**DESIGN AND FABRICATION OF A LOW-COST 3D-PRINTED MYOELECTRIC PROSTHESIS FOR TRANSRADIAL AMPUTEES**

**1. INTRODUCTION**

The World Health Organization (WHO) estimated in 2017, that around the world 0.5% of the total number of people need prostheses, orthoses and rehabilitation treatment, which is equivalent to approximately 35 to 40 million people. On the other hand, in that same study they pointed out that between 85% and 95% of people who require the use of some orthopedic support device such as prosthesis or orthosis, do not have access to these [1]. Meanwhile, according to a market study conducted by the consulting and market research company Grand View Research, there are more than 100 million people in the world with limb loss and about one million amputations are performed annually [2].

For instance, in Peru, according to the national census of the National Institute of Statistics and Informatics (INEI) in 2017, 15.1% of Peruvians with disabilities have a difficulty to move or walk and use arms or legs [3]. On the other hand, according to the first specialized national survey on disability by INEI in 2012, only 0.001% of people with locomotion and/or dexterity disability use arm prosthesis [4]. This may be due to various factors, such as the high cost of the prosthesis, the little or no functionality of the device, or the lack of esthetics.

The importance of the hand lies in the fact that this limb is extremely versatile, one can perform complex movements and grips that allow day-to-day activities [5]. For this reason, when a person loses his or her upper limb, the physician recommends acquiring a prosthesis that allows him or her to recover the necessary functionality to perform his or her tasks more easily [6].

As an example, the Peruvian market for prostheses for transradial amputees is strongly divided. On the one hand, the most accessible prostheses are offered by the National Institute of Rehabilitation (INR), these are aesthetic or mechanical, and have approximate costs that can be between S/. 3,885 [7] and S/. 5,634 [8], and are manufactured by the INR itself. On the other hand, in recent decades, prostheses that use myoelectric signals to improve their function have been developed and marketed [6]. However, the biggest problem with these prostheses is their high cost in the current market, since they have an approximate price that starts at $ 6,600 USD for prostheses such as the Hero Arm from Open Bionics and can reach up to $ 60,000 USD such as the Michelangelo Hand from Ottobock [9].

Leonardo, you need to write a paragraph for importance of having deep sensing function in the designed prosthetic hand. And, review the paper that I have passed you which had deep sensing with vibrators.

In that sense, the need persists to provide a more affordable alternative for upper limb amputees, without compromising the efficacy and utility of the prosthesis. Therefore, the focus of the project is to develop a low-cost myoelectric transradial prosthesis with different grasp types. To achieve this goal, it is necessary to have a classification algorithm that processes the myoelectric signals. This study aims to obtain EMG data from a low-cost, MYOstack from ELEMYO, and expensive, Trigno from DELSYS, EMG sensor located in the forearm of healthy people. It is hypothesized that with the EMG data obtained from MYOstack a good performance in the classification algorithm will be achieved, like the one from Trigno.

**2. Objectives**

The main objectives of this study is to provide different numerical and analytical models that can:

1. Map EMG signals to different grasp configurations; classification problem.
2. Map EMG signals to finger joint angels; regression problem.
3. Map forces on the fingertips to the vibrations on forearm skin; sensory substitution problem.
4. Closed loop model between bio-feedback, environmental feedback, and prosthetic hand action. EMG signals serve as bio-feedback, forces on the fingertips are considered as as environmental feedback, and prosthetic actuation system (both motors and vibrators) is considered as action.

**2.1 Specific Aims**

1. We will determine if the recorded EMG signals from ELEMYO’s sensor provide a good signal quality like the sensor from DELSYS.
2. We will identify which time-domain features extracted from the EMG data have more significance in the classification algorithm performance.
3. We will identify which classification algorithm, machine learning and deep learning models, have the best performance predicting the grasp types using the extracted EMG data.
4. We will determine whether changes in the number of grasp types are associated with the algorithm performance.
5. We will develop a function that maps fingertip forces to vibrations on the skin; this behavior should effectively substitute the lost sensory feedback from the amputee hand.
6. We will develop a closed-loop function which can effectively fuse the EMG signal and forces on fingertips and provides both motor movement and vibration on the skin.

**3. Hypothesis**

The quality of EMG data obtained using four channel MYOstack sensor will give good performance metrics in the classification algorithm, with similar values to the ones obtained from Trigno sensor.The vibrators on the skin provides sufficient information to transfer force applied at fingertips to the forearm skin.

**4. Methodology**

**4.1 Experimental design**

This study will compare the performance of classification models using MYOstack and Trigno four channel EMG sensor. Also it studies the performance of fingertip force sensors transfer to the forearm skin.

**4.2 Subjects**

After obtaining approval from the University of Alberta Research Ethics Board (REB), 40 healthy volunteers will be invited to consent and participate in this study. The sample size would be enough to have a normal distribution of the sample means, following the central limit theorem. Subjects will be recruited at 1) Sport Medicine Centre of the University of Alberta, 2) the Mechanical Department of the University of Alberta, 3) the University of Alberta Participate in Research website, 5) word of mouth and 4) ads placed in and around the university campus.

**4.2.1 Selection criteria for healthy subjects**

We will include males and females, aged between 20 and 65, able to walk independently and able to read and understand English instructions. The inclusion criteria will be no arm pain or stiffness in either arm/hand or use of medications for arm pain in the last year. Also, participants with the following will be excluded:

1. History of any inflammatory/infectious arthritis, fracture or surgical intervention in the studied arm
2. Pregnancy
3. Obesity (BMI ≥ 40)
4. No allergic reactions to skin electrodes.

**4.3 Procedures**

The EMG and motion capture data acquisitions will be carried out at the Neuromuscular Control & Biomechanics Laboratory at the Mechanical Department in the University of Alberta using a MYOstack and Trigno four channel EMG sensor.

* + 1. ***EMG acquisition and loading procedures***

The EMG parameters for the Trigno sensor will be as follows: number of channels: 16 (both EMG brands); sampling rate: 500 HZ (MYOstack) and 2 kHz (Trigno); muscles targeted: extensor digitorium, flexor carpi radialis, palmaris longus, and flexor digitorium superficialis; grasping types: pinch, power, tripod.

* + 1. ***EMG acquisition protocol***

Volunteers will be asked to sit in the laboratory’s chair and roll up the sleeve of their forearm. Then, the Trigno EMG sensors will be placed in their corresponding muscles, located with palpation. The participants will be informed that those sensors need an adhesive to stick in the skin. They will be asked to do three tests, one for each grasp type: pinch, power, and tripod. Each test has a two-minute duration which consist of performing the corresponding grasp for five seconds and resting for five more seconds, until reaching the specified time. Then, there will be a three-minute resting period before starting the next test. After finishing the tests, the participants will be asked to withdraw the EMG sensors and there will be a six-minute break before starting with the tests using the MYOstack EMG sensors. Those sensors will be fitted in the same muscle locations of the participants as the Trigno sensors using an elastic band; then the same tests will be done. After finishing the last test, the EMG sensors will be withdrawn from the participants.

* + 1. Motion capture data acquisition and loading procedures

Leonardo, please fill this section.

* + 1. Motion capture data acquisition protocol

Leonardo, please fill this section.

* + 1. Glove equipped with force sensors data acquisition procedure

Leonardo, please fill this section.

* + 1. Glove equipped with force sensors data acquisition protocol

Leonardo, please fill this section.

* + 1. Vibrators installation procedure

Leonardo, please fill this section.

* + 1. Vibrators usage protocol

Leonardo, please fill this section.

6.3.9 IMU

6.3.10 Flexible sensors

* + 1. ***Signal processing and segmentation***

EMG signal pre-processing will be carried out offline using Python scripts developed by our team. First, the program will be used to filter the raw EMG signal. Then, for every test, segments of each grasp repetition will be extracted. Some segments of the resting hand will also be extracted as an additional class of the three grasps. After that for every class, features will be calculated in every segment, some of the proposed features are [10]: 1) mean absolute value; 2) zero crossing; 3) slope sign changes; 4) waveform length; 4) log detector; 5) root mean square of EMG amplitude; 6) willison amplitude; and 7) maximum absolute value.

After obtaining the features, machine learning and deep learning algorithms will be used to get the classification model. Some of the proposed algorithms are: 1) logistic regression; 2) support vector machine (SVM); 3) linear discriminant analysis (LDA); 4) K-means clustering; 5) multilayer perceptron (MLP); 5) convolutional neural networks (CNN); and 6) long short-term memory (LSTM) networks.

Please add information for the vibrator sensors. And Glove with force sensors on its fingertips.

**References**

[1] Organización Mundial de la Salud, “Normas de Ortoprostésica Parte 1: Normas,” 2017.

[2] Grand View Research, “Prosthetics & Orthotics Market Size | Industry Report, 2020-2027,” 2020. https://www.grandviewresearch.com/industry-analysis/prosthetics-orthotics-market (accessed Feb. 01, 2021).

[3] Instituto Nacional de Estadística e Informática del Perú (INEI), “Perfil sociodemográfico de la población con discapacidad, 2017,” 2017. [Online]. Available: https://www.inei.gob.pe/media/MenuRecursivo/publicaciones\_digitales/Est/Lib1675/libro.pdf

[4] INEI, “Primera Encuesta Nacional Especializada sobre Discapacidad 2012,” 2012. [Online]. Available: https://www.inei.gob.pe/media/MenuRecursivo/publicaciones\_digitales/Est/Lib1171/ENEDIS 2012 - COMPLETO.pdf

[5] K. Østlie, I. M. Lesjø, R. J. Franklin, B. Garfelt, O. H. Skjeldal, and P. Magnus, “Prosthesis rejection in acquired major upper-limb amputees: A population-based survey,” *Disability and Rehabilitation: Assistive Technology*, vol. 7, no. 4, pp. 294–303, 2012, doi: 10.3109/17483107.2011.635405.

[6] L. E. Sánchez, M. Arias, E. Guzmán, and E. Lugo, “A Low-Cost EMG-Controlled Anthropomorphic Robotic Hand for Power and Precision Grasp,” pp. 1–17, 2019, doi: 10.1016/j.bbe.2019.10.002.

[7] Instituto Nacional de Rehabilitación, *Resolución Directoral 122-2015-SA-DG-INR*. Perú, 2015. [Online]. Available: https://www.inr.gob.pe/transparencia/transparencia inr/resoluciones/2015/RD 122-2015-SA-DG-INR.pdf

[8] Instituto Nacional de Rehabilitación, *Resolución Directoral 406-2015-SA-DG-INR*. 2015. [Online]. Available: https://www.inr.gob.pe/transparencia/transparencia inr/resoluciones/2015/RD 406-2015-SA-DG-INR.pdf

[9] A. Calado, F. Soares, and D. Matos, “A Review on Commercially Available Anthropomorphic Myoelectric Prosthetic Hands, Pattern-Recognition-Based Microcontrollers and sEMG Sensors used for Prosthetic Control,” *19th IEEE International Conference on Autonomous Robot Systems and Competitions, ICARSC 2019*, 2019, doi: 10.1109/ICARSC.2019.8733629.

[10] K. Z. Zhuang *et al.*, “Shared human-robot proportional control of a dexterous myoelectric.”