Mini-Symposia Title:

Emerging Neural Technologies for Neuroprosthetic Hand

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Mini-Symposia Speaker Name & Affiliation 3:

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Theme:

06. Neural and Rehabilitation Engineering

Mini-Symposia Synopsis:

Neural technologies for prosthetics are advancing rapidly in recent decades. In this special session, we present a few technical breakthroughs that are promising for human application in the near future. We will invite the following speakers to give presentations on their research work that may have an impact on neuroprosthetic applications in amputees.

Speaker 1: The Influence of Abduction Movement on the Grasp of Prosthetic Hand

Yu Wang, Beihang University

Abstract— **At present, the tasks that prosthetic hands can accomplish are far less than those of human hands. Part of the reason is the lack of DOFs (degree of freedom). For example, many prosthetic fingers can only bend but not abduct. This makes it difficult for the prosthetic hand to use the most appropriate grasp posture when handing over an object. In this paper we tested the condition of the prosthetic hand to use the most appropriate grasp posture when handing over an object. In this paper we tested the condition of the prosthetic hand grasping with and without abduction degrees of freedom. And compared it with the situation of the human hand. We concluded that the degree of**

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freedom of abduction can improve the grasp stability to some extent.

I. INTRODUCTION

The use of prosthetic hands instead of human hands is a long-standing desire of mankind, but the function of prosthetic hands is far from the flexibility of manpower. One reason is the lack of DOF (degrees of freedom). Of course, there are some hands with full DOFs, such as the Shadow Dexterous Hand and the Awiwi hand [1]. But such hands are often bulky and difficult to apply to patients. Most of the widely accepted prosthetic hand is currently without abduction DOFs. In our opinion, this will lose some of the flexibility. This is the purpose of our research to explore the impact of abduction movement on the flexibility of prosthetic hands.

II. METHODS

We have designed and development a prosthetic hand with DOFs of abduction. According to [2], a typical grasp, the spherical grip, is associated with maximum separation of the middle finger. Therefore, the abduction mechanism of the fingers should leave the middle finger fixed. So the index finger, the ring finger and the little finger of our prosthetic hand can all perform the abduction movement except for the middle finger.

The grasp test was performed in both cases with and without abduction movement. In the first set of experiments, a range of discs of different sizes were grasped by a precision grasp. In the second set of experiments, objects of similar shapes of similar size were grasped. Keep the bending angle of each finger consistent during the experiment.

III. RESULTS

The results of the experiments show that the use of abduction movement can improve the stability of the grasp to a certain extent, especially for the large objects.

We concluded that a fully open hand has a higher success rate when grasping an object than a hand that is not fully open. This is because the abduction movement makes the hand exert a more uniform force on the object when grasping, which is especially noticeable for these objects with a relatively uniform shape.

IV. DISCUSSION & CONCLUSION

We explored the effect of abduction movement of prosthetic hand on grasping in certain grasp modes, and the results show that having abduction DOFs is beneficial for grasp. So having the DOFs of abduction allows the prosthetic hand to have greater flexibility.

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Speaker 2: Flexible Nanosensors for Prosthetic Hand Applications

Yue Li, Suzhou Institute of Nano-Tech and Nano-Bionics, Chinese Academy of Sciences

***Abstract*— Flexible sensors endow prosthetics the ability to measure a diversity of multiplex sensations. Here, we demonstrated a flexible integrated sensor array based on three functionalized carbon nanotubes, which can real-time respond to pressure(0.65 mN to 0.6 N), humidity(5%-90% RH) and temperature(25 ℃-70 ℃). Besides, we also demonstrated a novel flexible tangential force sensor, which is able to selectively detect static friction and sliding friction force in real time. These flexible sensors are valuable for the applications in prosthetics.**

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I. INTRODUCTION

Nowadays, the flexible sensors are constructed to mimic the sensing capacity of human skin for perceiving outside stimuli information, which is of great significance to prosthetics. For the prosthetics system, sensors play the basic and crucial roles to fulfill the integrated loop of sensory feedback, resulting in the regeneration of bionic perception, such as tactile feeling of touch. Here, we demonstrated a flexible sensor array and a novel tangential force sensor, which provide multiplex sensing capabilities to prosthetics.

II. METHODS

The pressure sensing material is carbon nanotubes (CNTs)/polydimethylsiloxane (PDMS) composite, the temperature sensing material is Pt/CNTs nanocomposite, and the humidity sensing material is

2-(dimethylamino)ethyl methacrylate-bromobutane-ammoniumb-co-silane coupling agent (MEBA-co-KH570) with CNTs. Sensors array was fabricated by step-by-step screen printing.

As for flexible tangential force sensors, replicating method was employed to prepare spiral column-type capacitive-type sensor. Ag nanowires were used to be the conductive materials of the capacitive sensor. And PDMS ensured electrodes stretchable and flexible.

III. RESULTS

For pressure sensing, the range from 0.65 mN to 0.6 N can be detected with high stability. Humidity sensors respond to humidity change of RH 5%-90% , and temperature sensors respond to 25 ℃-70 ℃ with accuracy of 0.5 ℃. Besides, the flexible tangential force sensor based on capacitance sensing technology is able to selectively detect static friction and sliding friction force in real time, which can detect the weight of an object and slippage.

IV. DISCUSSION & CONCLUSION

In conclusion, these results reveal these flexible integrated sensors array and tangential force sensors have a huge potential application in the field of prosthetics.

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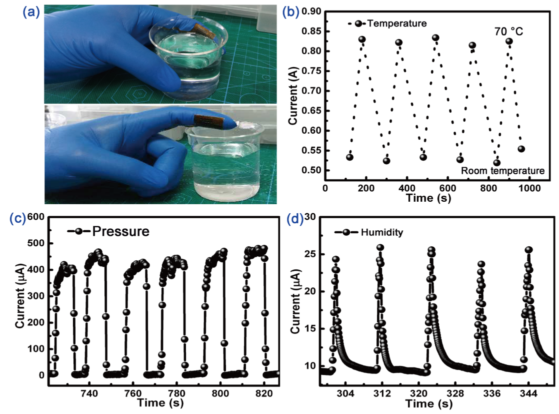

Figure 1. The performance of the integrated sensor array attached on a finger and to sense the common behavior of holding a bottle filled with hot water.

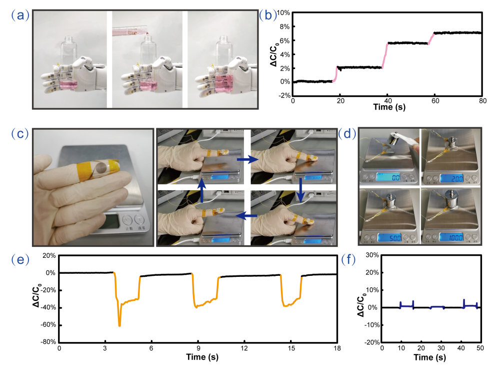

Figure 2. Flexible tangiential force sensors detect the weight of water and slippage.

Speaker 3: Information coding for sensory feedback in amputees with evoked tactile sensation

Manzhao Hao, School of Biomedical Engineering and Institute of Medical Robotics, Shanghai Jiao Tong University

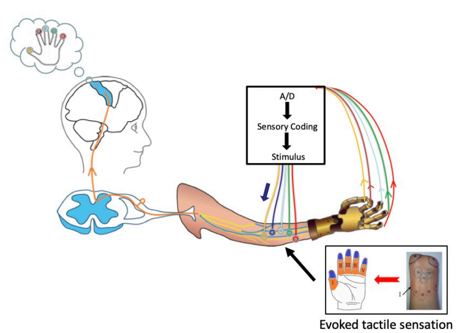

Figure 1. Sensory feedback for prosthetic fingers based on the evoked tactile sensation using transcutaneous electrical nerve stimulation.

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***Abstract*—The unique phenomenon of evoked tactile sensation (ETS) in amputees allows conveying sensory information from prosthetic hands to the human brain non-invasively. Many types of sensory modalities are sensed by both amputee and healthy subjects with transcutaneous electrical nerve stimulation (TENS). Modulation ranges of sensory modalities are essential for designing coding strategies for incoming sensory information from prosthetic hands.**

This study developed a protocol to evaluate the range of modulation for different sensory modalities elicited by TENS. Healthy subjects and amputees with ETS participated in the evaluation session. The range of pulse width and amplitude of stimulation of each sensation modality in different frequencies was recoded. The sensitivity modulated by the pulse width of the ‘buzz’ and the ‘vibration’ sensation was further evaluated. An ETS-based sensory feedback system was developed. In the first stage, the information of force sense from the prosthetic

fingers was converted to stimulus and to evoke the finger sensation of the amputee subject. Two coding strategies for force sense from prosthetic fingers were tested. They were linear coding from force to pulse width of stimulation. The coding intervals of one of the pulse width coding were correspond to the 'buzz' sensation. And the other coding strategies corresponds to the 'vibration' sensation. The amputee subjects performed the functional test.

The correct ratio of the finger-to-finger identification test was higher than chance probability of each area of ETS of each amputee subject under both the two coding strategies.

The preliminary results show that the protocol of evaluating range of sensory modalities could provide a basis for coding sensory information and there were at least two linear pulse width coding strategies corresponding to the 'buzz' sensation and the 'vibration' sensation.

Speaker 4: Targeted nerve-muscle reinnervation for prosthetic control

Peng Fang, *IEEE Senior Member* and Guanglin Li, *IEEE Senior Member*, CAS Key Laboratory of Human-Machine Intelligence-Synergy Systems, Shenzhen Institutes of Advanced Technology & Shenzhen Engineering Laboratory of Neural Rehabilitation Technology, Chinese Academy of Sciences

Abstract—**The control of multifunctional myoelectric prostheses is usually limited due to insufficient electromyography (EMG) signals, especially for individuals after above-elbow amputations. Targeted Muscle Reinnervation (TMR) and Target Nerve Functional Replacement (TNFR) are two methods to recover the lost EMG sources and enable the recording of EMG signals that are sufficient for prosthesis control. We studied and compared the two methods and achieved some results that would support the clinic applications of TMR and TNFR for prosthetic control.**

I. INTRODUCTION

More than five million individuals with limb amputation currently live around the world. In particular, amputees with above elbow and knee amputation cannot produce sufficient electromyography (EMG) signals for intuitive control of advanced multifunctional myoelectric prostheses, because of related nerve and muscle tissue loss. Targeted Muscle Reinnervation (TMR) [1-2] and Target Nerve Functional Replacement (TNFR) are two methods to recover the lost EMG sources and enable the recording of EMG signals that are sufficient for prosthesis control. In TMR, the nerves associated with residual limbs are transferred onto targeted muscles to grow; In TNFR, the nerves are connected to the targeted nerves for function replacement, i.e. the initial neural network is used. Following TMR or TNFR surgeries, the implanted nerves would require a relatively long time to grow during which the targeted muscles may atrophy due to denervation. To treat and accelerate the nerve growth, functional electrical stimulation (FES) has been proved to be an effective method [3-5]. In this study, we investigated the influence of FES on targeted muscles and nerve rehabilitation after TMR or TNFR surgery based on rat models.

II. METHODS

The experimental procedures for the current study were approved by the Animal Care and Use Committee of Shenzhen Institutes of Advanced Technology, Chinese Academy of Sciences. A total of 12 Specific Pathogen Free (SPF) Sprague Dawley rats were divided into two groups namely the randomly control group (n=6) and experimental group (n=6). The rats were treated with FES therapy a day after either TMR or TNFR surgery. The parameters of the FES stimulation were set as frequency of 20 Hz, pulse width of 200 μs, work-rest ratio of 10 s:10 s, and pulse amplitude range of 1-5 mA, depending on whether the targeted pectoralis slightly contracts or not. The FES treatment was done over a period of four weeks, and 30 minutes daily.

III. RESULTS

The results post the TMR and TNFR surgery indicate that the targeted muscle preservation rate, the maximal contraction, intramuscular nerve distribution, and EMG signal quality of the experimental groups were significantly better than those of the control groups, which demonstrated the effectiveness of FES on muscle and nerve rehabilitation after TMR or TNFR surgeries. Especially, the TNFR group shows obviously better performances than the TMR group, which would suggest that the TNFR is a method superior to TMR for nerve-muscle reinnervation.

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I. CONCLUSION

This preliminary result suggests that FES treatment could improve the rehabilitation procedure for targeted muscles and implanted nerves of rats after TMR or TNFR surgeries, which would potentially facilitate future clinic applications of the TMR and TNFR techniques.

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Speaker 5: Axon-stretch based bidirectional neural interface with micro-patterened flaxible film

Shirong Wang, Beijing Institute of Technology

Abstract— **To build a bidirectional interface that both senses (record) from the nerves and stimulates the nerves to affect the organ function. We developed an in vitro system with elongated neurons axons, light activated stimulation electrode and multi-electrode arrays (MEA) on micro-patterned flexible SU-8 film. This interface implied future application in intelligence prosthesis with sensory feedback.**

I. INTRODUCTION

Limb amputation immensely affecting thousands of patients each year, and their life quality can be improved by a controllable artificial limb with sensory feedback [1]. So the fundamental issue in the bidirectional interface is to bridge the biological tissue and the electronic prosthesis, with which has high-quality recording and effective stimulation electrodes to record from the nerves and stimulate them. With advances in materials and fabrication techniques, the recent development of device is able to stable stim and record neuronal activity, and also flexible enough for future implantation to avoid tissue damages.

II. METHODS

The use and care of animals was approved and followed the guidelines of the Animal care and use committee of Beijing Institute of Technology. Dorsal root ganglion (DRG) were dissected from the spinal columns of neonatal P3 SD rat pups [2]. The DRG neurons were seeded on flexible films with either photo activated stimulus electrode or multi-electrode arrays (MEA) in a 4-channel axon-stretch device with step motor with generate linear displacement to pull neuron axons at speed of 1mm/day.

The flexible stimuli and recording electrodes are realized using microfabrication techniques as previously described [3]. The contact pads on the MEA were aligned with ACF cable and connect to the customized board, which transfer signal to OpenEphs system (intan technologies, LLC, USA) for recording. Post recording analysis, including the sorting and classifying of recording data, was performed with a custom Matlab software.

III. RESULTS

Here we present an in vitro bidirectional neural interface with elongated neurons axons, light activated stimulation electrode and multi-electrode arrays (MEA) on micro-patterned flexible SU-8 film. Therefore, the interface stimulates the cultured dorsal root ganglion (DRG) neurons by the light and record from the nerves, which was guided to extend on direction to the recording MEA on the other side of the stimulation electrode (Fig.1).

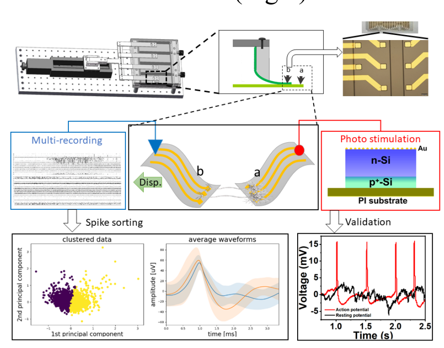

Figure 1. The in vitro bi-directional neural interface with enlongated axons, light-activated stimulation and multi-electrode arrays (MEA) on flxible film.

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I. DISCUSSION & CONCLUSION

In this study the in vitro bi-directional interface were placed on flexible Su-8 substrate, it is possible to cover the DRG irregular surface without suturing or adhesives which provide centralized access to primary afferent cell bodies and spinal reflex circuitry, which also anatomically isolated from motor neurons.

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Speaker 6: Validation of model-based biomimetic control for prosthetic hand

Chuanxin Minos Niu, School of Biomedical Engineering, Institute of Medical Robotics, and Ruijin Hospital, School of Medicine, Shanghai Jiao Tong University

Abstract— **Prosthetic hands controlled by surface EMG are frequently rejected due to frustrations in daily uses, particularly when handling objects that are deformable or fragile. One primary reason is EMG signals are supposed to activate the neuromuscular components involved with hand movements. However, most prosthetic hands are incapable of translating motor intentions into expected physical reality, mainly due to information mismatch between the amputee and the device.**

We have developed a model-based controller emulating human neuromuscular system. The controller implements well-known computational models of motoneuron, skeletal muscle, muscle spindle, monosynaptic circuitry, etc. Therefore, the informational consequence produced by a certain EMG command is compatible between the model-based controller and human neuromusculature in the hand. Muscle force generated by model-based controller is established by a torque motor to flex the fingers.

This study demonstrates the feasibility of implementing biologically inspired models with neuromorphic computation for real-time closed-loop control of prosthetic hand. Results show initial indication that mimicking biological properties in both feedback and feedforward control may improve the manipulation of objects by amputees using prosthetic hands.

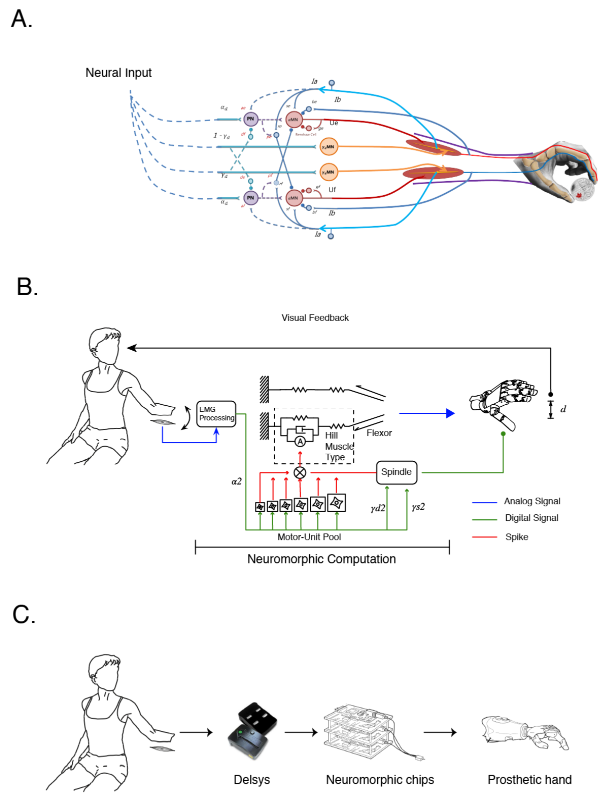

Figure 1. Model-based biomimetic control for prosthetic hand.

*Research supported by National Key Technologies R&D Program (2017YFA0701103 and 2017YFA0701104). National Natural Science Foundation of China (81630050).

Speaker 7: A Dry Electrode Cap and Its Application in BCI

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I. INTRODUCTION

A ready-to-use EEG cap is a decisive technology if BCI will be extended from laboratory to practical application [1]. A stable electrical connection between the scalp and the dry electrode is the base of high-quality EEG recording [2]. A proper press can tightly mount the dry electrode on the head with as less as uncomfortable feeling. It is a great challenge to meet these requirements on the hair-covered scalp. To address this deficiency, a prototype of a dry electrode cap was proposed and demonstrated in this study.

II. METHODS

A skeleton-structure-cap combined with a removable electrode panel was designed to reduce the weight and increase the flexibility, as shown in Figure 1. The cap mainly consisted of a horizontal hoop and a semi-circular hoop perpendicular to the horizontal one. The hoops were fabricated from polyurethane, a flexible but almost no elastic polymer material. With the help of rack-and-pinion structure, the length of the hoops can be adjusted to fit different head circumference by turning a rotary knob on them, either in horizontal or in vertical.

A multi-pin dry electrode fabricated in our laboratory was employed in this paper.A mechanically adjustable and electric connection handle was designed and developed for the dry electrode. The handle is mainly composed of two parts. The schematic diagram of the structure was shown in Figure 1(c).

The dry EEG cap and the headband, were worn and tested for comparison on twelve volunteers. In the experiment, the SSVEP data were acquired and analyzed to find the effects of electrode fixture on the accuracy of the BCI.

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III. RESULTS

The accuracy of the BCI test with the cap was higher than that with the headband at different data length. The mean classification accuracy with 2s-data-length can reach to 0.9753 with the proposed EEG cap, higher than 0.9575 with the headband for 12 subjects. Compared with the headband, the adjustable cap provided more options to the subjects, wearing the electrode loosely or tightly. To the subjects unfamiliar with EEG acquisition, the knob and screws on the cap make the adjustment easier.

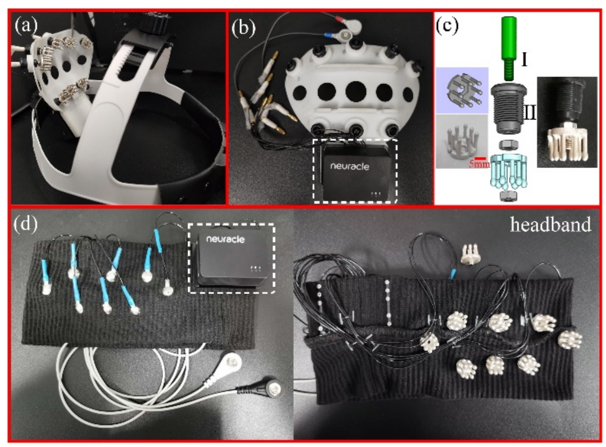

Figure 1. Adjustable EEG cap and the headband.a) EEG cap. (b) The electrode panel with eight adjustable electrodes and wireless acquisition module (as framed by the dotted line) on it. (c) multi-pin dry electrode and a mechanical adjustable and electric connection structure, part Ⅰ is tubular socket, part Ⅱ is a hollow screw, the left insert is the fabricated electrode and the right insert is the adjustable electrode. (d) the textile headband for comparison.

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