ROMANIAN JOURNAL OF INFORMATION SCIENCE AND TECHNOLOGY
Volume 19, Number 4, 2016, 321–330

Using pressure sensors for motion detection and actuation of remote manipulation devices

P.L. MILEA[1,2], Monica DASCĂLU[1], C.O. OPRIŞ[1], Eduard FRANŢI[3], M. DUMITRACHE[4], and Cristian Ioan STOICA[5]

[1]"Politehnica" University of Bucharest, Romania
Email: lucian.milea@upb.ro
[2]Solaris Consult SRL Bucharest, Romania
[3]IMT Bucharest, Romania [4] ICI Bucharest, Romania
[5]UMF Carol Davila Bucuresti
Email: stoicacristianioan@gmail.com

Abstract. Remote manipulation devices are used to extend the possibilities of human action over long distances or in environments inaccessible to man. In this paper we present an application to control a robotic arm with anthropomorphic effector, including a haptic feedback system, that provides the operator direct information on the interactions between effector and items handled by robotic arm. The system uses pressure sensors placed on the robotic hand palm and fingers connected and correlated with haptic actuators placed on the operator's control glove. Pressure information from the robotic hand is processed using a microcontroller development system, and then is transmitted to the operator's interface, where the specific vibration is generated using the haptic actuators. Experiments have shown that vibrations applied at different points of the palm and fingers of the operator were identified correctly most of the time, as sensations of pressure.

Keywords: pressure sensors, motion detection, haptic feedback, remote control.

1 Introduction

Different kinds of robotic arms have been implemented to ensure safe handling by a human operator, of hazardous materials [1] or those located in an environment unfit for human life. In most space exploration programs robotic arms or remotely operated vehicles were used by human operators from control desks equipped with control joysticks.

In such applications, end-effectors are attached at the distal terminal of the robot arm, for the proper manipulation of the various items, allowing the effective gripping of objects. These effectors may have various structures and morphologies, such as: screw, magnet, pliers, gripper, anthropomorphic hand etc. For the studied application, presented here, the anthropomorphic effectors are of interest, allowing a point to point implementation of a haptic feedback system, from its own elements to the corresponding elements (phalanges, palm) of the hand controller.

The robotic arm remote control can be performed either by mapping the movements of the human operator, of their kinematic modeling algorithms and their conversion to the motion of the robotic arm or through the development of predictive control methods of the robotic arm by a human operator [2].

2 State of the art

Remote control of a robotic arm, operating in hazardous environments for the human operator can be approached in several ways. In the scientific field, several approaches to applications of this kind were published. One of the first implementations [3] relates to a remotely controlled mechanical arm for manipulation by a human operator of radioactive materials. Other similar applications include vehicles with remote controlled robotic arms for defusing bombs or remote controlled vehicles for explorations made on the moon or Mars.

Another category of applications includes those with humanoid robots such as Honda Asimo 2, HRP-1 [4]. They are particularly suited for performing various operations in urban or human specific environments, repetitive operations in relation to people etc. On the other hand, the use of remote controlled robots is well suited for complex operations in hazardous environments and provides a more intuitive control for remote video monitoring.

Many space exploration programs have used robotic arms or vehicles. These were remotely operated using control desks equipped with joysticks for controlling movements and visual surveillance via video screens. However, modern telepresence and teleoperation applications and systems use a haptic feedback system, in addition to the video surveillance system, which gives the operator tactile information from the operating environment. One of such systems already known in the literature, is the robotic HIT/DLR arm, equipped with 4 fingers and 13 degrees of freedom [5]. This arm has a total of 100 sensors implemented at fingers phalanges, on the palm and the wrist.

The command and haptic movement control of the robotic arm can be made using a exoskeleton [6] type system, in order to duplicate and limit the movements that the human operator performs [7]. The limitations of this system are related to the high complexity of the system detecting the human operator's movements and the complete lack of coordination of movements of the elbow and shoulder monitoring for human operator joints. Another exoskeleton, with data glove which is used to control the movements of the HIT/DLR robot arm, is equipped with a lever system, which provides pressure feedback, in addition to haptic feedback. This allows control of the movements made by human operator when handling fragile objects that may be damaged due to too high forces and pressures compared to their mechanical structure [8].

The most common devices for detecting hand movements in real time are data gloves or systems containing such gloves; this provides a complete solution that determines with great accuracy the movements of the wrist and fingers [9]. Processing circuitry dedicated to data can be made [10] or can be made to the microprocessor [11]. Data gloves allow the mounting of sensors on the fingers, as well as tracking systems, accelerometers and force-feedback systems. Their main advantages are simplicity of design, low weight and freedom of movement.

3 Design of the haptic feedback system

The presented system is based on a data glove on which we have assembled a matrix of haptic actuators. Haptic feedback system has to offer human operator tactile sensations in the fingers and palm phalanges of the hand that controls the robotic arm based on information obtained from pressure sensors placed on robotic hand items. Tactile sensations are produced by means of vibrations of haptic actuators mounted on the glove worn on human operator's hand. These tactile sensations vary in intensity and are proportional to the pressure between the fingers of the robotic arm and the objects that it manipulates.

The system solves the problem of adequacy of the force applied by the robot arm on the objects handled, depending on their size, volume and weight. The pressure information is transmitted to the human operator in the form of vibration, with frequency and amplitude related to the force of the object's reaction. Therefore the operator can perceive the difference in hardness and weight between different objects, which allows him to act effectively on them.

The designed system (Figure 1) contains: an array of pressure sensors mounted on the phalanges of the robotic arm, a unit for processing pressure signals (tactile feedback), a communications channel, a haptic control unit and an array of haptic vibratory actuators mounted on the control and monitoring interface, in contact with the operator's hand.

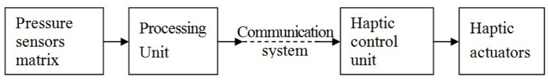

Fig. 1: The block diagram of the system

The sensory matrix (Figure 2) includes 19 pressure sensors mounted on the inner face of the phalanges of the robotic hand (14 sensors) and of the palm (5 sensors), as shown below. The processing unit converts and multiplexes digital pressure sensor information, and then transmits it via a serial communication system suitable to the application. The haptic control unit decodes the received information and processes it, generating the final control signals for the haptic actuators, whose frequency and amplitude of the vibration are correlated with the pressure exerted by the robotic arm of the objects being handled (or vice versa) at each pressure sensor.

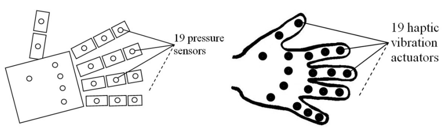

Fig. 2: The matrix of pressure sensors (left) and the haptic actuators' one (right)

The haptic actuators (Figure 2) matrix is distributed on the ventral surface of a control and monitoring glove, as shown above, following closely the pressure sensor arrangement of the robot hand.

The pressure signals from the sensors placed on the robotic hand will be processed to obtain a linear variation of the numerical output value. This processing will be based on the dependence of the electrical output of the sensors on the exerted pressure.

Another problem to be solved is that the pressure sensors occupy only part of the ventral surface of the phalanges and palm of the robotic hand. Because of this, certain objects with sharp or high rough protrusions can press pressure sensors differently, resulting in a haptic stimulation different from reality that will be applied to the operator's hand. To alleviate this problem, the linear pressure signals will be summed weighted so that haptic stimulation is distributed to multiple actuators to correct any errors caused by the high roughness of the surface of the manipulated object. For this purpose, we consider both the correlation of values from both adjacent sensors on the same finger and from the adjacent fingers' sensors by weighted sums (with different weights).

For this weighting, we count the sensors on each finger from 0 to 3, the index 0 being assigned to the terminal phalanx and 3 to the sensor placed on the corresponding metacarpian (2 in the case of the thumb). The fingers will be numbered from 0 to 4, starting with the thumb. This will result in a sensory matrix, denoted by S:

$$S = \begin{bmatrix} s_{00} & s_{01} & s_{02} & s_{03} \\ s_{10} & s_{11} & s_{12} & s_{13} \\ s_{20} & s_{21} & s_{22} & s_{23} \\ s_{30} & s_{31} & s_{32} & s_{33} \\ s_{40} & s_{41} & s_{42} & s_{43} \end{bmatrix} \quad (1)$$

In this array, the lines represent the 5 fingers and the columns are the values from the sensors on the phalanges and the metacarpines of the fingers, as in the figure below.

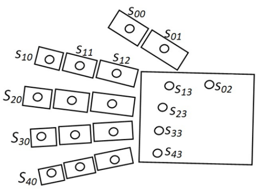

Fig. 3: The matrix of pressure sensors and their correspondence with S matrix elements

The S matrix will be multiplied by a weighting matrix, P, to apply different weights to phalanges of the same finger, which will be comprised into haptic stimulation signals.

$$P = \begin{bmatrix} p_{00} & p_{01} & p_{02} & p_{03} \\ p_{10} & p_{11} & p_{12} & p_{13} \\ p_{20} & p_{21} & p_{22} & p_{23} \\ p_{30} & p_{31} & p_{32} & p_{33} \end{bmatrix} \quad (2)$$

This will result in an array M = S·P.

On the other hand, in order to correlate the haptic simulation with the pressure signals from the adjacent phalanges, another matrix, L, will be multiplied by the previously obtained matrix M:

$$L = \begin{bmatrix} l_{00} & l_{01} & l_{03} & l_{03} & l_{04} \\ l_{10} & l_{11} & l_{12} & l_{13} & l_{14} \\ l_{20} & l_{21} & l_{22} & l_{23} & l_{24} \\ l_{30} & l_{31} & l_{32} & l_{33} & l_{34} \\ l_{40} & l_{41} & l_{42} & l_{43} & l_{44} \end{bmatrix} \quad (3)$$

, thus obtaining the matrix of haptic stimuli, V:

$$V = L \cdot M = L \cdot S \cdot P = \begin{bmatrix} v_{00} & v_{01} & v_{02} & v_{03} \\ v_{10} & v_{11} & v_{12} & v_{13} \\ v_{20} & v_{21} & v_{22} & v_{23} \\ v_{30} & v_{31} & v_{32} & v_{33} \\ v_{40} & v_{41} & v_{42} & v_{43} \end{bmatrix} \tag{4}$$

If we assume that the share of the corresponding sensor of a particular actuator is a, and the values provided by the sensors are denoted by s_{ij}, then the relationships that define the values of the matrix elements M(m_{ij}) will be the ones below.

For the thumb:

$$\begin{aligned} m_{00} &= a \cdot s_{00} + (1-a) \cdot s_{10} \\ m_{10} &= a \cdot s_{10} + (1-a) \cdot (s_{00} + s_{20})/2 \\ m_{20} &= a \cdot s_{20} + (1-a) \cdot s_{10} \end{aligned} \tag{5}$$

For other fingers:

$$\begin{aligned} m_{i0} &= a \cdot s_{i0} + (1-a) \cdot s_{i1} \\ m_{i1} &= a \cdot s_{i1} + (1-a) \cdot (s_{i0} + s_{i2})/2 \\ m_{i2} &= a \cdot s_{i2} + (1-a) \cdot (s_{i1} + s_{i3})/2 \\ m_{i3} &= a \cdot s_{i3} + (1-a) \cdot s_{i2} \end{aligned} \tag{6}$$

This results in the following weighting matrix, P:

$$P = \begin{bmatrix} a & \frac{1-a}{2} & 0 & 0 \\ 1-a & a & \frac{1-a}{2} & 0 \\ 0 & \frac{1-a}{2} & a & 1-a \\ 0 & 0 & \frac{1-a}{2} & a \end{bmatrix} \tag{7}$$

For the correlation between the sensor values from the different fingers, we will also take into account the values provided by the adjacent fingers sensors (with the weight *b*) and the degree of flexion of each finger (f_i, i from *1* to *4*). Thus, if two adjacent fingers have an identical degree of flexion, we can assume the existence of a correlation between the signals from their sensors of the same order. If the degree of flexion is different, then we will consider that there is a lower correlation.

To model the dependence on the degree of flexion, we consider that they have values between *0* and *1*, so that their difference module also falls between *0* and *1*.

The haptic commands associated with the thumb will not correlate with those of other fingers, as it is usually in a position opposing or deviating from the index.

$$\begin{aligned} v_{0i} &= m_{0i} \\ v_{1i} &= [1 - (1 - |f_1 - f_2|) \cdot b] \cdot s_{1i} + (1 - |f_1 - f_2|) \cdot b \cdot s_{2i} \\ v_{2i} &= \frac{(1 - |f_1 - f_2|) \cdot b}{2} \cdot s_{1i} + \left[1 - \left(1 - \frac{|f_2 - f_3| + |f_1 - f_2|}{2}\right) \cdot b\right] \cdot s_{2i} + \frac{(1 - |f_2 - f_3|) \cdot b}{2} \cdot s_{3i} \\ v_{3i} &= \frac{(1 - |f_2 - f_3|) \cdot b}{2} \cdot s_{2i} + \left[1 - \left(1 - \frac{|f_2 - f_3| + |f_3 - f_4|}{2}\right) \cdot b\right] \cdot s_{3i} + \frac{(1 - |f_3 - f_4|) \cdot b}{2} \cdot s_{4i} \\ v_{4i} &= (1 - |f_3 - f_4|) \cdot b \cdot s_{3i} + [1 - (1 - |f_3 - f_4|) \cdot b] \cdot s_{4i} \end{aligned} \tag{8}$$

This generates the following general form for the L matrix:

$$L = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 \\ 0 & 1-(1-\mid f_1-f_2\mid)\cdot b & (1-\mid f_1-f_2\mid)\cdot b & 0 & 0 \\ 0 & \frac{(1-|f_1-f_2|)\cdot b}{2} & 1-\left[1-\frac{|f_2-f_3|+|f_1-f_2|}{2}\right]\cdot b & \frac{(1-|f_2-f_3|)\cdot b}{2} & 0 \\ 0 & 0 & \frac{(1-|f_2-f_3|)\cdot b}{2} & 1-\left[1-\frac{|f_2-f_3|+|f_1-f_2|}{2}\right]\cdot b & \frac{(1-|f_3-f_4|)\cdot b}{2} \\ 0 & 0 & 0 & (1-\mid f_3-f_4\mid)\cdot b & 1-(1-\mid f_3-f_4\mid)\cdot b \end{bmatrix} \tag{9}$$

In the case in which, for various reasons, we admit that there must be a correlation between the fingered signals, regardless of their degrees of flexion, then we assume that $\mid f_j - f_k \mid= 0$ and obtain:

$$L = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 \\ 0 & 1-b & b & 0 & 0 \\ 0 & b/2 & 1-b & b/2 & 0 \\ 0 & 0 & b/2 & 1-b & b/2 \\ 0 & 0 & 0 & b & 1-b \end{bmatrix} \tag{10}$$

The operation of such a haptic feedback system takes place in a control loop, presented in Figure 4. This loop includes a system for controlling the motions of the robotic arm. In the absence of an exoskeleton that limits the movements of the operator, the system operation is based on conditioned reflexes of the operator being acquired after training.

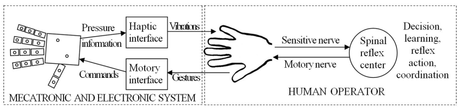

Fig. 4: Robotic arm control loop using the haptic feedback system

The touch of the object that is manipulated is notified to the operator in the form of a fine vibration, and firm pressing is felt in the form of an extensive and rapid vibration. Based on this distinction, the operator will gradually learn to associate his movements with adequate thrust exerted on the objects, while maintaining continuous contact with the surface of the object. The control loop includes operator's nervous system: sensitive, motory and decisional (both central and spinal) nerves. In the first stage of familiarization with the system and haptic control loop, the operator decisions will be taken after a conscious evaluation, involving the central nervous system. At this stage, the operator will learn to associate tactile sensations from the control glove with the reaction forces from the handled objects. Then he will be able to take decisions and carry out appropriate control actions. After a certain period of training, this loop will become automatic. Then, the learned decisions will be taken in spinal nerves, as conditional reflex. Thus, controlling the robotic arm will be done spontaneously, based on tactile perceptions instead of the opposing force of the monitoring device (as it is the case when using an exoskeleton).

4 Implementation

The haptic feedback system that has been implemented (Figure 6) is composed of an array of resistive pressure sensors (CZN-CP6 [12]) mounted on the robotic arm phalanges, a processing and control unit and an array of haptic actuators mounted on the glove used by human operator in control of the robotic arm.

The transfer characteristic of this sensor is shown in Figure 5.

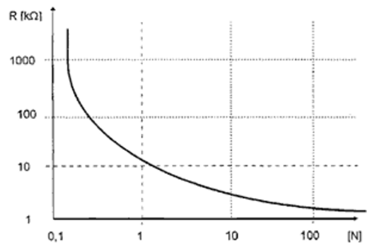

Fig. 5: CZN-CP6 Sensor characteristics [12]

For our application, the force applied to a sensor ranges from 0.25 to 10 N, which corresponds to a quasi-linear variation in resistance between 100 kΩ and 3 kΩ. We approximated this variation as linear, defined by the function:

$$R = k/F, with\ k = 25\ k\Omega/N \tag{11}$$

Both the pressure information processing unit and haptic control block are made using microcontroller (ATmega 2560) based development board, as presented in Figure 6 and Figure 8.

The implementation presented was made in simplified form, without taking into account in these calculations the values provided by flexion sensors. The two weights were chosen experimentally as $a = 0.8$ and $b = 0.1$.

The resulted weighting matrices have the following forms:

$$P = \begin{bmatrix} 0.8 & 0.1 & 0 & 0 \\ 0.2 & 0.8 & 0.1 & 0 \\ 0 & 0.1 & 0.8 & 0.2 \\ 0 & 0 & 0.1 & 0.8 \end{bmatrix} \quad \text{and} \quad L = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 \\ 0 & 0.9 & 0.1 & 0 & 0 \\ 0 & 0.05 & 0.9 & 0.05 & 0 \\ 0 & 0 & 0.05 & 0.9 & 0.05 \\ 0 & 0 & 0 & 0.1 & 0.9 \end{bmatrix} \tag{12}$$

This microcontroller board is working at 16 MIPS processing speed and has 54 digital I/O pins, 16 analog inputs with 10-bit resolution (from 0 to 5V), 4 hardware serial ports (UARTs). Also, 15 I/O pins can be used as 8-bit PWM outputs [13]. The full duplex communication between these boards is made using serial ports with TTL logic levels, at 115200 baud rate.

In processing unit, 11 of the pressure sensors outputs (voltage divider circuits) are connected directly to 11 of microcontroller's analog inputs and the rest of them (those placed on the middle phalanx and metacarpus of fingers from pinky to index - $s_{11}, s_{21}, s_{31}, s_{41}, s_{13}, s_{23}, s_{33}, s_{43}$) are connected to the 12th input via an analog multiplexer (CD4051B). The flexion sensors (one for each finger, used here only for command controls) are connected to the 13th input via another analog multiplexer. Two digital I/O pins are used to address the multiplexer in order to read these 4 sensors, with a clock of about 2kHz. The 14 actuators placed on fingers are controlled from PWM I/O pins via drivers while the 5 actuators placed on the palm are controlled by normal I/Os (via drivers), with a constant level of intensity (experimentally adjustable).

The glove used by the human operator has a dual role:
– using bending electrodes /sensors, the movements made by the human operator are detected, and then they are duplicated in the robotic arm
– using haptic actuators, the human operator feels, in the form of vibrations of different frequencies and intensities, the pressing force exerted by the phalanges of the robotic arm over the manipulated objects.

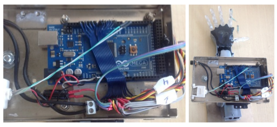

Fig. 6: The development board that will processes the pressure information from the robotic hand

The implemented haptic block consists of 19 vibrating haptic actuators (proposed maximum) that are placed on the phalanges of the control glove used by the human operator. Depending on the signals level obtained from pressure sensors placed on robotic arm's phalanges, the control unit of the sensory interface will control the pressure exerted by actuators placed on the glove used by the human operator. Each phalanx of the robotic arm's fingers has correspondingly one actuator placed on the phalanges of the glove used by the human operator. So, the haptic feedback system includes 19 pressure sensors placed on the phalanges of the robotic arm and 19 actuators placed on the phalanges of the haptic control glove.

Fig. 7: Placing pressure sensors on robotic hand and haptic transducers in glove phalanges

Each of the actuators starts performing a first step of vibrating the phalanges of the hand of the human operator when the phalanges of the robotic arm are touching the manipulated object. When the force exerted on the object being handled increases greatly and may result in the destruction of the object, the signals from the pressure sensors reaches a maximum set level, then the fingers actuators are stopped, and the actuators of corresponding fingers will perform the second step of vibration. In this way the human operator can feel if the movements of all fingers touch the robotic arm or just one of it are stopped. In this way, the human operator has haptic feedback from each finger (and even phalanx) of the robotic arm.

Haptic stimulation is performed in steps in order to be more easily discernable by the operator. Each actuator on the fingers performs a first step of intensity when corresponding pressure sensor gets in touch with the handled object. The second step applies when the pressure exerted on the corresponding sensor reaches 50% of the maximum level of the electro-mechanical structure.

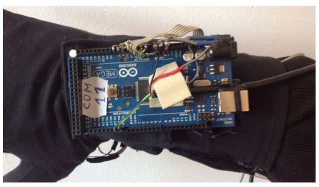

Fig. 8: Development board controlling the haptic actuators

When the signal from the pressure sensor of one of the fingers reaches the stop level, the corresponding actuator performs the third step of pressing on the operator's finger. In this way, the operator receives specific tactile sensations on fingers, when one finger of the robotic hand is stopped. This arrangement of haptic transducers has the advantage that it allows the human operator to easy correlate hand gestures that control robotic arm on tactile stimuli he receives from haptic actuators and thus the haptic feedback may become reflex in a relatively short time by means of a suitable training.

5 Results

After installing the sensory interface on the robotic arm's phalanges and the haptic actuators on the control glove, some experiments were performed to test the functionality of the haptic feedback system. The system was functioning fine, being able to track all movements available for the robotic assembly's degrees of freedom (shoulder, elbow, hand, fingers).

During training, the human operator took time to accommodate the tactile sensations provided by haptic feedback system in order to efficiently and accurately control the robotic arm. At the beginning of the exercise it was found that the human operator sensations stimulated by haptic actuators glove were quite different from those which he experienced when handling an object with his own hand.

When handling an object with his own hand, the human operator can spontaneously appreciate size, hardness, texture and weight of the object in question and therefore it will instinctively contract different muscle groups of the upper arm, forearm, palms and fingers, being able to control the robotic arm and hand (Figure 9).

The main difficulties which the operator encountered in controlling the robotic arm were due to lack of familiarity with the haptic feedback sensations and their correlation with human operator reflexes, necessary to control the robotic arm. After training, the human operator was able to command the robotic arm to manipulate objects.

Fig. 9: Training performed by the human operator with an object similar to that handled by the robot arm

6. Conclusions

Based on previous experience [14] and first author's education in medical electronics, an improved system of haptic feedback was designed and implemented then tested for its usefulness. It was mounted on an anthropomorphic robot hand mounted as end effector of a fully articulated robotic arm. Resistive pressure sensors were installed diagonally to each phalanx's axis on an anthropomorphic robotic hand, which allowed greater freedom of movement to the previous versions.

Pressure data acquisition was done with a microcontroller ATmega 2560, the sensors being mounted on analog inputs, whose number has been extended by multiplexing with CD4051B. Haptic actuators on the fingers were driven in steps of intensity, while the palm ones were kept at a constant level of intensity when suitable stimuli exist. System performance was experimentally evaluated by a human operator in some phases of training. Results showed an acceptable system operation and gradual improvement in operator's performance.

Acknowledgements. This work was supported partly by the grant 82/2013 of the Romanian Space Agency, Space Technology and Advanced Research Programme STAR.

References

[1] BICCHI A, KUMAR V. *Robotic grasping and contact: a review*. IEEE Intl Conf on Robotics and Automation Proceedings 2000; 1:348-353.

[2] MILEA L., DASCALU M., FRANTI E., CISMAS S., MORARU D., LAZO F., ELTETO Z. *Detection and Tele-replication of Human Hand Motions by a Robotic Hand*. American Journal of Aerospace Engineering. Vol. 2, No. 4, 2015, pp. 30-35. doi: 10.11648/j.ajae.20150204.11.

[3] GOERTZ R., THOMPSON R., *Electronically controlled manipulator*. Nucleonics, Vol.12, No.11, pp.46-47, 1954.

[4] HONDA, Honda ASIMO, http://world.honda.com/ASIMO/4C.

[5] MEUSEL P., LIU H., *DLR-HIT-Hand: Multisensory 4-Finger-Hand*, Institute of Robotics and Mechatronics, August 2015, http://www.dlr.de/rmc/rm/en/Portaldata/52/Resources/dokumente/sah/9DLR-HIT-HAND2006Handout.pdf.

[6] POGĂRĂSTEANU M.E., BARBILIAN A.G., *Bionic hand exoprosthesis Perspectives for the future in Romania*, Journal of Medicine and Life, 2014 Oct-Dec; 7(4): 601-603.

[7] FANG H., XIE Z., LIU H., *An exoskeleton master hand for controlling DLR/HIT hand*, in Intelligent Robots and Systems, 2009. IROS 2009. IEEE/RSJ International Conference on, October 2009, pp. 3703-3708.

[8] HU H., LI J., XIE Z., WANG B., LIU H., HIRZINGER G., *A Robot Arm/Hand Teleoperation System with Telepresence and Shared Control*, Proceedings of the 2005 IEEE/ASME International Conference on Advanced Intelligent Mechatronics, Monterey, California, USA, 24-28 July, 2005, http://www.cs.nott.ac.uk/ pszjl/index_files/01511192.pdf.

[9] CYBERGLOVE, CyberGlove Systems LLC, http://www.cyberglovesystems.com/.

[10] MAICAN V., *Minimum Spanning Tree Algorithm on Map Reduce One-Chip Architecture*, Romanian Journal of Information Science and Technology (ROMJIST), vol 18, no 2, pp. 127-143, 2015.

[11] OLTU O., VOICULESCU V., DASCĂLU M., POPESCU V., BARBILIAN A., *Advanced Power Monitoring of an ARM Processor*, in volume "Computational Engineering in Systems Applications" selected papers from WSEAS Conf. in Heraclion, Greece, july 2008.

[12] TME, CZN-CP6 Sensor, http://www.tme.eu/hr/katalog/senzori-sile-pritiska_100439/.

[13] ARDUINO, Arduino MEGA 2560, https://www.arduino.cc/en/Main/arduinoBoardMega2560.

[14] DASCALU M., MILEA L., FRANTI E., LAZO F., ELTETO Z., ISPAS I., *Haptic Feedback Experiments for Improved Teleoperation of a Robotic Arm.* American Journal of Aerospace Engineering. Vol. 3, No. 3, 2016, pp. 36-42. doi: 10.11648/j.ajae.20160303.13.