Decoding of motor information in non-human primates using a chronic implantable system

Swathi Sheshadri[1], Frederic Michoud[1,2], Jukka Kortelainen[1],
Sudip Nag[1], Kian Ann Ng[1], Faith A. Bazley[1], Anoop Patil[1,3], Josue Orellana[1], Louiza Chan[4], Camilo Libedinsky[4], Amitabha Lahiri[5], Keefe Chng[4], Annarita Cutrone[6], Silvia Bossi[6], Silvestro Micera[2,6],
Ignacio Delgado-Martínez[1*], Shih-Cheng Yen[1,3], Nitish V. Thakor[1,3,7]

***Abstract*— Proximal nerve injury is a neurological condition of increasing incidence throughout the world. Complete transection, such as traumatic brachial plexus injuries, is the most severe, resulting in complete dysfunction of the motor and sensory functions of the arm. From the engineering and medical point of view, the ideal treatment would be a direct linkage of the complex nerve signals to the end-organ, providing immediate functional recovery. In the present work, we developed two implantable recording systems that allowed us to simultaneously acquire nerve and muscle signals using a 4-channel thin-film longitudinal intrafascicular electrode (tf-LIFE, SMANIA Inc.) and 9 endomysial muscle electrodes. Movement-dependent muscle activity from the flexor muscles of the forearm was matched in the time domain to the corresponding nerve signals from the median nerve in a *M. fascicularis* using power spectrum analysis and classification with support vector machine. Wavelet denoising allowed us to identify the spikes (i.e. local compound action potentials), which encoded the information for the muscle activation. This work will allow us to develop a neuroprosthetic solution for lesions of peripheral nerves in the future.**

[1] Singapore Institute of Neurotechnology (SINAPSE), National University of Singapore, 117456, Singapore
[2] School of Life Sciences Swiss Federal Institute of Technology (EPFL), Lausanne, 1015, Switzerland
[3] Department of Electrical & Computer Engineering, National University of Singapore, 117576, Singapore
[4] Singapore Institute for Clinical Science, A*Star, 117609, Singapore.
[5] Department of Hand & Reconstructive Microsurgery. National University Health System, Singapore
[6] SMANIA, Viale Rinaldo Piaggio 34, Pontedera, Pisa, Italy
[7] Department of Biomedical Engineering, Johns Hopkins University, Traylor 701/720 Rutland Ave, Baltimore, MD 21205, USA
*Corresponding Author: I.DM. ✉ignacio.delgado@nus.edu.sg

FUTURE WORK

This work is inside the framework "*Peripheral Nerve Prostheses – A paradigm Shift in Restoring Dexterous Limb Function*", aimed at developing an implantable peripheral nerve prostheses for the treatment of proximal nerve injuries. Our current work focuses on improving noise removal algorithm using SYMLET wavelets, spike detection and sorting using templates, feature detection, and neuromorphic classification.

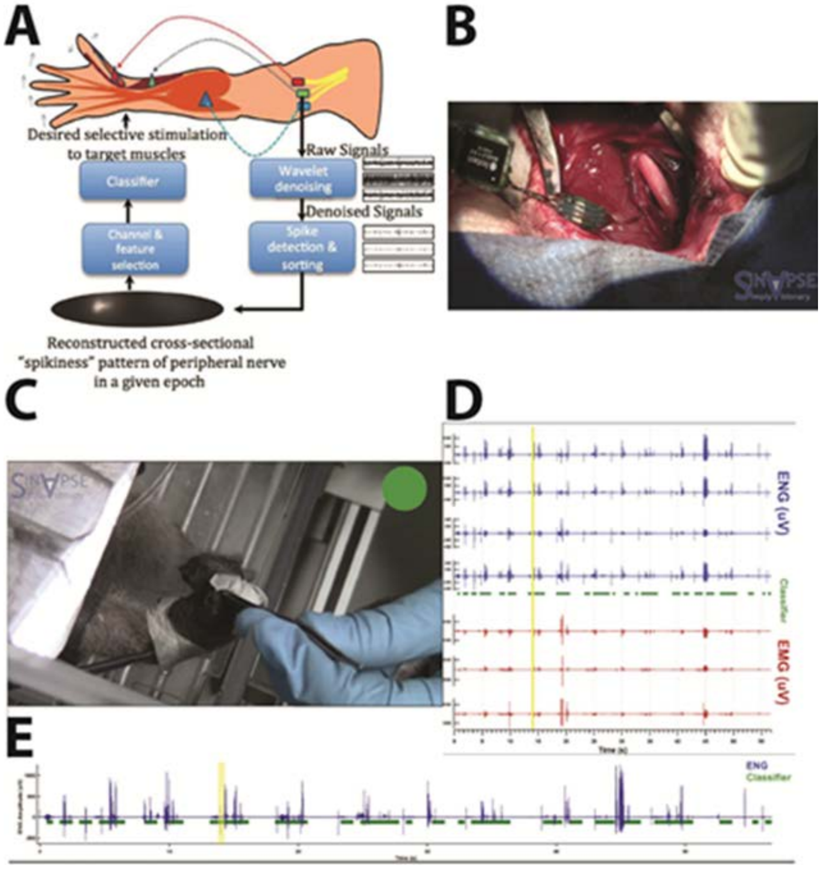


Figure 1. Experimental Design. **A.** Nerve signals were recorded from the nerve bundles corresponding to different muscule groups using tf-LIFE electrodes. Corresponding muscle activity was simultanously recorded with intra-muscular electrodes. All the electrodes were connected to an implanted RHD2132 chip (InTan Tech, Inc.) for data acquisition. Raw signals were then processed offline. After pre-processing and filtering, the muscle activation patterns were matched to the corresponding nerve signal using power spectrum analysis and support vector machine classification. Wavelet denoising was used to identify compound action potentials that coded for muscle contraction. **B.** Photograph showing the location of the implanted neural system with the tf-LIFE and the Intan chip in the median nerve at the brachial level in a *M. fascicularis*. **C.** Photograph of the NHP performing the grasp task while neural signals and forearm muscles were monitored. **D.** Typical recording showing, from top to bottom, the nerve activity from 4 contacts of a tf-LIFE in the median nerve (blue), result of the classification algorithm (green), and muscle activity from the *M. flexor carpi radialis*, *M. flexor digitorium superficialis*, and *M. flexor carpi ulnaris*. **E.** Inset showing the nerve activity recording from the first contact of the tf-LIFE and the resulting classifier. The yellow vertical bands correspond to the time of the photograph in C.

Electrode Interfaces for Peripheral Nerve Prosthesis

Anoop Patil[1,2] , Frederic Michoud[1,3] , Swathi Sheshadri[1] , Josue Orellana[1] , Sudip Nag[1], Kian Ann Ng[1] , Faith A. Bazley[1] , Camilo Libedinsky [1] , Annarita Cutrone[4], Silvia Bossi[4], Silvestro Micera[3,4] , Amitabha Lahiri[5] , Ignacio Delgado-Martínez[1], Shih-Cheng Yen[1,2], Nitish V. Thakor[1,2,6]

[1] Singapore Institute of Neurotechnology (SINAPSE), National University of Singapore, 117456, Singapore
[2] Department of Electrical & Computer Engineering, National University of Singapore, 117576, Singapore
[3] School of Life Sciences Swiss Federal Institute of Technology (EPFL), Lausanne, 1015, Switzerland
[4] SMANIA, Viale Rinaldo Piaggio 34, Pontedera, Pisa, Italy
[5] Department of Hand & Reconstructive Microsurgery. National University Health System, Singapore
[6] Department of Biomedical Engineering, Johns Hopkins University, Traylor 701/720 Rutland Ave, Baltimore, MD 21205, USA

anoopcpatil@nus.edu.sg, ignacio.delgado@nus.edu.sg

Keywords
neural interface, electrode, long term neural recording, peripheral nerve recording, neural probes

ABSTRACT

An ideal prosthesis system is one that is directly interfaced with the peripheral nerve stump of a patient, enabling him to use it naturally and control it. The motivation to study the reliability of the neural interfaces arises from the requirement of neural interfaces to sense the nerve signals from peripheral nerves, as these recordings provide information that can be used to control the limb muscles. The current focus is to study how much useful information can be extracted from the peripheral nerves. This promotes a direct interest in the design of neural interfaces and subsequently prosthetics that can restore the lost limb functions. We review the use of nerve interfaces to pick up peripheral nerve signals in the framework of peripheral nerve prosthesis, and propose critical requirements for the next generation neural probes.

I. Introduction

There has been a significant amount of interest in designing neural prosthetics to mimic the basic functionality of the underlying peripheral nerve circuitry. However, the current prosthetics provide a small portion of functionality of the natural limb. The technologies used in the neural interface (NI) for prosthetics are in two major areas: Central NI and Peripheral NI. Central NI is marked by significant amount of invasiveness arising from the need to insert the electrodes into the brain. Peripheral NI is comparatively less invasive and offers an advantage in recording nerve signals that are required for muscle activation. This is because decoding is taken care of, to a large extent by the existing nerve circuitry from brain to the peripheral nerves.

Conventional recording approaches include the use of cuff electrodes that wrap around the nerve. This type offers minimal damage to the nerves and long term stability, relatively to intra-neural types. This comes at the cost of reduced specificity in recording and stimulating nerves as this is carried out at extra-fascicular level. Intra-neural types like UTAH Slanted electrode array, Longitudinal and Transverse intra-fascicular electrodes (LIFE & TIME), are penetrating electrodes and offer direct contact with the axons. Increased recording specificity comes with increased risk of nerve damage, inflammation and scar tissue formation, impeding the nerve signal acquisition. The current work involved recording of nerve signals from the nerve bundles corresponding to different muscle groups using thin film LIFE (tf-LIFE) electrodes implanted in a non-human primate (NHP). Corresponding muscle activity was simultaneously recorded with intra-muscular electrodes.

II. Review

Reliable chronic application in recording and stimulation of nerve fibers has been the focus of electrode development over the latter half of the previous decade. Efforts to improve the electrode biology interfaces have been mainly focused on using new substrate materials, creating a low impedance bio-compatible contact with the nerve tissue and reducing the form factor of electrodes to make them thin and flexible.

Fabrication of low impedance electrode arrays has been reported where the recording surface is modified with nano-flake structures or nano-porous metal deposits. Carbon fiber array for long term neural recording have been developed[1]. Recent work has also seen a significant shift from bulky electrode structures to thin flexible forms. Silicon electronics on a silk base have paved the way for implantable devices with a dissolving base [2]. The capability to create thin circuits has primarily aided the drive to achieve ultrathin tissue interfaces. The use of new substrate materials, interface mechanisms and advancements in fabrication techniques can further promote high-quality interfaces that can integrate conformably with the soft, curvilinear nerve surfaces. These capabilities create promising opportunities for chronic, reliable nerve signal recording.

III. Future Work

On-going work is being performed in the project “*Peripheral Nerve Prostheses – A paradigm Shift in Restoring Dexterous Limb Function*”, aimed at developing an implantable peripheral nerve prosthesis for the treatment of proximal nerve injuries. The current work focuses on developing neural interfaces using bio-materials.

References

[1] G. Guitchounts, J. E. Markowitz, W. A. Liberti, and T. J. Gardner, "A carbon-fiber electrode array for long-term neural recording," *J Neural Eng,* vol. 10, p. 046016, Aug 2013.

[2] J. Viventi, D. H. Kim, L. Vigeland, E. S. Frechette, J. A. Blanco, Y. S. Kim*, et al.*, "Flexible, foldable, actively multiplexed, high-density electrode array for mapping brain activity in vivo," *Nat Neurosci,* vol. 14, pp. 1599-605, Dec 2011.

A novel voice recognition system for speech impaired people

*S.Ganesh, Syed Mustafa,Kameshwaran Velu

Research scholar, Sathyabama University, Chennai , Tamil Nadu, India

Engineering graduate,Department of ECE. Panimalar Institute of technology, Chennai, Tamil Nadu, India.

U.G student,Department of ECE, Panimalar Institute of technology, Chennai, Tamil Nadu, India.

ganesh8461@gmail.com

Keywords : Speech impaired people, Lip movement, Speech recognition, Sound detection, Transceiver

.

ABSTRACT

Information Communication Technology (ICT) can support people with physical disabilities by enabling them to access the information along with others. Physical challenge either temporary or of permanent nature put limitations in learning process of an individual as it can limit accessibility, can hamper understanding thus making it difficult for such persons to be at par with others. A person can choose a technology based on his or her ability and ease in using a technology This paper analysis how ICT can meet requirements of education and employment of physically challenged people. This paper is basically aims in making mobile phones that can be easily accessible by the speech impaired people, who are not hearing impaired. The primary aim lies in capturing the lip movements of the speech impaired people and converting these into vibrations and consequently into sound signals which are later transmitted to the receiver as such. Basically a device needs to be fitted in their mouth to sense the lip movements and consequently convert them into vibration. Then the process of recognizing the speech from vibrations takes place. The recognized speech is sent to receiver. Thus this product will prove effective for conversing with speech impaired people, thereby bringing a great impact in improving their communication with others and for understanding and sharing their thought and feelings. This product will be “SERVICE TO HUMANITY”.

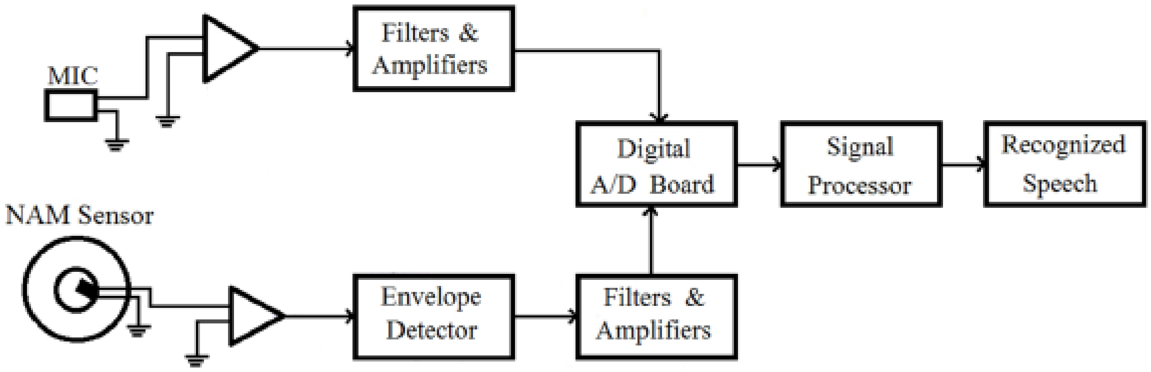


Figure 1. The Block diagram

Prototype

Sigview is a real-time and offline signal analysis software package with wide range of powerful signal analysis tools, statistics functions and a comprehensive visualization system. Sigview is mainly used for analyzing the parameters in the signal and vibrations. A separate NAM module is used for testing purpose. It consists of a Stethoscope NAM, microphone, audio jack and blocking capacitors.

Figure 2. NAM microphone test module

Results

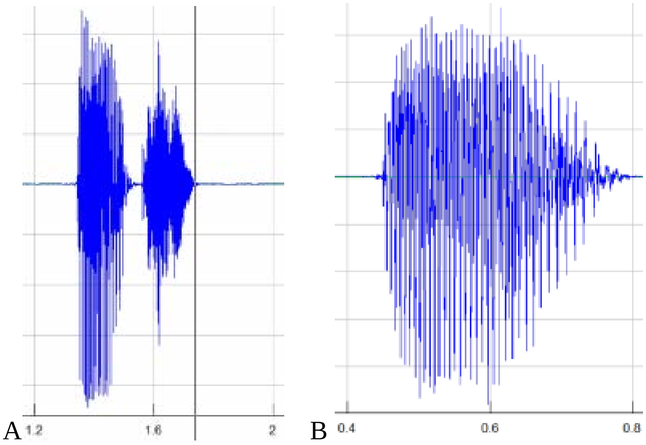


Figure 3 .Letters A) ‘a’ and B) ‘e’ in sigview.

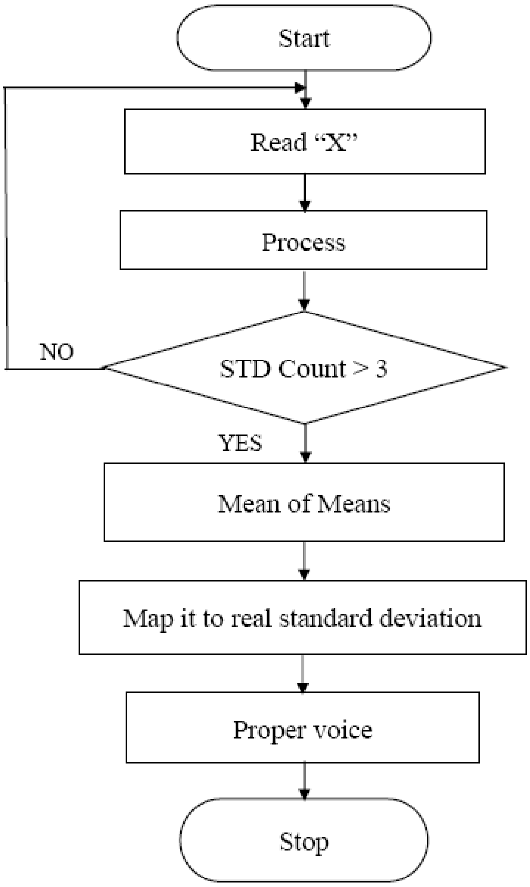


Figure 4.Flow chart of the program

Implantable, Low-Noise, Power-Efficient Neural Amplifier System

Kian Ann Ng[1], Yong Ping Xu[2], Shih-Cheng Yen[1,2], Ignacio Delgado-Martínez[1], Nitish V. Thakor[1]

[1]Singapore Institute for Neurotechnology (SINAPSE), National University of Singapore, Singapore
[2] Dept of Electrical and Computer Engineering, National University of Singapore, Singapore

***Abstract*— Neuroprosthetic solutions are gaining popularity in treatment of neurological disabilities and neuronal related diseases. Neuroprosthetic applications such as Brain Machine Interface, cochlear prosthetic implants and others require acquisition and amplification of signals from the nervous system. Such task is usually achieved with the use of neural recording amplifiers. In the case of implantable application, the amplifiers are required to operate at low power to allow extended periods of operation without periodic replacement of power pack as well as restrict heat damage to the surrounding tissues. In this paper, we report a fully implantable system based on our earlier reported neural recording microelectronic circuits and propose future work.**

I. INTRODUCTION

Neuroprosthetic solutions are gaining recognition in treatment of several neurological diseases, for example retina and auditory related neural prosthesis. One limitation is the design of a fully miniaturized and implantable neural recording device but thanks to the rapid progress in VLSI microelectronic design and manufacturing techniques, we are now able to fabricate low power yet low noise neural recording amplifier circuits on small silicon chips. Recently we have fabricated low-noise and low power neural recording systems on ICs[1]–[3]. They have been reported to be capable of performing acute in-vivo neural recording. In this work, we extend the capability of these chips to allow them to perform implantable, chronic neural recording on the peripheral nerve system.

II. IMPLANTABLE NEURAL RECORDING CIRCUITS

Our recent works [1]–[3] have demonstrated low power consumption of less than 6 µW and low noise efficiency factor (NEF) of less than 2.58. Further work is now being done to package such chips into a form factor that is suitable for chronic implantation into animal models such as rats and non-human primates. Fig. 1 shows a recent implementation of such encapsulation whereby a single chip is packaged onto a custom designed Chip-on-Board (COB) package. Besides the amplifier chip[1], only four external passive components are needed to form a single COB package measuring just 7mm x 7mm x 1mm. Prior to implantation, we directly attach an intrafascicular electrode (tf-LIFE)[4] as well as external power and interface lines, which are insulated with biocompatible materials such as PFA or PTFE. The full package is then further encapsulated with biocompatible silicone before the implantation.

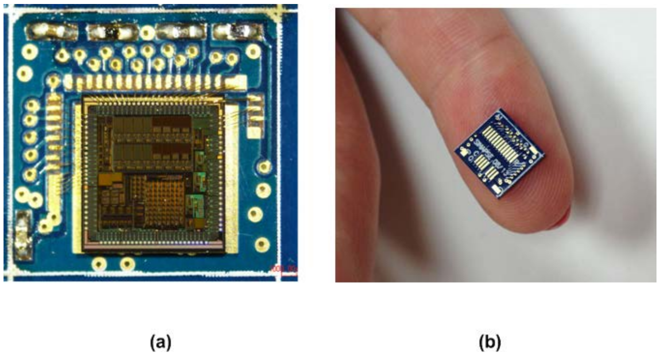


Fig. 1 Fully implantable neural recording amplifier package. (a) COB before epoxy encapsulation. (b) After epoxy encapsulation and ready for integration with electrodes

FUTURE WORK

This work would be used as a recording vehicle in the project “Peripheral Nerve Prostheses – A paradigm Shift in Restoring Dexterous Limb Function”, aimed at developing an implantable Peripheral Nerve Prosthesis for the treatment of proximal nerve injuries.

REFERENCES

[1] K. A. Ng, L. Xu, X. Li, S. Yen, M. Je, Y. P. Xu, and T. C. Tan, “An Inductively Powered CMOS Multichannel Bionic Neural Link for Peripheral Nerve Function Restoration,” in *IEEE Conf. Asian Solid State Circuits*, 2012, pp. 181–184.

[2] Y. P. Xu, S. C. Yen, K. A. Ng, X. Liu, and T. C. Tan, “A Bionic Neural Link for peripheral nerve repair,” *Proc. Int. Conf. IEEE Eng. Med. Biol. Soc.*, pp. 1335–8, Aug. 2012.

[3] K. A. Ng and Y. P. Xu, “A compact, low input capacitance neural recording amplifier with Cin/Gain of 20fF.V/V,” in *Biomedical Circuits and Systems Conference (BioCAS), 2012 IEEE*, 2012, pp. 328–331.

[4] P. Dario, C. Cipriani, K. Yoshida, M. C. Carrozza, G. Assenza, K.-P. Hoffmann, M. Tombini, S. Micera, J. Rigosa, L. Citi, X. Navarro, J. Carpaneto, S. Raspopovic, and P. M. Rossini, “Decoding of grasping information from neural signals recorded using peripheral intrafascicular interfaces,” *Journal of NeuroEngineering and Rehabilitation*, vol. 8, no. 1. p. 53, 2011.

Synchrony Analysis of Paroxysmal Gamma Waves in Meditation EEG

Jing Jin[a], Justin Dauwels[a], François B. Vialatte[b], Andrzej Cichocki[c]

[a] Nanyang Technological University, School of Electrical and Electronic Engineering, Singapore

[b] ESPCI Paris Tech, Laboratory SIGMA, Paris, France

[c] RIKEN Brain Science Institute, Laboratory for Advanced Brain Signal Processing, Wako-Shi, Saitama, Japan

Keywords
Paroxysmal gamma wave, electroencephalogram, meditation, Bhramari Pranayama, stochastic event synchrony.

ABSTRACT

Mediation is a fascinating topic that is still relatively poorly understood. To investigate its physiological traits, electroencephalograms (EEG) were recorded during meditation sessions. In a recent study, paroxysmal gamma waves (PGWs) have been discovered in EEG of meditators practicing Bhra-mari Pranayama (BhPr). In this paper the synchrony between those PGWs is investigated, revealing functional connectivity patterns in the brain during BhPr. Specifically, the method of Stochastic Event Synchrony (SES) is applied to pairs of PGW sequences in order to assess their synchrony. From those pair-wise synchrony measures, large-scale functional connectivity patterns are extracted.

Three subjects possessing different levels of expertise in BhPr are considered. Strong synchrony can be observed in the temporal lobes for all 3 subjects, in addition to long-range inter-hemispheric connections. Consistent connectivity patterns are present for exhalation periods, while those patterns are substantially less stationary for inhalation periods. Interestingly, the synchrony seems to increase gradually during the meditation session. Moreover, the distribution of synchrony values seems to depend on the level of expertise in practicing BhPr: the higher the expertise, the more concentrated the intensity values.

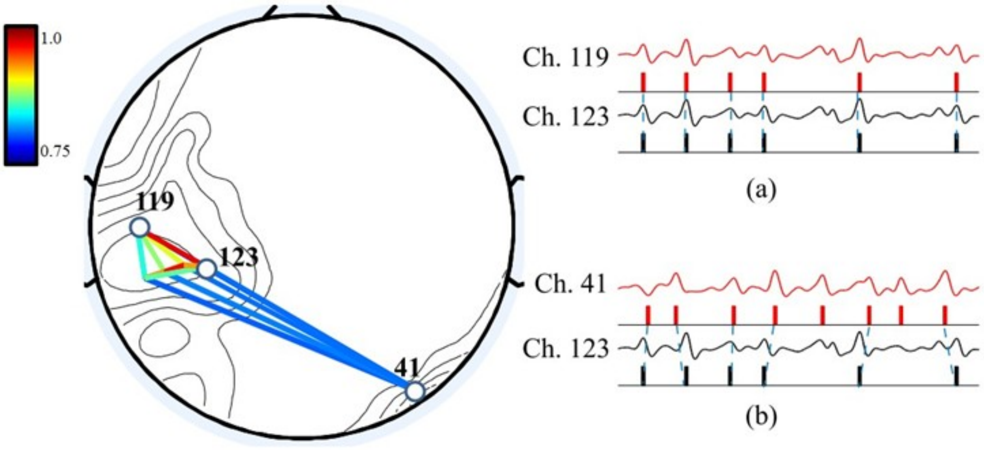


Figure 1: Connectivity map with connection strength in color (left), and EEG (right) in the 3rd exhalation period of subject B with extracted PGW sequences from a pair of (a) adjacent channels Ch. 119 and Ch. 123, and (b) distant channels Ch. 41 and Ch. 123.

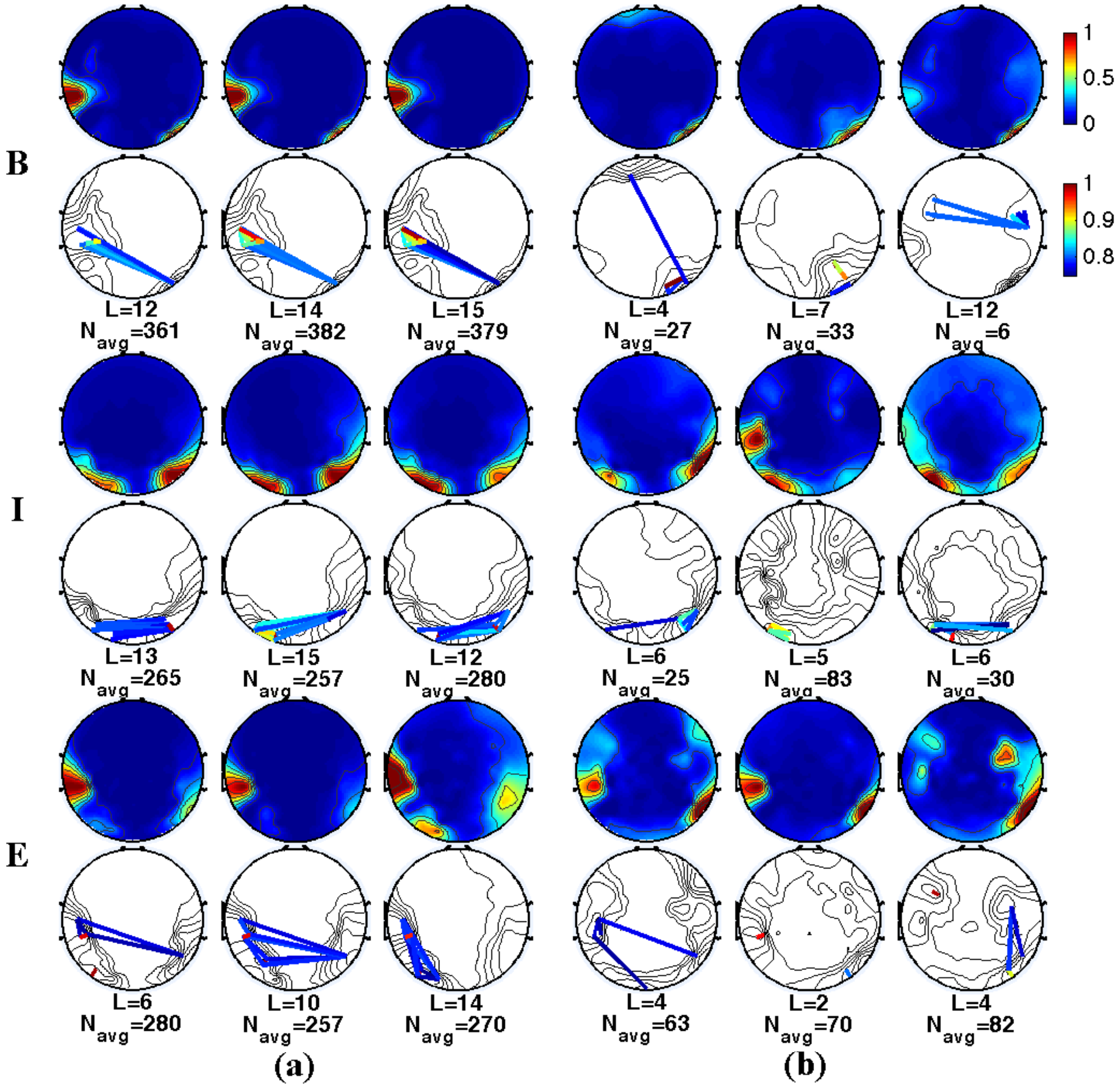


Figure 2: Power distribution and connectivity networks for three subjects (B, I, and E) with three successive periods of (a) exhalations, and (b) inhalations. L is the total number of connections, and N_{avg} is the average PGW count of each connection.

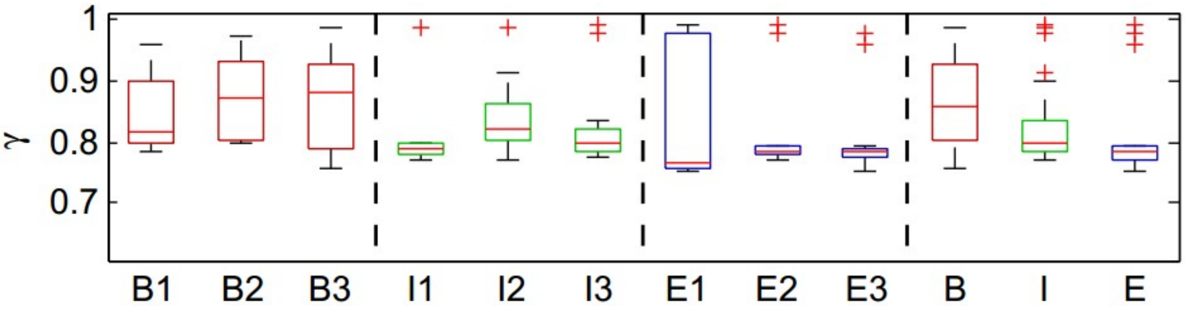


Figure 3: Synchrony measure for the three subjects. First three groups from left: Boxplot of connection strength for three successive exhalation periods for B, I and E. Right: Boxplot of connection strength for the three subjects (jointly for the three exhalation periods).

Localization of the Seizure Focus from Interictal Intracranial EEG

Jing Jin[a], Justin Dauwels[a], Sydney Cash[b]

[a] Nanyang Technological University, School of Electrical and Electronic Engineering, Singapore

[b] Massachusetts General Hospital and Harvard Medical School, Cambridge, MA, USA

Keywords
Epilepsy, seizure focus, intracranial EEG, interictal spikes, high frequency oscillations.

ABSTRACT

For approximately 30% of epilepsy patients, seizures are poorly controlled with medications alone. Those patients may be successfully treated by surgically removing the brain area(s) where the seizures originate. It is crucial to accurately localize the seizure foci, which often resorts to semi-chronic invasive recordings of cortical activity, as non-invasive methods are frequently inconclusive. Neurologists rely heavily on seizures to determine the foci. The invasive recordings usually continue for days or weeks until enough seizures are captured, as seizures are infrequent in nature. The procedure is costly, uncomfortable, and risky of side effects.

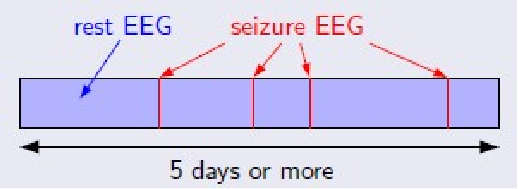
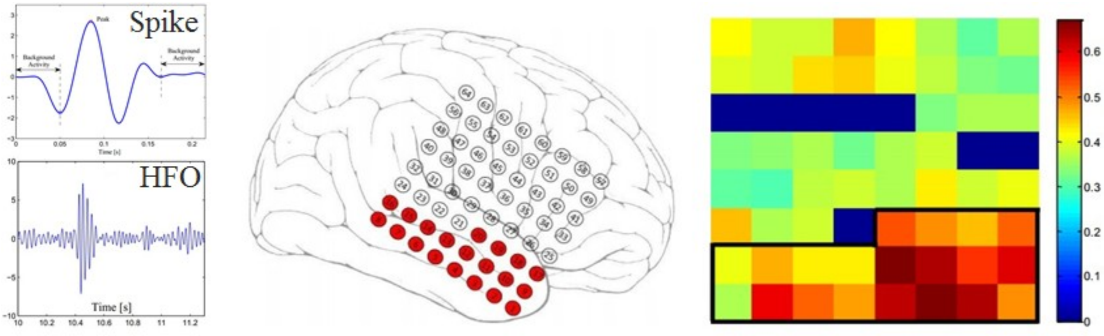


Figure 1: Semi-chronic EEG recording containing epileptic seizures.

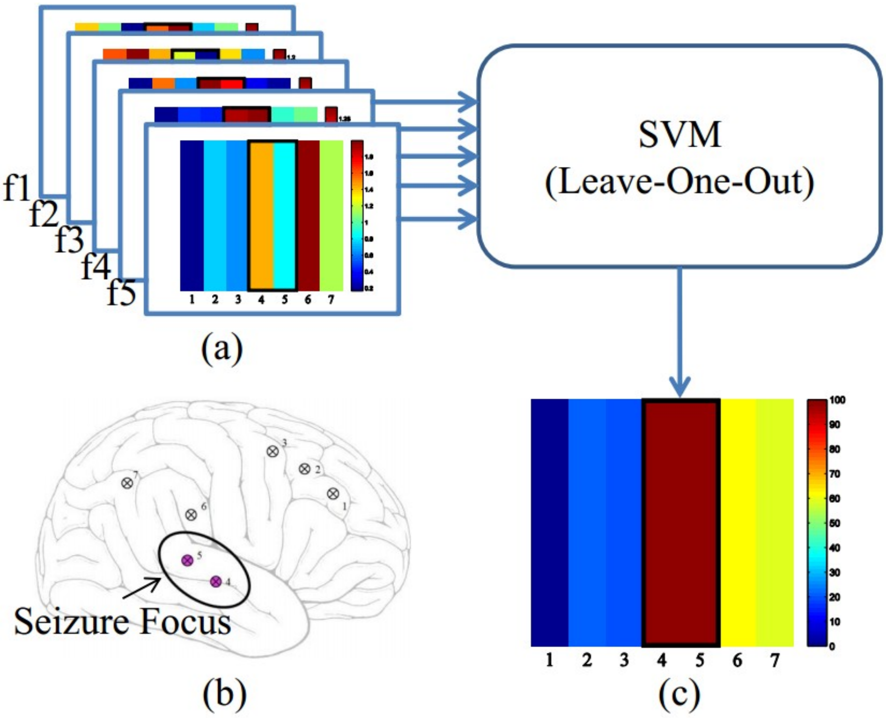
Our long-term objective is to drastically shorten the hospitalization of epilepsy patients, from weeks to a few days: We hope to localize the seizure foci from short invasive recordings made in the operating room, before the resection surgery. The goal of the proposed project is to explore the feasibility of this idea, building upon our promising preliminary results. Our hypothesis is that, even at rest, the seizure focus is characterized by seizure measures such as interictal spikes, high frequency oscillations (HFOs), slowing and synchrony.



(a) (b) (c)

Figure 2: (a) Signatures of epileptic EEG activity: spikes (top) and HFO (bottom); (b) physical locations of surface electrodes, where the actual focus is red-color labeled by doctors from ictal EEG; (c) the distribution of a measure (e.g. spike rate) over all electrodes, where the corresponding ground truth is marked using back-color squares.

Our novelty is to exploit combinations of all measures in a machine-learning framework to localize the seizure foci. We have proposed methods for detecting spikes and HFOs respectively. We have applied signal processing techniques to invasive semi-chronic recordings between seizures, in order to extract signatures of the seizure foci. We have applied statistical decision algorithms that leverage those signatures to determine the seizure foci in an automated fashion. In future work, we will apply those algorithms to short invasive recordings made in the operating room.



(a)

(b)

(c)

Figure 3. (a) Feature arrays of epileptic EEG activity (depth electrodes); (b) electrode placement with the ellipse depicting the seizure focus, determined by trained electroencephalographers from seizure EEG (blinded to the results of this analysis); and (c) fuzzy decision map [%] after classification with the corresponding ground truth marked in back-color squares.

The proposed procedure may have enormous impact on clinical practice of epilepsy, and would substantially reduce treatment costs. Moreover, our novel automated approach to medical decision making is not only relevant for neurosurgery but many other medical disciplines.

Study of the Cortical Functions of Photothrombotic Ischemic Stroke and Applied Sensorimotor Stimulation as a Treatment Method

Lun-De Liao* [1], Aishwarya Bandla[1, 2], Yu-Hang Liu[1, 3], Nitish V. Thakor[1, 4].

Affiliations: 1 Singapore Institute for Neurotechnology (SiNAPSE), Singapore
2 Department of Biomedical Engineering, National University of Singapore, Singapore
3 Department of Electrical and Computer Engineering, National University of Singapore, Singapore
4 Department of Biomedical Engineering, Johns Hopkins University, USA

gs336.tw@gmail.com

Keywords (up to 5)
Acute ischemia, forepaw electrical stimulation, collateral circulation, ECoG, fPAM.

ABSTRACT (up to 1000 words, no longer than 2 pages)

Discovering an optimal solution for acute ischemic stroke recovery employing knowledge about brain plasticity mechanisms is a substantial issue. In our previous study, functional electrical stimulation has been proven effective for recovery in rodent models of acute ischemia. It has been shown that blood flow redistribution can be elicited through collateral circulation, improving cortical functional activities due to the stimulation. However, it is still challenging to benchmark and optimize the parameters for administering functional stimulation as treatment. In this study, forepaw stimulation treatment is applied to either the contralateral forepaw or both forepaws with intensities of 2 mA or 4 mA to determine the optimal method and intensity for ischemic stroke recovery. Electrocorticography (ECoG) recordings and fPAM (functional photoacoustic microscopy) are integrated to evaluate the cortical functions in rats, following photothrombotic ischemic stroke. Bilateral six-channel ECoG recordings are obtained over the motor and somatosensory cortex. A 6 × 3 mm cranial window is performed for fPAM imaging, including the chosen ischemic region over the somatosensory cortex. The cortical functions are assessed via somatosensory-evoked potential (SSEP) recordings and evoked hemodynamic response, respectively obtained by ECoG recordings and fPAM at a 32 × 61-μm spatial resolution. Experimental results indicate that electrical forepaw stimulation effectively enhances stroke recovery when administered at an intensity of 2 mA on both forepaws compared to stimulation of contralateral forepaw. While intensity of 4 mA on single/both forepaws leads to improved results as in the case of 2 mA, prolonged stimulation leads to infarct expansion. The beneficial effect can be attributed to the global hemodynamic response, with compensatory flow from the unaffected hemisphere to the ischemic region. In contrast, excess treatment causes deleterious effects because neurons can only sustain certain external electrical stimulation. According to the results, the treatment with 2 mA intensity on both forepaws could facilitate functional recovery when it is administered appropriately.

Real-Time Visual Tracking and Recognition using an Event-based Vision Sensor and Convolutional Neural Network

Rohan Ghosh, Abhishek Mishra, Garrick Orchard*, Nitish Thakor

Affiliations: Singapore Institute for Neurotechnology (SINAPSE), National University of Singapore,
garrickorchard@nus.edu.sg

Keywords
Neuromorphic, Object Recognition, FPGA, Convolutional Neural Network

ABSTRACT

In this poster we will show details of a real-time system for visual tracking and recognition. The system uses the Asynchronous Time-based Image Sensor as a front end sensor to capture visual information from the scene. A simple activity tracker is used to track and create a bounding box around moving objects in the scene. A region of interest is created within the bounding box and converted to a static image, which is then classified by a Convolutional Neural Network (CNN) using the NeuFlow architecture running on a Xilinx Virtex 6 ML605 FPGA evaluation board. The system is capable of simultaneously tracking and recognizing multiple objects within the scene in real-time.

Further, we will show how a classifier can be trained to treat different views of the same object as different classes, thereby allowing us to classify not only the object itself, but also its current orientation. Knowledge of an object and its orientation is useful for manipulation tasks, such as grasping using a prosthetic arm and hand. Fine dextrous control of a prosthesis via the limited bandwidth available from a neural interface is a cognitively burdensome task for the user. Incorporating the visual sensor into the prosthesis to locate, detect the object to be grasped and its orientation, offers the advantage of fast and accurate grasp planning. We also validate the performance of the classifier at different speeds of the object and also the number of objects to be classified.

Figure 1: A snapshot from the system while running live. The left shows which pixels have recently experienced a change in intensity. White pixels represent intensity increases, while black pixels indicate decreases. Grey indicates no change. On the right is a grayscale image of the scene. Boxes indicate the locations of moving objects within the scene currently being tracked. The color of the box indicates the class of object, with green indicating car. The classifier in this example was trained to distinguish between cars, pedestrians, motorbikes, and background.

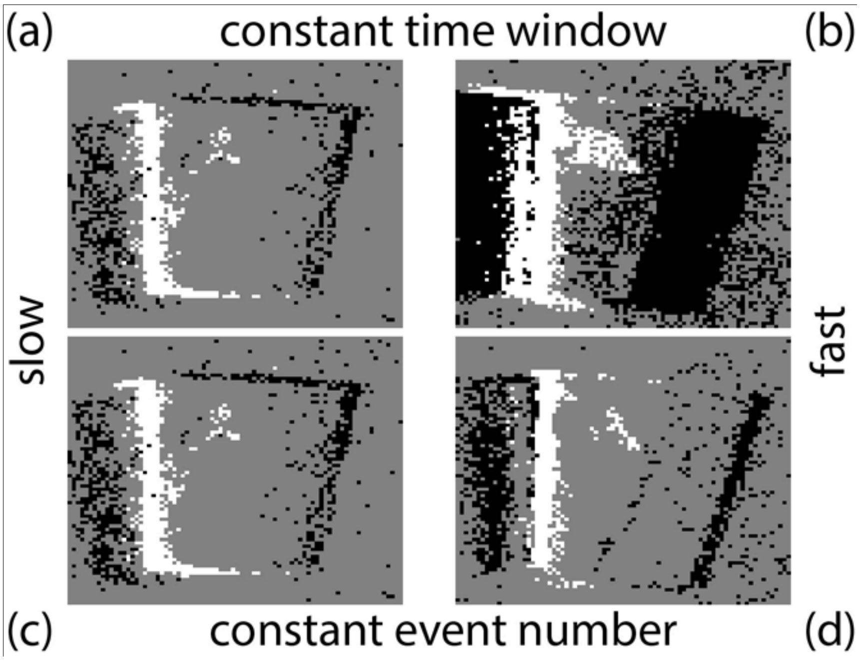


Figure 2: Removing speed dependence using a dynamic time window. The top row show views of the same object moving slow (a) and fast (b) extracted using a constant time window method (each image contains 33ms of data), while the bottom row shows views of the object moving slow (c) and fast (d) at the exact same points in time, extracted using the constant event number method (each view contains 1500 events). The constant event number method provides a more consistent view of the object as speed changes.

Future work will include implementing the sensor on the prosthetic and performing the grip movements appropriately.