PREFACE

Upper-limb amputations seriously affect a patient's life by restricting the ability to perform various tasks. Prosthetic arms are considered the primary solution to such amputations. The existing externally-powered prosthesis is able to regain the lost capability of amputees to some extent. These mainly include the myoelectric prosthesis and the prosthetic devices controlled by signals from switches, force sensors, accelerometers, etc. Nowadays, a majority of available upper-limb prostheses in the market are myoelectric because electromyography (EMG) signals are easy to acquire, and these also provide user intention-based control to the prosthesis. However, several issues lead to rejection of these devices among amputees: (1) high cost, (2) limited functionality, (3) unnatural control, (4) slow operating speed, (5) complexity, (6) lack of skill, (7) weight, and (8) large size.

This work addresses several sub-objectives towards the development of a dexterous, affordable, externally powered prosthetic hand that can fulfill the basic needs of amputees: (1) Design of low-cost and novel sensors for faithfully detecting muscular contractions from the residual upper-limb of amputees. (2) Formulation of control strategies for translating the muscle contraction information (from the designed sensor) into control commands for intuitive operation of the prosthetic hand. (3) Preparation of prosthetic hand, its actuation mechanism, and its socket assembly. (4) Testing and validation of the designed sensor and hand prototype on different amputees.

A low-cost and sensitive surface electromyography (sEMG) sensor was designed for the application of myoelectric prosthesis. The sensor consists of a skin interface, signal conditioning circuitry, and power supply unit, all encased in a single package. The tuned RC parameters-based envelope detection scheme employed in the sensor enables faster as well as reliable recognition of EMG signal patterns regardless of its strength and subject variability. The output performance of the developed sensor was compared with a commercial EMG sensor regarding signal-to-noise ratio (SNR), amplitude sensitivity, and response time. EMG signals with both the devices were acquired for ten subjects (three amputees and seven healthy subjects) to perform this comparative analysis. The results showed greater SNR values and higher sensitivity of the developed sensor than the commercial EMG sensor. Also, the designed sensor depicted a faster response time than the commercial sensor in producing the desired output. Further, the sensor was successfully tested on amputees for controlling a 3D printed hand prototype utilizing a proportional control strategy. The enhanced output parameters of the sensor were responsible for the smooth, faster, and intuitive actuation of the prosthetic hand fingers. One of the main limitations of the designed sensor was that it requires the use of disposable Ag/AgCl electrodes whose performance degrades with time. Therefore the sensor cannot be the right choice for prosthetics, which is used for a longer duration.

In order to overcome the limitation associated with the previous sEMG sensor, a new sensor consisting of dry silver electrodes was introduced. Except for the electrode interface, the hardware circuitry and the power supply unit were the same as that for the earlier sensor. The performance of dry electrodes employed in the sensor was compared with the conventional Ag/AgCl electrodes in terms of electrode-skin impedance and SNR, and the results were found similar. Moreover, a comparison was carried between the dry electrode-based sensor and a conventional sensor regarding the parameters such as amplitude sensitivity, SNR, and response time, while recording EMG signals from the forearm muscles of subjects. The upgraded sensor presented better performance characteristics than the standard EMG sensor. The sensor was further tested on amputees to control the operation of a self-designed 3D printed prosthetic hand. With a proportional control scheme, the myoelectric hand setup was able to provide quicker and gentle grasping of objects as per the strength of the EMG signal. The disadvantage of such a hand setup is that it can give only a single grip pattern for grasping objects.

A multifunctional prosthetic hand was developed that can perform six different grasping activities using only a single-channel EMG signal from the sensor. EMG signals for fifteen subjects (five amputees and ten intact) were acquired for six contraction levels of forearm muscles using the designed sensor. These levels were further classified to recognize six predefined hand gestures, utilizing fuzzy logic classifier. The implemented system showed an excellent performance in terms of classification accuracy (>98%), sensitivity (>96%), specificity (>99%), precision (>97%), and F_1 score (>96%). The classification-based control scheme was realized in real-time to achieve six distinct grip patterns for a custom-built prosthetic hand. With these predefined grip patterns, the hand was able to accomplish the skillful operation of grasping various shaped objects using distinct strength of EMG signals. The proposed approach is modest, efficient, and provides a low-cost solution to amputees for controlling the prosthetic hand with multi-degrees of freedom (DOF) utilizing only a single channel EMG system.

EMG is the predominant technique to measure muscular contraction, which has a wide range of biomedical and rehabilitation engineering applications. However, the EMG system requires the use of electrodes in electrical contact with skin, complex preprocessing circuitry and is also susceptible to external electrical interference. Force Myography (FMG) is an alternative method that can measure muscle activity from muscle volume variations during contraction. Due to several limitations related to the EMG system, a dual-channel, non-invasive FMG sensor was fabricated to extract muscle contraction information for controlling hand prosthesis. The sensor was prepared using a pair of force-sensitive resistors (FSRs) mounted inside a rigid base for sensing the force exerted by contracting muscles through polydimethylsiloxane (PDMS) couplers. It employs a dedicated preprocessing circuitry for producing an output voltage proportional to the muscular contractile force. The static and dynamic characteristics of the sensor (i.e., sensitivity, drift, precision, hysteresis, and frequency response) were determined and analyzed using the recorded data to show its effectiveness. The frequency response of the designed sensor obtained was large enough to detect the rapidly varying FMG signals. The output assessment for simultaneous acquisition of EMG and FMG from the flexor muscles of subjects was performed using a two-tailed paired t-test, which showed a high correlation coefficient ($r > 0.87$) with a p-value < 0.0001. Further, a successful trial of the FMG sensor was made on five different subjects to control hand prostheses in real-time, employing a proportional strategy. These experiments revealed that the designed sensor could serve as a perfect substitute for the EMG sensor.

Existing myoelectric prostheses can provide solutions to amputees for performing activities of daily livings up to some extent. Nevertheless, there are several drawbacks related to these prostheses: (1) their price is excessively high (2) their function mainly depends on electromyography (EMG) signals which are quite susceptible to sweat, motion artifact, electrode shift and other electrical interference (3) these have sophisticated hardware as well as the control system. An affordable transradial prosthesis controlled by the FMG signal was proposed to overcome these limitations. In this work, a unique and compact FMG sensor was designed for the reliable detection of muscular contractions from the remaining forearm of amputees. The sensor was fabricated using a unique mechanical assembly and specific signal translation circuitry. A 3D printed prosthetic hand was prepared with a proportional-based position control strategy that receives input from the designed sensor. The developed sensor was validated by extracting its various static and dynamic parameters. Moreover, its ability to detect muscular contractions was compared with that of a conventional EMG sensor. The designed sensor showed a good correlation

and higher SNR values as compared to the EMG sensor. Furthermore, the developed hand prototype was successfully verified on five amputees for performing various daily life activities. The amputees with the hand attached to their residual forearm stump could execute the dexterous operation of grasping different objects using their distinct intensities of muscular contraction.

Keywords:

Electromyography, Myoelectric Prosthesis, Force myography, Classification, Control strategy, 3D printing.