Anthropomorphic EMG-driven Prosthetic Hand

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Abstract — **Hazards in industry, wars and serious medical reasons determined the increase of the number of amputations and, thus, the need for designing prosthetics that replace the missing segment by imitating its natural movements. Research in prosthetics domain became, consequently, a primary activity both for engineers and physicians. Due to structural and functional acclimation to the complexity of human activities, one of the most difficult to approach limb of the human body is the hand. This paper is aimed to design an anthropomorphic prosthetic hand controlled based on surface electromyography sensors data acquired from two important muscles: flexor pollicis longus muscle and flexor digitorum profundus muscle. Another purpose of the paper consists in providing two main functions of the prosthetic hand, prehension and fingers flexion.**

Keywords — **anthropomorphic, EMG signals, finger flexion, prehension, prosthetic hand.**

I. Introduction

VASCULAR disease, as diabetes and peripheral arterial disease, trauma suffered due to industry hazards and cancer are the main causes for amputation [1]. Human hand is a very sophisticated component of the human body as its capabilities are complex and all-important [2]. Without hands, the quality of human life is severely diminished. To greet the needs of the persons affected by hand loss, different devices that try to imitate the anatomy, properties and functionality of the human hand were proposed [3]. If one hundred years ago, the prosthesis designed by Hosmer-Dorrance had reduced functionality (grabbing function) and was designed as a hook, the next prostheses developed usually in Russia and United States, especially after World War II, were improved. Thus, more functions were added, the prostheses became lighter and patient-molded [4]. With the advent and development of microprocessors and robotics, the prostheses were further enhanced. The need for enhanced functions, aesthetics and more comfortable devices intensified the research in electromyography and myoelectric prosthetics [5]. Moreover, the 3D printing technology contributed to the design of various lighter, cheaper and less time-consuming prostheses [6]. Atasoy et al [3] presented a mechanical design prosthetic hand having brushless DC motor and shape memory alloy (SMA) actuators to mimic the anatomy of the human hand. EMG signals were acquired through the MYO Armband device equipped with 8 surface EMG (electromyography) electrodes and the features were extracted using Wavelet Packet Transform (WPT), a method that decomposes a time signal into independent time-frequency signals known as packets and enables the localization (in time) of transitory events [3], [7]. The classification method used in [3] is based on neural networks and 7 hand postures and grasps are recognized with a success rate of 80% (when all subjects are trained for all data) and 95-98% when only one subject is trained for all seven events. In [6] a 3D-printed upper-extremity prosthesis equipped with pressure sensor is proposed and compared with Otto Bock myoelectric prosthesis from the point of view of functions, dexterity, cost, fabrication period and weight. Several tests were conducted: nine hole pegboard test, box&block test, hand strength measurement. The differences were minor in what concerns the first and the second test, but the hand strength of Otto Bock prosthesis was much greater than the one of the proposed prosthesis (13.6 kg vs. 5.9 kg). Also, due to some limitations, three out of five activities were not conducted by the patient wearing 3D-printed pressure-sensor prosthesis (to button, write, grip the small corn). With both prostheses, the patient succeeded in conducting the two other activities (to dress the socks, to transfer the paper cup). Kocejko et al. [8] proposed a hybrid solution comprising EMG and EEG (electroencephalogram) sensors along with an eye tracker with a use case for patients with whole arm amputation. The joints of the 3D-printed arm are controlled through eye tracking. The role of the eye tracker resides in capturing the point in 3D space towards which the user gazes in order to place the arm in the correct position. An EMG sensor placed on the trapezius muscle is used to prevent the undesired, false-triggered positioning of the arm at each changing of the gaze point. Unfortunately, in [8] the role of the EEG interface is not clearly defined. In [9], a two-finger prosthesis based on one EMG sensor is described. Mahanth et al. [9] implemented the 4 electronic circuits aimed to acquire, full-wave rectify, to integrate and to amplify the EMG signal used to drive the prothesis. The movement of the fingers was triggered by the exceeding of a threshold that discriminates between the inactivity of the muscles and the muscular activity. This approach, however, is not suitable for reaching the human fingers' dynamics. Sharmila and Ramachandran [10] propose a model for a prosthetic arm that contrives to classify two hand movements (fingers flexion and fingers extension) based on a single 3-electrodes EMG sensor whose signal is passed through several conditioning and amplification circuits

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(instrumentation amplifier, high pass filter, low pass filter, notch filter, DC coupling circuit). As features extracted from the EMG signal, Root Mean Square and Frequency Energy are mentioned. For classification, a Support Vector Machine and binary linear classifier were chosen in [10]. The success rate of the proposed model is 76.6 %. In [11], a method was developed to distinguish between the movements of wrist, finger and the combined action of wrist and fingers. A double differential electrode unit consisting in four anoxic copper electrodes was realized and tested. The discrimination is made by means of two methods, depending on the deviation between low-frequency component of EMG signal and the high-frequency one that is small for a wrist action and high for the other two possible cases. Next, if the deviation is large, the second method discriminates between the two other actions. In our work, an anthropomorphic EMG-driven prosthesis is proposed. The artificial hand is controlled by means of the signal acquired from two EMG surface sensors. Further, the paper is organized as follows: Section II comprises theoretical background related to electromyography, EMG sensors and signals, in Section III the experimental setup and conditions are presented, whereas Section IV is dedicated to the experimental results and discussions. Section V outlines conclusions, future improvements and research.

II. ELECTROMYOGRAPHY, EMG SENSORS AND SIGNALS

A. *Hand anatomy and muscle activation*

If an amputee misses the hand segment together with all muscles and tendons, the forearm muscles activity must be related to hand movements in order to develop an EMG-driven prosthetic hand. It is well known that, although a limb segment is missing, the brain continues to command muscle contraction when the subject intends to use his limb.

B. *Electromyography*

Electromyography represents a medical procedure that monitors the electrical activity in the muscle [12] and it is based on a phenomenon called electromechanical coupling in muscle [13]. Muscle cells or fibers generate an electrical potential (ranging from 50 μV to 30 mV) when they are electrically or neurologically activated [14]. There are two types of electromyography procedure. The clinical procedure called needle EMG is invasive and implies the use of a needle electrode that penetrates the skin. This method is the most accurate, providing fibre-level details of the physiology of the muscle. Needle EMG is necessary in medical and scientific studies to track and characterize pathological events and disorders that affect the muscle's motor units, that is, the motor neuron and the muscle fibers stimulated (or innervated) by this neuron [15]-[17].

Surface electromyography (sEMG) is a non-invasive method used to determine the electrical activity of the muscle. If needle EMG allows the monitoring of a motor unit at a time through the needle electrode, in order to obtain an objective quantification of the energy of the muscles using sEMG technique, several surface electrodes are needed. In this paper, sEMG will be employed, therefore, only surface EMG sensors will be described.

C. *Surface EMG sensors*

A surface EMG sensor consists in 2 or 3 surface electrodes and signal conditioning circuits. 2-electrode configuration provides a less stable signal – as it is affected by noise - compared to 3-electrode configuration [14]. For a 3-electrode sensor (Fig. 1), the electrodes are assigned and positioned as follows: MID (middle of the targeted muscle), END (at one end of the targeted muscle), GND (must be placed on an electrically neutral body area, usually a bony tissue [18], as the elbow). The size of the active area of the electrodes is crucial for the quality of the EMG signal while the distance that must separate the ground electrode from the other(s) electrode(s) is not so important [14].

Fig. 1. 3-electrode EMG sensors positioning (MID - in yellow, END - in violet, GND - in blue)

D. *EMG signals*

Compared to other biopotential signals (EEG, ECG), the frequency range of EMG signal is very wide, in general, between 20 Hz and 2000 Hz [19] and for surface EMG signals, between 10 and 500 Hz. The amplitude of raw EMG signals ranges from 0 to 10 mV [20], thus being necessary to include amplifying circuits to provide a signal for further processing.

III. PROPOSED PROSTHETIC HAND MODEL

A. *Overall architecture of the EMG-driven prosthetic*

Fig. 2 depicts the components of the proposed EMG-driven hand prosthesis. Two EMG sensors are attached to forearm's skin as emphasized in Fig. 1. *EMG Sensor 1* is positioned such that it records the activity of the flexor pollicis longus muscle and *EMG Sensor 2* is placed such that it provides EMG signal of both flexor digitorum profundus and superficialis muscles.

MCU-AU1 and *MCU-AU2* are two complex units, each consisting in a microcontroller (MCU) and an EMG acquisition unit (AU). MCU-AU1 will acquire the EMG signal of flexor pollicis longus muscle and will control pollicis servomotor. MCU-AU2 will gather data from *EMG Sensor 2* and will control the prosthetic fingers.

For our experimental setup, we chose Arduino Uno equipped with ATmega328P microcontroller and eHealth Shields v 2.0 [21] (Fig. 3). To acquire an EMG signal, as eHealth shield allows the acquisition of at least ten human body parameters and signals, the jumper ECG/EMG next to Analog Inputs connector must be in EMG position, i.e., it must connect pins 2 and 3.

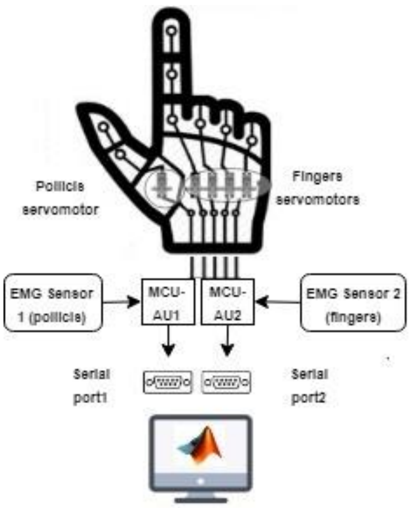

Fig. 2 Proposed architecture of EMG-driven prosthesis

Each eHealth shield comprises an EMG connector for three EMG electrodes. Also, the shield includes signal amplifying, rectifying and smoothing circuits.

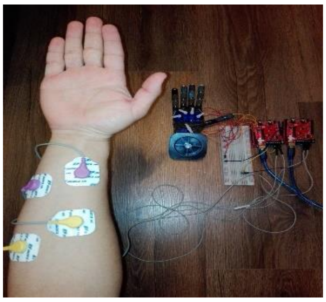

Fig. 3 EMG signals acquisition setup

MID and END electrodes of each sensor are connected to the corresponding complex unit. Nevertheless, only one GND electrode should be used to avoid the ground loops, as they can provoke electrical shocks to the subject [22]. Consequently, the reference electrode (GND) will be shared by both eHealth shields through jumper wires.

The prosthetic fingers are controlled through five servomotors SG-90 that are calibrated to rotate between 0-180°. To calibrate them, we wrote a script that commands their rotation to pre-defined positions, as 0°, 90° or 180°.

The implementation has two stages:

- **Signal acquisition and processing, decision-making.** In this stage, the data acquired from the two EMG sensors are sent through MATLAB software through the serial ports of a computer to process the signals and extract the most important features that distinguish the motions proposed in this work: prehension, fingers flexion and relaxation.
- **Prosthetic hand actuation.** In this stage, the prosthesis is no longer connected to the serial ports of the computer, the parameters computed by MATLAB are sent to and used by microcontroller to provide the correct rotation of the servomotors, and, thus, the actuation of the prosthetic hand becomes dependent on the EMG signals parameters.

B. Anthropomorphic 3D-printed prosthesis

As a prosthetic hand model, we used the one in [23]. The model was slightly modified in Catia V5R19 software and printed using Ultimaker S5 3D-printer. In Fig. 4, we represented the prosthetic hand model (front view) in Repetier-Host, a software compatible with the afore-mentioned 3D printer.

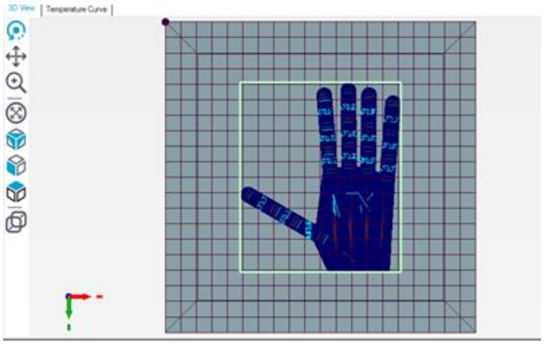

Fig. 4 Prosthetic Hand model in Repetier-Host software

IV. EXPERIMENTAL RESULTS

Ten experiments were performed: prehension (1), relaxation (2), strongly flexing (3) and extending all fingers (4), extending (5) and flexing (6) all fingers, except the pollicis, flexing (7) and extending (8) the pollicis, lifting the arm in lateral at a 90° with respect to the body and hold the hand at 90° with respect to arm (9), lifting the arm at 90° in front of the body (10). Experiments 1-8 were doubled by asking the subject to perform the tasks both sustaining the hand on a table and standing up. In Fig. 5, we represented the two EMG signals resulted during prehension and relaxation. For both cases, the mean values of the two signals are almost the same (flexor digitorum: 0.23 V, flexor pollicis: 0.11), but there is a higher deviation with respect to mean for prehension, than for relaxation.

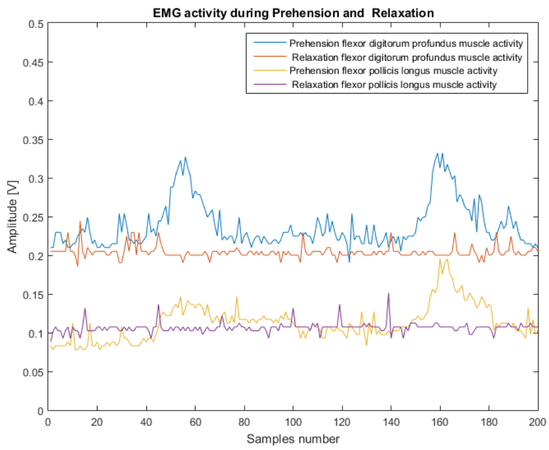

Fig. 5 EMG signals during two prehensions and relaxation

Fig. 6 depicts the graphical results when the subject was asked to extend and strongly flex all fingers. One can notice that for fingers extension, the maxima of amplitude of pollicis muscle and flexor digitorum muscle have similar values, while for finger flexion the maxima hardly reach comparable values. In what concerns, pollicis flexion, we noticed that, although the amplitude of pollicis muscle activity is significantly lower than that of flexor digitorum muscle activity, for the first one an increasing in amplitude corresponding to the flexion is observed, while the amplitude of the latter has a neglectable deviation from the mean. When slowly extending the pollicis (as a strong extension of the pollicis would have determined an extension of the other fingers), we noticed that the amplitude variation was inconclusive. In experiment 9, we observed a similar pattern with relaxation. Due to the position, arm muscles take over the sustaining effort and help to forearm relaxation. In experiment 10, however, the muscles activity increases and extremely high values of the EMG amplitudes (around 2V for pollicis muscle and 2.5 for flexor digitorum muscle) are obtained. When the subject was asked to stand up, very high values were obtained, too, and we could not describe a pattern.

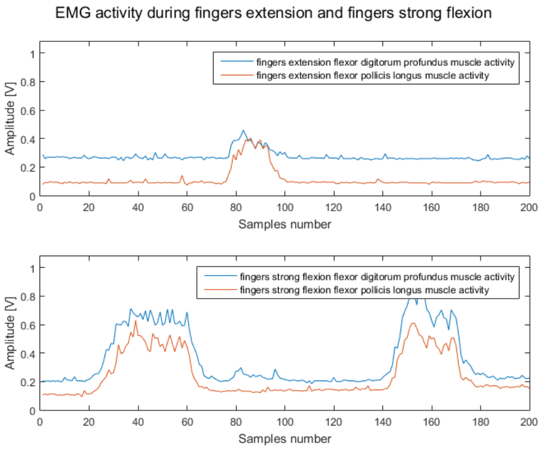

Fig. 6 EMG signals during all fingers extension (up) and two strong fingers flexions (down)

V. Conclusion

This paper reveals important methodological aspects concerning EMG signals acquisition and offers an experimental setup for an EMG-controlled prosthetic hand. Also, it presents and emphasizes the patterns of the amplitude of EMG signals acquired from flexor digitorum muscles, and flexor pollicis longus muscle. These patterns are aimed to distinguish fundamental hand movements as prehension, fingers flexion and extension, pollicis flexion, and relaxation. In future, we intend to develop a cheaper prototype able to render finer hand movements, to design, implement and test a system that uses EMG signals to control the prosthesis and useful actuators in a Smart Home and Smart Car use case dedicated to impaired people.

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