Towards a measure of the differences in cochlear implant stimulation strategies

Rafael Chiea[1], Bernardo Murta[1], Gustavo Mourao[1], Stephan Paul[1], Julio Cordioli[1], Hussnain Ali[2], John Hansen[2]

[1]Federal University of Santa Catarina, Brazil
[2]University of Texas at Dallas, USA

rafael.chiea@posgrad.ufsc.br, bernardo.murta@lva.ufsc.br,
[2]hussnain.ali, john.hansen@utdallas.edu

Index Terms: Cochlear implants, sound coding, objective metrics

1. Extended abstract

Development and evaluation of new algorithms which aim to improve speech intelligibility and sound perception quality for cochlear implant (CI) users are an important research field. In general, validation of signal processing strategies in CIs is based on subjective evaluations [1]. Human testing is generally time consuming and is subject to availability of sufficient number of CI users to participate in research. In addition, it requires specialized hardware to interface with implanted electronics as well as clinical implementation of speech processing strategies. Due to limited availability of hardware and software, not all researchers have access to the required tools to assess validity and effectiveness of their research ideas.

Validation of signal processing implementations of research ideas does not necessarily requires human speech assessments. Mathematical formulations can be used to characterize and compute normalized metrics which can enable signal processing engineers to compare their encoding schemes with standard implementations. Previous research in this domain, e.g. by Yousefian and Loizou [2], aimed at developing metrics that use the envelope of the processed and clean speech to estimate speech intelligibility. These metrics can be used for comparing strategies to a limited extend, as they are more suitable to evaluate robustness of noise reduction algorithms. Currently, there are not any standard metrics available to compare the output of different sound-processing strategies/implementations.

The goal of this study was to make a first step on the development of an objective tool to compare implementations of cochlear implant strategies. Such comparison may allow the validation of new implementations of existing strategies. The comparison between strategies is performed by the analysis of their electrodograms for a fixed set of input audios, and user parameters (such as threshold and comfort levels, pulse rate and shape). Two N-by-M matrices $\mathbf{A}$ and $\mathbf{A}^{\text{ref}}$ represent, respectively, the electrodogram of the strategy under test and the one of the reference strategy. Here rows are related to the signal in each one of the N electrodes and columns are related to the M time frames of stimulation.

First, the euclidean distance, d_i, between the i^{th} row of the two matrices is calculated, resulting in a N-by-1 array $\mathbf{d}$, according to equation (1). $a_{i,j}$ is the element in row i and column j of the matrix $\mathbf{A}$.

$$\mathbf{d}_i = \sqrt{\sum_{j=1}^{M} \left(a_{i,j} - a_{i,j}^{\text{ref}}\right)^2} \tag{1}$$

The sum of all elements of $\mathbf{d}$ leads to error associated with the audio file f, $ED_f = \sum_{i=1}^{N} \mathbf{d}_{f,i}$ and ED is the distribution of errors associated with all the files as the metric to compare two strategies.

In the present work, we have considered Advance Combination Encode (ACE) strategy as an example to demonstrate the effectiveness of the proposed approach. Three implementations of ACE strategy are compared: clinical implementation as outlined in Cochlear Corp.'s Nucleus Matlab Toolbox, an open-source version developed at the University of Texas at Dallas [3] and custom coded version developed at the Federal University of Santa Catarina [4], based on published data. The above metric was computed for several acoustic inputs of varying complexity and user parameters. These consisted of tones with varying intensities, calibrated chirp signals, consonants, vowels, and speech sentences. The output from these stimuli were used to generate reference electrodogram matrices with the *Nucleus Matlab Toolbox* (NMT).Student's t-test was used to compare error distributions of the two implementations, ED_{UTD} and ED_{UFSC}, to test for equivalence.

It is noted here that different implementations may result in distinct processing delays that may generate time misalignment issues between the pulses on electrodograms. In order to address this, a pre-processing for time alignment is performed. Also, slight variations in channel gains may result in variations in (timing and amplitude of) pulses across channels. The approach outlined in this paper could potentially allow the validation of new implementations of existing strategies, before performing any human testing. Future work will focus on quantifying the error in terms of its perceptual significance (intelligibility and quality), by means of subjective studies in order to understand how this metric relates to human speech perception. This may indicate possible adjustments on the metric, in order to also allow the comparison between different strategies.

2. References

[1] J. Wouters, H. J. McDermott, and T. Francart, "Sound coding in cochlear implants: From electric pulses to hearing," *IEEE Signal Processing Magazine*, vol. 32, no. 2, pp. 67–80, 2015.

[2] N. Yousefian and P. C. Loizou, "Predicting the speech reception threshold of cochlear implant listeners using an envelope-correlation based measure," *The Journal of the Acoustical Society of America*, vol. 132, no. 5, pp. 3399–3405, 2012.

[3] H. Ali, A. P. Lobo, and P. C. Loizou, "Design and evaluation of a personal digital assistant-based research platform for cochlear implants," *IEEE Transactions on Biomedical Engineering*, vol. 60, no. 11, pp. 3060–3073, 2013.

[4] K. Werner, R. Chiea, J. Cordioli, and S. Paul, "Analysis of cochlear implant vocoder simulation including the current spread effect in the presence of background noise." *In Proc. DAGA, Aachen, Germany*, pp. 36–39, 2016.