PROSTHETIC 6-DOF ARM MODEL CONTROLED BY EMG SIGNALS AND ULTRASONIC SENSORS

Patrik Kutílek, Ján Hýbl, Jan Kauler

Czech Technical University in Prague, Faculty of Biomedical Engineering, Czech Republic

Abstract

The paper describes a new method and system, designed for application to upper extremity prosthesis. Artificial limb with our new system is robot arm controlled by EMG signals and monitored and corrected by set of ultrasonic sensors. The control system used to control robotic arms measured EMG signals from muscles and the signal from the ultrasonic sensors detect obstacles in the robot's motion. By ultrasonic sensors is creating and updating map of robot environment. The sensor system can identify objects in 3D space and control system can chooses an adequate reaction. The system is designed as an assistive technology for disabled people. Prosthetic arm was controlled and method verified by MATLAB/Simulink.

1 Introduction

Common control system is based on point to point method for application in industrial manipulators. Common sensor systems designed for industrial manipulators uses CCTV or set of sensors which is composed only by limit switches, optical sensors etc. Advanced systems for prosthetic applications usually use the EMG signal to control arm motion. This arm is called as the myoelectric prosthesis. Sensors implemented in advance prosthesis are capacitive sensors, laser sensors, etc.

Currently, all used prostheses based on direct control based on EMG signal. EMG signal from one muscle is usually used to control the one direction of motion of one actuator. To control a one direction of movement of one actuator is always needed a one muscle motor unit to control the desired direction of actuator rotation. For this reason, myoelectric prostheses are equipped with up to three actuators. The patient has a limited ability to learn more than six muscle motor units that were not originally intended to control the rotary actuator motion. Advanced prosthetic upper limbs are equipped with sensors that identify the angles of each joint actuator. These sensors provide information about the relative position of the arm segments, but do not provide information about the robot arm environment [2]. Currently, the prosthetic upper limbs [3-4] do not use sensors to inform the control system of prostheses about the environment. Removal of the lack of control only one direction of rotation movement by one muscle motor unit [5] and complete information about robotic arm environment can lead to more effective control arm movements. Especially information about the surrounding environment can prevent conflict situations with obstacles during movement controlled robotic arm.

2 Methods

The measured EMG signal is used to control robotic arm. The signal is filtered and calculated formed EMG envelope signal. Envelope of EMG signal is adjusted according to whether it is used to control robotic arm methods of direct or inverse kinematics. If the robot is controlled by direct kinematics, EMG envelope signal is adjusted so that the angular velocity in the arm joint (i.e. actuator) is proportional to the amplitude envelope. Control of actuator using inverse kinematics requires adjustment EMG envelope signal so that the distance of displacement of the arm endpoint (in the defined axis of direction) will be proportional to the amplitude envelope EMG signal. As is the case with direct kinematic control, the envelope EMG signal carries information about the joint's angular velocity and direction of rotation.

To control the arm actuators are designed two methods: the method of two levels of EMG envelope signal intensity, Fig. 1, and the method of two levels of EMG envelope signal slope, Fig. 2.

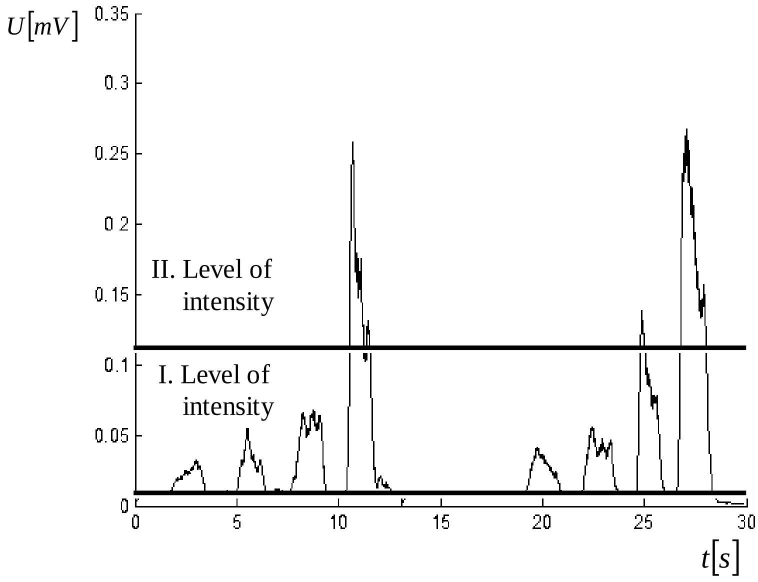

Figure 1: Method of two levels of EMG envelope signal intensity

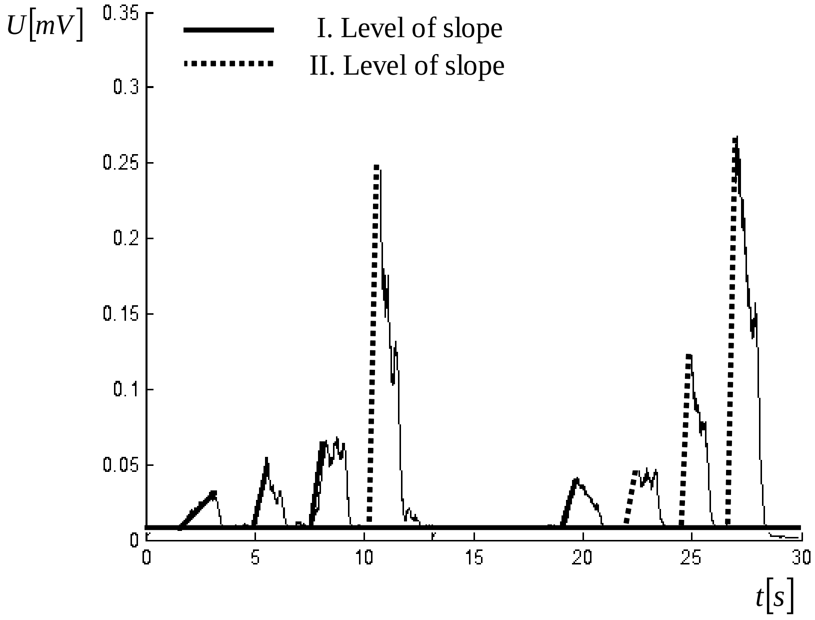

Figure 2: Method of two levels of EMG envelope signal slope.

Envelope EMG signal has different amplitudes. Control system uses a variable intensity of the EMG signal. The intensity is divided into two levels. The operator controls the actuators varying degrees of muscle tensing. Low intensity muscle contraction creates small amplitude of the EMG signal; high intensity muscle contraction creates high amplitude of the EMG signal and vice versa. The amplitude is directly proportional to the intensity of muscle contraction. The size of the intensity of muscle contraction i.e. the amplitude of EMG signals also determines what type of actuator motion (flexion, extension and so on) is used. The actuator will perform extension for exceeding a defined threshold. The actuator will perform flexion in terms of amplitude smaller than defined threshold.

The second method is a method of two levels of EMG envelope signal slope, which uses different envelope curve slope of EMG signal. To determine the type of movement are important values of slope of the envelope EMG signal. If the rate of the operator' muscle contraction is higher, the envelope signal slope is steeper. Value of the slope determines the orientation of the rotation and angular speed of rotor movement of actuator.

To avoid the collision with the objects around the robotic arm, we proposed a new sensor system based on the set of ultrasonic sensors for distance measurement, [7-9]. The sensor system can identify objects in 3D space and control system can chooses an adequate reaction. All signals from sensor system are processed into map of robot arm environment. The sensor system measure distances of the objects and creates spatial map of the environment. The map is used for object interpretation and automatic reaction of robotic arm.

The set of sensors is composed of nine USR (Ultra Sonic Range) sensors. Fig. 3 shows the position of the sensors on the robotic arm. Sensors are divided into three blocks:

Manus (hand) block: contains USR1 sensor, scanning the frontal space of the hand (distal map).

Antebrachium (forearm) block: positioned in 70 % length (distal direction), sensors USR2-USR5.

Brachium (arm) block: positioned in 70 % length (distal direction), sensors USR6-USR9.

In Antebrachium and Brachium block is each pair of sensors situated in the 25 % perimeter length of the forearm (arm). Scanned planes of Antebrachium and Brachium are perpendicular i.e. all directions (superior-inferior and anterior-posterior) are scanned. This sensor configuration, called 70/25 creates two Cartesian coordinate systems with beginning in the arm and forearm. The result of signal processing from individual sensors is position of the most dynamic parts of the robotic mechanism (arm, forearm, hand). Summation of the signals from all three blocks with beginning in upper limb girdle (cingulum membri superior - CMS) determines position of potential obstacles in the robot arm environment. The complete proposed system consists mainly of three types of sensors:

- USR (Ultra sonic range) sensor
- FS (Force sensor)
- 6-DOF gyro-accelerometer.

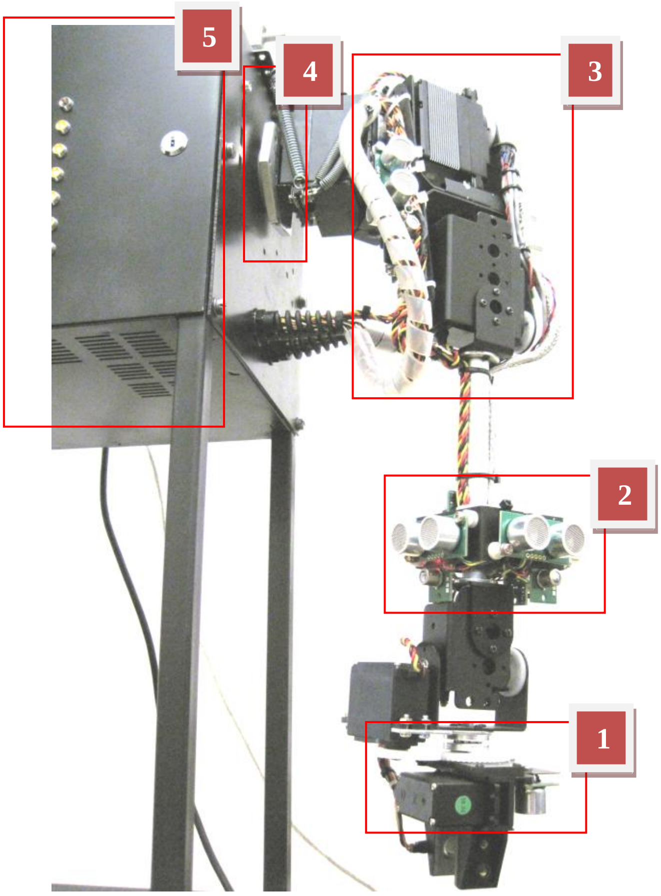

Figure 3: Designed myoelectric robotic arm sensor system; arm consists of: 1 manus, 2 antebrachium, 3 brachium, 4 CMS, 5 soma.

Signal data from the sensor microprocessor must corrected by a calibration curve be due to the nonlinearity of the sensors. Calibration can be done manually or automatically. Corrected data are sent to memory of the system to update the map of robot arm environment. If obstacles there are identified in the map, the robot arm performs an avoidance movement. The proposed sensor system is installed and tested on mechatronics robotic arm that allows simulation of human arm movements and is controlled by Matlab, [1], Fig. 4. The control methods are based on the forward and inverse dynamics.

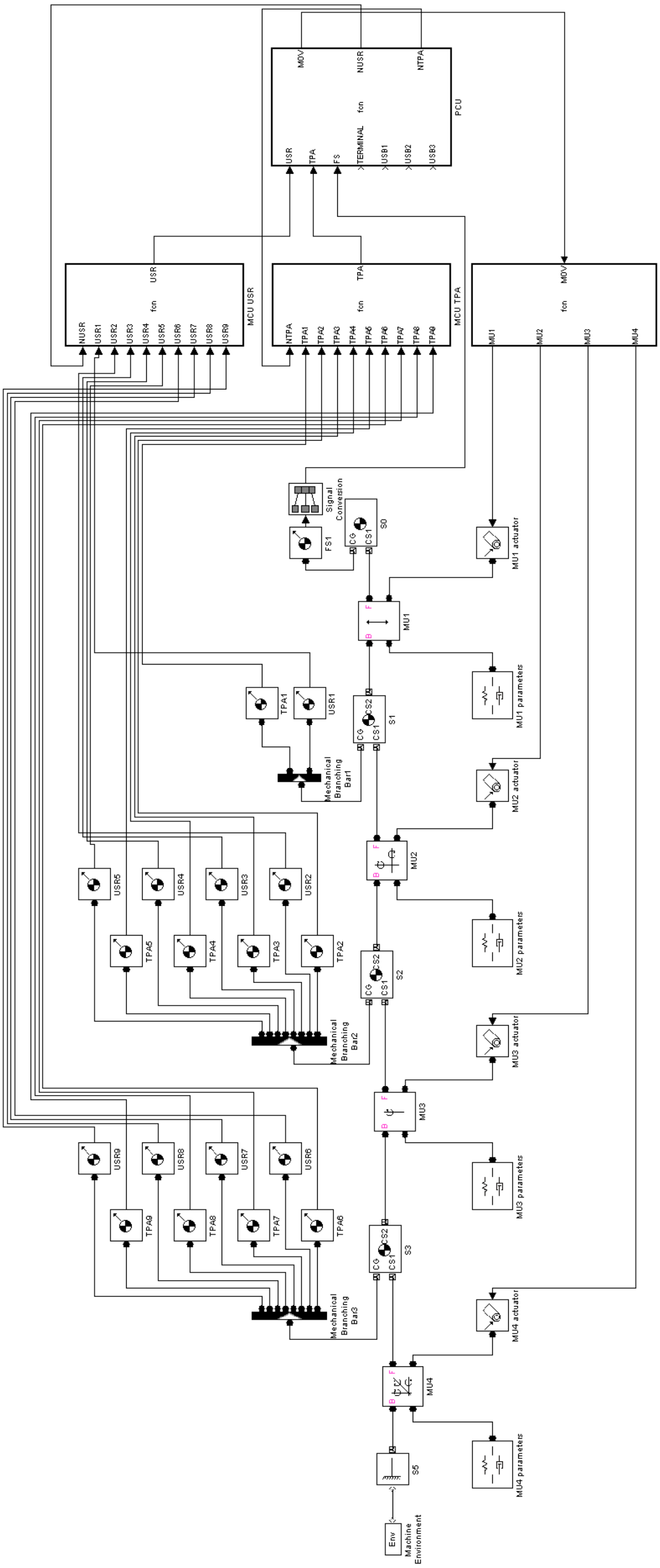

Figure 4: Matlab/Simulink model of robotic to identify position of the real robotic arm.

3 Results

New methods were designed and implemented to control the robotic arm by EMG signal in Matlab. We have verified the applicability of the new methods based on: the method of two levels of EMG envelope signal intensity and the method of two levels of EMG envelope signal slope.

The robotic arm with our new sensor system is able to obtain data on distance of surrounding objects i.e. potential obstacles. This information is processed in Matlab as well. The algorithm creates a feedback on the moving robot based on the evaluation of the signals. The robot arm can recognize the obstacles from the surrounding environment and respond appropriately to assist. The new system is suitable as an advanced system for myoelectric prosthesis of upper arm.

The sensor system use 16 sensors with resample time 1 second and less. It means that software must work with more than 1 kB information from sensors and driving system. The global spatial map of environment is created by information from sensor system. All measured data from sensor system are visualized in GUI on the PC for user diagnostic and verification of the methods. All information must be corrected from nonlinearity and compare with the sample data. All these complex processes use advance mathematics calculation which requires a very good computer technology.

The one second is very long period for good real-time working and for quick reaction on external signals. Optimal resample period is between 200 – 50 μs. When the system uses resample time 50 μs, computer must work with 250 kB information per second. In this situation is optimal to use parallel computing processing, when the software create one spatial map for every sensor with local information about environment. The global spatial map of environment is created at the last step of processing.

Important task is the identification and adjustment of optimal methods for analyzed and evaluation of bio-potential signals as EMG. The signal processing of EMG is same complicated, because every bio-potential is summation information of all useful information and background information (as capacity, inductance, unmeasured bio-potentials, motion artifact, etc.), [5].

4 Conclusions

Above method and system is an original contribution to the investigation of new prosthesis control method. The new method allows control the direction and velocity of actuator rotation by EMG signal. The new sensor system is able to recognize objects (according to the shape and size) in the surrounding space. Especially information about the surrounding environment can prevent conflict situations with obstacles during movement controlled robotic arm. Methods of artificial intelligence implemented in the Matlab offer great potential in control and signal processing, [10].

This example shows the wide range of further application of our proposed system in intelligent myoelectric prosthetics although is the system primarily used in education at FBME CTU.

Acknowledgment

This work was done at the Joint Department of Biomedical Engineering CTU and Charles University in Prague in the framework of research program No. VG20102015002 (2010-2015, MV0/VG), sponsored by the Ministry of the Interior of the Czech Republic.

References

[1] Grepl R. *Modelování mechatronických systémů v Matlab/SimMechanics.* 1. vyd. Praha: BEN - technická literatura, 2007. 152 pp. ISBN 978-80-7300-226-8.

[2] Mostýn V., Skařupa J. *Teorie průmyslových robotů.* 1. vyd. Košice: Edícia vedeckej a odbornej literatúry – Strojnícka fakulta TU v Košiciach, VIENALA Košice, 2000. 150 pp. ISBN 80-88922-35-6.

[3] Carrozza M. C., Massa B., Dario P., Zecca M., Micera S., Pastacaldi P. *A two dof finger for a biomechatronic artificial hand*. Technol. Health Care, vol. 10, no. 2, 2002, pp. 77–89.

[4] Carrozza M. C., Cappiello G., Micera S., Edin B. B., Beccai L., Cipriani C. *Design of a cybernetic hand for perception and action*. Biol. Cybern., vol. 95, no. 6, 2006, pp. 629–644.

[5] Light C., Chappell P., Hudgins B., Engelhart K. *Intelligent multifunction myoelectric control of hand prosthesis*. Journal of Medical Engineering & Technology, vol. 26, no. 4, 2002, pp. 139–146.

[6] Novak J., Feddema J. A *Capacitance-Based Proximity Sensor for Whole Arm Obstacle Avoidance*, IEEE Proceedings of the Intl. Conf. on Robotics and Automation, 1992. pp. 1307-1314.

[7] Martín P., Millán J. *Learning of Sensor-Based Arm Motions while Executing High-Level Descriptions of Tasks.* Auton. Robots 7(1), 1999, pp 57-75.

[8] Feddema J., Novak J. *Whole arm obstacle avoidance for teleoperated robots*, 1994, IEEE Proceedings of the Intl. Conf. on Robotics and Automation, pp. 3303-3309.

[9] Bennamoun M., Masound M., Bamsay A. *Avoidance of unknown obstacles using proximity fields*, 1991, IEEE Proceedings of the Intl. Conf. on Robotics and Automation, pp. 435-444.

[10] Pokorný M. *Umělá inteligence v modelování a řízení.* 1. vyd. Praha: BEN - technická literatura, 1996. 189 pp. ISBN 80-901984-4-9.

Authors: Patrik Kutilek, Jan Hybl, Jan Kauler
Institute: CTU FBMI in Prague
Street: nám. Sitna 3105
City: Kladno
Country: Czech Republic
Email: kutilek@fbmi.cvut.cz, jenda.hybl@seznam.cz, kauler@fbmi.cvut.cz