loss can be categorized by where or what part of the auditory system is damaged.

- **Conductive hearing loss**
  - Conductive hearing loss occurs when sound is not conducted efficiently through the outer and middle ears, including the ear canal, eardrum, and the tiny bones, or ossicles, of the middle ear.

- **Sensorineural hearing loss**
  - Sensorineural hearing loss occurs when there is damage to the inner ear (cochlea) or to the nerve pathways from the inner ear (retrocochlear pathway of the acoustic nerve) to the brain.

- **Central auditory processing disorders**
  - A central auditory processing disorder (CAPD) occurs when auditory centers of the brain are affected by injury, disease, tumor, heredity or unknown causes.

http://www.asha.org/public/hearing/disorders/types.htm
Cochlear Implant (CI) Background

- CI is the most useful solution for the treatment of severe to profound hearing loss.
  - Employ direct electrical stimulation of the auditory nerve to restore some degree of hearing.

A diagram (not to scale) of the human ear [1].

Motivation for Novel Electrical Stimulation Strategy

1. CI users gain little tonal information from present electrical stimulation strategies, although it has been well known that the tonal language uses different tones (or variation of fundamental frequency F0 of speech signal) to indicate diverse lexical meanings.

- Most present electrical stimulation only convey the envelope information from speech signal.

Continuous-interleaved-sampling (CIS) strategy

Motivation for Novel Electrical Stimulation Strategy (Cont.)

2. The neural firing pattern from electrical stimulation varies from that of normal acoustic hearing.
   - The neural firing from present electrical stimulation results in a highly synchronized firing pattern, which would cause a poor temporal presentation of the stimulus waveform [1].

The spread of action potentials across nerve position and time under electrical stimulation.

A Stochastic Model of Electrically Stimulated Auditory Nerve

• Since the electrical pulses straightforwardly talk to the auditory nerve (AN) in CI, modeling the AN’s response to electrical stimulation may
  – improve our understanding on how auditory percepts are produced by CI, and
  – facilitate our development of new electrical stimulation strategies.

• Integrate-and-fire based AN model

\[ V_{\text{noise}} \]: stochastic membrane potential fluctuation
\[ V_{\text{ref}} \]: refractory effect during neural firing
AN Response to Electrical Stimulation

- Predict pitch variation when electrical pulse train carries tonal information in its pulse rate

Pulse rate of electrical pulse train

(a) 
(b) 
(c) 
(d)

The tonal information could be conveyed to CI users by using electrical stimulation with pulse rate modulated by F0 trajectory

Analysis of spike intervals

Pick the most prominent intervals

Pitch perception model

Pitch
AN Response to Electrical Stimulation (Cont.)

- Response to high-rate electrical pulse train to encode the temporal fine structure

Modulation frequency: 220Hz
Modulation depth: 0.1
Pulse width/ intensity: 33 us/ 760uA

A loss of temporal resolution in that multiple fibers code the timing of the peak of a stimulus rather than its entire waveform

Improve the temporal resolution of the simulation fiber, and allow it to encode most of the attributes of the waveform

The post-stimulus time histogram.
1. Extract tonal information (F0 trajectory) by pitch extraction algorithm to modulate the pulse rate of electrical stimulation.
   - The electrical pulses in different channels work sequentially and non-simultaneously with the same rate to avoid the cross-talk from adjacent channels.

2. Use high pulse rate to reduce the synchrony of neural firing, and enhance the representation of speech waveform with improved resolution.
Summary

1. An integrate-and-fire based stochastic model of electrically stimulated auditory nerve was developed. Model based studies supported that:
   - The tonal information could be efficiently conveyed to CI users by using electrical stimulation with pulse rate modulated by F0 trajectory, and
   - The encoding of fine structure of speech waveform can be improved by using electrical stimulation with high pulse rate.

2. A novel electrical stimulation strategy was proposed, which incorporates the above two features.
Future Work

• The evaluation of the performance of proposed electrical stimulation strategy using auditory model, and

• The implementation of the proposed electrical stimulation strategy for CI stimulation studies.

Appendix:
Two papers have been resulted from this project supported by the Shun Hing Institute of Advanced Engineering.


(*) Submitted by Y.T. Zhang (ytzhang@ee.cuhk.edu.hk) and F. Chen at Dept. of Electronic Engineering.