How to cite this article:

Authors: Jaroslaw Jankowski, Klaudiusz Ziemek

Title of article: „Sterowanie manipulatorem nasobnym w oparciu o sygnały EMG" („Control method of the wearable manipulator based on EMG signals")

Mechanik, Vol. 91, No. 7 (2018): pages 582-584

DOI: https://doi.org/10.17814/mechanik.2018.7.90

Control method of the wearable manipulator based on EMG signals

Sterowanie manipulatorem nasobnym w oparciu o sygnały EMG

JAROSLAW JANKOWSKI
KLAUDIUSZ ZIEMEK *

Human integration with the exoskeleton, so that it correctly reflects the intentions of the user, requires the use of an appropriate control method containing an intent detection algorithm. The article presents the assumptions concerning the construction of the upper limb exoskeleton, the preliminary research procedure and the pre-developed methods of controlling the assistance manipulator based on the analysis of the electromyographic signal (EMG) characteristics and the use of neural networks.

KEYWORDS: exoskeleton, control method, EMG

In the modern world, very heavy physical work has been almost completely eliminated thanks to the mechanization and automation of many areas of life. However, there are situations when a man is irreplaceable, but the strength of his muscles turns out to be insufficient to carry out the tasks entrusted to him. This applies to emergency situations, such as accidents or catastrophes, when rescuers are required to use a lot of force (needed, for example, to transport wounded), as well as cases such as nursing a sick person. A special group are people with disabilities, with limited muscle strength. In their case, professional work and even simple activities of everyday life are significantly hampered.

In all these situations, an exoskeleton, i.e. a mechatronic system mounted outside the human body, which aims to strengthen the strength of its muscles, can be used to support a human being [1]. Assisted devices designed for upper limbs are divided into prostheses and orthoses. The prosthesis is an artificial substitute for the missing part of the body, while the orthosis is an orthopedic device used to support and correct the limb movements to improve their functionality [2]. Orthotics are divided into two main types:

- devices constructed to support user's users' effectors,
- devices whose individual movable joints are matched to the subsequent joints of the limb [3].

The first type of orthosis includes freestanding solutions whose principle of action is to apply force to the executive organ in such a way as to support or hinder its movement [4]. The second type of braces, called assisted exoskeletons, are devices applied to the user's body. The robot joints and their joints are well suited to the joints and limbs of the user, and the axis of rotation of the robot joints should be positioned in accordance with the anatomical capabilities of the upper limb.

Robotic exoskeletons are the subject of research in such areas as: rehabilitation [5], increased muscular strength of the human and sensory interaction in teleoperation and virtual environments [6]. Issues of rehabilitation and assistance of robotic devices are becoming more and more important due to the potential of this technology in supporting physically weaker older people.

A very important element of the exoskeleton is the control of its drives. The requirements for control systems of robotic exoskeletons differ significantly from the requirements for solutions used in classical industrial robots. This is due to the fact that man is not only the source of commands, but also part of the system in which the device implements these commands. The uniqueness of the situation also consists in the continuous exchange of information between the user and the exoskeleton. Thus, the basic principle of the control system design is the behavior of robotic elements in accordance with the user's intentions. This assumption is particularly important in the case of physically weaker people. It should be remembered that there are two cooperating control centers in each assisted exoskeleton system: robot controllers and the user's brain. Detection of intentions of human movement is still far from perfect and is an important topic of basic research in the development of exoskeletons. Depending on the type of information, such systems can be divided into two categories on the input:

- systems based on non-biological signals
- systems based on biological signals.

In solutions based on non-biological signals, joysticks [7] are used, which usually control the exoskeleton in a precise, but not very intuitive way, as well as force and rotation sensors that capture the user's movement intention and strengthen it with the work of the actuators. In the second category of systems, the most frequently used are

* Dr inż. Jarosław Jankowski (jajan@ciop.pl), mgr Klaudiusz Ziemek (klazie@ciop.pl) – Centralny Instytut Ochrony Pracy – Państwowy Instytut Badawczy

electromyographic signals (EMG) [8, 9]. Attempts are also made to interpret the activity of the cerebral cortex, but this area requires further development work. The signal collected from appropriately stuck electrodes can be interpreted and used to control the exoskeleton. In this case, the problem is to ensure the right precision of movements.

Regardless of the solutions adopted, the detection of movement intentions is a very complicated technical issue, the solution of which is one of the greatest challenges for the further development of assisted exoskeletons.

The possibility of obtaining and processing EMG signals (on selected muscles of the upper limb) recorded in real time and in a manner ensuring the achievement of accuracy as close as possible to achieve with manual control devices in the control of the upper limb exoskeleton is the main research issue within the project implemented in Central Institute for Labor Protection - National Research Institute.

The aim of this project is to develop an exoskeleton model controlled by a special system based on signals informing about muscle activity and manual control devices.

Methodology of research and applied tools

The developed supporting device, controlled by two different methods, will be tested and compared by five people (men), subject to receiving a positive opinion from the ethics and bioethics commission about the proposed tests.

Tests will be conducted with three people aged up to 35 years and two people over 60 years of age. Before testing, these people will undergo training and will be provided with information on how to use the device.

Tasks set for users of the device will consist in precisely guiding the final effector to a specific place, indicated and displayed on the screen with the rear projection. The hand movement will be carried out with the manipulator loaded with a weight of 1 kg, 2 kg or 3 kg and without load, for about 30 minutes (with short intervals). In addition, volunteers will be asked to change the distance from the screen, which will allow you to take full advantage of the exoskeleton's capabilities.

During the research, objective information will be collected regarding:
- accuracy of the effector's conduct,
- mistakes made,
- task execution time.

The subjective evaluation of the exoskeleton will refer to its usefulness, convenience of use and suitability. Before and after the tests, participants will make a subjective assessment of fatigue and mood using the Grandjean scale.

However, the following surveys will be used to directly assess the developed solutions:
- questionnaire on the technology acceptance model [10],
- system usability scale [11],
- author's questionnaire, referring to the subjective assessment of the comfort of use and usability of the tested solution.

Assumptions regarding construction and use

The task of the exoskeleton will be to assist the user in terms of the generated force. The basic group of recipients will be people with a deficit in this area (older people, people with physical disabilities). The control method based on EMG signals will be able to successfully use (in the area of elbow joint motion support and - to a limited extent - in the shoulder joint) also fully functional people - especially for tasks requiring increased strength, which will help reduce fatigue, e.g. during long-term and monotonous assembly or storage work.

The exoskeleton will be battery powered, with the possibility of changing the battery without interrupting work. It is planned to use 24 V batteries. The model of the right hand exoskeleton will support its movement in the sagittal plane of the elbow (bending and straightening of the forearm) and movement in the shoulder (bending and straightening the arm). The construction of the exoskeleton will not block the remaining movements of the forearm. The exoskeleton will be equipped with two servos with appropriate transmissions, so that the output torque of the constant operation is at the level of approx. 35 Nm in the case of supporting the arm and at least 10 Nm in the case of forearm support (for the lifting capacity of the effector is at least 30 N). The exoskeleton will be hung on a frame worn on the back with a hip belt and will be made of composite materials and aluminum. Prototyping will be carried out using the 3D printing technique. It is assumed that the construction of the manipulator will be attached to the upper limb by means of special bands enabling easy removal of the device. In addition, the keypad will end with a special hand grip.

The developed hardware solution is necessary for creating and testing control methods that will be compared on the basis of planned user tests in the final phase of the project. A special handle for the hand will also be retrofitted with a joystick. The manipulator design will limit the minimum and maximum deflections of its members. Assisted movement in the elbow joint within 120° of the angular position of the forearm, counting from full extension, and support in the shoulder joint in the sagittal plane within at least 60 ° angular position of the arm, counting from full extension. In addition, an emergency shutdown device will be used.

Method of controlling the assistance manipulator, using the EMG signal

In the proposed method, which will be tested in the next stage using the full exoskeleton model, there are three input elements: the level of EMG signal amplitude, information on the user's intent, i.e. the direction of movement of individual members of the upper limb considered, and information about the degree of manipulation by the manipulator (level this support will be decided by the user).

On the basis of information about the direction of movement of individual members, the support is activated by applying the moment in specific "joints" of the manipulator, proportional to the level of muscle activity (contemplated muscle dependent on the direction) and information about the degree of manipulation by the manipulator (this information depends on the user). The electric drives used will be controlled using the Profile Torque Mode profile, compliant with the CANopen DS402 standard.

As part of the control method presented above, the most important and at the same time the most difficult is to obtain information about the intentions of the user. For this reason, two algorithms for obtaining this information were developed and studied, based solely on the signals from the muscles: a two-headed arm and a three-headed arm. These muscles were selected on the basis of the conducted experiment - as the most involved in the course of the assumed motion, at which support should occur.

In order to recognize the intentional movement in the elbow joint, two signals of bicep and triceps activity should be compared. In the created algorithm, the difference in absolute values of these signals is a measure of the direction and strength of the forearm. A characteristic feature of EMG signals is the derivation of the derivative at the beginning of muscle work, which in this algorithm is used as a signal informing about the action of the muscles. Then it is checked whether there has been a leap in derivatives of both signals, which would mean isometric tension.

Once it is known that only one of the signals showed activity, the difference between the absolute values of both signals is determined. Such information suffices to distinguish the direction of intentions and to estimate the intended strength and, consequently, to use it to reduce muscle tone by acting with the appropriate moment of forces in the designated direction.

An alternative solution to the problem of identifying human intentions is to create a neural network recognizing EMG signal characteristics and determining a parameter whose sign corresponds to the direction of the intended action, and the absolute value translates into the intended force - similar to the first method. For this purpose, software was created to generate neural networks with different parameters (number of network layers, number of neurons in individual layers). In addition, the possibility of using various activation functions for a given neural network has been introduced.

A backward propagation algorithm that requires a large amount of preliminary data is used to teach the network.

Due to the difficulty of estimating the desired value for comparison and evaluation of the developed method using an electromyographic signal, a control system for two servo motors will be made, based solely on information coming from a potentiometric biaxial joystick. Joystick deflection in the *X* and *Y* axes will change the position of the effector relative to the shoulder joint - respectively the distance/zoom and raise/lower, the rate of change will be proportional to the degree of joystick deflection.

Conclusions

The exoskeleton must correctly reflect the intentions of the user and provide him with physical and mental comfort, which is why it is so important to integrate the exoskeleton with the human. For this it is necessary to develop an appropriate control method.

The article presents the assumptions concerning the construction of the upper limb exoskeleton as well as the initial research procedure aimed at assessing and comparing two control methods. Pre-developed control methods for the support manipulator based on the analysis of electromyographic signal characteristics (EMG) and the use of neural networks are discussed. In the next stages, the exoskeleton model will be developed, and moreover, work will be carried out on improving control methods and algorithms for detecting the movement intentions of the arm and forearm of the future user supporting the manipulator.

Publication based on the results of the fourth stage of the multi-annual program "Improving safety and working conditions", financed in 2017-2019 in the field of research and development works by the National Center for Research and Development.
Program coordinator: Central Institute for Labor Protection - National Research Institute.

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Translation of scientific articles, their computer composition and publishing them on the website www.mechanik.media.pl by original articles in Polish is a task financed from the funds of the Ministry of Science and Higher Education designated for dissemination of science.

Ministry of Science and Higher Education
Republic of Poland