Upper limb exoskeleton for neurorehabilitation with control via brain-computer interface

Vladimir Antipov
Neuroscience and Cognitive Technology Laboratory
Center for Technologies in Robotics and Mechatronics Components
Innopolis University
Innopolis, Russia
vantipovm@gmail.com

***Abstract*—This paper describes the results of developing control methods for an active exoskeleton for rehabilitation of human upper limb motor activity. The experimental setup, real-time software implementation of the control system, and also the developed software environment for stimulation of the subject during the neurophysiological experiment are described. The research object of the above system is the processes of activation of brain areas in terms of analysis of bioelectrical electroencephalographic signals registered during a motor activity, suitable for use in the tasks of motor rehabilitation. The purpose of this work is to develop a hardware-software part of the experiment to study real-time algorithms for control of the upper limb exoskeleton for rehabilitation and education tasks using "brain-computer" interfaces.**

***Index Terms*—electroencephalography, patterns, frequency-time analysis, motor activity, brain-computer interface, limb exoskeleton**

I. INTRODUCTION

Traditionally, one of the main applications of brain-computer interfaces is control of external devices, such as anthropomorphic manipulators, robots and exoskeletons, by means of neural activity generated by imaginary movements [1]–[6]. In this regard, the use of BCIs is aimed at improving the quality of life of people with impaired motor functions due to neurodegenerative diseases or loss of limbs. In particular, a large number of studies are devoted to the development of brain-computer interfaces for rehabilitation after stroke [7]–[9] and spinal cord injury [10], control of bioprosthesis after limb amputation [11] and paralysis [12]. Therefore, the field of development of brain-computer interfaces is particularly important.

II. EXPERIMENTAL SETUP

To conduct an experiment of real-time exoskeleton control algorithms investigation, an upper limb neurotrengager was chosen as the exoskeleton. The main components of the used neurotrenger are two robotic arms equipped with six active and six passive degrees of freedom. The main components and the appearance of the experimental setup are shown in Figure 1.

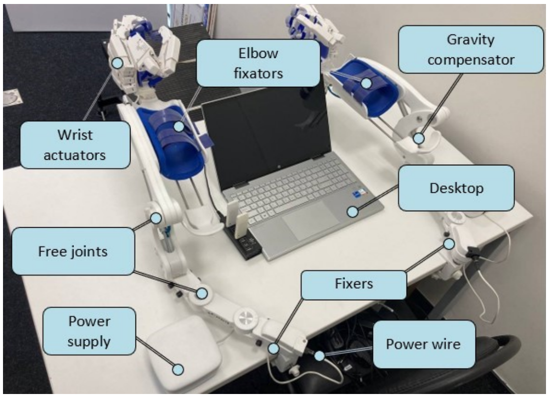

Fig. 1. Experimental setup.

Linear servo actuators are installed in each active joint to bend and unbend the individual fingers of the human hand. The installation of linear gears in the actuators is due to the high torque on the output shaft of the actuator. This makes it possible to overcome muscle resistance in case of spasticity, or if the test person has completely or partially lost motor functions.Each finger is securely fastened with flexible self-adhesive Velcro.

The fixation ensures the correct positioning of the fingers as well as the correct execution of the exercise. The neurotrainer is also equipped with an additional actuator for positioning the thumb in the frontal plane; this improves the ergonomic fixation and adapts the device to the individual characteristics of the test person. The elbow locks shown in Figure 1 are used to provide a more secure hold on the entire arm of the test subject.

A custom wireless communication module is used to control each individual arm of the neurotrainer. This module allows you to send and receive control commands from the device in real time and over long distances. To work with this module it is necessary to install additional drivers. To increase mobility, the neurotrainer is equipped with an external battery pack. This unit allows the device to work continuously for more than 4 hours.

III. REAL-TIME CONTROL

To control the robotic arms of the upper limb neurotrainer in real time, a software module was developed to control the

978-1-6654-6174-0/22/$31.00

position of each actuator of the system. The general functional scheme of the experimental setup, as well as the methods of interaction between the various blocks and coprograms of the system are shown in Figure 2.

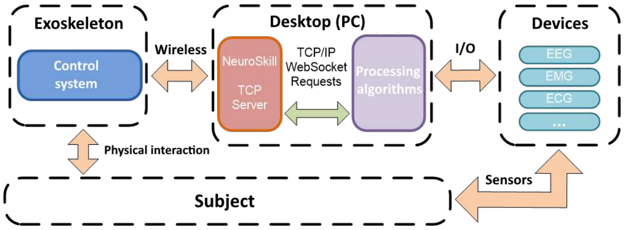

Fig. 2. Functional scheme of the experimental setup, interaction and methods of data transfer between the various units of the system.

The low-level servo drives are controlled by the ACS installed on the controllers of each robotic arm. The controllers, in turn, are connected wirelessly to the workstation using special modules. The basic functionality of the network interfaces is provided by the NeuroSkill software. This software deploys over TCP/IP stack a web-server in the local network. To access the server we provide an API based on WebSocket (http) requests. To work with this API a program module was developed - ”Rapper” in Python language. This module is a class that provides a programming interface to each active actuator on the neurotrainer. A set of methods allows you to flexibly control the speed, compression/extension force and position of each limb of the human hand. To detect the correctness of the commands, the program allows to get the current state of various system parameters in real time. For this a special GET-request to the server is sent and then a JSON-structure describing requested states is returned. Parsing of this structure and reading of each of its fields allows to get the required parameter and to correct the execution of the main program.

To provide real-time operation, the Rapper is run in a separate thread, which allows you to maintain a high operating speed and low latency of the system. This is due to the high load on the main program module, which processes and analyzes the EEG data. To measure the EEG signals, the ActiCHamp electroencephalograph is used, which allows reading 64 channels of sensor information at a frequency above 1000 Hz. The sensors are attached to the patient’s head with an individually fitted actiCap. In addition, 3 EMG sensors can be installed on each arm, which are recorded using the Encephalan-EEGR-19/27 module with a sampling rate of 250 Hz. Based on this, the developed functional scheme of the experimental setup can be described as follows: different sensors recording bioelectrical signals are attached to the subject; in turn, the sensors are connected to a measuring device (amplifier), which performs primary filtering and buffering of the measured information. Then the measuring devices are connected to a ”workstation” (for example: personal computer, single-board computer, etc.) and transmit the measured data to the ”BrainVision” (or similar) work program, which retransmits the data to the ”data processing algorithm” module. The algorithm implements methods to extract the pat-terns associated with imaginary upper limb movements. Then, via WebSocket requests, the control actions are transmitted to the ”NeuroSkill” software, which converts and retransmits the necessary data via a wireless communication module to the neurotrainer ACS. The device then begins to exercise and ”activate” the subject’s arms by flexion/extension movements, thereby closing the biofeedback loop, which allows increasing the efficiency of the process of rehabilitation of human upper limb motor activity using the active exoskeleton.

IV. Conclusion

In the course of the work, a method for controlling an active exoskeleton for rehabilitation of human upper limb motor activity was developed. The experimental setup and developed methods were tested Figure 3. The cross-platform software was developed, which allows to quickly implement various multimodal algorithms of the subject’s stimulation in the process of conducting various neurophysiological experiments.

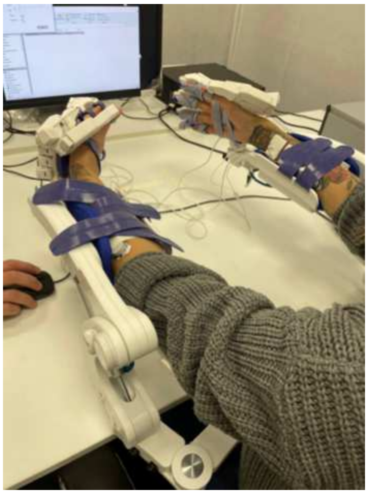

Fig. 3. Illustration of the process of conducting a neurophysiological experiment.

V. ACKNOWLEDGMENTS

This work has been supported by the Center for Technologies in Robotics and Mechatronics Components (Innopolis University)

References

[1] B. He, B. Baxter, B. J. Edelman, C. C. Cline, and W. Y. Wenjing, “Non-invasive brain-computer interfaces based on sensorimotor rhythms,” *Proceedings of the IEEE*, vol. 103, no. 6, pp. 907–925, 2015.

[2] A. A. Badarin, V. V. Grubov, A. V. Andreev, V. M. Antipov, and S. A. Kurkin, “Hemodynamic response in the motor cortex to execution of different types of movements,” *Izvestiya VUZ. Applied Nonlinear Dynamics*, vol. 30, no. 1, pp. 96–108, 2022.

[3] N. S. Frolov, E. N. Pitsik, V. A. Maksimenko, V. V. Grubov, A. R. Kiselev, Z. Wang, and A. E. Hramov, “Age-related slowing down in the motor initiation in elderly adults,” *Plos one*, vol. 15, no. 9, p. e0233942, 2020.

[4] V. V. Grubov, A. A. Badarin, N. S. Frolov, and E. N. Pitsik, "Analysis of real and imaginary motor activity with combined eeg and fnirs," in *Saratov Fall Meeting 2019: Computations and Data Analysis: from Nanoscale Tools to Brain Functions*, vol. 11459. SPIE, 2020, pp. 56–63.

[5] V. Maksimenko, V. Khorev, V. Grubov, A. Badarin, and A. E. Hramov, "Neural activity during maintaining a body balance," in *Saratov Fall Meeting 2019: Computations and Data Analysis: from Nanoscale Tools to Brain Functions*, vol. 11459. SPIE, 2020, pp. 6–11.

[6] G. Guyo, A. Pavlov, E. Pitsik, N. Frolov, A. Badarin, V. Grubov, O. Pavlova, and A. Hramov, "Cumulant analysis in wavelet space for studying effects of aging on electrical activity of the brain," *Chaos, Solitons & Fractals*, vol. 158, p. 112038, 2022.

[7] K. K. Ang and C. Guan, "Brain–computer interface for neurorehabilitation of upper limb after stroke," *Proceedings of the IEEE*, vol. 103, no. 6, pp. 944–953, 2015.

[8] V. Grubov, A. Badarin, N. Schukovsky, and A. Kiselev, "Brain-computer interface for post-stroke rehabilitation," *Cybernetics and physics*, vol. 8, no. 4, pp. 251–256, 2019.

[9] A. Chepurova, A. Hramov, and S. Kurkin, "Motor imagery: How to assess, improve its performance, and apply it for psychosis diagnostics," *Diagnostics*, vol. 12, no. 4, p. 949, 2022.

[10] G. R. Müller-Putz, P. Ofner, A. Schwarz, J. Pereira, G. Luzhnica, C. di Sciascio, E. Veas, S. Stein, J. Williamson, R. Murray-Smith *et al.*, "Moregrasp: Restoration of upper limb function in individuals with high spinal cord injury by multimodal neuroprostheses for interaction in daily activities," 2017.

[11] D. P. Murphy, O. Bai, A. S. Gorgey, J. Fox, W. T. Lovegreen, B. W. Burkhardt, R. Atri, J. S. Marquez, Q. Li, and D.-Y. Fei, "Electroencephalogram-based brain–computer interface and lower-limb prosthesis control: A case study," *Frontiers in neurology*, vol. 8, p. 696, 2017.

[12] K. Bowsher, E. Civillico, J. Coburn, J. Collinger, J. Contreras-Vidal, T. Denison, J. Donoghue, J. French, N. Getzoff, L. Hochberg *et al.*, "Brain–computer interface devices for patients with paralysis and amputation: a meeting report," *Journal of neural engineering*, vol. 13, no. 2, p. 023001, 2016.