BCI controlled robotic arm as assistance to the rehabilitation of neurologically disabled patients

Azhar, H.

TECH DAY 27.04.2021
Online Meeting

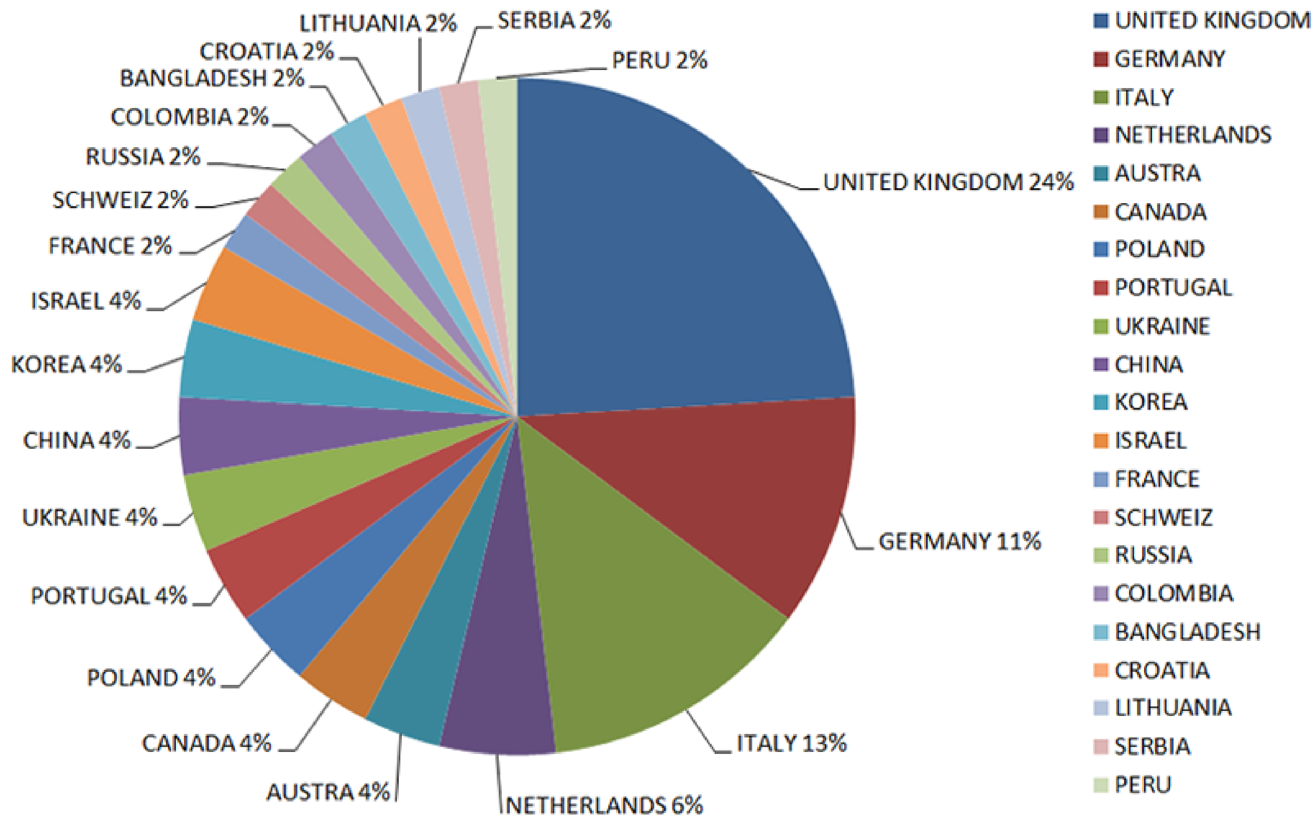
BRAIN CONTROLLING TECHNOLOGY FOR ASSISTIVE DEVICES

ABSTRACT BOOK

COUNTRIES OF ATTENDEES

2021 TECH DAY Online Meeting on
Brain Controlling Technology for Assistive Devices

Last updated: 26 April 2021



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Last updated: April 15, 2021 * Catalogue entry not received

EXOberlin

Berlin ROBOCHAIR
Intelligent Robotic Wheelchair Forum

2021 Online Meeting on Brain Controlling Technology for Assistive Devices

Tuesday, April 27, 2021

TIME	TOPIC	PRESENTER	COUNTRY
10:00-10:05	*Opening Remarks*		
10:05-10:15	A multi-gesture anthropomorphic hand online control: based on surface EMG signal and neural network	The University of Manchester	UNITED KINGDO
10:15-10:40	Towards a smart and intuitive controlled leg prosthesis: acquisition of intramuscular electromyography for motion intention detection. A pilot study.	Roessingh Research and Development	NETHERLAND
10:40-11:00	Shared Control of a Robotic Arm using Brain-Computer Interfaces and Robotic Vision	University of Bath	UNITED KINGDOM
11:00-11:15	Smart Robotic Device for Motor & Cognitive Learning of Individuals with Special Needs	Tel Aviv University	ISRAEL
11:15-11:30	EASY Walk: EEG Driven Walking Rehabilitation with Exoskeletons	INDI Ingénierie et Design	FRANCE
11:30-11:50	*Coffee Break*		
11:50-12:10	EDAN, the EMG-controlled Daily Assistant	German Aerospace Center (DLR)	GERMANY
12:10-12:35	Bionics: What's Behind	Inail Direzione centrale assistenza protesica e riabilitazione	ITALIA
12:35-13:00	BCI controlled robotic arm as assistance to the rehabilitation of neurologically disabled patients	Canterbury Christ Church University	UK
13:00-13:15	Development of an EEG Controlled Wheelchair Using Color Stimuli: A Machine Learning Based Approach	Bangladesh Army University of Engineering & Technology (BAUET)	BANGLADESH
13:15-13:45	*Coffee Break*		
13:45-14:00	Restoration of Hand Function Using Cognitive Nerve Transfers to Control Bionic Limbs DESIGN OF ELECTROOCULOGRAM BASED WHEELCHAIR CONTROL	Medical University of Vienna	AUSTRIA
14:00-14:15	Intelligent Assist Technology for Power Wheelchair: Problems and Challenges of Product Approach	Mobilis Robotics LLC	POLAND
14:15-14:35	Feel Your Reach: Continuous robotic arm control by non-invasive EEG signals	Graz University of Technology, Institute of Neural Engineering, BCI-Lab	AUSTRIA
14:35-14:50	ROS2 for Powered Wheelchairs	Heidelberg University	GERMANY
14:50-15:20	*Coffee Break*		
15:20-15:45	The novel approach to non-invasive BCI control of the motor rehabilitation robotics	The Center for Neurobiology and Brain Restoration at the Skolkovo Institute of Science and Technology	RUSSIA
15:45-16:05	Unlocking Independence: How BCI can be used to increase access to power mobility and independent movement	University of Calgary	CANADA
16:05-16:25	Learning to drive a brain-actuated intelligent wheelchair	Department of Information Engineering, Università degli Studi di Padova, Italy	ITALY
16:25-16:45	HyDRA-Walker project: a robotic walker guide for powered exoskeletons with neural interface	Department of Information Engineering, The University of Padova	ITALY
16:45-17:00	EEG signals, feedback, and brain-computer interfaces in support of upper and lower limb rehabilitation: current status.	Universidad Pedagógica y Tecnológica de Colombia	Colombia
	End		

/Be aware that the start and end times for each session are tentative. /This schedule is updated frequently and the meeting agenda is subject to change without prior notice. Check back again before the event. (Lasted updated: 16.04.2021)

Development of an EEG Controlled Wheelchair Using Color Stimuli: A Machine Learning Based Approach

Md Mahmudul Hasan

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Abstract: Electroencephalogram (EEG) signals are very sensitive to color stimuli and the signal changes due to different colors promises a significant detection rate. A methodology of brainwave-controlled wheelchair has been presented in this study utilizing the EEG changes due to different color stimuli. For the experimental study, Red, Green, Blue (primary colors) and Yellow (secondary color) were chosen as the color stimuli, which were utilized in a 2 × 2 color window for four-direction command, namely, left and right, forward and stop. After the data collection in the given experimental condition, several time and frequency domain features were extracted from the Delta, Theta, Alpha and Beta EEG rhythms. Four supervised learning algorithms were developed with the features extracted from different EEG frequency bands. The classification models, namely K Nearest Neighbours (KNN), Support Vector Machine (SVM), Random Forest Classifier (RFC) and Artificial Neural Networks (ANN) were trained and tested for assessing the performance of each of the EEG rhythm, with a five-fold cross-validation. Four different performance measures, i.e., sensitivity, specificity, accuracy, and area under the receiver operating characteristic curve were utilized to examine the wholescale performance. The results suggested that Beta EEG rhythm outperforms the other EEG rhythms for the effective detection of color stimuli. While comparing the performance of the classifiers with Beta EEG features, the ANN-based classifier outperformed the other classifiers with an accuracy of 82.5%. The outcome of the study indicates that EEG sensation to different color stimuli can be effectively used for wheelchair control where the Beta EEG rhythm could play a significant role.

BCI controlled robotic arm as assistance to the rehabilitation of neurologically disabled patients

Dr Hannan Azhar *et al.*[1], Senior Lecturer, School of Engineering, Technology and Design, Canterbury Christ Church University

Purpose: Brain–computer interface (BCI)-controlled assistive robotic systems have been developed with increasing success with the aim to rehabilitation of patients after brain injury to increase independence and quality of life. While such systems may use surgically implanted invasive sensors, non-invasive alternatives can be better suited due to the ease of use, reduced cost, improvements in accuracy and reliability with the advancement of the technology and practicality of use. The consumer-grade BCI devices are often capable of integrating multiple types of signals, including Electroencephalogram (EEG) and Electromyogram (EMG) signals.

Materials and Methods: This talk summarizes the development of a portable and cost-efficient BCI-controlled assistive technology using a non-invasive BCI headset "OpenBCI" and an open source robotic arm, U-Arm, to accomplish tasks related to rehabilitation, such as access to resources, adaptability or home use. The resulting system used a combination of EEG and EMG sensor readings to control the arm. To avoid risks of injury while the device is being used in clinical settings, appropriate measures were incorporated into the software control of the arm. A short survey was used following the system usability scale (SUS), to measure the usability of the technology to be trialled in clinical settings.

Results: From the experimental results, it was found that EMG is a very reliable method for assistive technology control, provided that the user specific EMG calibration is done. With the EEG, even though the results were promising, due to insufficient detection of the signal, the controller was not adequate to be used within a neurorehabilitation environment. The survey indicated that the usability of the system is not a barrier for moving the system into clinical trials.

Implication on rehabilitation

For the rehabilitation of patients suffering from neurological disabilities (particularly those suffering from varying degrees of paralysis), it is necessary to develop technology that bypasses the limitations of their condition. For example, if a patient is unable to walk due to the unresponsiveness in their motor neurons, technology can be developed that used an alternate input to move an exoskeleton, which enables the patient to walk again with the assistance of the exoskeleton.

This talk summarises the development of a portable and cost-efficient BCI controlled assistive technology using a non-invasive BCI headset "OpenBCI" and an open source robotic arm, U-Arm, to accomplish tasks related to rehabilitation, such as access to resources, adaptability or home use. The resulting system used a combination of EEG and EMG sensor readings to control the arm, which could perform a number of different tasks such as picking/placing objects or assist users in eating.

Reference:

1. Anthony Casey, Hannan Azhar, Marek Grzes & Mohamed Sakel (2019) BCI controlled robotic arm as assistance to the rehabilitation of neurologically disabled patients, Journal of Disability and Rehabilitation: Assistive Technology, Taylor and Francis, DOI: 10.1080/17483107.2019.1683239

HyDRA-Walker project:

a robotic walker guide for powered exoskeletons with neural interface

Stefano Tortora, PhD

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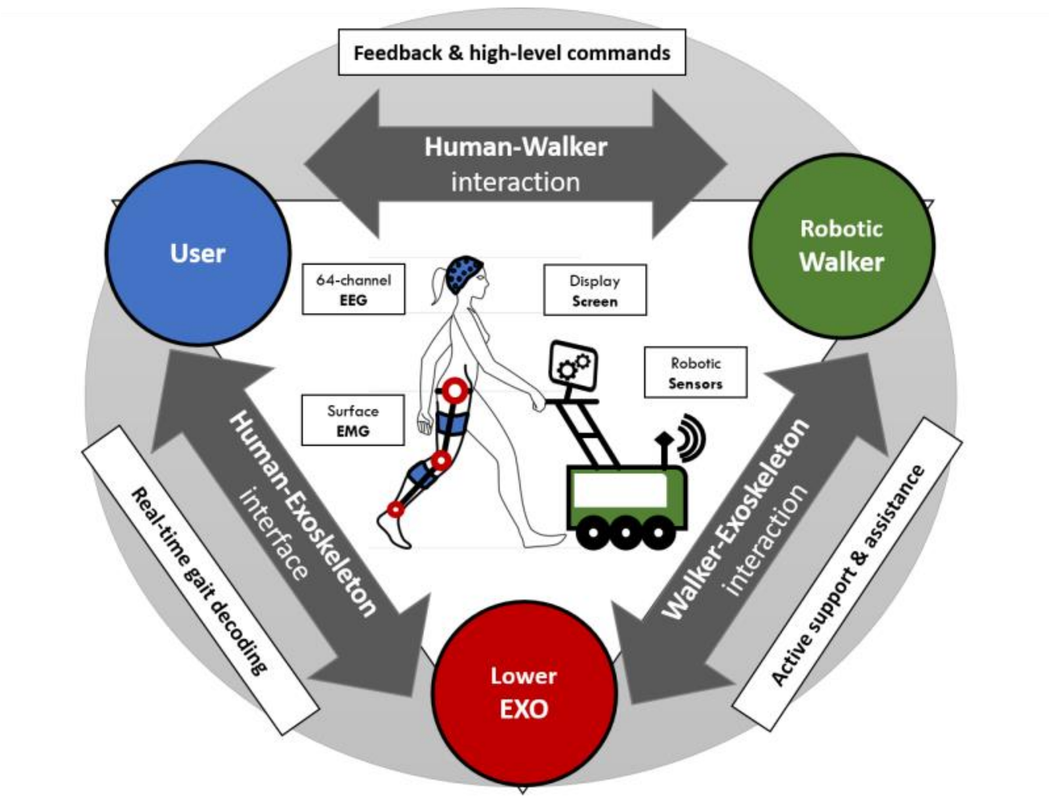
Abstract:

Powered lower-limb exoskeletons represent a recently emerging technology in the field of wearable robotics, enabling paraplegic people to walk again. However, their use is still restricted to clinical settings or controlled environments. To overcome this limitation, herein we present the HyDRA-Walker project, about the development of a robotic walker that will act as an intelligent guiding agent to control brain-actuated exoskeletons in daily-living situations. We further present our latest advancements on a hybrid brain-computer interface (h-BCI) for walking decoding. Finally, we introduce future insight on how this interface will be adopted to control the powered exoskeleton in our project.



Learning to drive a brain-actuated intelligent wheelchair

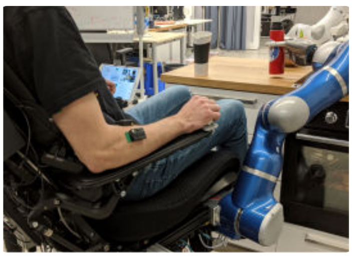
Luca Tonin,
Department of Information Engineering,
University of Padua, Italy

Among the several brain-actuated neurorobotic prototypes, brain-machine interface (BMI) driven wheelchairs represent the paramount promise for people suffering from severe motor disabilities thanks to the applicability in complete paralysis. Herein, we present the latest experimental results where three tetraplegic spinal cord injury users learned to control a non-invasive, self-paced BMI-driven wheelchair and execute complex navigation tasks in real-world surroundings. We further substantiate that user's learning and robotic intelligence are the two cornerstones for developing robust and effective BMI translational applications. Finally, we introduce the next directions of our research to promote human-machine learning interactions in brain-controlled neuroprostheses.

EDAN (EMG-controlled daily assistant)

The mobile robot EDAN is an assistive robotics system for people with severe motor impairments. The robot is controlled using muscle signals. Its integrated shared-autonomy capabilities facilitate everyday tasks such as drinking from a glass.

EDAN is a robotic research platform for people with severe motor impairments. The sensitive lightweight robot arm and the five-finger hand ensure safety for the user and allow a wide range of interactions with the environment. Instead of the usual joystick, muscle signals are measured on the skin surface (EMG) and subsequently processed to generate motion commands for the robot. Even in cases of advanced muscular atrophy, individual muscle signals are often measurable, making the use of EDAN possible. To make use of the robot as easy as possible, so-called shared-control techniques are implemented. The robot uses its knowledge of the world to predict the intentions of the user and to assist accordingly in the execution of the task. If, for example, the robot detects that the intention is to grasp a glass for drinking, the motion commands decoded from the EMG-signals are adapted to guide the hand securely to the glass and to grasp it.



Jörn Vogel
Institute of Robotics and Mechatronics
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DLR

Feel Your Reach: Continuous robotic arm control by non-invasive EEG signals

Gernot Müller-Putz
Graz University of Technology, Institute of Neural Engineering, BCI-Lab

Decoding intended movements from individuals with spinal cord injury (SCI) has been a central topic in brain-computer interface research for decades. Recent works, relying on neural spiking activity, demonstrated that the kinematics of intended movements can be detected and used by individuals with SCI to control end-effectors [1-4]. In this talk, we summarize our attempts towards realizing an EEG-based movement decoder. This includes goal-directed movement detection [5,6], detection of error-potentials during continuous movement [7,8], the impact of vibrotactile feedback [9], and continuous arm movement trajectory decoding [10,11]. Furthermore, we present first online control of a robotic arm decoded from EEG and continuous arm movements [12,13]. We summarize our efforts to address this topic from various perspectives, and we present results of a single case study with a non-disabled participant, where we decoded the intended movement trajectories [14].

Acknowledgements: ERC Cog-2015, Feel Your Reach 681231

References

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[2] Collinger, J.L. et al., (2013) High-performance neuroprosthetic control by an individual with tetraplegia. *The Lancet*, 381(9866), pp.557–564.
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[4] Bouton, C.E. et al. (2016) Restoring cortical control of functional movement in a human with quadriplegia. *Nature*, 533(7602), pp.247–250.
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[9] Hehenberger L., et al. (2020) 'Assessing the impact of vibrotactile kinaesthetic feed-back on low-frequency EEG in a center-out task' Journal of Neural Engineering.
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[12] Mondini, V- et al (2020), 'Online EEG-based Decoding of Arm Movement for the Natural Control of an Assistive Robotic Arm' Journal of Neural Engineering, 17(4).
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[14] Müller-Putz et al. (2021)"Decoding of continuous movement attempt in 2-dimensions from non-invasive low frequency brain signals", IEEE EMBS NER21, virtual conference, May 2021.

ROS2 for Powered Wheelchairs

Abstract:

The Robot Operating System is a set of open-source software libraries and tools for building robot applications. By applying state of the art algorithms and developer tools from mobile robotics research, higher level interfaces can be implemented efficiently. We present a solution of a conventional wheelchair combined with additional sensors for evaluation of human wheelchair interaction. The combination of such a system with an BCI can ensure safe and fast brain controlled wheelchair navigation.

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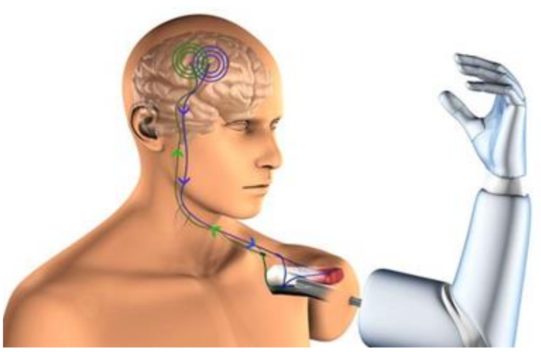
DIREZIONE CENTRALE
ASSISTENZA PROTESICA
E RIABILITAZIONE

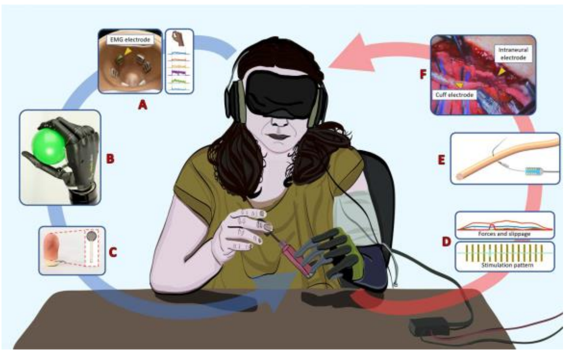
Bionics: What's Behind

Despite the advances in robotics and mechatronic made available high performance prosthetic devices, the state of art of prosthetic control has yet not evolved enough for developing fully integrated Bionic systems. Nevertheless, the Centro Protesi Inail* and its research network are currently investigating this field aiming to fuse in harmony the robotic technology and the human body. Indeed, exploiting artificial intelligence algorithms and innovative surgical techniques it has been possible to achieve simultaneous multi-limb control and restore the natural sensory feedback. Here we present the latest result of our research activity in this field showing that bionic prostheses represent a not so distant future.

The Centro Protesi Inail is a public health facility, providing rehabilitation treatment to injured workers and people with motor disabilities, applying the most advanced technologies in the field of custom made prosthetics and rehabilitation. In addition to producing prostheses, the Centre carries out significant research and experimentation activity to improve comfort, adaptability, cosmetics and functionality of prostheses and orthopedic aids.

* Italian Institute for Insurance against Accidents at Work





Inail - Direzione centrale assistenza protesica e riabilitazione (Central department of prosthetic assistance and rehabilitation)

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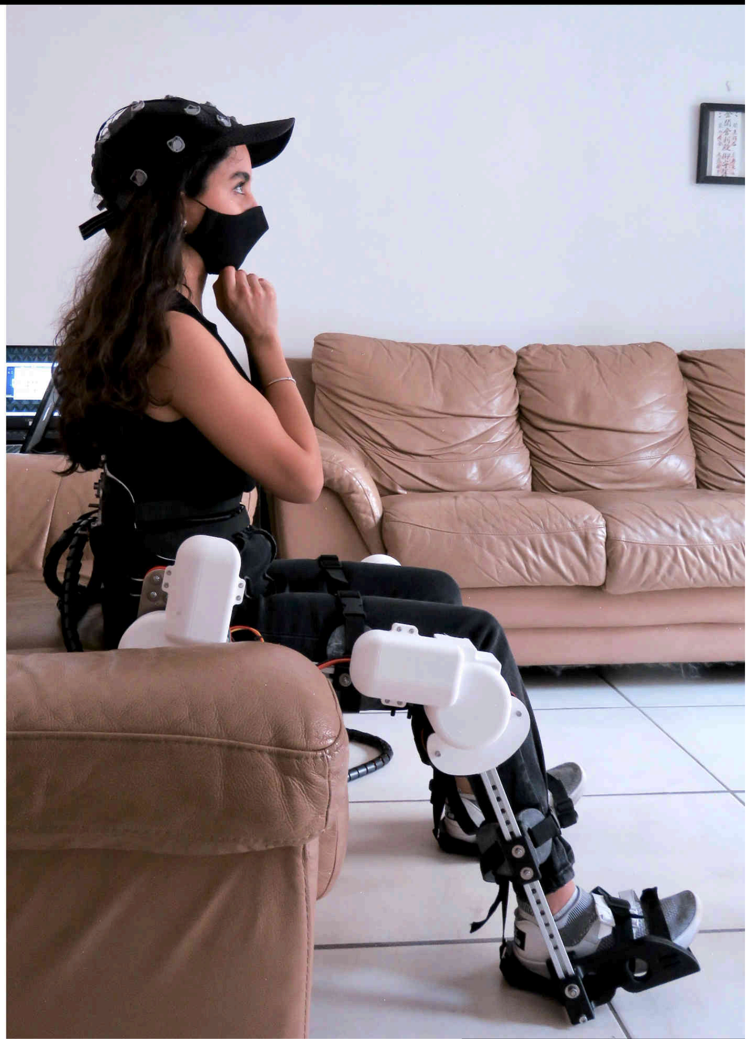
EASY Walk

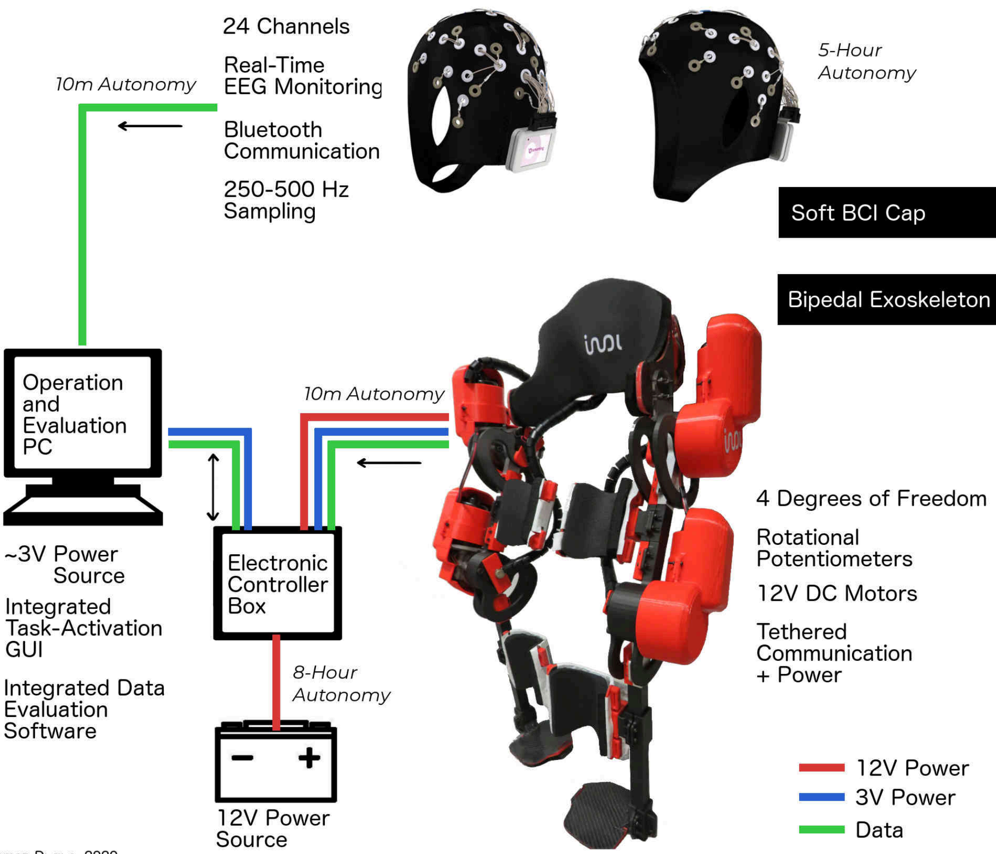
Brain-Driven Rehabilitation

- Ensure walking not only gets better, but also easier.
- Identify and track neural improvements, daily.
- Match motion data with brain data for detailed follow-ups.
- In the clinic and at home too.

Customizable Design and Functions

Lowers Costs and Frees Staff





Mobility Assistance:
Mental Workload Measurements for data-driven evaluation of motion improvement and usage naturality.

Quality of Life:
Data-Driven promotion of positive neural states for periodic therapeutic use.

Motor Functions:
Standing, Walking, Sitting, and Leg Raises.

Includes:
- **Bipedal Exoskeleton Module** with tethered Controller Box and Rechargable 12V Power Source
- **Soft BCI Cap** with wireless communications and rechargable batteries
- **EasyWalk Software** for Operation and Clinical Evaluation

Requirements and Specifications:
- PC + Windows OS
- Bluetooth Connectivity
- USB 2.0 Connectivity

AM EQUIPMENT — DIHERO — TEAM MINES Saint-Étienne — Tecnológico de Monterrey

EEG-based Brain-Machine Interface (BMI) Using Machine Learning to Control Upper Limb Robotic Arm for Rehabilitation

Junha Jung[1], Dong-Hwa Jeong[2], Adedoyin Aderinwale[1], Jaehyun Kim[1], Seungkyu Nam[3], JuYoung Yoon[3], Beomsu Kim[3], Dong Jin Hyun[3],Chulhyun Ahn[4] and Jaeseung Jeong[1]

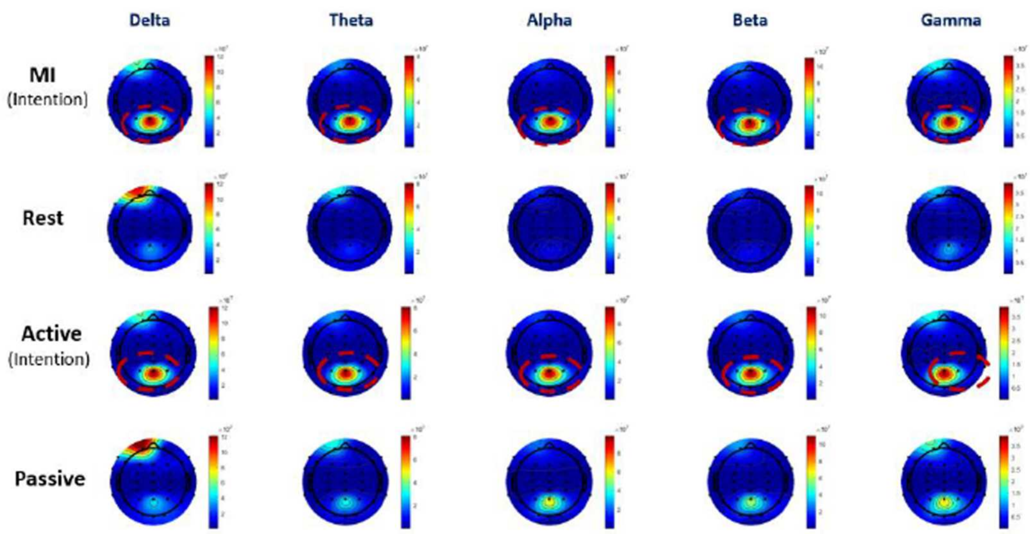
[1]Department of Bio and Brain Engineering, KAIST, [2]Department of Artificial Intelligence, The Catholic University of Korea, [3]Robotics Lab in the R&D Division of Hyundai Motor Company [4]Department of Physical Medicine and Rehabilitation, Geisinger Medical Center

Rehabilitation of stroke patients using brain computer interface (BCI) technique has been much advanced. It has been shown that rehabilitation therapy reflecting patient's motor intention is more effective for motor recovery, compared with passive robot-assisted or therapist-based rehabilitation. If the command sent to the robot reflects patient's motor intention, muscle movement and brain's motor circuit would become more synchronized, resulting in enhanced neural plasticity. The aim of this study was to examine the possibility of decoding motor intention during and without movement along with classification of various activities of daily life (ADLs) for rehabilitation.

Seven healthy subjects were asked to conduct six different types of ADLs that cover all joints of the upper limb and are most commonly practiced in neurorehabilitation. Electroencephalography (EEG) was recorded from 32 channels while subjects performed ADLs which consisted of four different conditions including motor imagery (MI), voluntary active movement, passive exoskeleton-assisted movement and resting state. To examine frequency power distributions of EEG signals, power spectral densities (PSDs) were calculated for the entire four seconds of motor task. PSDs were computed using 1 second window with 90% overlap over the 4 seconds task period. Average band power was calculated by averaging the PSD corresponding to five conventional EEG frequency bands (delta, theta, alpha, beta, and gamma), which were trained with linear discriminant analysis (LDA).

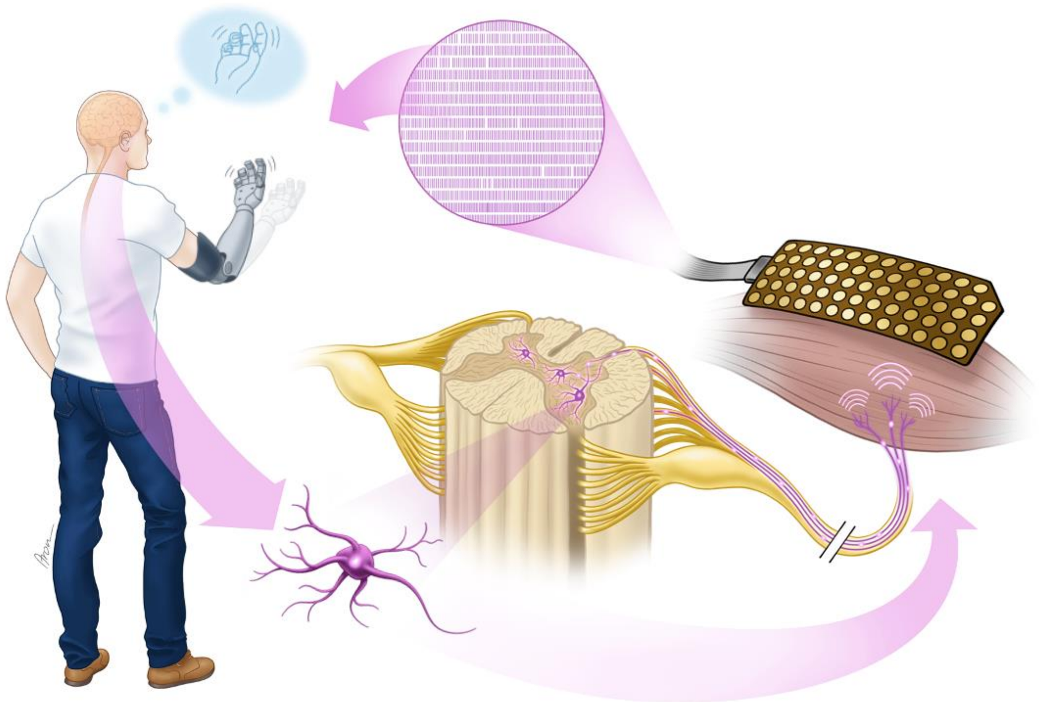
Average classification accuracy of MI and resting state was 77.42 ± 7.27% with maximum individual accuracy of 89.27%. The classification of active and passive movement was performed with 70.39 ± 0.09 % accuracy with maximum individual accuracy of 80.5%. Moreover, topographical maps of each EEG frequency band corresponding to active, passive, MI and resting state were compared to observe spatial patterns. Active and MI state, both of which contain motor intention, display similar spatial activation pattern that is different from passive and resting state. Higher activation in centroparietal area during active and MI state was a uniform pattern across all bands and was especially prominent in delta band. Such finding insinuates that the centro-parietal area is in charge of motor intention.

In this study, we were able to demonstrate successful classification of not only MI and resting state but also active and passive state. Thus, in the future study, such algorithm can be applied to BCI-based rehabilitation system for stroke patients by sending stroke patient's motor intention to the robot in real time.

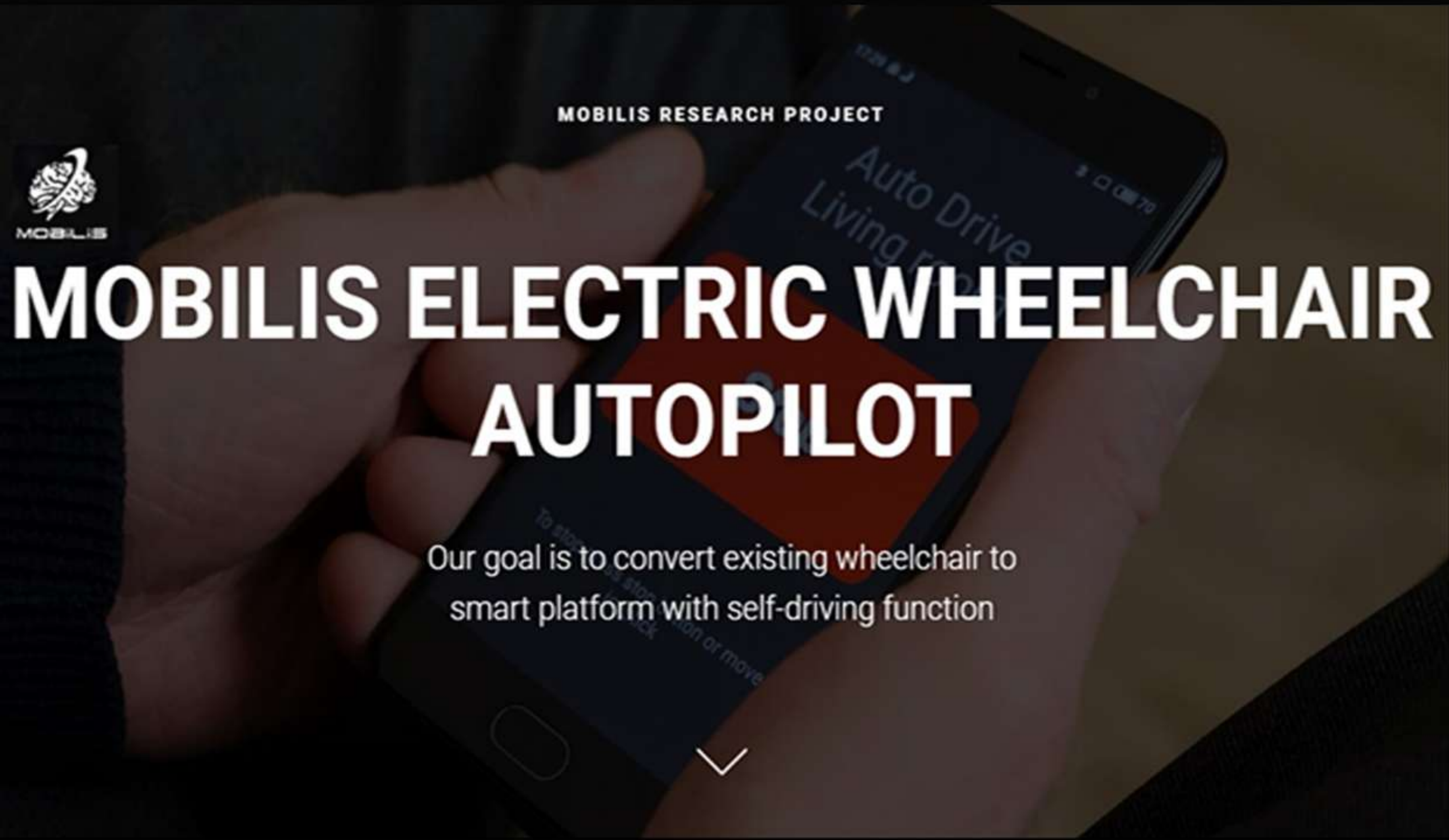


Restoration of Hand Function Using Cognitive Nerve Transfers to Control Bionic Limbs

Despite major improvements in primary prevention and acute treatment over the last decades, stroke is still a devastating disease and major cause of adult disability. Randomized controlled trials demonstrate the safety and efficacy of nerve root transfers for treatment of spastic arm paralysis after chronic cerebral injury. Here we present our first experience to restore hand function in patients with chronic spasticity after brainstroke using selective nerve transfers and EMG driven cognitive control of bionic limbs.
This treatment has the potential to be a real game-changer in this particular patient group.



INTELLIGENT ASSIST TECHNOLOGY FOR POWER WHEELCHAIR: PROBLEMS AND CHALLENGES OF PRODUCT APPROACH



TECH DAY Online Meeting focus:

The analysis of current status and future prospects of intelligent assistants for power wheelchairs (IAPW) is presented. The main problems of their real application at home are noted. In particular, despite some progress in smart PW research, people with cognitive/motor impairments still have significant problems using PW and are often barred from driving PW independently. Examples of diagnoses that can affect an individual's ability to drive PW safely include cerebral palsy, Parkinson's disease etc. The complex approach to formation of system requirements, offers and results of researches by R&D Project of Mobilis Robotics LLC on development of IAPW are presented.

http://mobilis.io/

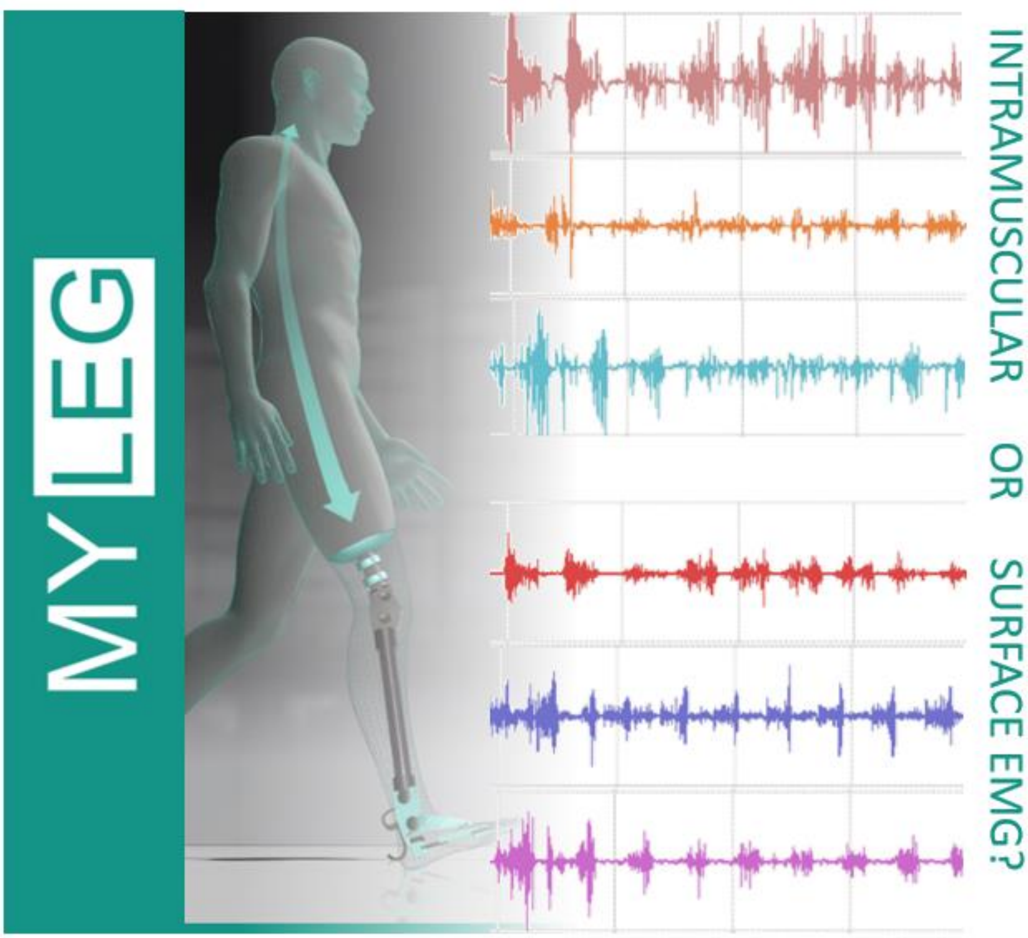
Towards a smart and intuitive controlled leg prosthesis: acquisition of intramuscular electromyography for motion intention detection. A pilot study.

E.S. van Staveren, R.V. Schulte, E.C. Prinsen, H.J. Hermens, J.H. Buurke

Objective: This pilot study explores the use of intramuscular EMG (iEMG) and targeted muscle reinnervation (TMR) to improve motion intention detection in transfemoral amputees. The hypothesis is that iEMG will improve intention detection because of reduced crosstalk and more consistent electrode sites. The TMR sites will provide valuable extra information for motion intention detection.

Methods: A study population of able-bodied individuals (n=5), transfemoral amputees (n=5), and transfemoral amputees with TMR (n=5) will be included in this observational study. During the measurements iEMG (fine-wires), sEMG (multi-array) and lower body kinematics are measured while participants execute activities like sitting down, walking on uneven terrain, and stair/ramp ascend/descend.

Results: Preliminary results will be presented.



SMART ROBOTIC DEVICE FOR MOTOR & COGNITIVE LEARNING OF INDIVIDUALS WITH SPECIAL NEEDS

Konstantin Sonkin and Jason Friedman

Technological solutions for supporting learning in people with special needs should be developed in order to satisfy a huge unmet demand. This project aims to solve the problem of low efficiency and availability of solutions for both cognitive and motor learning of individuals with cerebral palsy and brain injuries.

The developed solution aims at supporting learning of individuals with movement and cognitive impairments, through a real-time human-robot interaction system based on decoding of EEG signals and movement recordings performed by AI techniques.

The system allows users with special needs to interact in a fun way with a 3-D printed mobile robot controlled by their brain and body signals.

The project has three main goals:

1) make learning for target users personalized and playful,

2) perform simultaneous motor and cognitive learning, and

3) make the solution affordable through 3-D printed robots and off-the-shelf electronics.

The developed smart robotic device for learning and training was tested on healthy subjects, adjusted for specific requirements of individuals with cerebral palsy, and tested on the pilot group with a full longitudinal study to start soon.

Post-stroke rehabilitation with a BCI-robotics system that enables visuomotor transformation

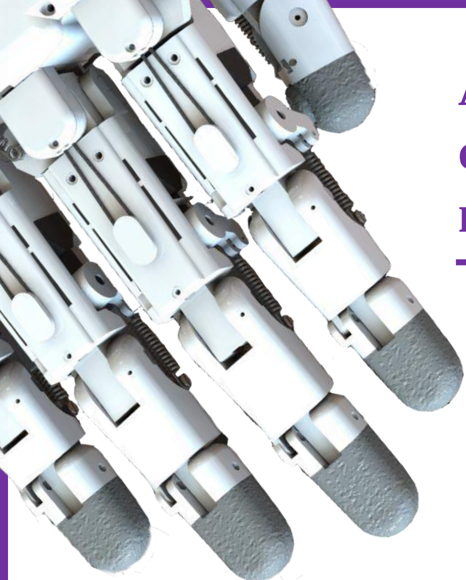
Mikhail Lebedev

V. Zelman Center for Neurobiology and Brain Restoration, Skolkovo Institute of Science and Technology, Moscow 121205, Russia

mikhail.a.lebedev@gmail.com

Post-stroke rehabilitation is a challenging task that could be aided by BCI technology. Here we report a novel approach to rehabilitation of motor function, which is based on BCI robotic control that enables visuomotor transformation of motor targets into arm reaching movements. The BCI classifiers event-related potentials triggered by potential targets, selects the target chosen by a patient and then uses a robotic device to carry the patient’s arm toward the target. These operations are enhanced by virtual reality settings. This approach significantly increases the number of patients, especially stroke survivors, that can be effectively treated at early stage of the disease when rehabilitation is most effective. This rehabilitation method has been successfully tested in clinical settings, with positive results.

Funding: This work is supported by the Russian Science Foundation under grant No. 21-75-30024.

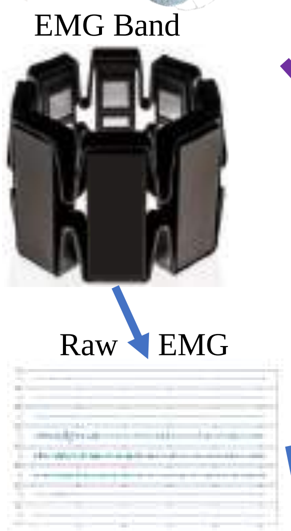


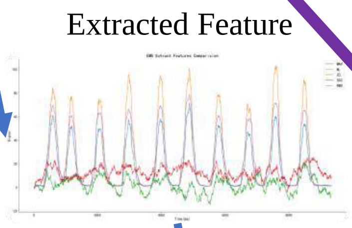
A multi-gesture anthropomorphic hand online control: based on surface EMG signal and neural network

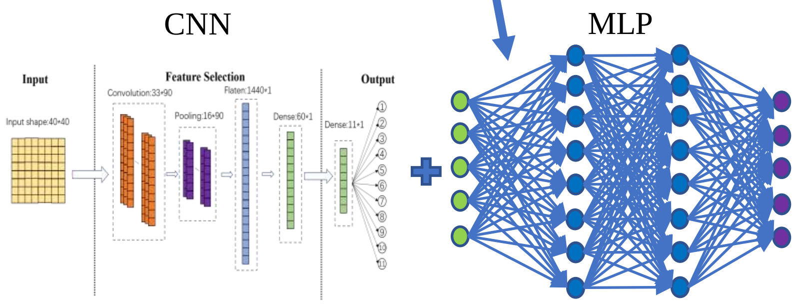
An sEMG-based real-time multi-gesture control system running on a published anthropomorphic robotic hand (MCR Hand). The raw surface EMG signal was extracted by 5 time-domine features in different sliding window size.

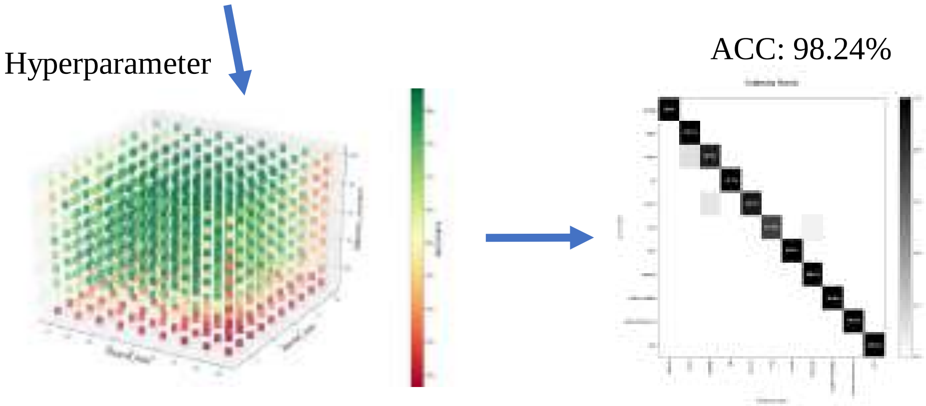
The features were standardized and classified by two neuron network models, i.e., MLP and CNN. Weighted-voting method was adopted to obtain the classification results from the models mentioned above.

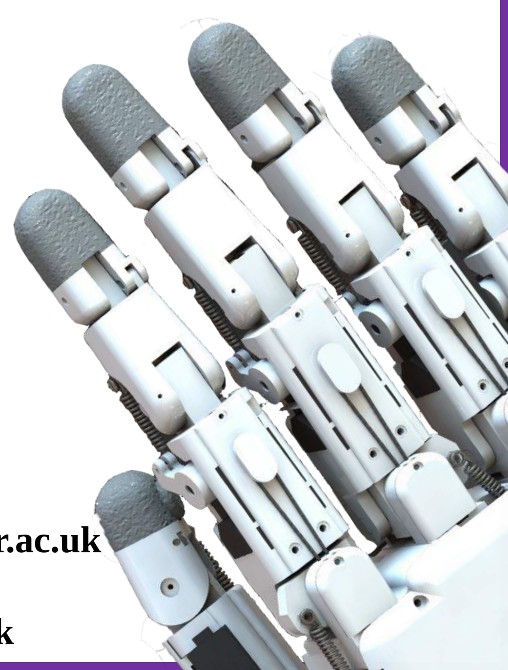
The anthropomorphic hand accomplishes 11 gestures based on real-time sEMG signal of a healthy subject with 98.24% accuracy.











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EEG signals, feedback, and brain-computer interfaces in support of upper and lower limb rehabilitation: current status

Review of the state of the art and limitations in the development of BCI for rehabilitating the upper and lower limbs of the human body. A systematic review was conducted in databases considering using EEG signals, interface proposals to rehabilitate upper/lower limbs using motor intention or movement assistance, and utilizing virtual environments in feedback, specification, processing, and control. It was identified that 61.11% corresponded to applications to rehabilitate upper limbs, 33.33% lower limbs, and 5.56% both. Likewise, 33.33% combined visual/auditory feedback, 11.11% haptic/visual, and 11.11% visual/auditory/haptic. In addition, 27.78% had fully immersive VR, 16.67% semi-immersive VR, and 55.56% non-immersive VR. In summary, the studies show that EEG and feedback within a BCI system increases the efficiency of the system, and that there is a need to further develop interfaces that are efficient, accessible to users, and that integrate visual, auditory, and/or haptic feedback techniques.

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Shared Control of a Robotic Arm using Brain-Computer Interfaces and Robotic Vision

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The brain-computer interfaces (BCIs) based on non-invasive electroencephalography (EEG) have been widely used. However, the low-quality of EEG signals may cause problems of poor decoding accuracy and low control dimension, which adversely affects the performance of non-invasive BCIs during real-time process control in complex tasks. In this work, a brain-actuated robotic arm system based on shared control was developed, which allowed noninvasive BCI users to manipulate a robotic arm with six degrees of freedom moving in a three-dimensional (3D) space and complete a pick-and-place task of multiple objects. We introduced a hybrid BCI scheme that integrated motor imagery and steady state visual evoked potentials to raise the control dimension of the robotic arm.

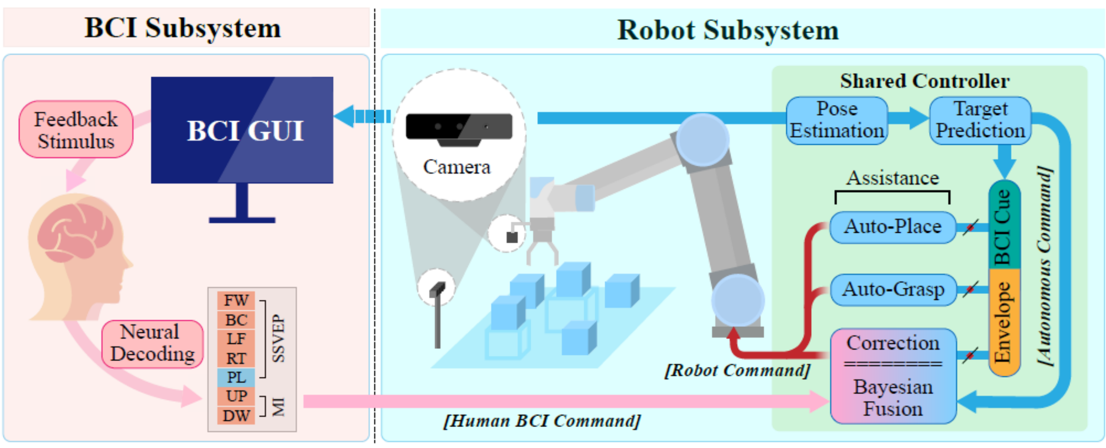

Figure 1: Architecture of the brain-actuated robotic arm system. The platform consisted of BCI (left box) and robot (right box) subsystems. The subject executed the hybrid paradigms through GUI and output BCI commands to the robot subsystem. The robot subsystem predicted user intention and generated autonomous commands, then fused human and machine agent commands into robot control instructions with Bayesian information fusion theory. One RGB-D camera was fixed at the end of the robotic arm to detect the objects, whose poses would be calculated as the knowledge base for shared control. The other camera was employed scene image feedback based on the third view angle.

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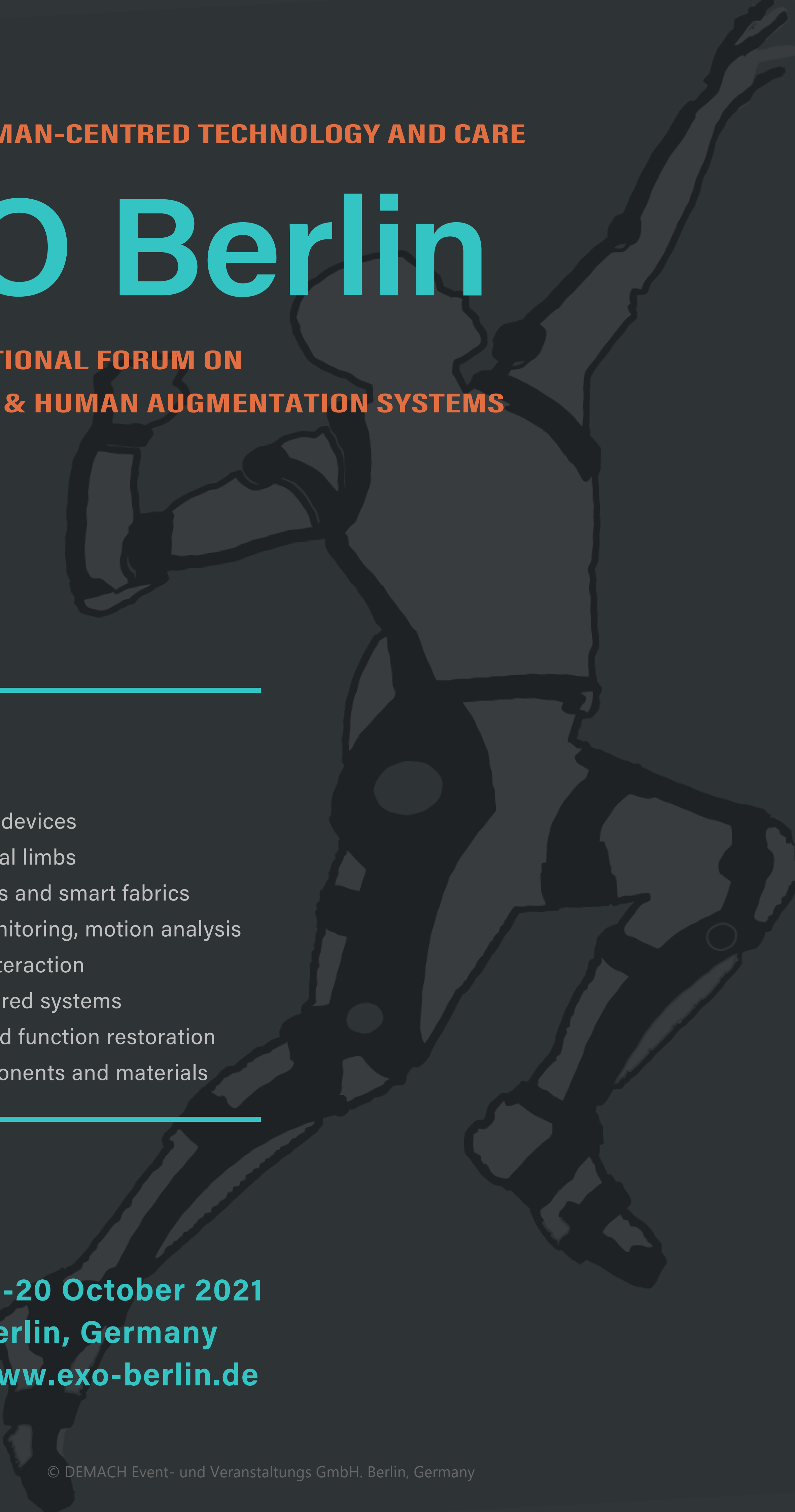

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