# Generation of Pulse Sequence Using EMG Signals for Application in Transfemoral Prosthesis

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# Generation of Pulse Sequence Using EMG Signals for Application in Transfemoral Prosthesis

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**Abstract:** The percentage of people having a lower leg amputation is high, and the incidence of unemployment among these amputees is likewise rising. Hence, it requires the intervention of an innovative solution to serve the function of a lost limb. Electromyogram (EMG) signals is a result of the potential generated by muscles during contraction. In this work, an attempt has been made to extract EMG signals from four set of muscle groups and the acquired signals were pre-processed and transformed to pulses to extract the contraction phase of the signal. Furthermore, the processed signals were subject to feature extraction process where in the Mean Absolute Value (MAV), Integrated EMG Feature (IEMG) and various statistical parameters associated with the signal such as the mean, median, standard deviation, variance, kurtosis, skewness was calculated in order to serve as an input to drive the stepper motor of a transfemoral prosthesis. To promote real time acquisition and control, a transfemoral socket with an ischial containment has been designed.

**Keywords:** Electromyography, Transfemoral Prosthesis, Integrated EMG

## 1. Introduction

According to the World Health Organization (WHO) there are nearly 30 million amputees with limb loss and about 80% of that population do not have access to an active and affordable prosthesis [1]. There are about 2,30,000 amputees living in India who are in need of a low-cost and effective prosthesis to assist them in walking and other activities [2]. Electromyography is a measure of the electrical activity of the muscle. An action potential is developed in the muscle fibers as a result of depolarization and repolarization [3]. Muscle activation resulting in generation of EMG signals is achieved by a sequence of events from cortical excitation to motor unit activation and excitation-coupling [4]. An Electromyograph detects the potential generated during muscle activation and records it as an Electromyogram (EMG). EMG is a bio signal that is very useful in the diagnosis of disorders related to muscles and also in assessing various parameters associated with muscle like muscle fatigue, muscle spasms etc. [4,5]. EMG signals are vital in the control of exoskeletons, prosthetic hands and legs, and wheelchairs, as well as in amputee rehabilitation [6,7,8,9]. Various assistive and rehabilitation devices were designed and developed using EMG signals. Mingxing et al., constructed an EMG-controlled knee exoskeleton to aid in the rehabilitation of stroke patients by allowing them to play a training game with a small-time delay of 64 ms [6]. Sudarsan et al., created a myoelectric prosthetic arm that was operated by the amputee's own EMG signals after appropriate processing [7].

Similarly, in the work conducted by Hayder et al., EMG signals were utilized to control wheelchair motions such as forward, backward, left and right turn, and stop situations, as well as one muscle position commanding five conditions and the control performance of such systems can be greatly improved by the use of wearable electrode systems [8,9]. Furthermore, to aid the amputees Amanpreet et al., designed and developed an EMG based Human-Machine Interface (HMI) which performed specific wheelchair motion control by using distribution of muscle power and frequency [10]. It is recommended to reduce the number of EMG recording channels in order to increase the number of commands for effective control of devices [11]. EMG signals also play a vital role in the development of Physiological Devices (PDs).

In this work, the surface EMG signals were acquired using the BIOPAC MP45 acquisition device and software system from a healthy individual with a particular focus on the hamstring (Bicep Femoris and Semitendinosus) and quadriceps (Sartorius and Rectus Femoris) muscles. The signals were acquired from the hamstring and quadriceps muscles [12,13] and the acquired EMG signals were processed using the MATLAB software version 2019. The EMG signals obtained from the residual limb were useful and significant to drive the stepper motor of the prosthetic limb thereby achieving mobility in the desired direction. A wearable Ischial containment socket embedded with surface electrodes to record the EMG signals was designed using Autodesk Fusion 360 software. The EMG signals obtained from the residual limb were useful and significant to drive the stepper motor of the prosthetic limb thereby achieving mobility in the desired direction [14].

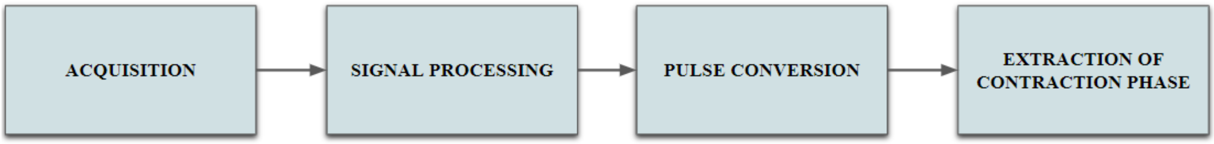


**Figure 1.** Block diagram of the proposed work

## 2. Methodology

### 2.1. EMG signal acquisition

The overall block diagram of the proposed work is shown in Figure 1. The EMG signals were acquired using surface electrodes placed on appropriate muscle locations. In this work, Kendall Covidien 200 series electrodes were used since it has a gel radius of 5 mm and easily sticks to the surface of the skin. The BIOPAC MP45 device and software was since it is flexible and easy to acquire the signals with minimal noise. BIOPAC MP45 is a two channel biomedical data acquisition device with an input voltage range of ±200 µV - 2V, an A/D sampling resolution of 16 bit and a signal to noise ratio of 89 dB. The sampling rate was set to be 250 Hz and a Notch filter was selected in order to remove the power line interference of 50 Hz. The participant's skin was abraded with spirit to reduce the impedance of the skin and to remove any dead skin cells that might affect the recording of EMG signal. The electrodes were positioned on the respective muscle locations and the subject was informed about the recording setup and was asked to stand in an erect position. The hamstring and the quadriceps muscles is activated producing an action potential during flexion motion and the EMG signals are generated, hence the subject was asked to exhibit flexion movement for 30 secs followed by a 10 secs baseline period [12,13]. The EMG amplitude is influenced by muscle activation [15]. During the Flexion motion of the knee both the agonist and antagonist muscles arebeing activated leading to generation of EMG signals on the anterior and posterior regions of the thigh [16].Hence the signal was acquired during the flexion phase. The subject was monitored carefully throughout the procedure and visual feedback of the signal recording was given.
In this work, the signals were obtained from four different muscles namely the sartorius, rectus femoris, biceps femoris and semitendinosus muscles which constitute the anterior and posterior

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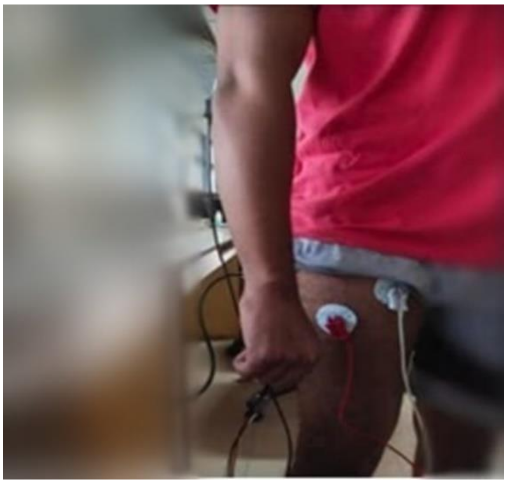
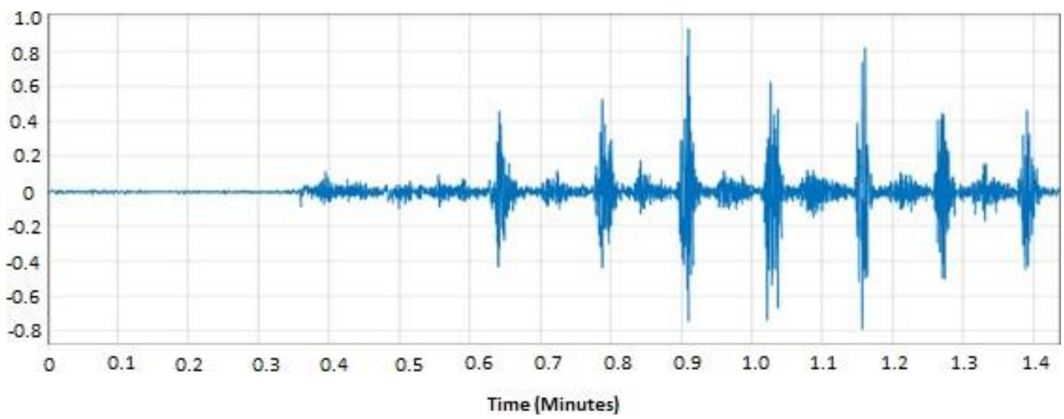
segment of the thigh respectively. The electrode location and placement are shown in Figure 2(a) and Fig 2(b). The EMG signals acquired from the anterior and posterior compartment of the thigh were stored as a text file and plotted in MATLAB as shown in Figure 3(a) and 3(b) respectively.



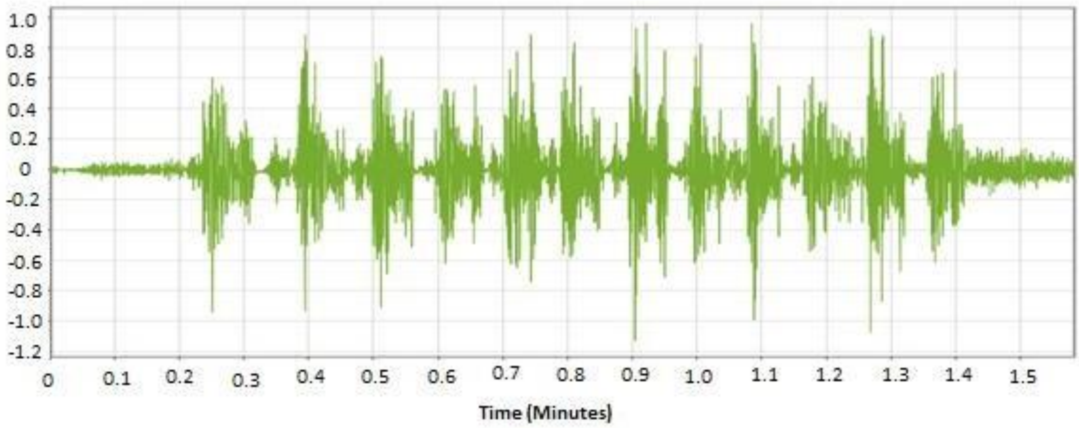
2(a)

2(b)

**Figure 2(a).** Electrode placement on the anterior segment of thigh. **2(b).** Electrode placement on the posterior segment of the thigh.




3(a)




3(b)

**Figure 3(a).** EMG signals acquired from the anterior segment of the thigh.

**3(b).** EMG signals from the posterior segment of the thigh plotted using MATLAB

## 2.2. EMG signal processing

The obtained raw EMG signal must be processed in order to extract information from it [17]. To remove the artifacts and noises present, the Raw EMG signal was processed by filtering, detrending, rectifying and smoothening to extract the unintended features [11]. The EMG signal possessed a lot of noise and hence was filtered with a suitable bandpass filter. In this work, a bandpass Butterworth filter with a cutoff frequency of 50-150 Hz was chosen since Butterworth filters are efficient when studies are related to processing EMG signals obtained from the lower limb [18,19]. An IIR Butterworth bandpass filter of order 78 was used and its magnitude and phase response is shown in Figure (4). Lower cutoff frequency of the bandpass filter removes the baseline drifts that occur due to movement, perspiration etc, and higher cutoff frequency removes higher frequency noises and prevents aliasing [19]. The filtered signal was rectified in order to remove the negative components and to get the absolute value. Furthermore, the signal was smoothened using the moving mean method with a window duration of 450 ms. The processed signal is shown in Figure 5(a) and 5(b) respectively.

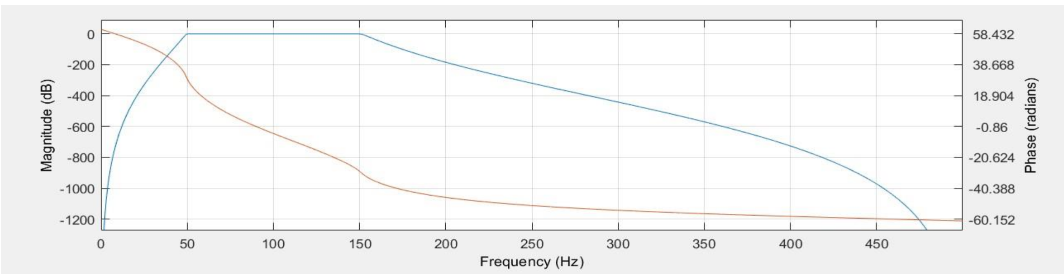



**Figure 4.** Magnitude and phase response of the designed filter

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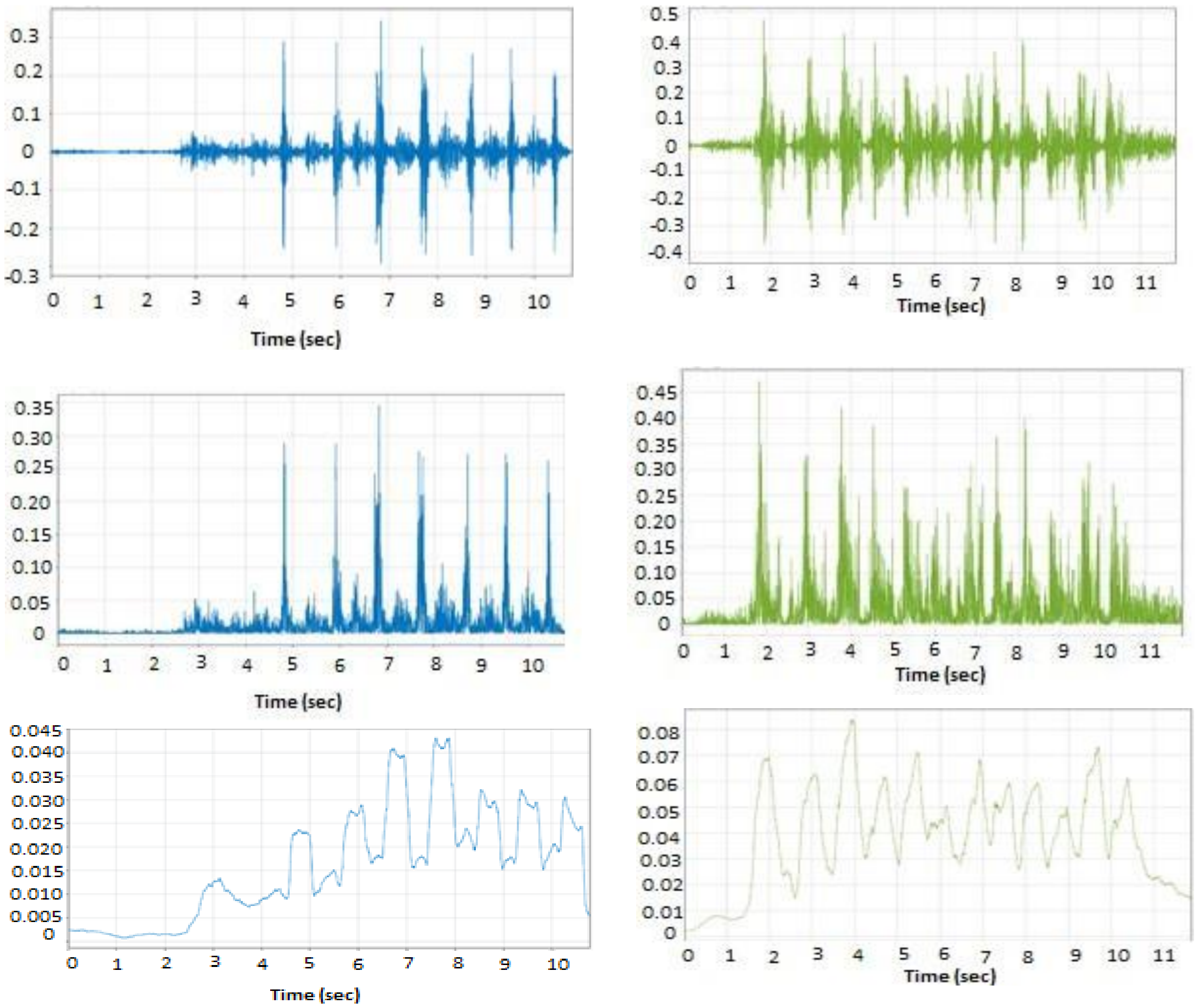


5(a) 5(b)

**Figure 5(a).** Filtered, rectified and smoothened signal obtained from anterior segment of the thigh. **5(b).** Filtered, rectified and smoothened signal obtained from the posterior compartment of the thigh

**Table 1.** Statistical parameters of the acquired EMG Signal

| Muscles Position | **Mean** | **Median** | **Standard Deviation** | **Variance** | **Kurtosis** | **Skewness** |
|---|---|---|---|---|---|---|
| **Anterior** | -0.004901 | -0.005085 | 0.064304 | 0.004135 | 40.582344 | 0.445286 |
| **Posterior** | -0.005502 | -0.00672 | 0.134531 | 0.018099 | 11.835418 | 0.174744 |

### 2.3. EMG feature extraction

Statistical parameters and features were extracted from the acquired bio signal in order to strengthen the implementation aspect of the current work. The statistical parameters that were obtained can be seen in Table 1. Furthermore, two features namely the Mean Absolute Value (MAV) and the Integrated EMG Feature (IEMG) were obtained from the raw EMG signal in LabVIEW software

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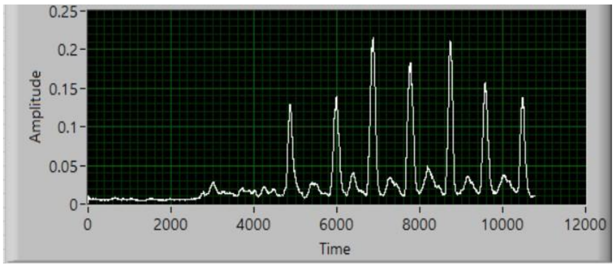
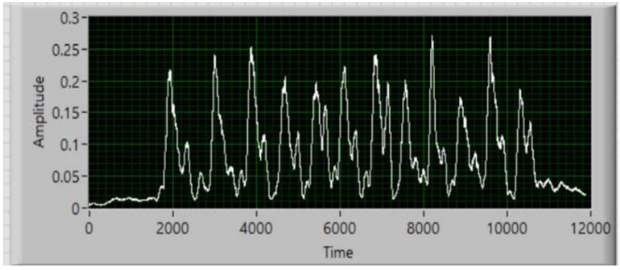
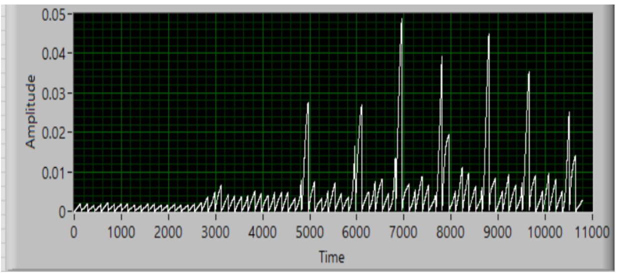
version 2019. The LabVIEW block diagram is shown in Figure 7. The mean absolute value is used to identify and assess muscular contraction levels, whereas the IEMG is used to determine the muscle's pre-activation index [20].The Mean Average Value was obtained using the Mean Average Rectifier block for both the anterior and posterior segment EMG signals. The output can be seen in Figure 6(a) and 6(b) respectively. The IEMG and MAV were found to be very efficient in constructing a bio signal powered prosthesis [14]. The IEMG of the signal was derived by rectifying the raw EMG signal followed by subsequent integration. The integration width was set to 142 and the obtained waveform was a sawtooth waveform which can be seen in Figure 6(c) and 6(d) respectively.



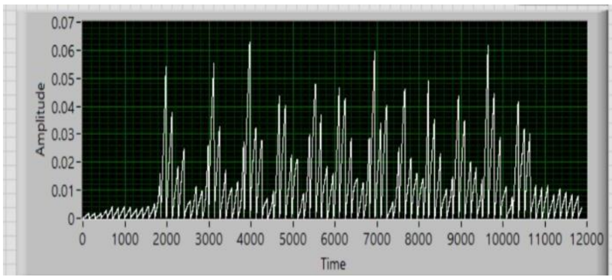

6(a)




6(b)




6(c)




6(d)

**Figure 6.** Mean Average value plot for **6(a)** anterior segment, **6(b)** for posterior segment EMG signals. Sawtooth waveform of **6(c)** anterior segment, **6(d)** posterior segment EMG signals.

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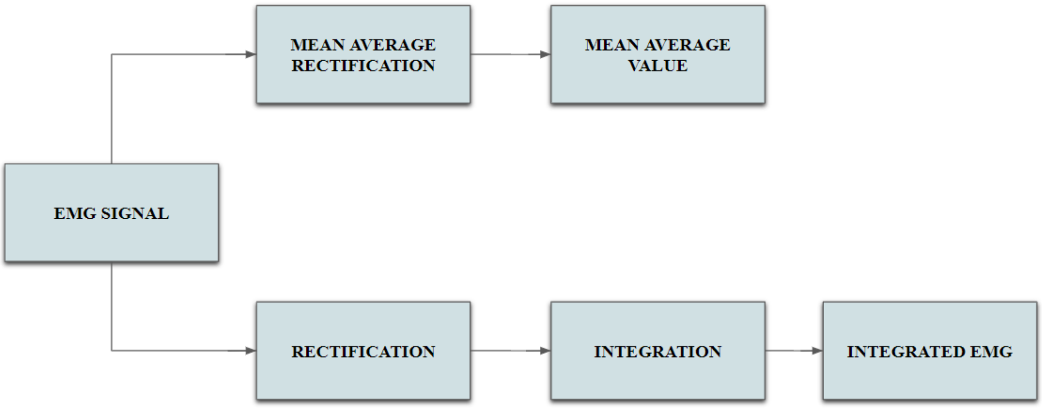
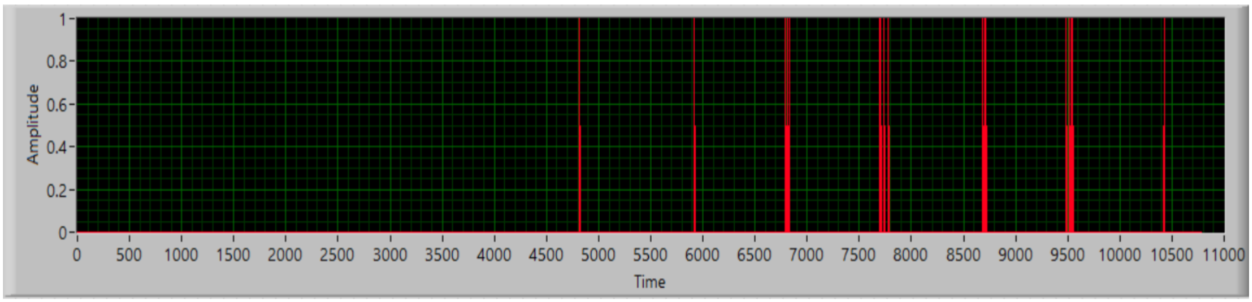


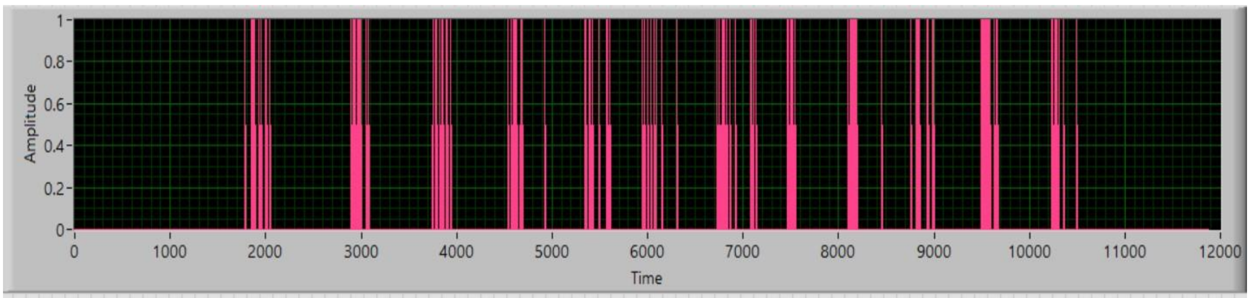

**Figure 7**. Overall block diagram of EMG signal processing and feature extraction

### 2.4. Pulse conversion

The processed EMG signal was converted to a pulse in order to trigger and drive a stepper motor. The signal was initially visualized in the LabVIEW software and positive comparators were used with a threshold of 0.4 in order to generate the pulse output. The output of the comparators is shown in Fig 8(a) & 8(b).




8(a)




8(b)

**Figure 8.** Pulse plot of the EMG signal from **8(a).** the anterior segment, **8(b).** the posterior segment.

## 2.5. Socket Design

To assist the transfemoral amputees, an ischial containment socket was designed using Autodesk Fusion360 software. An Ischial containment socket design is usually preferred over Quadrilateral socket design because of its superiority in terms of comfort and energy efficiency [21,22]. The comparison of features of the two types of prosthesis is given in Table 2.

**Table 2.** Comparison of properties of quadrilateral and ischial containment socket [21,22]

| **Quadrilateral socket design** | **Ischial containment socket designs** |
|---|---|
| It utilizes ischial weight bearing concept. | It utilizes weight bearing through narrow mediolateral ischium,ischial tuberosity and the ramus inside the socket. |
| Does not have a bony lock system. | By slanting the posterior wall and having a higher lateral wall, a locking or wedging action is created to stabilize the femur. To limit motion and promote stability, a three-point pressure mechanism is employed to lock the femur into adduction. |
| Femur stabilization is poor when the gluteus maximus activates. Quadrilateral socket moves laterally, as ischium has no effect of stopping weight bearing shift. | By bearing pressure on the skeletal parts, the narrow mediolateraldesign increases stability and reduces motion loss via soft tissue. |

Surface EMG Electrodes are placed inside the designed socket to record the EMG signals from the hamstring and quadriceps muscles. Two pairs of electrodes are placed in the anterior and posterior regions of the socket design. The 3D model of the socket design is shown in Fig 9(a) and 9(b) respectively. The designed 3D model can be used for additive manufacturing (3D printing) [15].

9(a) 9(b)

**Figure 9(a).** Top view of the designed prosthesis. **9(b).** Side view of the designed prosthesis

## 3. Results and Discussion

The raw EMG signals from the anterior and posterior regions of the thigh were obtained, and the signals were further processed to get the desired characteristics. An IIR bandpass filter of order 78 with a cut-off frequency of 50-150 Hz was designed. Graphical plots of raw, filtered, detrended, rectified and smoothenedsignals were plotted using MATLAB software. A moving mean filter with a window duration of 450 ms was adapted to smoothen the signal. To get more information about the data acquired from thigh muscles (anterior / posterior), a statistical analysis was performed and the following parameters were acquired such as mean (-0.004901 / -0.005502), median (-0.005085 / -0.00672), standard deviation (0.064304 / 0.134531), variance (0.004135 / 0.018099), kurtosis (40.582344 / 11.835418) and skewness (0.445286 / 0.174744). The various features of the EMG signal were determined. The integrated EMG (IEMG) feature, which helps identify and assess muscular contraction levels, and the mean absolute value (MAV) feature, which offers information about the muscle's pre-activation index, was determined. The IEMG and MAV were found to be very efficient in constructing a bio signal powered prosthesis. The contraction phase of the EMG signal was converted to a pulse for the purpose of driving a stepper motor. The threshold voltage wasset to 0.4 during pulse transformation. A 3D model of an Ischial containment socket design was designed using Autodesk Fusion 360 software in order to assist the transfemoral amputees.

## 4. Conclusion

In this study, the contraction phase of the EMG signal was identified and converted to a pulse in order to drive a stepper motor and a 3D model of the Quadrilateral socket was designed to help the transfemoral amputees. The EMG signal acquisition and its processing has been performed followed by the statistical study of the data. More information about the acquired raw data was obtained by determining the statistical parameters. The EMG signals were acquired from a healthy volunteer using surface EMG electrodes and the processing was carried out in terms of filtering, detrending, rectifying and smoothening. Valuable EMGsignal features such as Integrated EMG feature and Mean absolute value was extracted. It was found that the MAV and the IEMG features are efficient in the construction of a bio signal powered prosthesis. The study also found that the contraction phase of the signal that was converted to pulse was used to drive a stepper motor. A comparative analysis between the Ischial containment socket and quadrilateral socket design was performed. It was found from the comparison, that the Ischial containment socket design is usually preferred over Quadrilateral socket design because of its superiority in terms of comfort and energy efficiency it provides. Hence, a 3D model of the Ischial containment socket design with a provision for electrode placement was designed to record the EMG signals from the hamstring and quadriceps muscles to promote real time acquisition. It was also found that the proposed design can be 3D printed using additive manufacturing. This Ischial containment socket design model was proposed in order to help the transfemoral amputees wherein the surface electrodes which are placed within the socket acquire the EMGsignals and those acquired signals are processed and converted into pulse. This pulse signal is then used in the control of a stepper motor, thereby helping the amputees control their own movement with their own bio signal with the help of a comfortable prosthesis.

### Conflict of interest

No conflict of interest was declared by the authors.

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