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Electrically evoked auditory steady-state response detection in cochlear implant recipients using a system identification approach

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Introduction

Regular **Cochlear Implant (CI) fitting** is a crucial part of successful hearing restoration with Cochlear Implants. Unfortunately, the process is time consuming, difficult to perform and with variable outcomes, due to large variabilities across clinicians and CI recipients. **Electrically evoked auditory steady-state responses (EASSRs)** are neural auditory responses, resulting from neural phase-locking to continuous electrical stimuli. They can serve as objective measure to determine CI stimulation levels ([1, 2]) and are therefore a promising step towards fully **automated, objective fitting** of CIs.

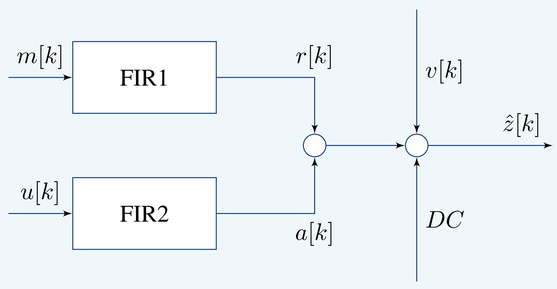
A major challenge when recording EASSRs are the **stimulation artifacts** of the implant, which contaminate the EEG recording. These artifacts are highly correlated with the EASSR and overlap the response in time as well as in the frequency domain. They are therefore difficult to distinguish from the real response and may lead to a false-positive response detection in the absence of an EASSR, which is highly undesireable for objective T-level detection.

Existing **artifact removal** techniques such as Linear Interpolation (LI, [1, 2]), Template Subtraction (TS, [3]) and Independent Component Analysis (ICA, [4]) rely on several EASSR recordings from different modulation frequencies to safely evaluate the artifact removal quality and interpret the determined responses. This evaluation is based on the so-called **apparent latency** [5] of the EASSR.
In [6], a new approach, based on a **system identification (SI)** procedure has been introduced. It aims to identify the group delay of a finite impulse response system, which is equivalent to the apparent latency of the EASSR.

The goal of this work is to illustrate the newly developed approach and present the most recent results obtained from a dataset of 16 CI users.

Idea

- EEG recording $z[k]$ = EASSR $r[k]$ + artifact $a[k]$
- EASSR and artifact can be modeled via separate finite impulse response systems (FIR)
- Group delay FIR1 := apparent latency EASSR
- Stimulation model $u[k]$ filtered with FIR2 yields artifact model $a[k]$
- Correct identification of FIR1 and FIR2 allows separation of EASSR and artifact

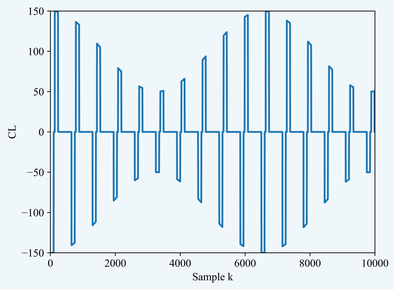


Block diagram of modeled EASSR recording

Stimulation and Measurement setup

Stimulation

- Amplitude modulated pulse train
  - Symmetric biphasic, cathodic-first pulses
  - Subject dependent phase width $25\mu s$ or $37\mu s$, IPG $8\mu s$
  - **900pps**
  - Active electrode ICE15 in **Monopolar mode**
  - Amplitude modulation between C-level and C-50CL
  - Modulation frequencies at $37Hz$, $40Hz$, $43Hz$



Example stimulus train to elicit EASSR

Recording

- 8-channel Biosemi ActiveTwo Hyper-Rate EEG
- $300 \cdot 1.024s$ epochs per modulation frequency
- Sample rate: 262.144kHz
- Reference electrode C_z

Participants information

- 16 adult CI users
- Cochlear Ltd. device

Model definition

Recording model

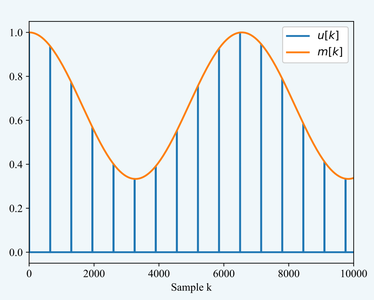
$$\hat{z}[k] = r[k] + a[k] + DC + v[k]$$

EASSR model

$$r[k] = \mathbf{M_k} \cdot \mathbf{b_{resp}} = \begin{bmatrix} m[k] & m[k-1q] & \dots & m[k-Mq] \end{bmatrix} \cdot \mathbf{b_{resp}}$$

Artifact model

$$a[k] = \mathbf{U_k} \cdot \mathbf{b_{arti}} = \begin{bmatrix} u[k] & u[k-1] & \dots & u[k-N] \end{bmatrix} \cdot \mathbf{b_{arti}}$$



Input models $m[k]$ and $u[k]$

Model definition 2

Complete model

$$\hat{\mathbf{z}} = \underbrace{\begin{bmatrix} \mathbf{M} & \mathbf{U} & \mathbf{1} \end{bmatrix}}_{\mathbf{H}} \cdot \underbrace{\begin{bmatrix} \mathbf{b_{resp}} \\ \mathbf{b_{arti}} \\ x_{DC} \end{bmatrix}}_{\mathbf{x}} + \mathbf{v}$$

Combine recordings

$$\hat{\mathbf{z}} = \begin{bmatrix} \hat{\mathbf{z}}^{37} \\ \hat{\mathbf{z}}^{40} \\ \hat{\mathbf{z}}^{43} \end{bmatrix}$$

Combine models

$$\mathbf{H} = \begin{bmatrix} \mathbf{M}^{37} & \mathbf{U}^{37} & \mathbf{1} \\ \mathbf{M}^{40} & \mathbf{U}^{40} & \mathbf{1} \\ \mathbf{M}^{43} & \mathbf{U}^{43} & \mathbf{1} \end{bmatrix}$$

- Improves system identification

EASSR detection

FIR1 evaluated at modulation frequencies

$$FIR1(z = e^{j2\pi f_m}) = \begin{bmatrix} 1 & e^{-jq2\pi f_m} & e^{-j2q2\pi f_m} & \dots & e^{-jMq2\pi f_m} \end{bmatrix} \cdot \mathbf{b_{resp}}$$

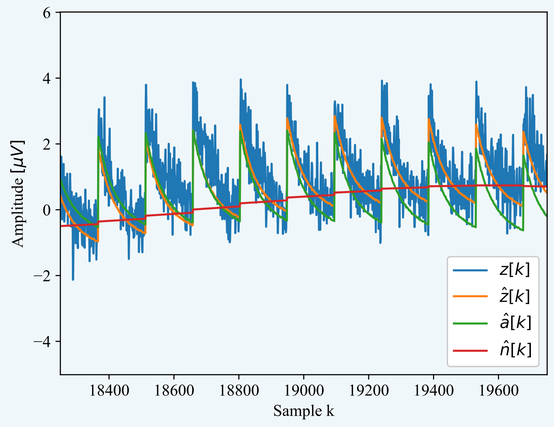
EASSR amplitude

$$A(f_m) = |FIR1(z = e^{j2\pi f_m})|$$

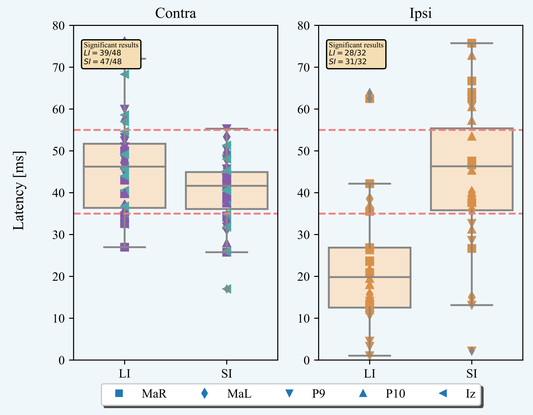
EASSR phase

$$\theta(f_m) = \angle FIR1(z = e^{j2\pi f_m})$$

Results and Discussion



Separation of recording (z) into estimated recording ($\hat{z}$) and individual components $\hat{n}$ and $\hat{a}$.



Determined latencies with LI and SI for contralateral and ipsilateral recording electrodes

- Based on determined apparent latency/ group delay
- **Expected latency of 35-55ms** indicates good artifact removal and EASSR presence
- Comparison of LI with max interpolation length ($1.1ms$) and SI

- Good artifact removal and EASSR detection in contralateral electrodes for both methods
- Low latencies for LI in ipsilateral electrodes
- Good artifact removal and EASSR detection in ipsilateral electrodes with SI

Conclusion

- Identification of EASSR and stimulation artifact via FIR systems possible
- Separation of EASSR and artifact in recording
- EASSR detection with clinical stimulation settings
- Successful artifact removal in contralateral electrodes with LI and SI
- Successful artifact removal in ipsilateral electrodes only with SI

Acknowledgements and References

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