RESEARCH PAPER

3D Printed Bionic Arm for Upper Limb Amputation

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ABSTRACT

The restoration of the ability to lead an independent lifestyle and improve the quality of life following upper limb amputation continue to pose serious problems. While there have been many improvements in prosthetic designs, the high cost and advanced technological design of these devices makes them inaccessible to many people around the world, particularly developing countries. The primary objective of this study is the development of affordable prosthetic arms which make use of additive manufacturing technology and surface electromyography signal control. The design detects electrical impulses generated by muscles within the forearm and converts them into actions using the application of microprocessors and actuators. The preprocessing and feature extraction processes improve the precision of the EMG signals, and intelligent algorithms are used to interpret the commands of the user. The hardware of the prosthetic device can be manufactured by means of 3D printing using light weight materials to allow customized production based on the requirements of patients.

Keywords: Bionic Arm, Electromyography, Prosthetics, 3D Printing, Rehabilitation Engineering, Signal Processing, Machine Learning

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1. Introduction:

Human upper limb is very important for interactions with surroundings and provides an individual with a chance to do various activities, whether simple everyday tasks or those that demand coordination and preciseness. An amputation of upper limbs can lead to a number of issues connected with a patient's mobility, dependence on other people, and decrease in the quality of his/her life. Therefore, prosthetic technology has existed for a number of years and aimed to help patients cope with problems connected with such disorders. Originally, prosthetic limbs had mostly an aesthetic value and could not be used in order to perform different operations. However, with time, scientists created body-powered devices, which allowed patients to do some movements using the help of harness system and mechanism. Although they were reliable and relatively inexpensive, these devices were not very effective as far as energy consumption was concerned.

The latest advances in the area of additive manufacturing and embedded systems have paved the way for new opportunities in creating prosthetics. The technology of 3D printing will help create not only prototypes but also prosthetics tailored specifically for each individual. Moreover, the progress made in the sphere of signal processing and machine learning has contributed significantly to improving the accuracy of detection of bio-signal information.

In other words, the objective of this study is to develop an affordable and printable bionic arm with the help of the bio-signal information from surface electromyography.

2. Background and Motivation:

The development of prosthetic technology has always aimed at compensating for missing capabilities and providing better comfort for the patient. However, even though traditional arm prostheses have many benefits, they cannot satisfy the demands of the patients fully because of low movement freedom, control, and adaptation ability.

One of the most significant innovations in prosthesis engineering was myoelectric control since it provided the opportunity to use the electrical activity in muscles to move the artificial limbs. Nonetheless, such technologies remain expensive and difficult to install.

Costs of prosthesis, however, are not the only problem associated with traditional prosthetic manufacturing since it lacks adaptability and individuality since all products can be bought only in limited sizes. Besides, there are problems concerning control since it may be too complicated to use them and adjust to varying signals in different conditions.

This paper focuses on the issue of creating an innovative product which will help people in need by providing them with a comfortable prosthetic tool at an affordable price.

3. Problem Statement:

Even with advances made in prosthetic devices, there are a number of difficulties still present. Firstly, high-end prosthetic arms have been found to be prohibitively expensive for a wide swath of the population. In contrast, low-cost prosthetics tend not to include any active movement and instead simply act as replacements to look like arms.

The second major problem involves signal noise. EMG signals vary greatly from patient to patient, and also depend on many different conditions outside of the user's body.

Thirdly, comfort and adjustability are important problems as well. The weight of current prostheses and poor fit lead to discomfort and lower acceptability among users. Sensory input is also not available, which prevents natural interaction with one's surroundings..

4. Literature Review:

Numerous technologies and methodologies were explored in the realm of prosthetic arms creation. At the first phase of researches, researchers paid attention solely to mechanical systems which were controlled via body movements. Though being simple and efficient, such systems lacked capabilities for performing complex actions.

The emergence of myoelectrical prosthesis made it possible to use electromyography for precise control over prosthesis operations. As it appeared, such a way of control can increase the possibilities of the system under study. Nevertheless, when developing myoelectric systems, researchers faced the problem of inadequate gesture recognition.

In connection with technological progress, scientists used advanced machine learning algorithms for gesture detection. In particular, the usage of Artificial Neural Networks and Support Vector Machines became quite common practice. Such classification algorithms have proven their efficiency during the course of laboratory experiments.

Additive manufacturing plays a significant role in the process of creating prosthetic devices. Due to the capabilities of 3D printers, engineers can create any part of the device quickly and cost-effectively. Various instances of effective application of 3D printers in developing prosthetic arms can be given.

5. System Architecture:

The intended bionic arm setup operates on the principle of human machine interface, where the biological muscle action is translated into mechanical motion. It adopts a hierarchical structure where every module has a distinct operation and is able to communicate effectively with neighboring modules.

In the beginning, sEMG signals are acquired from the subject's forearm through use of electrodes. The placement of these electrodes over relevant muscle groups, which are involved in the movement of wrists and fingers, ensures sensitivity of the signals. The acquired EMG signals are weak, and hence susceptible to distortion by other signals in the environment, thus there is need for a sophisticated signal conditioning process. In this stage, the signal is amplified using an instrumentation amplifier, with the aim of achieving high common mode rejection ratio in order to avoid noise interference.

After amplification, the EMG signals undergo analog filtration in order to remove unwanted signals. The band-pass filter is used to ensure only the frequencies within the range of EMG signals, between 20Hz to 450Hz, pass through. Besides, there is also a notch filter in the signal processing stage, which blocks any power line interference at 50Hz frequency.

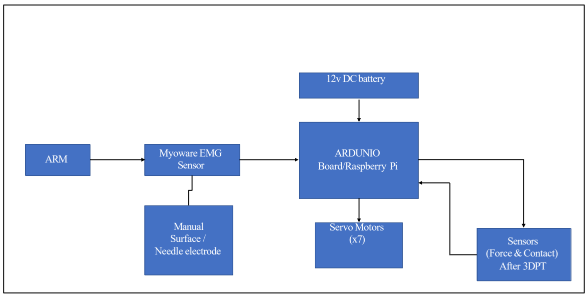

Fig. 01 – Block diagram of the proposed system

Conditioned analog signals are converted to digital form through analog-to-digital conversion performed by the converter built-in to the microcontroller itself. The digital signals are processed further by a signal processing unit via preprocessing methods such as normalization, segmentation, and smoothing. The objective is to ensure consistent data collection regardless of different sessions of acquisition.

The preprocessed biological signals will be fed into a feature extraction module which computes the parameters to characterize the underlying muscle activity. The output of the feature extraction step will then be entered into a classifier for interpretation of the muscle activity in terms of specific gestures like hand opening, closing, and gripping.

Classification output is sent to the control unit responsible for generating the required PWM signals to activate the prosthetic actuators. The actuators used in the project are the servo motors which connect the prosthetic fingers with the tendon-like mechanisms. Servo motors generate the required mechanical movement from electrical signals.

The mechanical part of the prosthetic limb can be manufactured using additive manufacturing processes. The design is modular to allow modifications easily. Thus, the complete project comprises the integration of these individual modules.

6. Methodology:

The approach used in this study comprises a systematic and cyclical series of steps in order to achieve correct interpretation of the input signals and subsequent mechanical reaction. First, the surface electrodes are placed on the arm of the user. The importance of correct electrode placement cannot be underestimated since the quality of the signal acquired depends greatly on it.

EMG signals are recorded for various muscle activities. The acquired signals are then amplified in order to obtain an input signal and processed with filters. As part of preprocessing, normalization is also performed in order to reduce the differences in the amplitude of input signals for various users.

Feature extraction constitutes one of the most important steps in the methodology presented in the research. Time-domain features include such parameters as the mean absolute value, root mean square value, waveform length, and zero-crossing rate. Frequency domain features are calculated by means of spectral analysis methods and indicate the energy distribution in the signal.

Features extracted from the signal are used to train a classifier using the supervised learning method. The training dataset consists of EMG signals recorded for various gestures and labeled accordingly.

In actual operation, the EMG input signals will be processed and presented to the trained model, which then generates the output that is needed to perform the corresponding action.

System validation is also part of the methodology, in which the system is assessed using parameters such as accuracy, speed, and adaptability. Improvements to the system can then be made iteratively based on the test outcomes.

7. Signal Processing:

The importance of signal processing is not to be understated for an EMG-based control system as EMG signals are quite often corrupted with noise and non-stationary in nature. The performance of gesture recognition in many cases will depend on the quality of signal processing algorithms.

Short-Time Fourier Transform is utilized to study the signal from time and frequency perspectives simultaneously. The signal is split into several short overlapping segments and then the Fourier Transform is computed for each window. With this technique, it becomes possible to detect any transient changes within the analyzed signal.

To improve the quality of STFT results, preprocessing is required. Preprocessing implies filtering (band-pass and notch filter is used to remove noise) and signal smoothing using several other filters.

Feature extraction helps extract useful parameters that reflect muscle activity within a certain timeframe. In our case, both time domain and frequency domain features are used since computational efficiency of time domain parameters is crucial for real-life implementation.

Normalization is another stage that helps to make results obtained from multiple sessions comparable. It is necessary because of the high variability of the data.

8. Design and Fabrication:

The design of the prosthetic arm is done using computer-aided design software, and this entails making sure that the functional characteristics of the arm are similar to those of the human hand. The design comprises fingers that have joints, and also the palm area is included, as well as the wrist joint, which supports limited rotation.

Each finger has several joints that simulate natural movement in the fingers. Also, tendon systems are implemented to ensure that the actuator can push the fingers by transmitting force through the tendons. This design helps in reducing weight and mechanical effectiveness.

The manufacturing of this project utilizes 3D printers, a process which supports quick production and customization. The material that is used during production is the poly-lactic acid because of its lightweight nature and mechanical adequacy.This design makes it easy to replace parts of the robot when necessary.

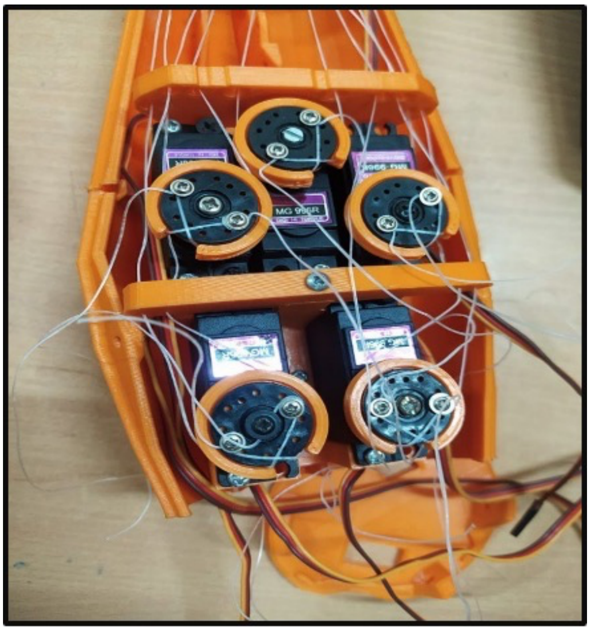

Fig. 02 – Servo motor and Fixations

Fig. 02 – Final Assembly of the prototype

9. Hardware Implementation:

In terms of hardware implementation, it involves integrating the sensing, processing, and actuating aspects. The EMG sensors are used as the main interface for detecting muscle signals. This means that EMG sensors transform the biological activities to electrical signals for use by the system.

Microcontrollers are used in hardware implementation as the main processor. These processors acquire, preprocess, classify and control muscle activities using algorithms.

The Servo motors are used as the main actuator component in the process because of their accuracy. The motors are controlled independently from each other since each one is attached to a finger. The finger movement is controlled by pulse-width modulation signals.

The issue of power supply should not be neglected in hardware implementation. In this case, battery systems will provide power to all parts of the system.

10. Applications:

In terms of rehabilitative engineering, the proposed system of bionic arm can provide great opportunities for those patients who suffered an injury of their upper limbs and who cannot independently execute grasping, holding, and lifting actions.

The system can be implemented in physiotherapy and medical rehabilitation when working with patients who suffer from nerve or muscular issues. The control based on EMG helps train muscle coordination and enhance motor control due to repeated exercises.

Moreover, the system can also be useful for assistive technology applications for those who suffer from restricted hand mobility. Also, because the system involves human muscle signals and mechanical devices, it is useful for studying human-machine interaction and robotics.

Finally, because the cost of manufacturing and implementation of the system is relatively low, it can be successfully applied in educational and research purposes. It allows students to understand concepts associated with bio-signal processing and designing embedded systems. **11. Conclusion:**

In the current research study, a low-cost 3D-printed bionic arm powered by surface electromyography (sEMG) signals was designed, developed, and implemented. The proposed approach proved to be effective in acquiring the required muscle signals from the user's forearm and transforming them into control signals. Using signal processing methods along with machine learning models allowed the system to recognize the user's intention and translate it into basic functions such as opening, closing, and gripping of the artificial hand.

The application of additive manufacturing technology made it possible to obtain a design that is light, flexible, and cost-effective. Compared to other prosthetic devices, which are usually very costly, the presented model shows that it is possible to create functional designs with cheap materials without compromising any necessary properties.

Tests have shown that the system responds reasonably well to user's gestures and recognizes them. Yet there are some challenges associated with sEMG signal acquisition (variability of the signals and susceptibility to noise), and a small number of DOFs limits its applicability in complex situations. Nevertheless, the presented design is suitable as the basis for future developments.

The proposed bionic arm has marked a milestone on the road to an effective prosthetic design. Not only does it contribute to improving the capability of restoring the normal function of hands, but it also provides a platform for further research and development in the field.

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