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electro-hydraulic positioning system,
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parallel manipulator

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BRAIN-COMPUTER INTERFACE FOR CONTROL OF ELECTRO-HYDRAULIC SERVO DRIVE

The aim of the study was to perform bioelectric signal analysis focusing on its applicability to control of the electro-hydraulic servo drive. The natural bioelectric signals generated by brain, facial muscles and eye muscles read by the NIA (Neural Impulse Actuator) are translated into control commands in the controller of electro-hydraulic servo drive. Bioelectric signals detected by means of special forehead band with three sensors are sent to the actuator box, where they are interpreted as control signals. The test stand was constructed to control of the electro-hydraulic servo drive by means of bioelectric signals generated by the operator. The control signals from the actuator box are transmitted via a wireless network to the controller of electro-hydraulic positioning drive.

1. INTRODUCTION

The ideal of the Brain Computer Interface (BCI) would be human communication with the machine “by means of thought”. Currently, BCI systems working with the use of EEG and EMG signal do not allow free communication using “direct thoughts”. The brain and body provide a wealth of information about a person’s physiological, cognitive and emotional states. There is an increasing trend to use physiological signals in computerised systems as an input control, and since entry level physiological sensors have become more widespread, physiological interfaces are liable to become pervasive in our society (e.g., through mobile phones). The three main components of the brain are cerebellum, cerebrum and brain stem. Cerebellum is located between brain stem and cerebrum. Cerebellum controls facial muscle coordination, thus affecting signals (eye movements and muscle movements) by Brain-Body Interface (BBI) [1]. Various devices read bioelectrical signals (e.g. electrocorticographic signals, skin biopotential or facial muscle tension) and translate them into computer understandable input. The concept of BCI involves communication between a human brain, and an external computer device. Stimulating muscles, eyeball

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movement or a bioelectrical change in the brain's activity causes a change in people biopotentials, which may be measured and used as a control signal. Human-Computer Interface (HCI) enables people to control computer applications using bio-electric signals recorded from the body. Bioelectrical potentials (bio-potentials) are made up of four different signals: electrooculography (EOG), .electromyography (EMG) and Electro-encephalography (EEG) [2]. Bioelectrical signals may be also used for operating electro-hydraulic servo system. The machine operator's reaction time may be significantly reduced if become equipped with an appropriate interface which measures and analyses bioelectric signals. Then sends appropriate control signals to the operated electro-hydraulic servo system. A good example is an emergency stop of a device activated by pressing the emergency stop button using "thoughts", which would contribute to the safety of the elctro-hydraulic control systems.

The use of wireless communication will also contribute to improvements in safety, particularly if the operator is right next to the operated machine. In order to test the use of bioelectric signals and wireless communication in the control of electro-hydraulic position system a Wireless Network Interface Controller (WNIC) was built.

2. ELECTRO-HYDRAULIC SERVO CONTROL

At the beginning of technological machines, hydraulic drives had by far the best static and dynamic characteristic that led to their widespread use. Today, in the machines dominate the electric drives with continuous rotary motion and linear electric motors [3]. To meet the competition, which is caused by motor driven systems it necessary to solve the constant changes of hydraulic power circuits. The hydraulic servo applications are particularly important to stabilize the position of machine elements that are working for the whole range of displacements at which the characteristics of the propulsion system must be capable of obtaining stable positions at any point throughout the operating range. Along with servo control systems they form servos with software or follower position control, speed or strength. Attempts to use electro-hydraulic servo actuators, which would be competitive to electric servo motors, focus on the area of heavy-duty machines, which use high velocity and acceleration of movement [4]. An example of an integrated electro-hydraulic servo drive is shown in Fig. 1.

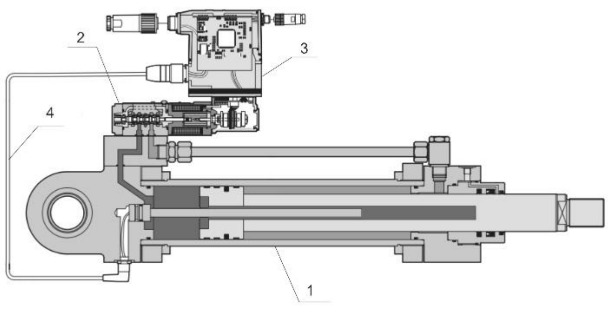

Fig. 1. Electro-hydraulic servo actuator: 1 – servo cylinder with position transducer, 2 – proportional valve, 3 – integral digital controller, 4 – position feedback signal [5]

Control systems for hydraulic systems enable the precise control of position and speed component that are produced even under overload and load changes. This is made by performing control, using a complex algorithms which minimizes some of the disadvantages of these drives. With the ability to develop high power with compact dimensions and relatively low weight, electro-hydraulic servo drives are widely used in machines in various industries. Very easy to control basic operational parameters provide great opportunities for automation and remote control. Designing of electro-hydraulic servo system is difficult because their manufacturers, in contrast to the electric servo drive manufacturers do not provide precise methods and tools to support this process [6].

2.1. BASIC POSITION CONTROL SYSTEM

The control systems of this type takes continuous measurement of the position of the piston rod (Fig. 2). The control modules distributor proportional or servo valve, are constructed from the level of electronics distributor via the controller working together with a position sensor in a closed system. Electro-hydraulic positioning systems are those systems in which changes of position, velocity and acceleration actuator refer to the changes of technological load. In these techniques both proportional valve and servo valve control are used. To control there are used the digital cards and groups of regulators, amplifiers cards, set-point modules as well as sensors and setting units.

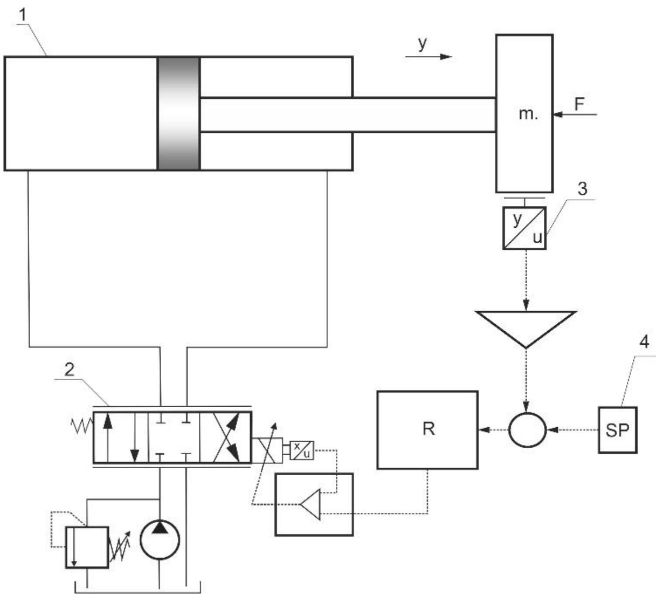

Fig. 2. Position control system of the electro-hydraulic servo actuator: 1 – cylinder, 2 – proportional flow control valve, 3 – position or velocity measuring system, 4 – set point generator (SP)

The card amplifier of valve control module is cooperating with inductive position measuring system of the slider separator (position control) or module where it is controlled by the voltage (pressure control). This card usually contains standard classical regulators P, PD or PID, a correction of nonlinearity, hysteresis restrictions distributor, steepness of the fall and rise of the control signal, zero offset adjustment. Digital controllers are a new generation of flexible, programmable devices with a high degree of miniaturization, they are intelligent and integrated in the hydraulic system. Also replacing analogue devices with digital ones with their possibility of networking, greatly expanded the range of applications of computer science. In the valves there are used microcontroller, they are at the same class of PC microprocessor, but with more computing power, and with the possibility of on-line communication [7–9].

2.2. ELECTRO-HYDRAULIC PARALLEL MANIPULATOR

In Department of Mechatronic Devices at Faculty of Mechatronics and Machine Devices of Kielce University of Technology (Poland) was constructed the three axis and three-degrees-of-freedom hydraulic parallel manipulator. The advantages of parallel manipulators include high stiffness and positioning precision. The manipulator arms are not affected by any bending forces as these act along the axis of each arm. A parallel manipulator possesses several arms connected at one point. The number of drives and kinematic chains is equal to the number of variables describing the state of the physical model (a Tripod or a Tricept with three degrees of freedom and a Hexapod with six degrees of freedom). Figure 3 shows a prototype of the manipulator.

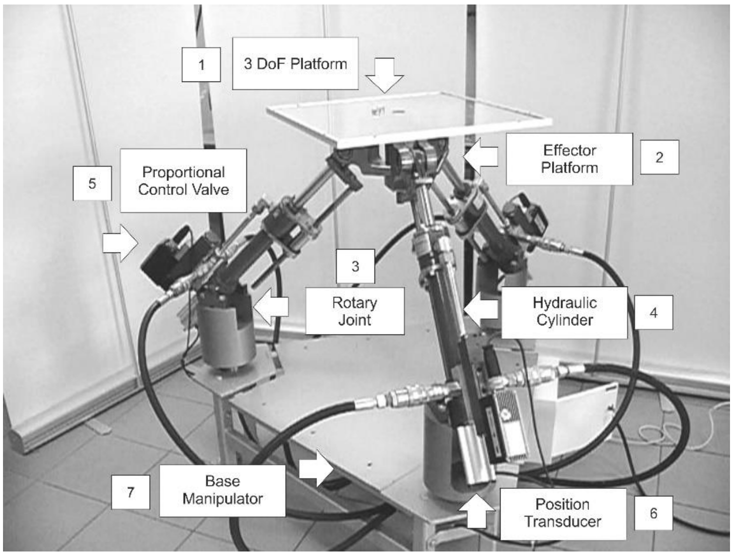

Fig. 3. Prototype of the 3 DoF parallel manipulator

The manipulator consists of a moving platform (1) connected to a fixed base (2) by several arms. The arms are mounted with rotary joints (3). The position of the end effector platform (2) is dependent on the position of the arms. Each arm incorporates an electro-hydraulic servo drive (4), controlled by a proportional valve (5), which is able to generate power of up to 20 kN for each axis. A single electro-hydraulic axis consists of CS (Bosch-Rexroth) type cylinder (4) internally integrated with the magnetostrictive linear position sensors (Novostrictive) (6) and externally integrated with 4/3-way high response directional valve (4) directly actuated with electrical position feedback of type 4WRSE.

3. TEST STAND

The test-stand using bioelectric signals operator-generated signals for a wireless remote control of electro-hydraulic positioning system was constructed. The natural bioelectric signals generated by brain, facial muscles and eye muscles read by the NIA (Neural Impulse Actuator) are translated into control commands in the controller of electro-hydraulic servo system. The idea of wireless remote control of a electro-hydraulic positioning control system using bioelectric signals is shown in Fig. 4.

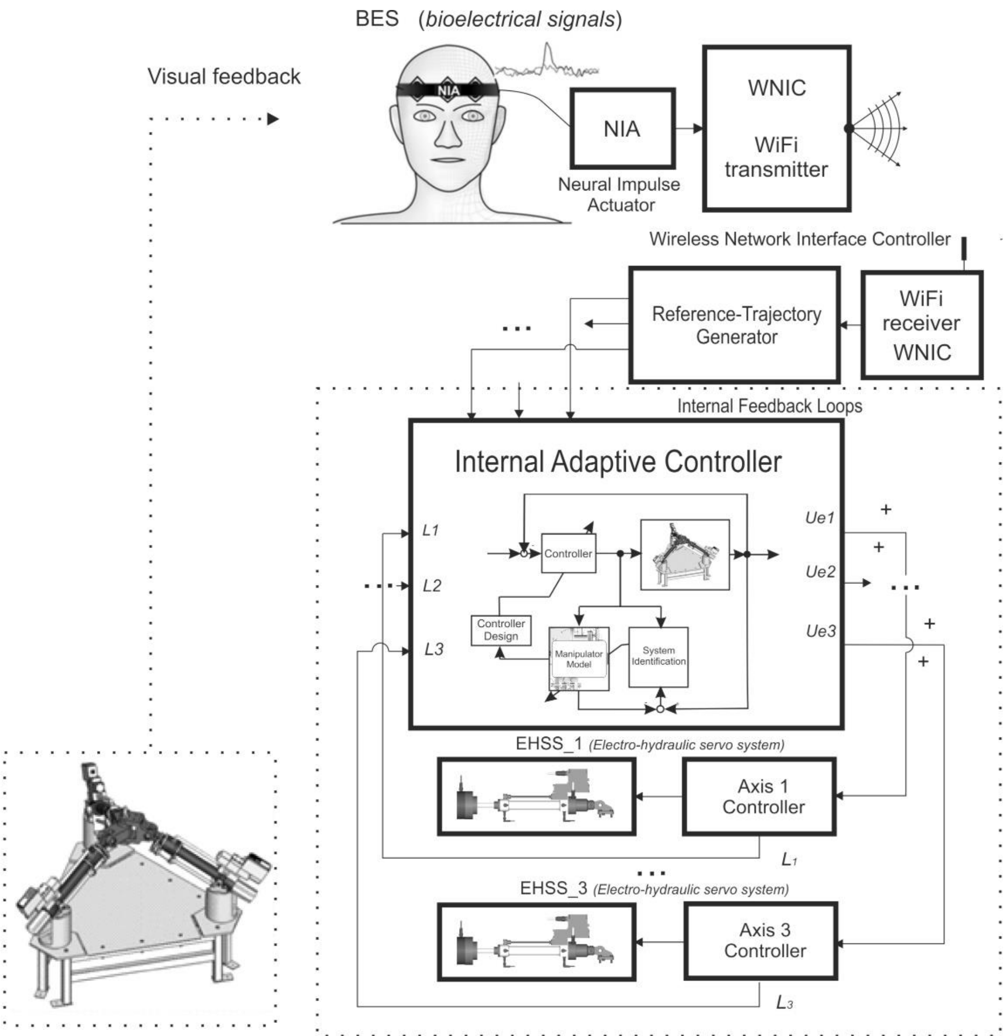

Fig. 4. The electro-hydraulic positioning system using the bioelectrical signals (BES) and a wireless network interface controller (WNIC)

Biosignals detected by means of special forehead band with three sensors are sent to the actuator box, where they are interpreted as control signals. The control signals from the actuator box are transmitted via a wireless network to the controller of servo-drive.

The control operator has a band on their head with three electrodes, which record bioelectrical signals generated by the brain, face and eye muscles. The signals are then enhanced by the Neural Impulse Actuator (NIA), fed into a Wireless Network Interface Controller (WNIC) and analysed by appropriate software which is included with the device. The software generates control signals which are passed onto the application responsible for the controller-computer communication. Data between the computer and the controller are sent via a wireless IT network. On the basis of the value of the intended actuator position received from the operator and the current position the controller generates appropriate control signals. The current actuator position is sent to the operator in order to verify the intended position. Figure 5 shows the test stand of the control system using the Neural Impulse Actuator (NIA).

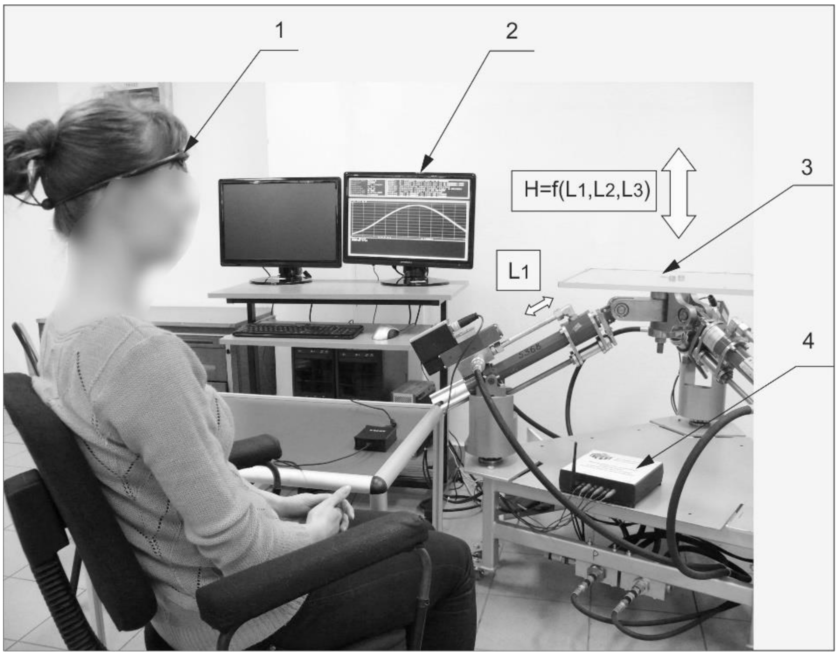

Fig. 5. Test stand: 1 – Neural Impulse Actuator (NIA), 2 – internal adaptive control system, 3 – hydraulic parallel manipulator 4 - (WNIC) Wireless Network Interface Controller

The wireless remote controller builds on a biosignal reader – Neural Impulse Actuator (NIA), microcomputer board ALIX.1D PC, data acquisition device MicroDAQ USB-1208FS and a wireless card Ubiquiti XR2 WiFi card. The ALIX.1D system board is equipped with an AMD Geode 500 MHz processors and 256 MB of RAM. It is powered by a 12 V supply and has low power consumption, in the range of 0.4 to 0.5 A. The software for the servo drive and controller was written using the LabVIEW environment.

The NIA device by OCZ is a BCI (Brain-Computer Interface) type interface equipped with a neurosignal reader [10, 11]. The signals originating from the neural activity of the brain are captured by NIA in the form of electrical biopotentials which occurred as a result of Alpha and Beta brain waves, movement of the facial muscles and eye lids. Effective control of technical devices with the use of NIA requires a snug fit of the brain wave reader sensors to the forehead, calibration of the device and training. A dedicated application analysis of EEG, EMG and EOG biosignals together with one basing on appropriate bioelectric signal values as defined by the user, generate signals for pressing keys in the keyboard [12].

3.1. BIOSIGNAL PROCESSING

To collect the EEG, EMG signals, electrodes are applied to the scalp with a gel. Recorded biosignals come from the collective activity of neurons and are the result of the so-called biological measurement. The measurement consists of many side factors, which often have a huge impact on the measurement result. During the detection and recording of the biosignal, there are two main problems. The first problem is the signal to noise ratio. It means the energy ratio of the biosignal to the noise signal energy. The noise is defined as an electrical signal that is not part of the desired biosignal. Another issue is the signal interference, which means that the relative contribution of any frequency element in the biosignal should not be changed (Fig. 6b). Two types of methods: invasive and non-invasive are used to obtain the appropriate biosignal. The applied non-invasive method consists of mounting the electrodes directly on the forehead of the head. Due to the relatively easily gained biopotentials (tongue pressure on the palate, teeth clenching or facial expression) there is no need for many sensors. In the carried out tests, it was enough to use three electrodes (sensors) on the forehead to obtain a clear signal. The biosignal can have both positive and negative voltage (Fig. 6a). The resulting biosignal can be processed to eliminate noise or other possible interference. Consequently, the signal is often straightened and averaged indicating the amplitude of the biosignal. The amplitude range of the biosignal before amplification is 0-10 mV (+5 to –5).

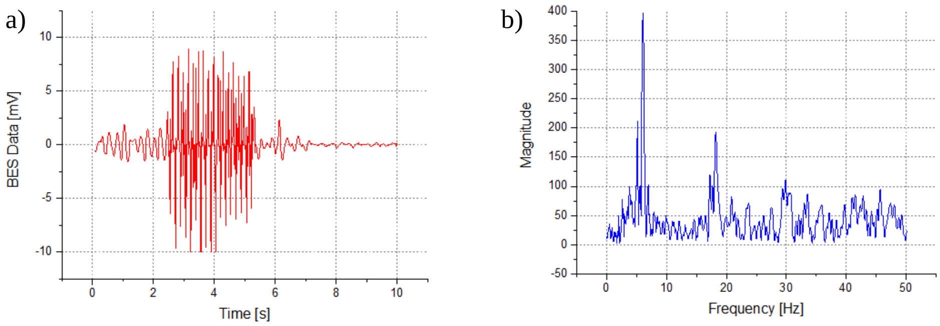

Fig. 6. Generating characteristics of a single channel signal (a) using a frequency analysis (b)

Initial biosignal processing usually involves signal filtration and other methods of removing noise and interference (e.g., physiological artifacts). At this stage, digital filters, spatial filters and signal whitening methods are used. The capabilities of today's computers enable an easy and quick check of the biosignal frequency distribution. Useful biosignals are between 10 and 250 Hz. The power distribution can be calculated by means of the "Fast Fourier Transformation" (FFT) and graphically represented as the Total Power Spectrum of the biosignal. The raw signal record always contains very important information and it can be used as the first objective source of information (Fig. 6a).

It is known that the useful biosignal band is in the range from 0.5 Hz to 50 Hz. Due to the overall power spectrum, it is possible to identify a disturbance of the biosignal baseline and distinguish it from the increased bioelectric signal activity. In order to convert the biosignal to a useful control signal, all negative amplitudes are firstly converted into positive ones. Negative peaks are transferred into the positive direction. In addition to the transparency of the record, the result of this action is to obtain the ability to plot curves for standard amplitude parameters such as mean, peak – maximum and field values (raw biosignal record has an average amplitude value equal to zero).

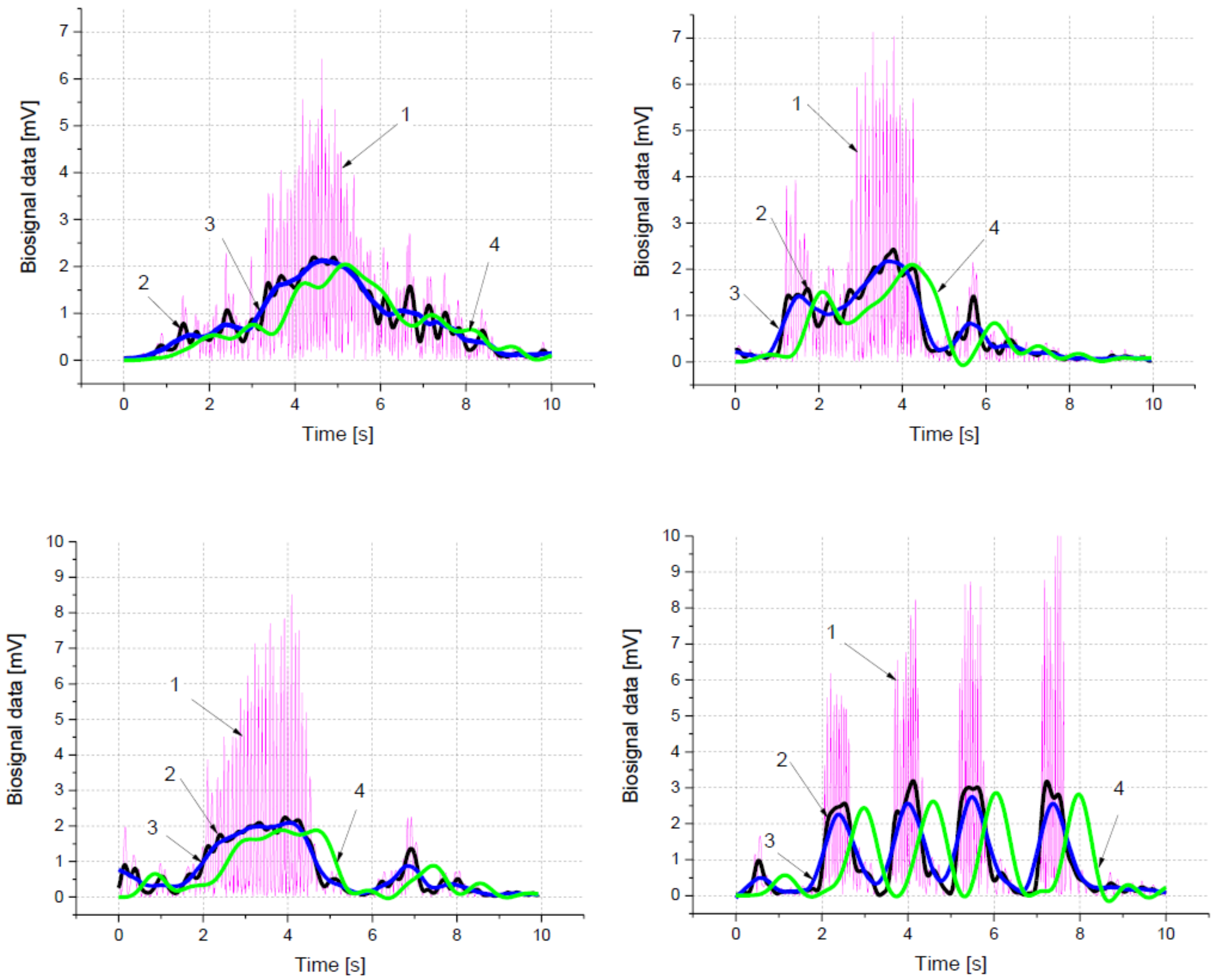

Fig. 7. Processing for smooth biosignal data: 1 – BES data (absolute valve), 2 – FFT filter, 3 – lowess method (LM), 4 – low pass filter (15 Hz cutoff)

The biosignal interferential pattern is accidental. As a result of the phenomena, it is impossible to repeat the biosignal discharge with exactly the same shape. To solve this problem, a unique part of the signal is minimized by using digital smoothing algorithms that emphasize the main direction in which the signal travels (Fig. 7).

Peaks with excessive amplitude are trimmed; the signal is linearized. Three algorithms are used here: application of the FFT filter, the low pass filter and the Lowess method (LM) weighted local polynomial regression fitting.

4. CONTROL RESULT

All available application level biosignals: muscle tension measurement and eyeball movement were used in the experiment. As a result of the conducted experiment, it was confirmed that the use of biosignals, for example by regulating the pressure of the tongue on the upper palate or clenching teeth with a larger or smaller force provides the best control biosignal generating effects. Other bioelectrical signals did not facilitate determination of the hydraulic actuator (rodless cylinder) position, as it was difficult to obtain their appropriate level. The precision of position control of the electro-hydraulic servo drive may be increased by the operator undergoing appropriate training. As a result of the experiment the positional control characteristics of electro-hydraulic servo mechanism for different input signals were obtained. The manipulator control is performed on a single channel. At a given time, it is possible to move only with one arm (axis) of the manipulator. With the synchronized movement of all three axes (all axes are operated at the same reference signal), the manipulator moves its end effector (platform) only in the vertical direction (up-down). Figure 8 shows the reference signal given by the Wireless Network Interface Controller (WNIC) and the position signal of a single electro-hydraulic servo actuator. From analysis of above graphs it results that there is a delay between the value of set signal and actuator position. By virtue that driver performs the role only as control system of the delay isn't significant in the process of position control. The control system using bioelectrical signal and remote wireless communication network was constructed and practically applied in hydraulic positioning systems.

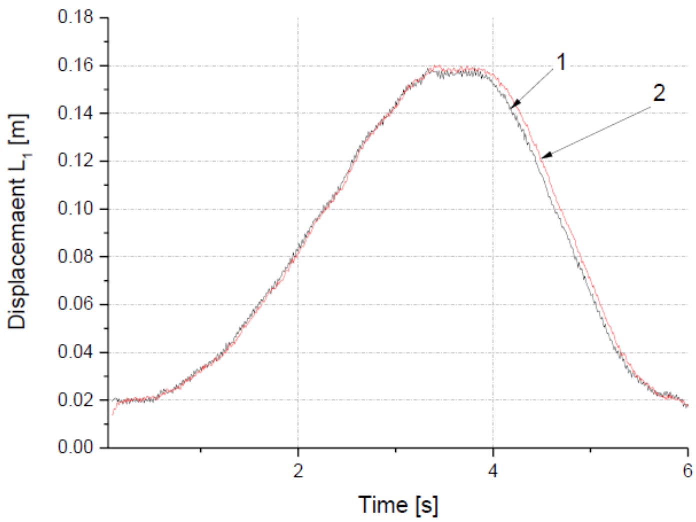

Fig. 8. Experimental position control results of a single manipulator axis: 1 – reference signal from Wireless Network Interface Controller (WNIC), 2 – displacement the single axis L_1 of the manipulator

5. CONCLUSION

The conducted laboratory tests confirm that various bio-electrical signals may be used in the control process. It is easiest to use electrical activity signals generated by muscle movements (eyeball movement, clenching of teeth). The bioelectrical signals subjected to appropriate training control may be used in systems not requiring significant position precision of hydraulic positioning system. They can also improve safety of a device by reducing operator's reaction time to sudden events, e.g.: emergency stop or faster operation of a break. Conducted simulations in the test stand confirm that it is possible to use the wireless computer network to communication of the operator with the remote control of electro-hydraulic positioning systems. The use of wireless communication increases operator's safety during device operation, as he does not have to be in the direct vicinity of the device. It also improves the mobility and reduces the cost of network infrastructure development and expansion.

REFERENCES

[1] FAIRCLOUGH S.H., GILLEADE K., NACK L.E., MANDRYK R.L., 2011, *Brain and body interfaces: Designing for meaningful interaction*, The ACM CHI Conference on Human Factors in Computing Systems, Vancouver 2011, 1–4.

[2] GNANAYUTHAM P., GEORGE J., 2007, *Inclusive design for Brain Body Interfaces*, D.D. Schmorrow, L.M. Reeves (Eds.), Foundations of Augmented Cognition, Springer Verlag, 103–112.

[3] AHMADNEZHAD M., SOLTANPOUR M., 2015, *Tracking performance evaluation of robust back-stepping control design for a nonlinear electrohydraulic servo system*, World Academy of Science, Engineering and Technology International Journal of Mechanical, Aerospace, Industrial, Mechatronic and Manufacturing Engineering, 9/7, 1341–1347.

[4] KHEOWREE T., KUNTANAPREEDA S., 2015, *Adaptive dynamic surface control of an electrohydraulic actuator with friction compensation*, Asian Journal of Control, 17, 855–867, DOI: 10.1002/asjc.935.

[5] Catalogue allison hydraulics, 2014, http://www.allisonhydraulics.com/x/img/products/ah_catalogue.pdf

[6] LIU Z., DONG X., XUE J., ZHANG L., 2015, *Adaptive tracking control for nonlinear systems with a class of input nonlinearities*, Asian Journal of Control, DOI: 10.1002/asjc.1085.

[7] MERCORELLI P., 2015, *Robust adaptive soft landing control of an electromagnetic valve actuator for camless engines*, Asian Journal of Control, doi: 10.1002/asjc.1250.

[8] TAKOSOGLU J., ŁASKI P., BŁASIAK S., 2012, *A fuzzy logic controller for the positioning control of an electro-pneumatic servo-drive*, Proceedings of the Institution of Mechanical Engineers, Part I-Journal of Systems and Control Engineering, 226/I10, 1335–1343.

[9] TAKOSOGLU J.E., LASKI P.A., BLASIAK S., 2014, *Innovative modular pneumatic valve terminal with self-diagnosis, control and network communications*, Edited by FUIS V., Proceedings of 20th International Conference on Engineering Mechanics 2014, Brno University of Technology, 644–647.

[10] HAGEDOORN H., *OCZ NIA Review – Neural impulse actuator*, http://www.guru3d.com/articles-pages/ocz-nia-review-neural-impulse-actuator,1.html.

[11] REYNOLDS B., WAECHTER A., 2009, *Brain computer interfacing using the Neural Impulse Actuator*, A usability and statistical evaluation, California Polytechnic State University.

[12] DINDORF R., WOŚ P., 2015, *Brain computer interface for wireless remote control*, MCSB'2015 – International Conference Cybernetic Modelling of Biological Systems, Krakow, DOI: 10.1515/bams-2015-0011, 15–16.