307. Development of threshold based EMG prosthetic hand

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(Received 21 March 2007, accepted 18 June 2007)

Abstract. There is a real need of EMG (Electromyogram) based prosthetic hand for the amputee which should be economical as well as reliable. The cheap prosthetic hand available in market works passively. In those cases the patient does not feel the feeling of natural human hand. EMG based prosthetic hand provides the amputee feeling of natural human hand. The work that has been discussed here is to develop a prosthetic hand with one degree of freedom. The two motions developed were open and close. Most of the work is done at electronic level. The main work was to acquire the noiseless EMG signal and further to convert it into control signal for prosthetic hand, after suitable processing. For classification a threshold based technique has used rather than any classification technique like Artificial Neural Network (ANN), Fuzzy Logic and Genetic Algorithm (GA). It was tried to use the minimum hardware, without making any compromise with performance. It was done so, to achieve the target of developing a economical and reliable prosthetic hand. The threshold value used was variable and was controllable from outside by just varying the knob of potentiometer. This adds an additional dimension for tuning the device and scope to adjust the threshold according to muscle activity of subject. So the same prosthetic hand can be used by different amputees by just changing the threshold values only. The mechanical hand was having only two fingers to grasp the objects. The work was also extended to develop the frequency based Prosthetic hand. The scheme was to find out the frequency bands where the amplitude of open and close motions is different. The FFTs (Fast Fourier Transform) of EMG signal were calculated in MATLAB. The DSO (Digital Storage oscilloscope) was also having the facility of displaying the FFT of signal. It was found that there is certain possible frequency band which classifies the open and close motion of hand.

Keywords: Electromyogram, Artificial Neural Network, Fast Fourier Transform

Introduction

Electromyography control uses the EMG electrical signal due to depolarization of the cell membrane of the muscle fibers during contraction. It was first used in prosthetics by Reiter in the early 1940s [1]. Traditional approaches are relatively successful but suffer from the drawback of being relatively slow and often requiring human intervention. So, neural network appear to be slightly better option [2, 3]. The discrimination of eight kinds of prehensile postures was successfully justified by using the forearm EMG signals. Combination of IEMG (Integrated Electromyogram), Variance, WAMP (Wilson Amplitude), Wavelength, Zero-Crossing and 2nd order AR (Auto Regressive) parameters has the best performance for the pattern recognition of those postures. The spectral estimation method, short-period AR model show poor result for this rapid movement discrimination. The identified success rate for neural network is about 85% in off-line testing and 71% in on-line testing [4]. The nonlinear properties of the neuromuscular system were realized by using a position control system of the finger movement, force feedback and variable gain which was modulated by amplitude of rectified and smoothed EMG signals [5]. Due to the complexity of the EMG signal and the portable consideration of the controller, a controller based on digital signal processor (DSP) was designed and implemented in the descriptive system. The parameter extracted from the feature selection stage can be used to separate different input patterns into different number of classes. Back propagation Neural Network Classifier (BPNN) was used as a powerful classifier to solve the nonlinear discriminative system of the EMG signal. The classifier has one hidden layer and the entire system is a three-layer perceptron. The gradient steepest descent method was adopted o solve the minimization error of each input pattern. The DSP integrates the signal preprocessing module, the digital filter module and pattern recognition module into the controller. The on-line DSP Controller can provide 87.5% correct rate for the discrimination of eight hand motions [6]. Supervised Feature Mining (SFM) method is an intelligent approach based on genetic algorithms (GAs), fuzzy measure, and domain knowledge on pattern recognition. The SFM can find the optimal EMG feature subset automatically and remove the redundant from a large amount of feature candidates without taking trial-and-error. The central concept of the SFM is to change the class structure in the feature space according to the relative importance of features. By introducing a set of weighting factors to each feature, the classes structure the index Fuzzy-entropy-based Feature Evaluation Index (FFEI) becomes a function of these factors in feature space. A weighting factor implies the relative importance of a feature. Hence, the genetic algorithm (GA) is performed to search the optimal weighting factor automatically. We can select the optimal feature subset according to the weighting factors. The larger the value of the weighting factor is**,** the more important the feature is. The features ARM (Auto Regressive Model) and HEMG (Histogram of EMG) obtain high classification rates for all postures especially for HEMG. The classification rates of all postures are above 80%. On the other hand, the other six features get lower classification rates except for the third posture, the wrist flexion. The features ARM and HEMG get higher average classification rates than others [7]. The fuzzy based controller has been designed also to serve as controller for prosthetic hand. Fuzzy logic techniques are used to detect EMG onset and classify user intent. Membership functions for each EMG channel are based on EMG signals acquired during a training session. Standard clinical techniques were used to locate the four sites for interfacing the Fuzzy logic controller. Rules recognizing the different EMG levels associated with a particular function are automatically generated based on the recorded EMG training data. This controller is capable of providing seamless sequential control i.e. sequential control without the intermediate switching steps with an update rate of 50 mS. The automatically generated fuzzy systems produced results of 91% to 95% for the subjects with trans-radial length residual limbs and 96% to 98% , for the intact-limbed subjects respectively. Comparing the fuzzy control accuracies to currently implemented algorithms in standard commercially available prostheses, it was found that the fuzzy systems performed better in general than all other modes [8]. Even if the force generated by the hand is low, a better distribution of contact areas between the three fingers and the grasped object can be obtained thanks to the novel kinematics. This result can partially compensate for the reduction in actuator force and ultimately allows retaining almost the same grasping stability as traditional prostheses when grasping objects of complex shape [9]. Current prosthetic hands can require high-energy consumption. Since bending is typically restricted to two joints that cannot move independently, the grip is not adaptive. That is, the fingers do not wrap around the object as fingers in the human hand do. Consequently, there is little contact area between hand and object, requiring high pinch forces at the fingertips to grasp the object. The prosthetic gripper that locks itself into place and avoid a constant current drain to maintain the force exerted in the fingers [10, 11]. The present work is aimed at realizing a simple EMG operated prosthetic hand with minimum hardware and reliability. The various steps taken for this work has been explained in the following sections.

EMG Acquisition

The first step in this direction is to place the electrodes at the required muscle. Two electrodes were used for differential measurement of EMG Signals. Bunching was implemented between the wires of electrodes to cancel the common noise. Reference electrode was placed at unconcerned muscle. Two electrodes were placed at below the elbow with less than 1cm apart. EMG jelly was pasted on the inner part of all three electrodes to make a good contact. The hardware includes Instrumentation Amplifier (AD524), Notch Filter (50 Hz) and Operational Amplifier (Op-07) for EMG acquisition.

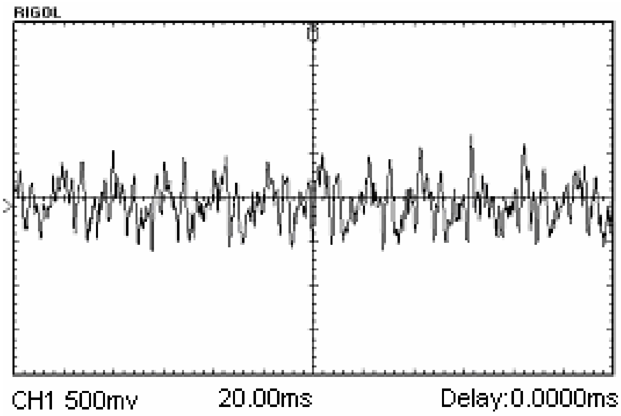

Fig. 1. EMG acquired in Relax position

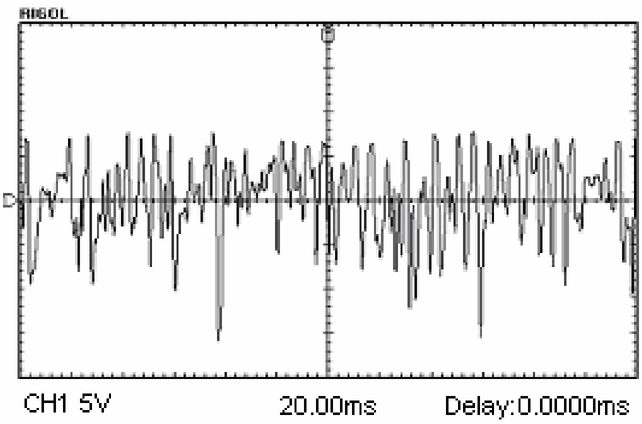

Fig. 2. EMG acquired in Hand open Position

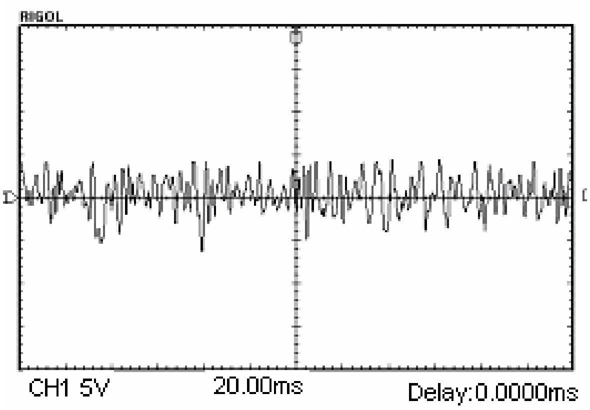

Fig. 3. EMG acquired in Hand Close Position

It can be conclude by analyzing above three graphs that the amplitude of EMG signal in close position was less than in open position and it was observed so many times and they both have very high magnitude in comparison to the magnitude of EMGF signal in relax position.

EMG Classification and movement implementation

As three different EMG signals for three different motions has been recorded i.e., relax, open and close. By seeing them it can be concluded that they can be classified on the basis of their difference in amplitude. For performing this type of amplitude-based classification Peak Detector was implemented.

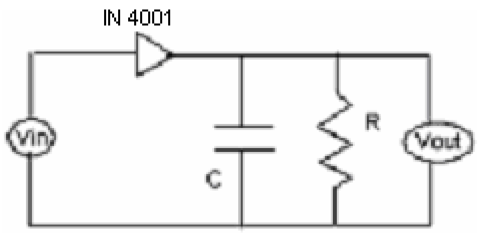

Fig. 4. Peak detector circuit (Classifier) with R = 200 K, C=10 μF, 16 V

The output of Peak Detector (Classifier) for three different motions was observed as following:

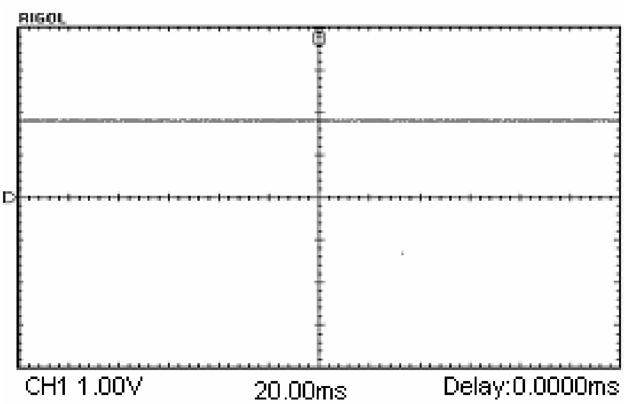

Fig. 5. Output of classifier (peak detector) for relaxed position

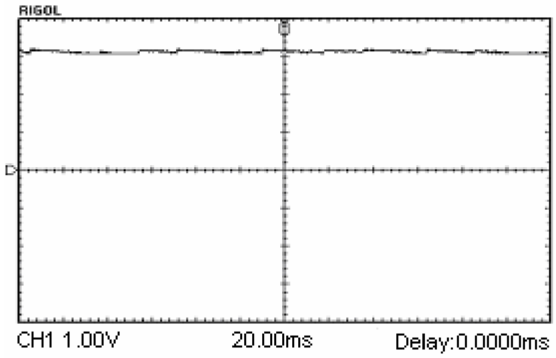

Fig. 6. Output of classifier (peak detector) for open position

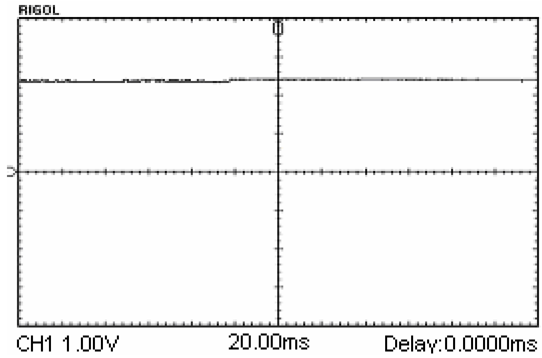

Fig. 7. Output of classifier (peak detector) for close position

A table has been drawn (in various recording from the same subject) on the basis of above outputs of Peak detector between the amplitude level and motion of hand as following:

Table 1. Peak amplitude for three different hand motions

MOTION OF HAND	PEAK AMPLITUDE (V)
RELAX	1.8
CLOSE	2.4
OPEN	3.2

Now these analog values were converted to digital one by deciding the proper values of threshold to the comparator. Based on experiments threshold values for two comparators were decided as 2.1V and 2.8V.

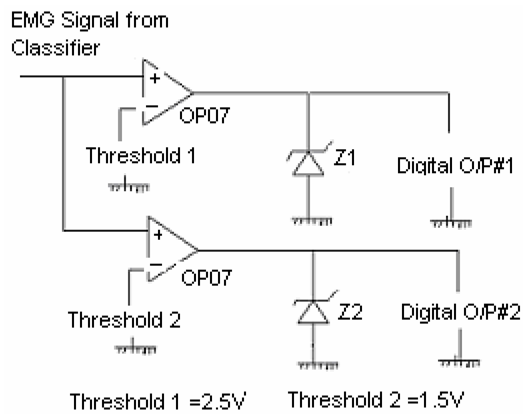

Fig. 8. Circuit to get digital output from classified results.

Then when the hand was in relax position both comparators will have value "LOW" and when hand is in close position one comparator will go "HIGH" and another one will ho "LOW" and when hand will be in open position both comparator will give "HIGH" output. So this digital o/p's was mapped to hand motion as following:

Table 2. Mapping of digital outputs to hand motion

Digital O/P#1	Digital O/P#2	HAND MOTION
LOW	LOW	RELAX
LOW	HIGH	CLOSE
HIGH	HIGH	OPEN
HIGH	LOW	DON'T CARE

It was also shown by the DSO that the outputs of comparator represent the motion of hand in three different patterns

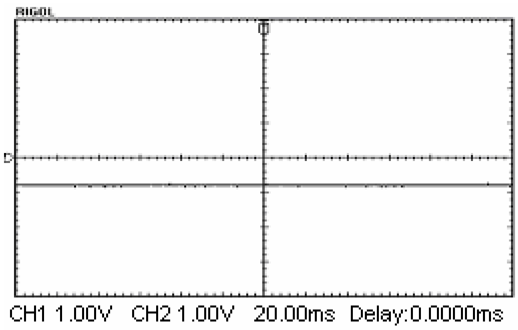

Fig. 9. Output of the two comparators in relaxed position (0,0)

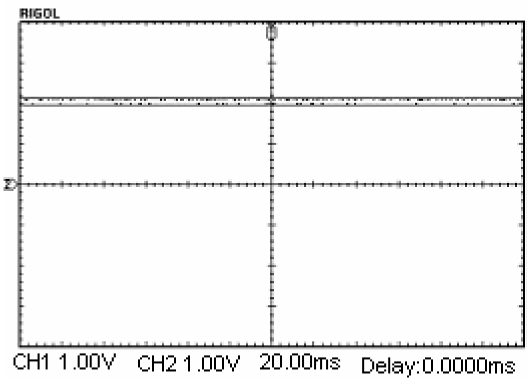

Fig. 10. Output of the two comparators in open position (1,1)

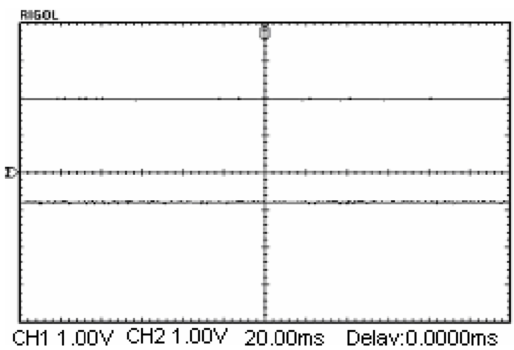

Fig. 11. Output of the two comparators in close position (1,0)

Fourth condition is don't care condition. Because it has been observed that the amplitude of EMG signal in open position is higher than in close position. Now the remaining task is to implement these digital outputs for motion of motor. Motor requires reverse biasing of voltage for the reverse motion. This was implemented by H-Bridge circuit. In H-Bridge there are four switches. At one instant of time two switch conduct. When the one set of two switches are conducting motor moves in clockwise direction and if rest of two switches conduct motor moves in anti-clockwise direction. If no switch conducts the motor is off and is in rest condition. Now the task is to develop a logic circuitry, which will control the conduction of these four switches as per our requirement.

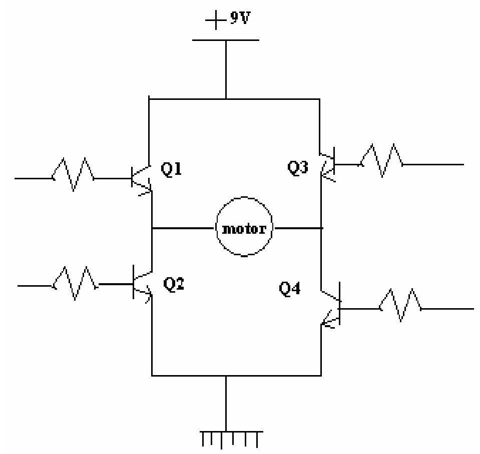

Fig. 12. H-Bridge circuit as driver circuitry for motor control

Two outputs from comparators say A and B were observed. It was required to control these four switches Q1, Q2, Q3, Q4 from these two comparators output. For that purpose it was required to conduct two diagonal switches at a time. Following truth table was drawn accordingly.

Table 3. Table for switching control from digital outputs
This is the truth table for our required motion

A	B	Q1	Q3	Q2	Q4
0	0	0	0	0	0
0	1	1	0	0	1
1	1	0	1	1	0
1	0	*	*	*	*

This logic will work in this way that Q1 and Q4 are following same logic so they will turn on at same time so the motor will move in one direction as they are diagonal switches (in H-Bridge), while Q2 and Q3 are following same logic so they will turn on at same time so the motor will move in reverse direction as they are diagonal switches. When all switches are off, no motion will occur.

Realization of Frequency based Prosthetic Hand

The work presented in this thesis is based on amplitude threshold. But a concept of frequency based prosthetic hand has been discussed with some result. The classification is decided by the two filters which output different amplitudes for different motion based on their frequency component. This can be explained better by the following figure3.1

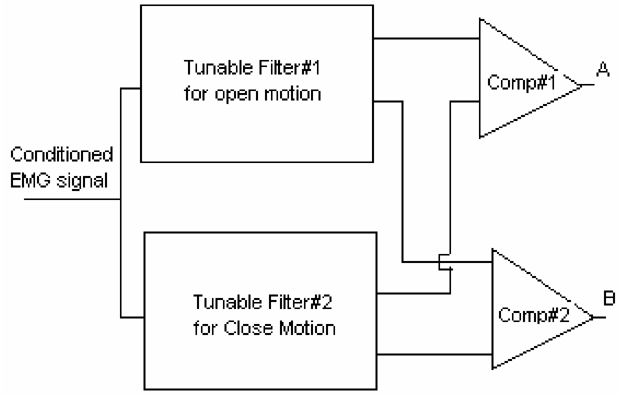

Fig. 13. Scheme for EMG frequency based Prosthetic Hand

The above figure shows scheme of EMG frequency based prosthetic hand. Initially it was found offline that there are two frequency bands where the amplitude of open and close motion EMG has significant difference. This is the key to classify the motions of hand. Two filters are designed with two different frequency bands corresponding to open and close motions. When the EMG signal corresponding to open is there at the input the frequency component corresponding to open motion are dominating and hence the frequency component corresponding to close motion are not present so the output of filter#1 will be larger than of filter#2. That's why the output of comparator #1(A) is 'high' and output of comparator#2(B) is 'low' i.e. A=1 and B=0. Similarly When the EMG signal corresponding to close is there at the input the frequency component corresponding to close motion are dominating and hence the frequency component corresponding to open motion are not present so the output of filter#2 will be larger than of filter#1. That's why the output of comparator #2 is 'high' and output of comparator#1 is 'low' i.e. A=0 and B=1. And finally when the EMG signal corresponding to relax is there at input there will be no any frequency component corresponding to open and close motion so the output of both the filters will be zero and hence the output of both the comparator will be 'low' i.e. A=0 and B=0.. So now on the basis of above analysis following table can be created:

Table 4. Truth table for EMG frequency based Prosthetic Hand

A	B	Hand Motion
0	0	RELAX
0	1	CLOSE
1	0	OPEN
1	1	DON'T CARE

Now the rest of the part is same. It is the same truth table as it was in the EMG amplitude Threshold based prosthetic hand. So rest of the part is to map these digital motions into motor motions through some logic circuitry and H-Bridge. The frequency components of EMG signals were calculated through FFT (Fast Fourier Transform). The DSO (Digital Storage Oscilloscope) used was having the inbuilt facility to show the FFT of the signals. Three FFTs for open motion and three FFTs for close motion were recorded. One FFT for relax and one FFT for relax with arm movement has been recorded.

Results and Discussion

The developed prosthetic hand was tested on many subjects and the performance was found quite satisfactory. Further there was a facility of varying the threshold by just varying the knob of potentiometer from outside. So the device can be tuned for the different subjects as per the amplitude of EMG signal. Also the results for Frequency based prosthetic hand were analyzed in MATLAB. Following are the results showing the FFTs of EMG signals of subject for different motions. The FFT signals that are captured from DSO are with the mentioned settings (500 μV rms/div, 31.25Hz /div, sampling rate = 5 KHz)

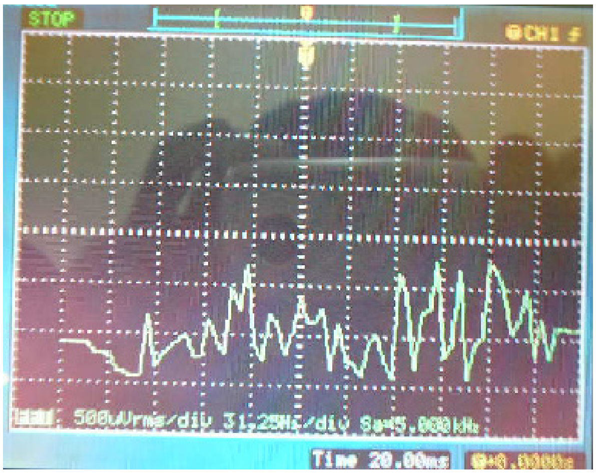

Fig. 14. FFT for close motion (500 μV rms/div, 31.25Hz /div, sampling rate = 5 KHz)

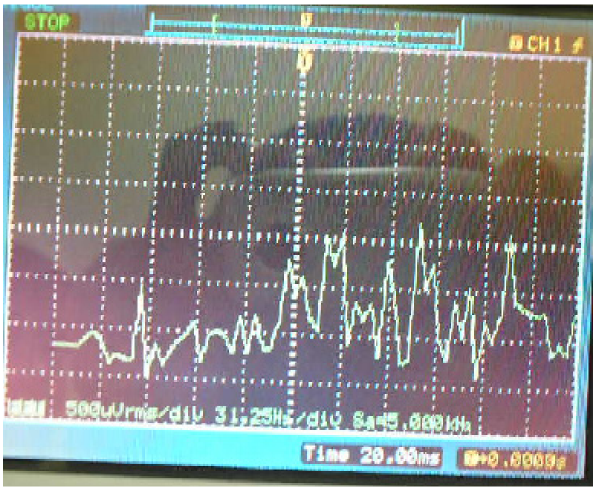

Fig. 15. FFT for open motion (500 μV rms/div, 31.25Hz /div, sampling rate =5 KHz)

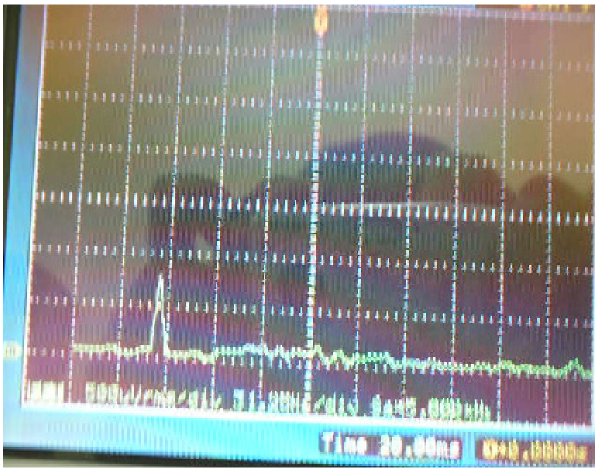

Fig. 16. FFT for relax motion (500 μV rms/div, 31.25Hz /div, sampling rate =5 KHz)

Fig. 17. FFT for relax motion with arm movement (500 μV rms/div, 31.25Hz /div, sampling rate =5 KHz)

The signals were also captured and were sampled by the DSO and were further analyzed by the MATLAB. Following are the signals and graphs corresponding to these data, recorded at sampling frequency of 25 KHz, are shown below:

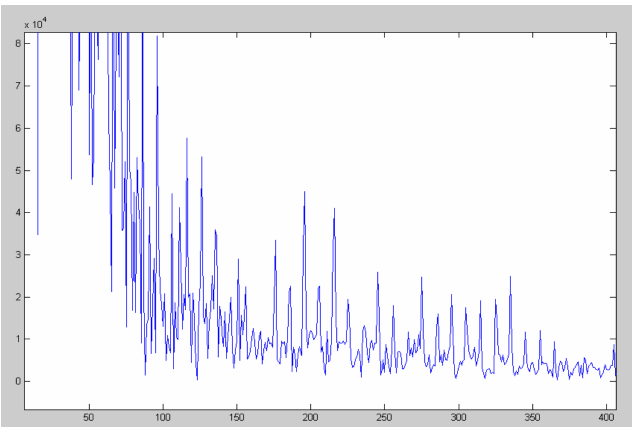

Fig. 18. FFT for open motion

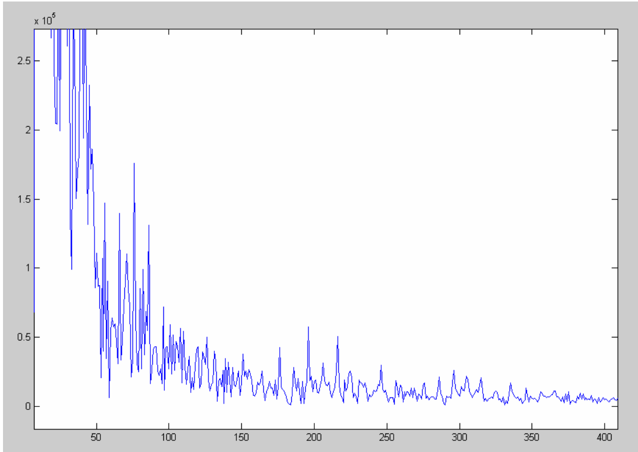

Fig. 19. FFT for close motion

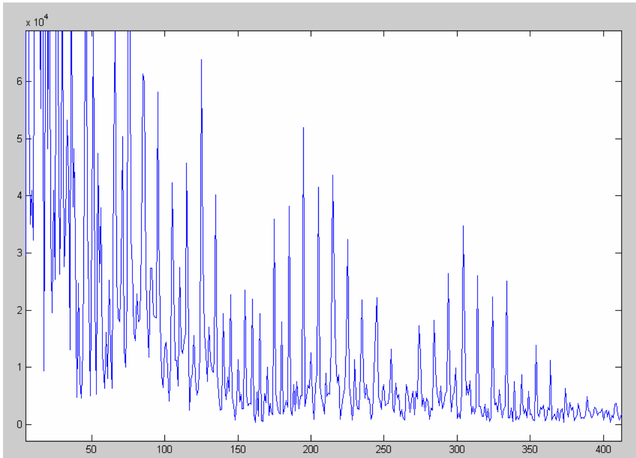

Fig. 20. FFT for relax motion

Above graphs shows the EMG signals for different motions of hand as well as the Fast Fourier Transform (FFT) of the signals. FFT of a signal shows that how much a frequency component contribute for that signal i.e. Frequency spectrum. The FFT of the signals shows that a frequency band exists, in which the frequency components contributing for different hand motions are different. This makes the key point to develop the frequency based prosthetic hand. Two filters having the different frequency band corresponding to open and close motion classifies the two motions on the basis of the frequency components. Further the output for the two motions is different for different motions which are mapped to motor motion accordingly. The high amplitude on lower frequency sides of the FFTs is due to motion artifacts which are to be removed from the signals to extract information from the FFTs. The selection of frequency band is important criterion because it decides the false triggering also. If the frequency band is selected such that there is a significant difference in amplitude of open and close motion then there are very less chances of false triggering, but if the difference is too low the chances of false triggering are increases. So the frequency band is chosen carefully. Following tables shows the result drawn from the above graphs:

Table 5. Observation table of frequency band from above graphs

Hand Motion	Frequency band (Hz)	Observation
Close	218-282	No frequency component having amplitude more than 2 mV but some frequency component having amplitude greater than 1 mV
Open	218-282	One frequency component (235 Hz) having amplitude more than 2 mV
Relax	218-282	No frequency component having amplitude >.2mV

Table 6. Observation table of frequency band from above graphs

Hand Motion	Frequency band (Hz)	Observation
Close	218-282	No frequency component having amplitude more than 2 mV but some frequency component having amplitude greater than 1 mV
Open	218-282	One frequency component (224 Hz) having amplitude more than 2 mV
Relax	218-282	No frequency component having amplitude >.2mV

Table 7. Observation table of frequency band from above graphs

Hand Motion	Frequency band (Hz)	Observation
Close	93-166	One frequency component (131Hz) having amplitude 2 mV
Open	93-166	No frequency component having amplitude 2mV
Relax	93-166	No frequency component having amplitude >.2mV

Table 8. Observation table of frequency band from above graphs

Hand Motion	Frequency band (Hz)	Observation
Close	125-156	one frequency component (133Hz) having amplitude more than 1.5 mV
Open	125-156	No frequency component having amplitude more than 1.5mV
Relax	125-156	No frequency component having amplitude >.2mV

Above table shows that there is a possible frequency band which can differentiate between open and close motion. That frequency band when implemented the output in amplitudes of different motions differ very much each other which shows the possibility of designing a frequency band prosthetic hand.

The schematic will be now as following:

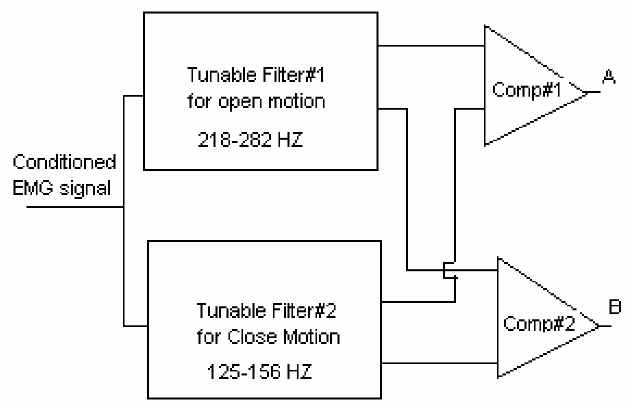

Fig. 21. Schematic diagram of Frequency based Prosthetic hand with possible frequency bands.

Conclusion

The result has shown that the performance of developed prosthetic hand is satisfactory. Also the same prosthetic hand can be used by different amputees by just varying the knob of potentiometer from outside i.e. varying the threshold. The motions of hand were totally controlled by the EMG signals. There are few frequency bands which show the different amplitude of open and close motion in that frequency bands, which shows the possibility of designing frequency based EMG Prosthetic hand. Performance of frequency based Prosthetic hand depends on accuracy of filter that has been designed while in the Amplitude based prosthetic hand it is not the case. If the filter is designed in Microcontroller or in DSP processor, which provide higher accuracy of cut-off in filter designing, the chances of false triggering are reduced very much, which highly exist in Amplitude based prosthetic hand. Further by introducing digital devices like Microcontroller or DSP Processor increases the cost of prosthetic hand as well.

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