Mini-Symposia Title:

Brain-Computer Interfaces for neuromodulation, language decoding and high-gamma mapping and control.

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Nuri Firat Ince, University of Houston

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Tomek Rutkowski, Riken AIP

Mini-Symposia Speaker Name & Affiliation 4:

S Mini-Symposia Speaker Name & Affiliation 5:

Mini-Symposia Speaker Name & Affiliation 6:

Theme:

- ( ) 01. Biomedical Signal Processing
- ( ) 02. Biomedical Imaging and Image Processing
- ( ) 03. Micro/ Nano-bioengineering; Cellular/ Tissue Engineering &
- ( ) 04. Computational Systems & Synthetic Biology; Multiscale modeling
- ( ) 05. Cardiovascular and Respiratory Systems Engineering
- ( ) 06. Neural and Rehabilitation Engineering
- (•) 07. Biomedical Sensors and Wearable Systems
- ( ) 08. Biorobotics and Biomechanics
- ( ) 09. Therapeutic & Diagnostic Systems and Technologies
- ( ) 10. Biomedical & Health Informatics
- ( ) 11. Biomedical Engineering Education and Society
- ( ) 12. Translational Engineering for Healthcare Innovation and Commercialization

Mini-Symposia Synopsis— Max 2000 Characters

Brain-computer interfaces are realized with non-invasive and invasive sensors and allow to realize important medical applications. The session will show scientific results of three important areas: (i) functional mapping of the eloquent cortex with real-time detection of different tasks to control external devices, (ii) neuromodulation and direct brain stimulation in Parkinson patients and (iii) language decoding from the auditory cortex.
Brain-Computer Interfaces (BCIs) can analyze Electrocorticogram (ECoG) data with invasive electrode grids implanted on the human cortex. Normally between 64-256 electrodes are implanted and this allows to find the most important cortical regions for fingers, face regions, auditory cortex, visual cortex and many more. The mapping is an important step for the surgical planning with epilepsy and tumor patients. After finding these centers high-gamma signals can be used to control external devices with very high precision. The ECoG signal also can be used to decode information from the auditory cortex in order to reconstruct language. For this procedure electrodes are placed over the auditory cortex and the high-gamma signal is fed into a decoding algorithm. In the mini-symposium an overview of the most promising algorithms and paradigms will be given. Additionally, an overview of different research centers performing this task will be made.
In Parkinson patients deep-brain stimulation in the thalamus is used to reduce tremor. This is a very efficient technique developed and researched in the past few years. In the symposium the necessary steps for running such a neuromodulation application are described. An overview of current research and future steps in this domain is given.

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Improved movement decoding for invasive brain-computer interfaces via time-variant linear discriminant analysis

Christoph Guger, Johannes Grünwald, Andrei Znobishchev, Christoph Kapeller, Kyousuke Kamada

Abstract— **Brain-computer interfaces are used to decode finger movements for prosthetic control. In the current study the Electrocorticogram was used as input signal and time-variant linear discriminant analysis allowed to decode the hand gestures with up to 99% accuracy. This has important implications for much more accurate prosthesis control.**

I. INTRODUCTION

Brain-Computer Interfaces are realized with the Electrocorticogram (ECoG) and perform a feature extraction and classification of the signal in order to control an external device. Of special interest in ECoG recordings is the high-gamma signal which can be used to map e.g. the motor cortex, sensory cortex, visual cortex, auditory cortex [1, 2]. In this paper the impact of optimal classification methods will be shown to decode hand gestures in epilepsy patients.

Linear discriminant analysis (LDA) is the de-facto standard for classification in non-invasive and invasive brain-computer interfaces. It is however static in nature and not suited to exploit transient information in features. We therefore developed a time-variant extension of linear discriminant analysis, termed TVLDA. Besides its time-variance, TVLDA also features an internal feature reduction stage. This makes manual channel selection or spatial projection approaches (such as common spatial patterns) obsolete in the given context. TVLDA is easy to implement, fully automatic and deterministic. It is suitable for real-time applications.

II. METHODS

We assessed the performance of TVLDA on experiments involving motor tasks for invasive brain-computer interfaces. Our study comprises six epilepsy patients with temporarily implanted subdural grids, who volunteered to participate in additional research experiments besides clinical treatment. We conducted two types of experiments involving three high-level gestures (rock, paper, scissors) and individual finger movement. We used log-transformed band-power features from the high-gamma band (50 Hz – 300 Hz). We evaluated our processing pipeline by 20 repetitions of a full 10-by-10 cross-validation.

III. RESULTS

TVLDA outperformed LDA by 11.3% on average and yielded more stable results, even if only few trials were available. For the experiment involving three high-level gestures, TVLDA achieved 88% accuracy on average for standard-sized grids, and 99% on average for high-density grids. In the finger-movement experiment, the average accuracy over all subjects was 97% (chance level 20%). To our knowledge, this is the highest ever reported brain-computer interface performance for three-class gesture control and five-class finger control.

IV. DISCUSSION & CONCLUSION

The convincing offline classification performance of TVLDA opens the door to high-performance online applications. For example, a real-time and asynchronous TVLDA classification framework will enable online prosthetics control at very high accuracies. As well, TVLDA produces a reliable output metric for trial-based high-gamma mapping. And lastly, first evaluations have shown that the results from invasive data extend to the non-invasive domain, where TVLDA reliably outperforms CSP and LDA in motor-imagery experiments. This may have a considerable impact for motor-imagery based rehabilitation systems, such as for stroke recovery.

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Speech Synthesis using Intracranial Signals

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Abstract—**Recent studies have demonstrated the possibility of decoding various speech representations such as phonemes, words, and phrases directly from intracranial recordings of brain activity. With the aim of progressing toward a transparent speech neuroprosthetic, the present work presents two distinct approaches for directly synthesizing modal speech using intracranial activity from speech-production areas.**

I. INTRODUCTION

Intracranial brain recordings including electrocorticography (ECoG) and stereotactic electroencephalography (sEEG) can provide insights about networks for speech production, while simultaneously providing localized information for decoding nuanced aspects of the underlying speech processes. Thus, such intracranial recordings are instrumental for investigating the detailed spatiotemporal dynamics of speech. In pursuit of the ultimate objective of developing a natural speech neuroprosthetic for the severely disabled, the present work investigates two distinct approaches for the synthesis of modal speech directly from brain activity.

II. METHODS

Intracranial data were collected from subjects undergoing clinical monitoring for epilepsy. The subjects performed a battery of speech tasks including modal speech based on word and sentence prompts. The high gamma-band power (70-170 Hz) was extracted from the intracranial signals

corresponding to speech-production areas.

For the first synthesis approach, the gamma-band features are used to train a densely-connected 3D convolutional neural network (CNN) to estimate the audio spectrogram of the corresponding speech [1]. The resulting spectrograms are synthesized into audible speech using a Wavenet vocoder. The second synthesis approach, referred to as *Unit Selection* [2], computes the cosine similarity between incoming gamma-band features to a bank of gamma-band training data with associated acoustic speech units. The corresponding speech unit that maximizes the similarity is selected and the resulting sequence of speech units are combined to produce a continuous acoustic waveform.

III. RESULTS

Figure 1 shows an example spectrogram generated by the unit selection approach [2]. The CNN [1] achieves similar spectrogram reconstruction results. For the unit selection approach, a 4-option forced intelligibility test with 55 human listeners resulting in an average accuracy was 66.1%, which was above the chance level for all listeners.

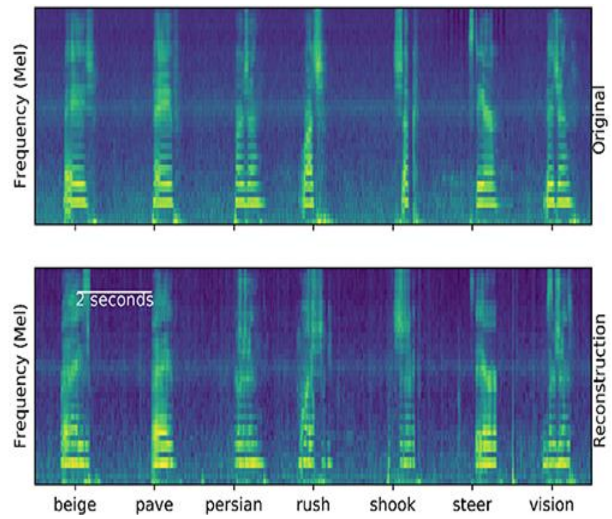

Figure 1. Examples of actual (top) and generated (bottom) audio spectrograms of seven words spoken by a selected participant.

IV. DISCUSSION & CONCLUSION

These results demonstrate that it is possible to synthesize intelligible speech directly using intracranial activity from speech-production areas. In particular, the unit selection approach has the advantages of utilizing the user's own voice and the potential for real-time implementation.

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This work is credited to Christian Herff, Miguel Angrick, Tanja Schultz, and the team members from [1, 2].

Towards Automated and Real-Time Prediction of STN-DBS Electrode Implantation Track in Parkinson's Disease by Using Local Field Potentials

Nuri Firat Ince, University of Houston

Abstract— **Deep brain stimulation of the subthalamic nucleus (STN) is a highly effective treatment for the motor symptoms in patients with Parkinson's disease. However, precise intraoperative localization of STN remains a practical challenge. In the present study, the functional utility of local field potentials (LFPs) recorded from microelectrodes during awake brain surgeries were investigated for targeting of STN. Obtained results indicate that fused information from beta and high frequency oscillations can lead accurate localization of the target structure with around 80% accuracy.**

I. INTRODUCTION

Optimal placement of the DBS electrode is critical for therapeutic efficacy. Inter-subject anatomical variability and limitations in stereotaxic neuroimaging increase the complexity of physiological mapping performed in the operating room. Microelectrode single unit neuronal recording remains the most common intraoperative mapping technique but requires significant expertise and is fraught by potential technical difficulties including robust measurement of the signal. In contrast, local field potentials (LFPs), owing to their oscillatory and robust nature and being more correlated with the disease symptoms, can overcome these technical issues. Therefore, we hypothesized that multiple spectral features extracted from microelectrode recorded LFPs could be used to automate the identification of the optimal track and the STN localization.

V. METHODS AND RESULTS

Following insertion of three brain cannulas and microelectrodes, single unit activity (SUA) was recorded from 25 STNs at 12 kHz from the tip of the electrodes. Simultaneous LFPs were recorded with at 2 kHz from a stainless-steel contact which is 3 mm above the SUA recording tip. All microelectrodes were advanced towards the estimated target using a NeuroDrive with 0.5 to 1mm resolution. Duration of recordings at each depth was 15-30 seconds.

At each depth the power spectrum of the LFPs were estimated using Welch periodogram. The method was repeated for each depth and all spectra were concatenated to visualize depth-varying power spectrum of LFPs in each track. Generated depth-frequency maps were resampled with a 0.25mm depth resolution and linearly interpolated to obtain equidistance depth values. The maps were smoothed using a Gaussian kernel filter to suppress noise and to reveal beta and high frequency band oscillations (HFOs).

Among 3 tracks, the optimal microelectrode track was selected by the neurosurgeon based longest span of the SUA through the STN. In order to predict this decision from LFP activity, the sub-band power in 11-32 Hz for beta band and 200-450 Hz for HFOs were used in conjunction with a linear discriminant analysis (LDA).

VI. RESULTS

Microelectrode track classification based on beta power provided 72% accuracy while HFO power-based classification accuracy was only 68%. When the sub-band power features were used together, the prediction rate for the optimal track rose to 80% indicating that the classifier can predict the track targeted to the STN in 20/25 recordings. It was also noted that the average post-operative stimulation voltage used in correctly classified group is 1.72±0.63 V while it is 2.12±0.69 V in misclassified group.

VII. DISCUSSION & CONCLUSION

The present study describes an automated approach for electrophysiological localization of STN, using microelectrode recorded LFPs acquired during DBS surgery simultaneous to SUA. The classification results show that LFPs provide an additional perspective to interpret pathological neural patterns of basal ganglia in PD for clinical decision making. Our observations establish the initial evidence that real-time processing of LFPs with computational intelligence in the operating room can be strategically used for STN localization and the selection of the track for chronic DBS electrode implantation

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EEG and fNIRS Biomarkers of Dementia Prediction and Monitoring

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***Abstract*— Dementia, especially the age-related memory decline, is one of the most significant global challenges in the 21st century's mental well-being and social welfare. The presented results showcase the potential social benefits of artificial intelligence applications for the elderly and establish a step forward to develop ML approaches, for the subsequent application of simple wearable devices. We present a behavioral and brainwave (EEG or fNIRS) data collection concept for a subsequent AI-based application together with a range of machine learning encouraging results of Montreal Cognitive Assessment (MoCA) scores in the leave-one-subject-out cross-validation setup.**

I. INTRODUCTION

Worldwide, the increased longevity and mainly for elderly adults of above 65 years old, dementia numbers, and costs are rising. The Cabinet Office in Japan announces annual reports on an aging society to address the difficulty. We present a practical health-theme machine learning (ML) application concerning 'AI for social good' domain with our previously developed EEG biomarkers for dementia [1,2,3,4] as well as our preliminary results obtained from a combined EEG and fNIRS neuroimaging techniques. We review methods concerning the problem of a potential elderly adult dementia onset prediction in aging societies.

II. METHODS AND RESULTS

We conducted experiments with human subjects with guidelines and approval of the RIKEN Ethical Committee for Experiments with Human Subjects in the Center for Advanced Intelligence Project (AIP). All participants gave informed written consents, and they received a monetary gratification for their participation in the study. Each subject experiment consisted of 72 video presentation trials (5 $\sim$ 7 seconds each) with 24 different emotion categories [1, 2]. Three different videos portrayed every emotion with actors differing in age, gender, and skin color. The order of the videos was randomized before the experiment but was the same for every participant. During the data recording experiments valence and arousal responses, as well as the reaction times were also recorded by the stimulus presentation application developed in a visual programming environment MAX by Cycling '74, USA. We recorded EEG and fNIRS brainwaves using g.Nautilus fNIRS wearable headset by g.tec medical instruments GmBH, Austria.

III. DISCUSSION & CONCLUSION

The current project resulted in encouraging results with a sample of older adults confirming a possibility of regression-based prediction of MoCA levels using EEG- and fNIRS-derived biomarkers in the spatial- and implicit-working-memory task.

We also expect that future involvement of AI methods for fully interactive stimuli in closed-loop user behavior and brainwave monitoring shall lead to even more impactful results possible to implement in wearable devices for daily use for patients at home.

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