TESTING PARADIGM FOR ASSISTIVE HEARING DEVICES IN DIVERSE ACOUSTIC ENVIRONMENT

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Cochlear Implant Laboratory

1 Introduction

Assistive Hearing Device (AHD's):

- AHDs such as hearing aid (HA) & cochlear implants (CI) are common choices for restoration and rehabilitation of auditory function (hearing loss)[1]

Figure 1. Cochlear implant (CI) (left) and hearing aid (HA) (right).

- HAs provide acoustic amplification with approaches such as dynamic range compression and automatic gain control
- CIs provide an acoustic to electric mapping of the input signal via electrical stimulation

[1] Ali, H; Lobo, A.P.; Loizou, P.C. (2013) *IEEE Transactions on Biomedical Engineering,* 60(11), 3060–3073.

2 Introduction

CCi-MOBILE Research Interface (RI)

- A versatile and computationally powerful speech & sound processor emulator which provides acoustic and/or electric stimulation (i.e. compatible with both CI/HA)
- Enables & promotes signal-processing (sound coding) development
- Easy to use, low-level programming language (MATLAB) for both clinical & engineering based research investigators[2]
- Note: Only compatible with implants manufactured by Cochlear Corp.
- Note: Compatible with all HAs

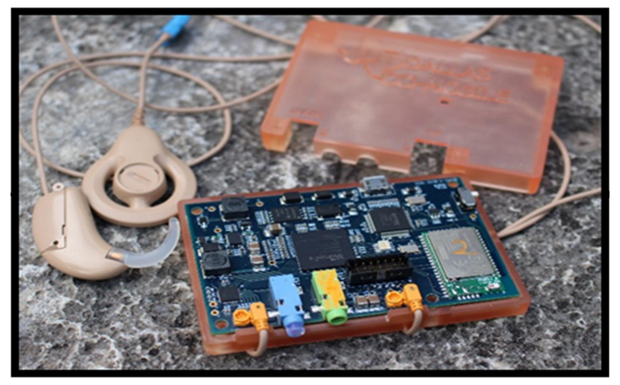


Figure 2. CCi-MOBILE RI (Unilateral CI setup shown).

[2] Hansen, JHL; Ali, H; Saba, JN. (2018) *IEEE EMBC-18: Engineering Medicine and Biology Conf.,* Honolulu, Hawaii, July 17- 21, 2018

3 Motivation

AHD Design Limitations

- All AHDs must comply with biological safety and stimulation levels (current/charge)
  - Cooperation and regulation via the USA Food and Drug Administration (FDA)
  - IEC 60601

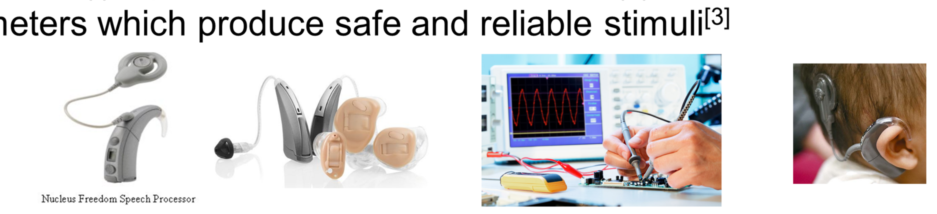
  FDA U.S. Food and Drug Administration — Information: Medical Device FDA Requirements, IEC 60601-1 Standards
- Lack of user freedom or parameters of company specific research platforms (NIC – Cochlear Corp., SONNET and RONDO – MedEL, Naída CI Q – Advanced Bionics)
- Signal processing algorithms cannot be tested for subjective evaluation due to proprietary software and company data
  - Inability to replicate or by-pass proprietary software/firmware

[3] Ali, H; Lobo, AP; Loizou, PC. (2012) *IEEE EMBS,* San Diego, California USA, 28 Aug - 1 Sep, 2012

4 Innovation

Aim I.

- Determine (i) input acoustical conditions and (ii) MAP stimuli parameters which produce safe and reliable stimuli[3]



Aim II.

- Verify the integrity of CI/HA strategies under all acoustic & stimulation conditions
- Create signal processing design guidelines to enable safe stimulus presentation[4]
- To encourage use of CCi-MOBILE Research Interface as a research platform for use in research & engineering domains by investigators

[3] Ali, H; Lobo, AP; Loizou, PC. (2012). *IEEE EMBS San Diego, California USA, 28 Aug - 1 Sep, 2012.*
[4] Kąkol ,Krzysztof; Kostek, Bożena; *SPA 2016, Sep 21- Sep 23rd, 2016, Poznań, Poland.*

5 Motivation

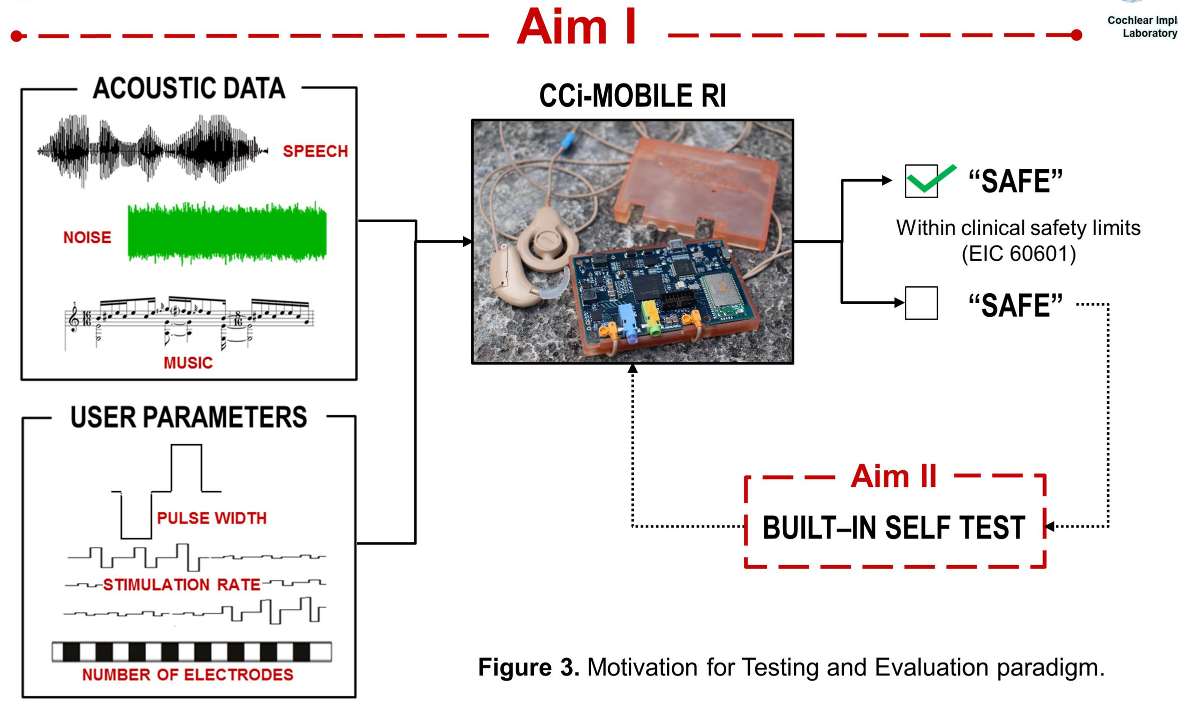


Figure 3. Motivation for Testing and Evaluation paradigm.

6 Audio Corpus Test Battery

Audio Databases

Speech:
- AzBio
- IEEE
- NOIZEUS
- LRE
- TIMIT
- DARPA RATS

Noise:
- ESC
- Freesound Project
- Urbansounds
- Gunshots

Music:
- MARYAS GTZAN MUSIC
- MARYAS GTZAN MUSIC SPEECH

Input	Length
Speech	260hrs
Music	46hrs
Noise	76hrs

Table 1. Audio Test Battery.

7 Testing Setup

- CCi-MOBILE RI uses both direct-connect configuration via USB[5] and also with Wi-Fi
- Program & computation using software suite (MATLAB) on local PC/tablet
- Radio frequency (RF) link is setup using RF coil, to transmit stimulus over to the intracochlear electrode array

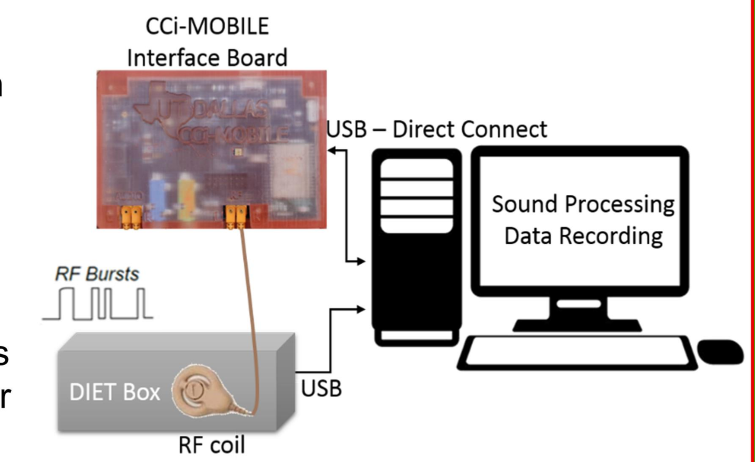


Figure 4. Testing setup for CCi-MOBILE RI.

- RF coil is connected to the DIET (CIC4 Decoder Implant Emulator) box (Cochlear Corp.) for testing and evaluation.

[5] Ali, H; Sandeep, A; Saba, Juliana; Hansen, JHL; *CHAAT, Stockholm, Sweden. Aug 19, 2017.*

8 Processing Flow

1. Loaded audio (offline) to PC
2. Run SP (sound coding) strategy (CI – using CIS)
3. Acoustic to electric mapping (stimuli generated) and sent to board
4. Streamed electric stimuli to FPGA (RI) via USB

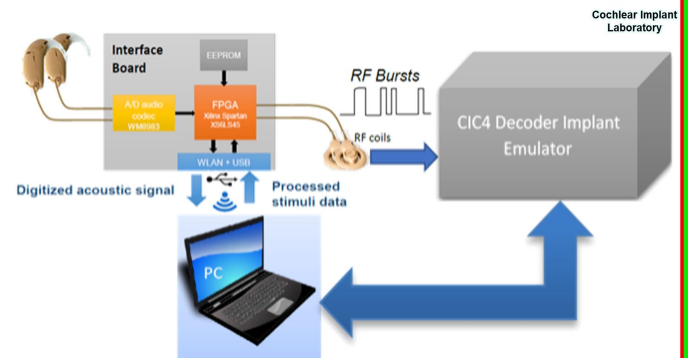


Figure 5. Functional block diagram for testing and evaluation.

5. FPGA receives EAS stimulation, encodes stimuli in clinical levels to RF current values or bit values and transmits through RF communication
6. FPGA streams time synchronous acoustic data to CI/HA transducers using the RF coil
7. Decoded RF output signal, comprising of electric stimuli data for all electrodes, is recorded and stored for error analytics

9 Stimuli Characteristics

Stimuli Error Measures:

- **ΔIPG** – Observed interphase gap discrepancy
- **ΔT** – Observed timing discrepancy
- **ΔPW** – Observed pulse width discrepancy
- **PWBal** – Imbalance in biphasic pulse widths
  - '+': more anodic | '-': more cathodic

Stimuli Errors	Δ (Difference)
ΔIPG	$IPG_{set} - IPG_{DIET}$
ΔT	$IPD_{set} - IPD_{DIET}$
ΔPW	$PW_{set} - PW_{DIET}$
PWBal	$\Delta PW_{Anodic} - \Delta PW_{Cathodic}$

Table 2. Stimuli errors.

User Parameters:

- A standard biphasic and symmetric pulse
- User MAP clinical levels: 100 - 200

Stimuli Type	Biphasic
Stimulation Rate	1000 pps
Pulse Width	25 μs
Nmaxima	8
IPG	8 μs

Table 3. Stimuli parameters.

10 Experimental Results

Simulated Intracochlear Current (SIC):

- Higher SIC increases perceptual loudness
- The average and peak SIC values follow similar trends
- In order from highest to least, SIC values are observed as follows: Noise > Music > Speech
- Higher SICs observed due to noise (distortion) of the DARPA RATS and NOIZEUS databases

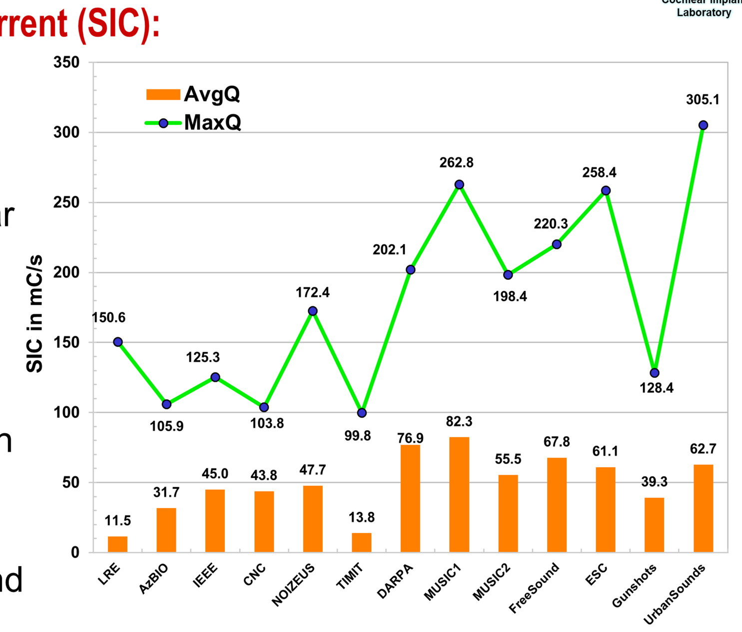


Figure 6. Performance of SIC across databases (average SIC per database – orange; maximum SIC per database – green).

11 Experimental Results

Stimuli Errors:

- Total Pulse Time
  - $T = 2*PW+IPG+IPD = 1/(SR*Nel)$[†]
- PWBal: Difference between cathodic ΔPW & anodic ΔPW
  - PWBal < (ΔPW or ΔIPG)
- ΔT: Additive or subtractive combination of ΔPW and ΔIPG.
  - ΔT < (ΔPW or ΔIPG)

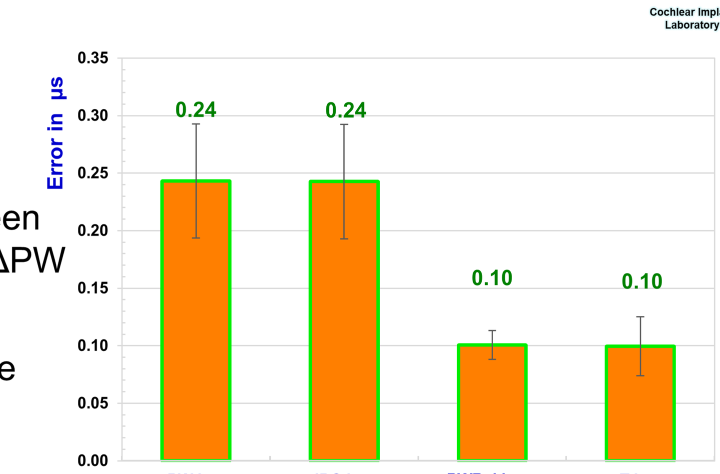


Figure 7. Statistical properties of stimulation errors: mean errors shown in orange bars and standard deviation shown in error bars.

- Residual PWBal may increase the irreversible corrosion of electrodes and the potential deposit of metal oxides at the electrode–tissue interface[6]

[†] T- Total pulse time; IPD – Inter pulse duration; SR – Stimulation rate; Nel – Number of electrodes

[6] Ramekers, D; Versnel, H; Strahl, S; Smeets, E; Klis, S; Wilko G; *(2014) JARO.*

12 Conclusions

Aim I.

- All stimulation parameters investigated sent to CCi-MOBILE RI **DID NOT** exceed safety limits for 380+ hrs of audio data

Aim II.

- CCi-MOBILE RI can function within clinical safety limits
- Discrepancy in stimulation parameters may affect perceptual loudness, quality, and implant life[7]

General Conclusions

- Potential for standardization for all audio types (acoustic conditions) as a safety-compliance task
  - Can be used in both spaces of AHDs: HAs and CIs
- Introduction of standard testing paradigm will help ensure acoustic and electrical safety for CI/HA users

[7] Fu, Q.J.; Shannon R.V.; *JASA* 107, 1637 (2000).