HMI for cooperative robot Kuka youBot based on Electromyography technique

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***Abstract*—The ways in which humans and machines interact have changed as new technologies have been introduced into practice. At this moment, the trend is to simplify the interaction between man and machine, making the interfaces as intuitive and easy to use as possible. In this purpose, human-machine interfaces based on voice commands, gestures and even interfaces based on electrobiological signals generated by human body have been successfully developed. In this paper, the authors show the current stage, steps and experiments performed to develop a human-machine interface based on the electromyography technique. The proposed procedure involves the collection of electrical signals generated by muscles and their transformation into usable signals for the control of a robot by processing them. The interface was connected with the Kuka youBot two-arm cooperative robot and allowed control of its joints. Thus, the movement of the user's arm, resulted by muscle contraction, is transposed into joints movement of the robotic arm. At the end of the paper are presented the conclusions of the experiments performed, the utility, but also the directions of future development for the proposed concept.**

Keywords— HMI, Electromyography, Robot control, Kuka youBot.

I. INTRODUCTION

Since forever the humans tried to simplify their work by developing interfaces for the machine they operate. These interfaces have evolved together with machines and have grown with the advancement of technology. Today, the interfaces are everywhere around us and help us to use devices that surrounds us.

HMI's take various forms and functions, but regardless of this, the HMI purpose is to provide the user with insides of the process. Having this in mind, one can easily say that HMI must be intuitive and easy to use. [1]

Trends in HMI evolution are directing the research and development to include new methods of interacting with machines, like eye gaze, gesture, voice or electromyography.

Electromyography (EMG) is a technique used to record electrical activity of muscles. [2] Sensors are detecting the electric potential of muscle when electrical or neurological stimulation is applied. Sensors, also called electrodes, are used to detect electrical activity and a display or oscilloscope is used to show the signal. [3] This measurement is a differential one, as typically the muscle does not produce electricity during rest, so, by contracting the muscle, a potential difference is recorded. In muscle each cell (fiber) is stimulated individually, so the more contraction force is applied, the more action potential is created. To detect this electrical activity electromyographs machines are using signal amplifier, as the voltage generated by muscle varies in a small range (0 – 10 mV). [4][5] This value needs to be amplified in order for a microcontroller to be able to read it.

For a long time, motricity and muscle activity have been studied using visual inspection [6][7], however, along with technology evolution, new techniques were developed. Development of EMG technologies allowed doctors to record muscle activity, and so it become common in medical diagnose and biomedical research. Most common use for EMG is neuromuscular disorder diagnose and rehabilitation. [8] Based on EMG signals a variety of prosthetic limbs could be developed and help amputees to control them by detecting signals sent by brain. [9][10]

Along with medicine, this theology was adopted in other fields, for example robotics, and used as interfaces to control robotic arms. However, considering the nonlinear relationship between EMG signals and arm motion [11], in previous work control interfaces were limited to a part of the arm, like wrist [12] or multifingered hands [13], but also exoskelets for arm have been developed with control interfaces based on EMG signals. [14] More recently, new methods of robotic arms control based on EMG signals have been developed. [15][16]

This paper presents the development stages and tests performed in order to validate if a control interface based on EMG signals for Kuka youBot is feasible. The robotic structure is presented in Fig.1.

Figure 1 Kuka youBot

Kuka is a robotic structure with a mobile platform and two 5 DOF arms. As can be seen in Fig. 1 Kuka youBot has omnidirectional wheels, this together with the robotic arms increase the mobility of the structure and, at the same time, it makes the robot harder to control. Previously, an HMI for controlling the robotic structure has been developed and development stages have been already published. The interface was designed to communicate wireless with Kuka and was developed for Android OS (Operating System), both providing more flexibility for user, for robot, as well as for developer. The HMI had multiple screens that allows a facile menu selection, offer the possibility of manual control, but also memorizing programs that will be run automatically. Two screens of the final stage of HMI are shown in Fig. 2a and Fig. 2b. [17]

Figure 2a Create a program screen

Figure 2b Run a program screen

II. SYSTEM CONCEPT AND DESIGN

The reason for choosing Kuka youBot for this study was based on the fact that an interface was already developed and because the structure is similar with human arm, but also following the trends to make HMI more intuitive for users, the concept of using EMG signals as inputs was just the next step.

Kuka youBot robotic platform comes from supplier without any software implemented, meaning that, to operate the platform the developer firstly needs to get access to the robot's joints. To be able to do this, has to:

- install an operating system (Ubuntu Linux is the most suitable for Kuka youBot);
- install a robotic operating system (ROS);
- install youBot API and drivers.

Once, all the above steps have been performed, the next step is to develop and implement a control algorithm. The previous algorithm implemented is able to receive inputs from a wireless device, process them and send to robot's joints as commands. Having the wireless communication from previous HMI already implemented the authors decided it is time to enhance the interaction between operator and robot and transform it into a more fluent control, making the robot follow the user's movement by using as input EMG signals.

The new interface based on EMG signals will provide to the user a more intuitive way of controlling the robot. The studies and experiments conducted by authors are centered around Kuka's gripper and "elbow" joints. The focus of this paper is to demonstrate that such control based on EMG signals is possible and is reflected in the attempt to control a robot joint. Thus, the steps followed in order to obtain this achievement are presented, but not the implementation of interface itself for controlling the full robotic structure.

When developing an HMI, one must consider few mandatory steps: define and gather the inputs, define the application requirements, map the signals to fulfill this requirement and, last, but not least, provide output. The system proposed by authors shall read the information from EMG electrodes placed on user's arm, amplify the signal to a value readable for microcontroller, transform them into instructions for Kuka and transmit them to Kuka's controller. In Fig.3 is presented the overall system architecture, which briefly describes end to end functionality.

Figure 3 Overall system architecture

As it can be seen in Fig.3, the first element in chain flow is represented by the EMG electrodes which are providing the inputs signals when the muscles are being contracted. These signals are then recorded by the system developed which consists of an EMG amplifier and NodeMCU board. At the same time, NodeMCU fulfills the task of data processing and transmission via wireless communication.

Considering that in previous HMI implementation the communication was also wireless compatible, the transition and upgrade to NodeMCU did not require much adaption in robot controller algorithm and neither in its operating system. The only restriction for the system would be that both the robot and the NodeMCU controller have to be connected to the same network.

The developed concept was constructed from two main components namely NodeMcu controller and EMG amplifier. After studying several already existing medical devices, it was decided that the amplifier should be made from scratch because of the expenses of the devices. The developed amplifier is centered on INA128, an integrated circuit capable of detecting such signals from Texas Instruments. According to the datasheet provided by the manufacturer, the maximum gain of INA126 is 10000 with respect to the value of the gain resistor used, which allows reading of very low voltage level generated by muscle contractions. The exact calculus of the gain is represented by formula (1).[18]

$$G = 1 + \frac{50k\Omega}{R_G} \tag{1}$$

Before physical implementation, simulation have been conducted in order to study the functionality and response of the designed EMG amplifier to test its capabilities. The environment used to perform the simulation is Micro-Cap software package. Schematic and simulation results are presented in Fig.4.

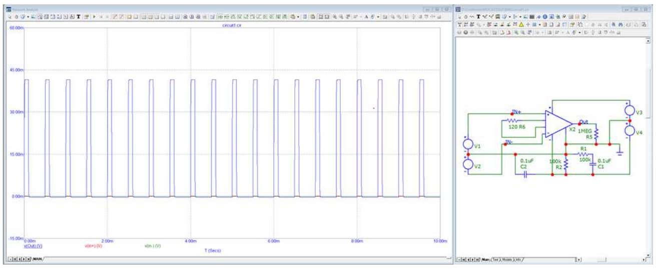

Figure 4 Simulation of EMG amplifier in Micro-Cap

The results of simulated circuit reveals that the amplifiers act as expected and is suitable for proposed application. Based on simulation results it was concluded that this circuit with $R_G = 120\Omega$ has an amplification factor of 900.

Following the satisfactory results of the simulation, the further step was physical device. Designing the schematics and PCB layout of the final circuit were achieved with the help of KiCAD tool, that will be printed later. This development phase is exposed in Fig.5a and Fig.5b.

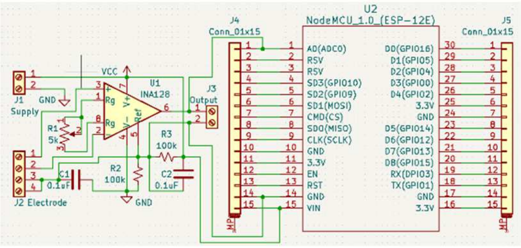

Figure 5a Amplifier schematic diagram

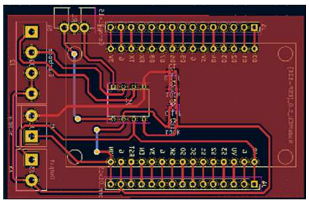

Figure 5b PCB layout

Final result after accomplishing each stage of development is shown in Fig.6. Also, a housing was created in order to have cable management and to allow an easier manipulation of the final device.

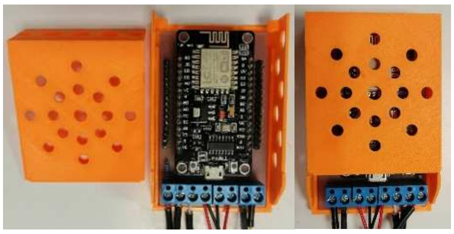

Figure 6 Final physical implementation

III. TESTING AND VALIDATION

Besides simulation inside a professional environment, authors considered it was necessary to conduct several experiments on the final EMG amplifier in order to confirm the results obtain during simulation with the actual device. Physical testing was conducted in several stages which were related to testing the amplifier and integration with NodeMCU controller. During the testing activities, the input for the amplifier was provided by a signal generator and the output was monitored with an oscilloscope, setup can be observed in Fig.7. Furthermore, the software code tested on NodeMCU was also tested keeping the same pre-conditions: a stable signal input and a monitored output.

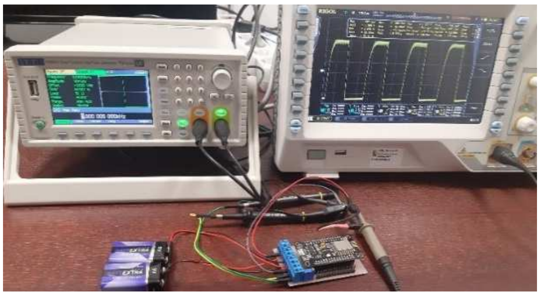

Figure 7 Testing setup

Final testing phase was conducted by having the NodeMCU read the real signal of a muscle and the data obtained was plotted in order to further study the behaviour of the signal. The scope was to observe certain patterns in the signal generated by muscle contractions, in order to be able to develop a software that can extract relevant data. This data will be later converted into a command for the robot. In focus for this activity, two main muscles were chosen to provide the signal: forearm (grasping objects) and biceps (elbow flexing).

Position of the electrodes on the forearm for grasping object command is shown in Fig.8.

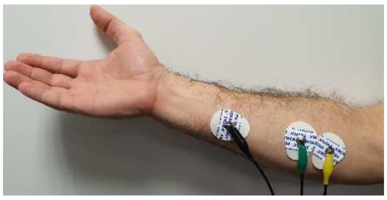

Figure 8 Forearm electrodes position

The raw signal detected was plotted to better observe the pattern of signal and is presented in Fig. 9.

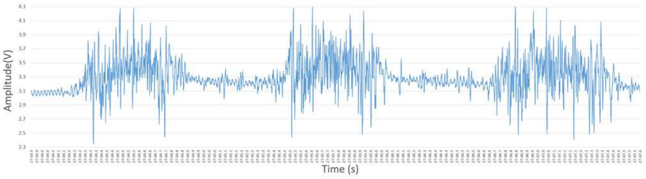

Figure 9 Raw signal of forearm muscle

In this specific scenario the forearm muscle motion controls the opening and closing robot's gripper. On the raw data a filter was applied in order to use only the superior part of the signal. Based on this filter, as it is presented with orange line in Fig. 10, the pattern was transformed into a square signal. Data resulted after the completion of the forearm experiment stands as basic input for robot gripper commands, where the rising edge is command for closing gripper and falling edge is the command for opening gripper.

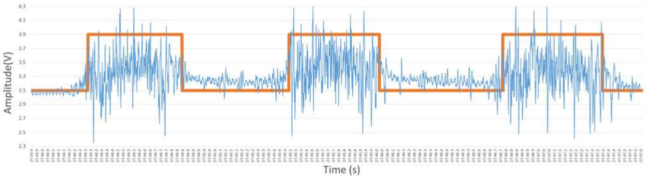

Figure 10 Square signal pattern

The next experiment was performed on biceps muscle for controlling the robot elbow. The placement of electrodes for this scenario is presented in Fig.10.

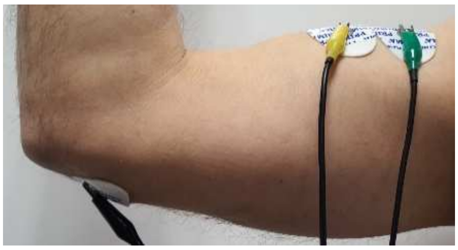

Figure 10 Biceps electrodes position

Similar as for the forearm experiment, the results for the second experiment - raw signal and filtered signal pattern are presented in Fig.11.

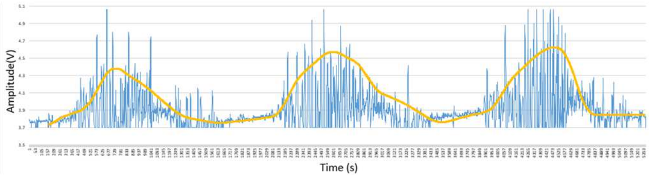

Figure 11 Raw signal of biceps muscle

The basic control movements of robot's joints have been accomplished but full control is yet to be developed. Angle, rotations and translation of certain joints require much more complex and deeper analysis in order to obtain a precise motion that will follow with accuracy the user's movement.

IV. CONCLUSION

It is already known that electrobiological signals present in human body can be used in various medical scenarios in order to study certain affections and also to help a person recover from suffered injuries. The current paper provides conclusions that these signals can prove their usefulness not only in such situations but also in scenarios applicable for industry context revealing a new method of controlling a mechatronic structure. This brings us closer to overcome the human-machine border.

The experiments conducted and presented in the paper show the first steps in constructing a more complex system that the authors intend to further develop in order to obtain a fully controlled mechatronic structure that rely on EMG signals. Such system will not only stand as a state of the art but also will simplify the control of robots used in industrial environments and will help operators to faster gain required knowledge to operate the equipment, thus reaching a maximum productivity in a shorter amount of time.

Further development is focusing on integrating more electrodes and other sensors that will provide sufficient raw data in order to provide much more functionalities.

As a conclusion, the integration of Kuka robot with the developed system for capturing EMG signals, that act as control commands, shows real potential in solving the proposed problem and furthermore to develop a more complex system.

ACKNOWLEDGMENT

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