APARATURA
BADAWCZA I DYDAKTYCZNA

Design and development of EMG controlled bionic prosthesis hand

JACEK S. TUTAK, BARTŁOMIEJ KLATKA
RZESZOW UNIVERSITY OF TECHNOLOGY, THE FACULTY OF MECHANICAL ENGINEERING AND AERONAUTICS, DEPARTMENT OF APPLIED MECHANICAL AND ROBOTICS

Keywords: bionic prosthesis hand, mechatronics, EMG system

ABSTRACT:

This paper suggests a new approach to an EMG controlled prosthetic hand. The biomechanical, ergonomics, electrical/electronics, hardware/software aspects of the design are described in the article. The most important objectives of this project include: simplified model of fingers and thumb, the basic functionality (especially opening and closing the hand), a simple controlling model to fulfil user's expectations, simplified construction with a minimum number of drives, modular construction for the future expansion. The rapid prototyping was used to make selected elements of a prototype.

Projekt sterowanej sygnałami EMG bionicznej protezy dłoni

Słowa kluczowe: bioniczna proteza ręki, mechatronika, sterowanie EMG

STRESZCZENIE:

W artykule opisano projekt bionicznej protezy dłoni, w której zastosowano sterowanie sygnałami EMG. Przedstawiono aspekt biomechaniki, konstrukcję, układ elektryczny, elektroniczny i oprogramowanie. W projekcie uwzględniono współpracę wszystkich palców (wskazującego, środkowego, serdecznego, małego oraz kciuka). Zaprojektowany oraz wykonany prototyp bionicznej protezy ręki zapewnia możliwość realizacji najważniejszych chwytów oraz gestów. Projekt wraz z przygotowanym prototypem powstał w oparciu o mechatroniczne podejście do projektowania. Do wykonania funkcjonalnych elementów prototypu protezy zastosowano metodę rapid prototyping.

1. INTRODUCTION

Hand amputees are people who have lost last part of their upper limb due to accident or disease. These people cannot perform typical daily functions which require using the hand, not even routine activities in day-to-day life e.g. taking and moving the objects during eating [1, 2]. Most of these people are self-sufficient, but their life is very complicated. The muscles in the remaining part of the arm function in a normal way, enabling the electromyogram (EMG) signals from them to be used in limb replacement techniques [3, 4]. Good solution for these people is used a bionic prosthesis, which uses the EMG or EEG signals from the patient and controls movement of the prosthetic hand [4-10]. The advantage of this technique is that the signal will be acquired from the patient's body and after suitable processing it is used as a control input to drive motors which are coupled to the prosthetic hand [11, 12]. The hand prosthesis is not only a cosmetic supplement after the loss hand but the newest mechatronic solutions have the control mechanism which it is initiated by the user's own EMG or EEG signals [13-15].

2. THE AIM OF THE PROJECT

This paper suggests a new approach to a prosthetic hand. The biomechanical, ergonomics, electrical/electronics, hardware/software aspects of the design are described in the article. This project of the prosthetic hand allows the user to realize of the most important gestures and basic types of prehension for necessary to "normal" life. The majority of patients are looking for a simple and cheap solutions. Simple – means that it allows to capture light objects, press switches or move meshes with shopping. This paper presents one of the prototype but it is not a commercial version yet. The final version will be smaller because it will contain dedicated sensors, high-quality micro motors and microchips. Presented version demonstrates only a basic features of our project. The described project proposes EMG control.

The most important objectives of this project include: simplified model of fingers and thumb, the basic functionality (especially opening and closing the hand), a simple controlling model to fulfil user's expectations, simplified construction with a minimum number of drives, modular construction for the future expansion.

This project of bionic prosthesis hand allows the user to motion of all hand fingers (index finger, middle finger, ring finger, little finger – pinky and thumb) in certain dependencies and simplifications. One of the basic simplifications is value of the degrees of freedom in each finger. Each of the finger has two rotation joints. The length of the fingers are equal. The another simplification in the project was the connection of the end of each fingers with motors by the lines. These lines are placed in fences included in each joints. This simplification provides the need to buy one motor for one finger. In our solution, five lines was used to connect fingers with motors. Motor shaft rotated to the desired angle allows the movement of the mechanism of finger. It is possible to place all of the fingers to the desired position and realize the most important gestures and basic types of prehension necessary to "normal" life. Moreover, it should be noted that the closing hand with all fingers will be implemented by electric drives. Straightening the fingers will be implemented by the springs. It will be realized automatically when the motors does not works (Fig. 1).

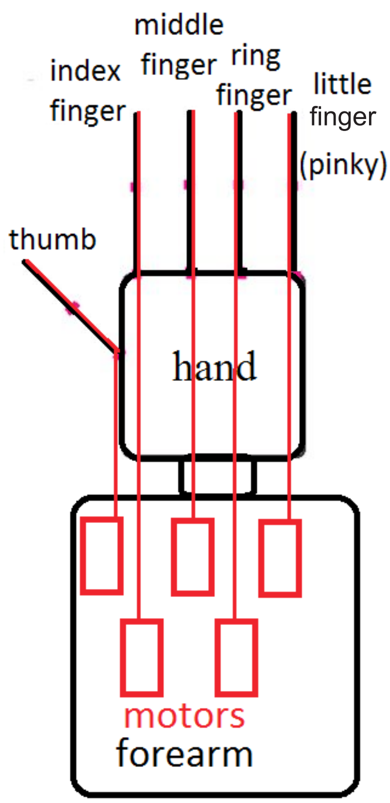

Figure 1 Simplified diagram connection of the fingers with motors

It is worth noting that the movement of the thumb is held in one plane. There is a possibility to manual change the plane of action of thumb depending on user needs, but this part of project will not be analyzed in this article.
All of these features were proposed in order to simplify the construction of the prototype.

3. CONSTRUCTION OF THE BIONIC PROSTHESIS HAND

The developed design is shown in Figure 2 and Figure 3. The design is dimensionally consistent with that of an average male human hand [16]. The anthropomorphic aspect of the hand is intended to enhance the amputee's acceptance and usability. CAD model was generated using NX 9 software [17]. The range of motion of the finger can be changed in the range of 0° – 90°. This range of motion was defined in software and in mechanical construction. In the finger construction was performed two holes for a cord which was used to connect fingers with motors (Fig. 2). One on the top and one from the bottom to receive a possibility to opening and closing finger.

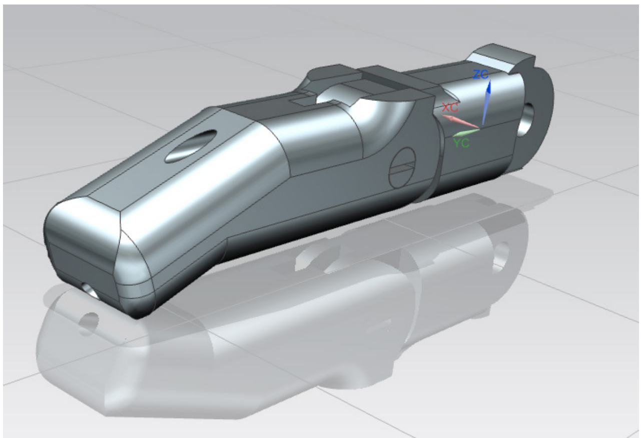

Figure 2 CAD model of the finger

Grooves from the top and bottom of the fingers' construction allow to fast and smooth action of cord. The typical bearings were used in order to further simplify. Most of the fingers constructions can be printed on a 3D printer as well as the rest of the elements of the bionic prosthesis hand. The construction of thumb is similar to the other fingers, but its attachment to the base is a little different (Fig. 3). Therefore, it was slightly modified to allow it to turn. On each of the fingers connection to the prosthesis base (palm), it was prepared the mechanical interlocks for desired anthropometry range of motion of the fingers.

The prosthesis base (palm) is the component that connects all the fingers and thumb (Fig. 3 and Fig. 4). An important element of construction is the proper placement of the holes, so that the cord between end of the finger and motor works properly.
It was decided to use a motor Servo Tower-Pro

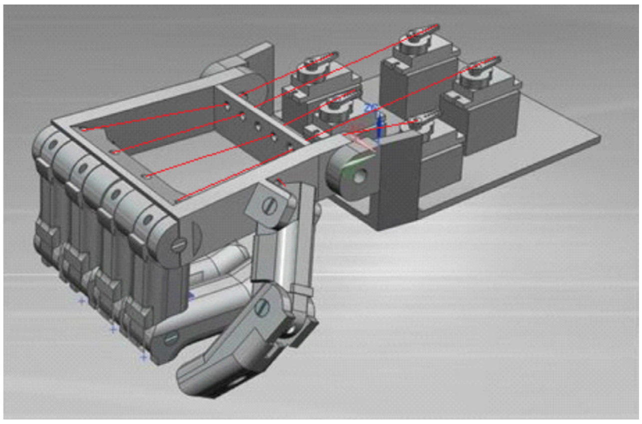

Figure 3 CAD model of the prosthesis hand

SG-92R. This micro servo was used in this project due to its tiny and lightweight construction with high output power. Servo can rotate approximately 180 degrees (90 in each direction). The control was realized with the PWM. This solution gives a possibility to determine the rotation angle according to the control signal.
To provide adequate motion of bionic prosthesis hand, the system must recognize the intentions of the user to make the desired position of the hand . These intentions will be recognized based on the EMG signal, referred to as electromyography. Recognition of the intentions, and then activation of the device must be initiated by the servo, with the shortest possible delay. In the past it has traditionally been used for medical research e.g. for neurological diseases. However, with the beginning of still shrinking yet more powerful microcontrollers and integrated circuits, EMG circuits and sensors have found their way into all kinds of control systems e.g. for bionic prosthesis hand. Muscle sensor V3 measures the filtered and rectified electrical activity of a muscle; outputting 0-Vs Volts depending on the amount of activity in the selected muscle, where Vs signifies the voltage of the power source. These sensors require a biomedical electrodes. During measurements the analog signal is obtained, which can be captured by any microcontroller with analog--digital converter, e.g. Arduino.

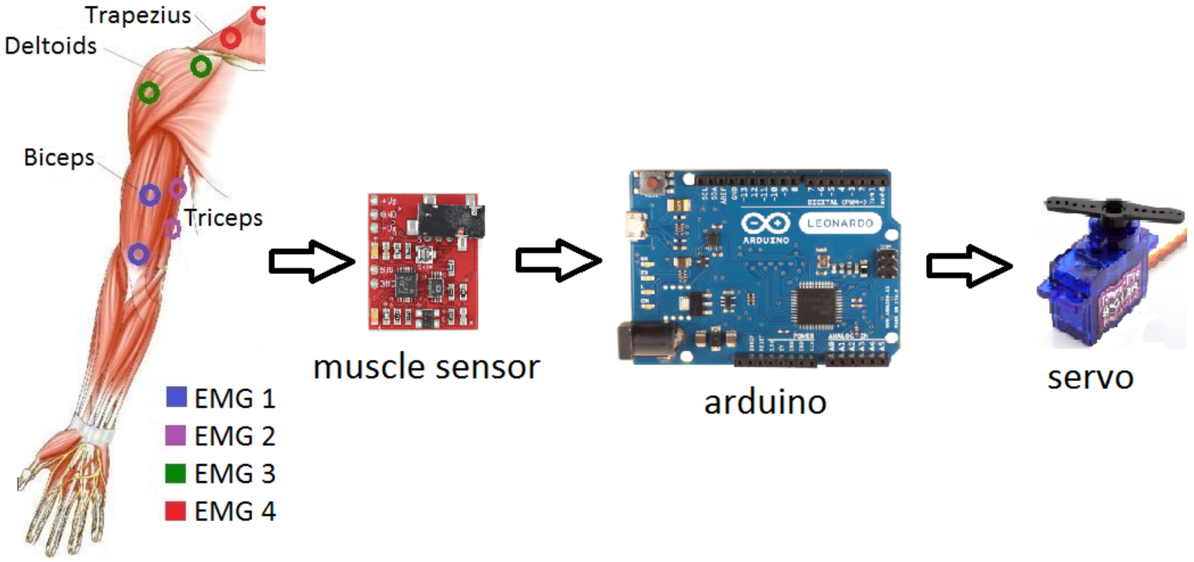

Figure 4 Scheme of the device

This project was based on Arduino Leonardo. It is a microcontroller board based on the ATmega32U4. It has 23 digital input/output pins (of which 7 can be used as PWM outputs and 12 can be used as analog inputs), a 16 MHz crystal, a USB connection, a power jack, an in-circuit system programming (ICSP) header. Another chapter of this article was devoted to the description of the software. This program was written in the environment of Arduino IDE. Arduino is usually programmed in C / C ++ [18, 19].

4. PROTOTYPE

The rapid prototyping was used to make selected elements of a prototype. The first step was to design a model in the CAD software [20]. The next step was to export STL files of this model to the CURA 15.04 software (Fig. 5).

With the help of CURA software, the CAD model was divided into layers, which were the path for the 3D printer. Moreover, it was necessary to create a support structures that can be created in the CURA interface or design in the CAD software. The next step was to generate a file of G-code that describes all the moves of the printer. Then this file is imported into the software YARRHv0.2.0. Furthermore, it is necessary to calibrate the printer for reference points and set up the final parameters of the printer (if it was not included in the CURA software).
After receiving the required elements, and completion of the printing process, it started an assembly process. Then we tested different tricks on bionic hand prosthesis. The results of these tests were very successful (Fig. 6). The bionic prosthesis hand works according to the principles based on four EMG (Fig. 7-10).

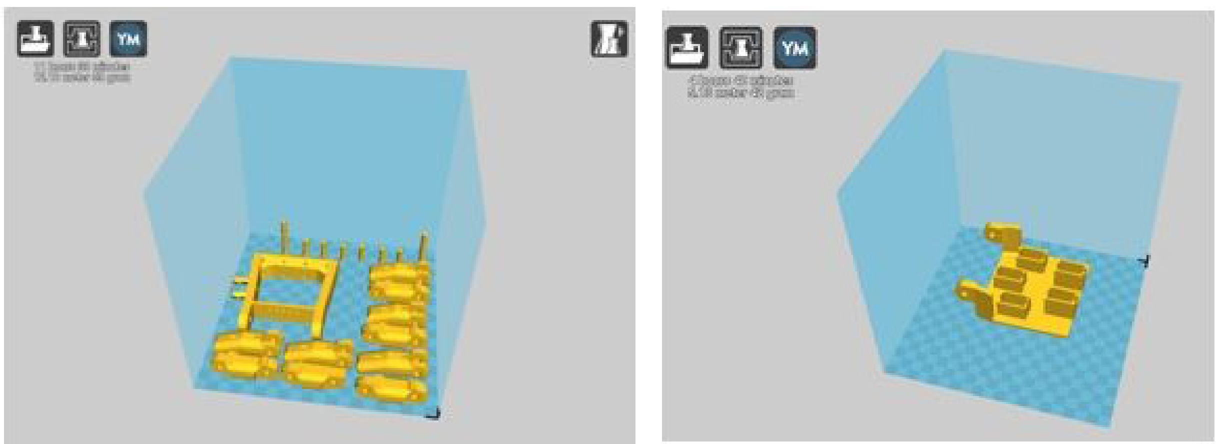

Figure 5 Parts of prosthesis hand in CURA software

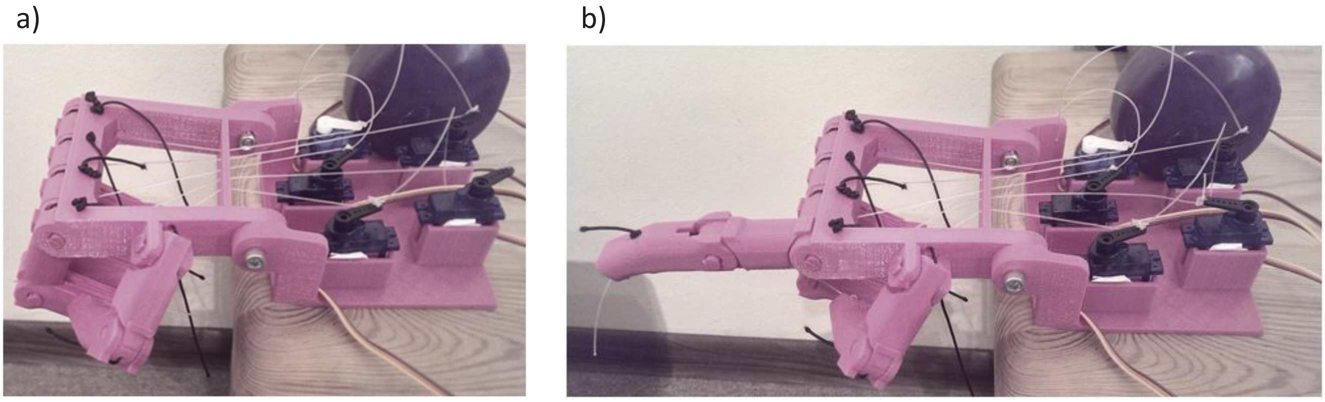

Figure 6 The first tests of the prosthesis – grip configuration e.g. hook or snap (a) and touch pointing finger (b)

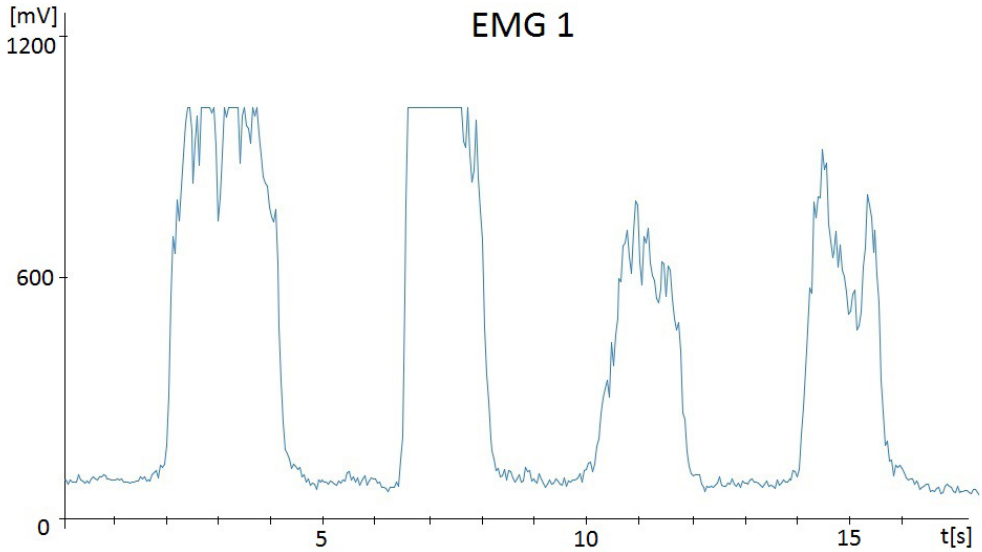

Figure 7 EMG 1 signal controlled bionics prosthesis hand

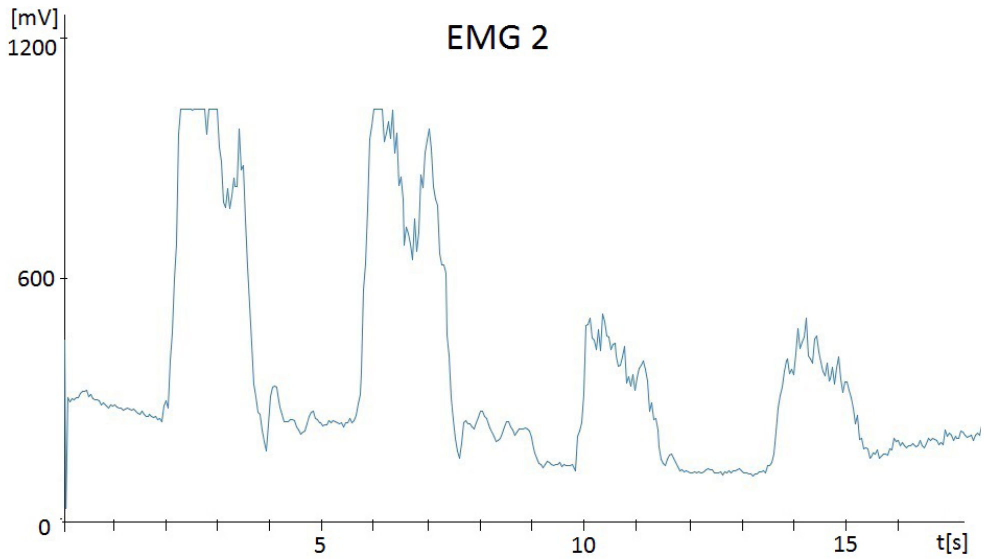

Figure 8 EMG 2 signal controlled bionics prosthesis hand

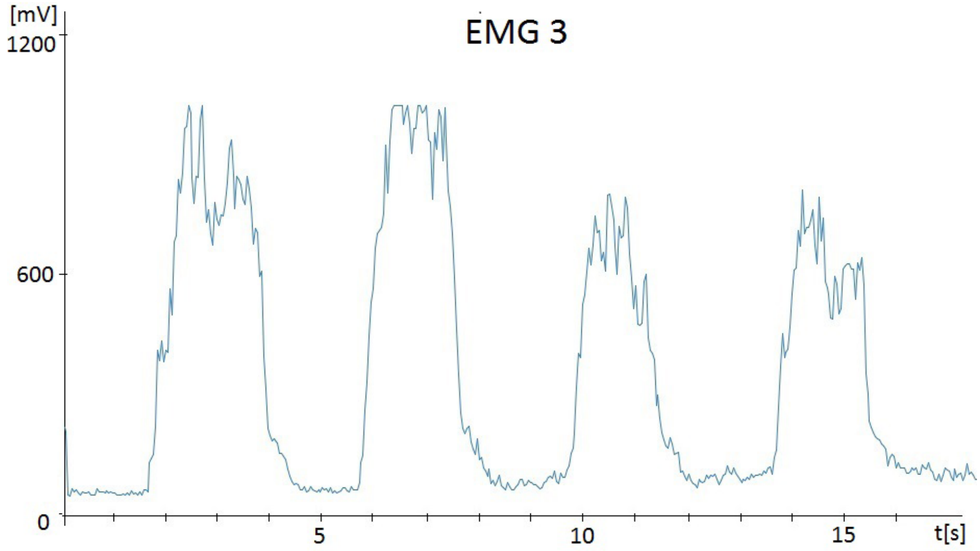

Figure 9 EMG 3 signal controlled bionics prosthesis hand

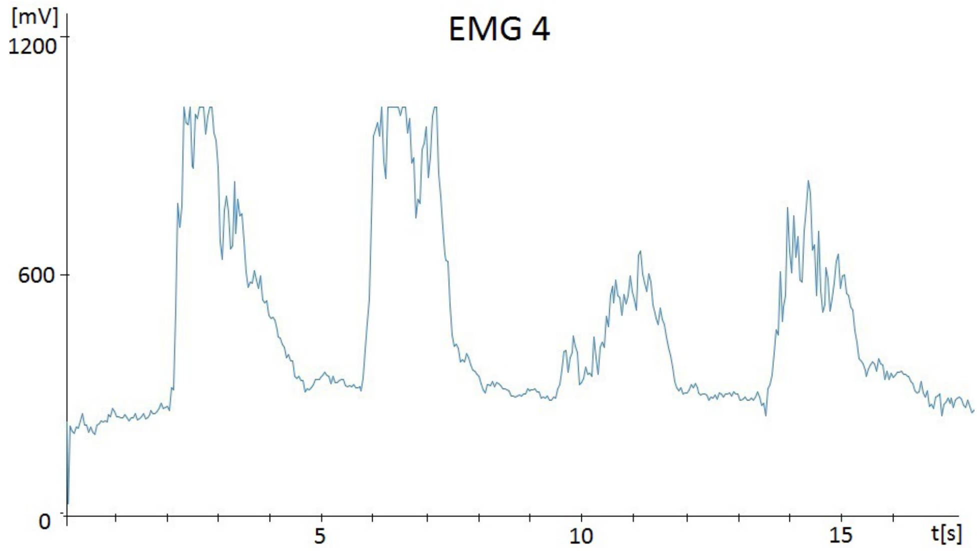

Figure 10 EMG 4 signal controlled bionics prosthesis hand

5. CONCLUSION

This paper presents a new/modern design and actuation system for a bionic prosthetic hand. The described prototype realizes design assumptions. Human hand is a very sophisticated part of our body. The mobility of the hand is extremely complicated in the point of view of construction and controls. For this reason, it was necessary to limit the degrees of freedom in our project. This simplification was described in the design process and in prototype. The main simplification in the project was to the connection of all the joints in each finger by the line. This simplification eliminates the need to buy minimum one motor for one joint. In our solution, five lines was used to connect fingers with motors. To provide adequate motion of bionic prosthesis hand, the system must recognize the intentions of the user to make the desired position of the hand . These intentions will be recognized based on the EMG signal. This project was based on Arduino Leonardo, which is a microcontroller board based on the ATmega32U4. The proposed solution requires positioning engine in the region of the forearm. We wanted to get an effective prototype. In the future, there will be used smaller components so it will be possible to reduce the size of the structure and get a more natural look prosthesis hand.

Acknowledgment
This work was supported in part by the Vice--Rector for Research the Rzeszow University of Technology (U-778/DS/M).

LITERATURE

[1] Feigin V. L., Lawes C. M., Bennett D. A., Barker-Collo S. L., Parag V., Worldwide stroke incidence and early case fatality reported in 56 population-based studies: a systematic review. Lancet Neurol. 2009;8: 355-369.
[2] Laver K., George S., Ratcliffe J., Crotty M., Virtual reality stroke rehabilitation – hype or hope? Australian Occupational Therapy Journal. 2011;58: 215-219.
[3] Seale G. S., Berges I. M., Ottenbacher K. J., Ostir G. V., Change in positive emotion and recovery of functional status following stroke. Rehabil. Psychol. 2010;55: 33-39.
[4] Hayward K., Barker R., Brauer S., Interventions to promote upper limb recovery in stroke survivors with severe paresis: a systematic review. Disability and Rehabilitation. 2010;32: 1973-1986.
[5] Pignolo L., Robotics in neuro-rehabilitation. J. Rehabil. Med. 2009;41(12): 955-960.
[6] Balasubramanian S., Klein J., Burdet E., Robot-assisted rehabilitation of hand function. Current Opinion in Neurology. 2010(23): 661-670.
[7] Iqbal J., Tsagarakis N., Fiorilla A., Caldwell D., A portable rehabilitation device for the hand. 32nd IEEE Annual International Conference of Engineering in Medicine and Biology Society (EMBC). 2010;9: 3694-3697.
[8] Pons J. L., Rehabilitation exoskeletal robotics the promise of an emerging field. IEEE Eng. in Med. and Biol. Magazine. 2010;29(3): 57-63.
[9] Iqbal J., A human hand compatible optimised exoskeleton system. 2010 IEEE Int. Conf. Rob. and Biomimetics. 2010: 685-690.
[10] Brokaw E. B., Hand spring operated movement enhancer (handsome). IEEE Trans. Neur. Sys. and Rehab. Eng. 2011;9(4): 391-399.
[11] Blake J., Gurocak H. B., Haptic glove with MR brakes for virtual reality. IEEE/ASME Trans. Mech. 2009;5: 606-615.
[12] Chiri A., Mechatronic design and characterization of the index finger module of a hand exoskeleton for post-stroke rehabilitation. IEEE/ASME Trans. Mech. 2012;17(5): 884-894.
[13] Vitiello N., NEUROExos: A powered elbow exoskeleton for physical rehabilitation. IEEE Trans. Rob. 2013;29(1): 220-235.
[14] Cempini M., Self-Alignment mechanisms for assistive wearable robots: A kineto-static compatibility method. IEEE Trans. Rob. 2013;29(1): 236-250.
[15] Schabowsky C. N., Godfrey S. B., Holley R. J., Lum P. S., Development and pilot testing of HEXORR: Hand EXOskeleton rehabilitation robot. J. Neuroeng. Rehabil. 2010;7: 36-54.
[16] Gedliczka A., Atlas miar człowieka. Dane do projektowania i oceny ergonomicznej. Centralny Instytut Ochrony Pracy, Warszawa, 2001.
[17] Ventimiglia P., Design of a human hand prosthesis, WPI, Worcester (USA), 2012.
[18] Botland, http://botland.com.pl/
[19] Bitsophia, http://www.bitsophia.com
[20] Budzik G., Burek J., Dziubek T., Turek P., Zastosowanie systemów RE/CAD/RP w procesie projektowania i wytwarzania modeli medycznych żuchwy. ABiD. 2016;1: 4-9.