# A step towards home-based robotic rehabilitation: An interface circuit for EEG/SEMG actuated orthosis

Amogh R. Raichur, Gunadi Wihardjo, Subhasis Banerji, John Heng

*Abstract*— **The effectiveness of rehabilitation will be increased substantially (e.g. stroke patients) if the patients are able to use a robotic rehabilitation system at home, after having trained on it at the hospital.**

**Due to high cost and complex architecture, most robotic orthoses are limited to use in the hospital. The "active" orthoses that make use of bio-signals for control purposes, are at present limited in their versatility, portability and usability. At the same time, studies show that rehabilitation speeds up when the level of patient engagement is higher.**

**To make home-use a reality, it is of paramount importance that the system is low-cost, portable and simple to operate. The quality of bio-signal acquisition for an "active" robotic device must be good enough to enable stable, repeatable and reliable control signals. An acquisition and control system which satisfies these goals will create a significant impact on patient adoption of robotic rehabilitation devices.**

**The sub-system design that is described in this paper is part of a wider research work to develop an accelerated stroke rehabilitation platform utilizing an EEG/SEMG based upper extremity robotic orthosis. This sub-system forms the 'interface' between the patient and the computer / controlling device used for signal processing and orthosis control. Cost and weight is reduced significantly. The circuit can interface with industry standard data acquisition devices and switch seamlessly between surface electromyography (SEMG) and electroencephalography (EEG) operation. Test results are presented both with simulated signals as well as actual SEMG signals.**

*Index Terms*—**EEG, EMG, Stroke, UE Orthosis**

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## I. INTRODUCTION

Literature and products available in the market show that there are limitations in the portability and versatility of robotic rehabilitation devices [1], [2]. At the same time, there is increasing evidence that rehabilitation is most effective when the patient is fully "engaged" in the task [3].

The number of deaths and discharges for stroke from Singapore hospitals has been steadily rising over the past 30 years. There was more than a two-fold increase in the number between 1986 and 1996. With rising number of stroke patients, there will be rising demand for rehabilitation therapists, which subsequently will raise their duties and responsibilities [4].

Rehabilitation therapists support manipulation of the paretic limb for rehabilitation purposes. This procedure must be conducted frequently for several months. The length of rehabilitation varies for every patient. A large amount of time and resources is needed, both for patient and therapist. The patient may need to reach the clinic where the treatment is provided. This will create inconvenience to the patient. During the rehabilitation, the therapist needs to completely dedicate himself for a single patient only. This may lead to high therapy cost which must be taken into account as well [5].

One solution to solve these problems is for the patient to do rehabilitation by himself at his home [6]. Home-use greatly aids stroke patient recovery and rehabilitation after being discharged from the hospital [7], [8]. Many laboratories involved in robotics and bio-medical engineering have started projects to design and experiment automatic or semi-automatic systems for hand rehabilitation which are user friendly.

One of the ways of achieving patient engagement is through "Active" Rehabilitation Orthosis which is controlled by EEG or SEMG signal. In order to acquire these signals, a bio-potential data acquisition sub-system was needed. This sub-system had to adhere to the project goals of portability, versatility and cost. The designs proposed by the authors focus on solving issues with the 'interface' between the patient and the computer / controlling device.

There are commercially available EEG and SEMG measurement systems and devices to do the task of data acquisition. However they fall short of the requirements of our project for the following reasons:

1) They are limited in the functionality of recording multiple types of bio-potentials (eg. EEG, SEMG, or Electrocardiogram (ECG))
2) They are bulky and are problematic for portable operation.
3) They are complex to operate.
4) They are very expensive (several thousand dollars).
5) Most of these devices operate only with proprietary software and there is very limited support provided for development of third-party applications. This is a critical shortcoming because it leads to an integration problem in the orthosis platform development.

It was decided to tackle hardware shortcomings by innovative circuit design with low cost and complexity. Software issues could be greatly reduced by adopting LabView 8.0 (From National Instruments Corporation, USA) as a development platform for the entire project.

## II. SYSTEM DESCRIPTION

It has been established that bio-potentials like SEMG and EEG require faithful amplification before they can be captured [9]. There are inherent differences between the two types of signals (EEG signals are much smaller in magnitude than SEMG, in the range of μV as compared to mV. They also lie in a different frequency range). Due to this fact, some part of the acquisition circuitry is different for the individual signal types. This can be seen in Fig. 1 which describes the proposed DAQ (Data Acquisition) system.

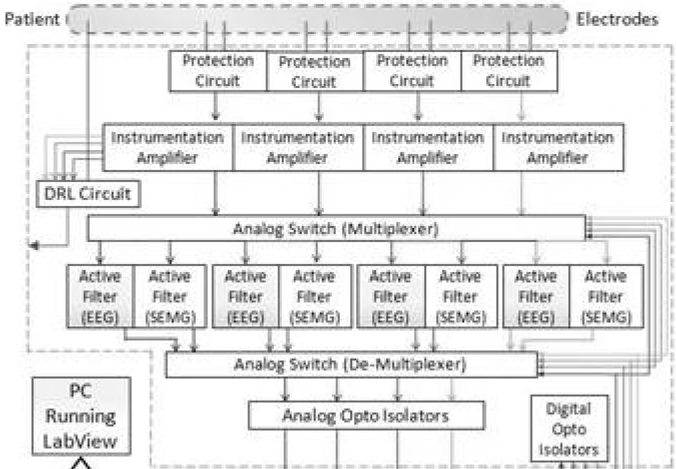


Fig. 1. Interchangeable SEMG / EEG DAQ System Block Diagram

The bio-potentials (SEMG or EEG) from the patient are picked up by the electrodes (Ag-AgCl type) and passed through the Protection Circuit. Ag-AgCl electrodes are chosen since they provide a stable transition with low noise and are easily available commercially [10]. This circuit protects the user from failing circuitry, and also protects the circuits downstream from electrostatic discharge [11], [12], [13]. There are capacitors which suppress radio-frequency signals that might enter the cable. A network of double-diodes and resistors perform the protective functions. After the protection circuit, the bio-signal gets amplified with a gain factor of 12 by a high quality instrumentation amplifier.

One of the problems of recording SEMG or EEG is that the measured signals are often corrupted by low and high frequency interferences [14]. Amplification is carried out in several stages, as a result of which the design of the first stage becomes crucial. If it is not designed well, the system will pick up more noise which will be amplified further by the following stages. This will cause highly undesirable distortion of the signal to be monitored. An instrumentation amplifier is hence used in the first stage due to its various advantages suitable for medical instruments [15].

The instrumentation amplifier is connected in differential mode due to the benefits of common-mode noise reduction and improvement in signal to noise ratio. It amplifies the EEG and lowers the impedance, making it less sensitive to noise [15].

The ICs (Integrated Circuits) that were considered for this job were AD620, AD622 (From Analog Devices, Inc.) and INA118, INA114 (From Burr-Brown semiconductor). They have similar performance and are recommended for use in medical instrumentation. The following table shows a simple comparison based on the major parameters of input impedance, Common-mode Rejection Ratio (CMRR), and power-consumption (based on quiescent current).

TABLE I
COMPARISON BETWEEN AD620, AD622, AND INA118

| Type | Input Imp. (Differential) | CMRR (Min) | Quiescent I |
|---|---|---|---|
| AD620 | 10\|\|2 GΩ\|\|2pF | 100 dB | 0.9 mA |
| AD622 | 10\|\|2 GΩ\|\|2pF | 66 dB | 0.9 mA |
| INA118 | 10\|\|2 GΩ\|\|1pF | 110 dB | 0.35 mA |

AD620 was chosen as it proved to be a good balance between cost and performance. The AD620 is a low cost, high accuracy instrumentation amplifier that requires only one external resistor to set gains of 1 to 1000.

What follows is a Multiplex/De-multiplex system of Active filters that provide the 'interchangeable' property of this circuit.

Two sets of Quad 2:1 analog switch ICs form the multiplex/de-multiplex system which allows the user to choose if each channel acts as an EEG or SEMG channel. This is achieved by providing digital control signals to the analog switches and channelizing the bio-signal from the instrumentation amplifier stage to the appropriate Active Filters (EEG or SEMG). These control signals are provided from the USB-6259.

Each active filter section consists of a High Pass (HP) and Low Pass (LP) filter circuit. The high-pass filters not only remove DC offset voltages (due to occasional electrode polarization) [11], but also suppress movement artifacts (usually below 10Hz) for SEMG signals. The low-pass filters remove unwanted high-frequency noise and ensure higher quality bio-signal capture. Being 'active' filters, these stages also provide additional amplification which brings the bio-signals to a level that can be detected by the USB-6259 and displayed/analyzed in LabView 8.0.

The maximum signal amplification or gain value for our circuit is about 20,000 for EEG signals and 200 for SEMG signals. The system was designed to provide a maximum peak-to-peak output of 4V to the NI USB-6259. This means that the range for differential EEG signals detectable is 0-200uV and that for SEMG signals is 0-20mV. The actual gain values obtained by using the component values obtained from FilterPro were 1108 to 1630 (for EEG filter).

The HP and LP filters designed around op-amps have unique purposes, some constitute to the EEG filtering section and some constitute to the SEMG filtering section. Potentiometers are provided for variable gains on the EEG and SEMG filters respectively. The IC is TLC279 (LinCMOS precision quad operational amps) from Texas Instruments Inc. USA.

TABLE II
GAIN ACHIEVED AT EACH STAGE

| Part Name | Characteristics | Gain |
|---|---|---|
| Pre-Amplifier | Differential Input Impedance:<br>10\|\|2 GΩ\|\|2pF<br>CMRR: 100 dB<br>Quiescent Current: 0.9 mA | 12 |
| High Pass Filter | 2nd-Order Butterworth Filter<br>Cutoff Frequency: 0.16 Hz (EEG)<br>Cutoff Frequency: 10 Hz (EMG) | 64 (EEG) or 4 (EMG) |
| Low Pass Filter | 2nd-Order Butterworth Filter<br>Cutoff Frequency: 0.16 Hz (EEG)<br>Cutoff Frequency: 10 Hz (EMG) | 1024 to 1664 (EEG) or 8 to 16 (EMG) |

The outputs of both these filtering sections are then given to the de-multiplexing block. Similarly from the other 3 channels there are 6 other outputs going to the de-multiplexing block.

A de-multiplexing system was introduced between the filters and isolation circuitry to collect the signals back again after filtering. As a result, at any given time a channel would act as an EEG channel or SEMG channel depending on which filtering block the multiplex/de-multiplex system routes the analog input signal from the instrumentation amplifier.

This system is implemented using the 4 ICs MAX4619 (triple SPDT CMOS analog switches From Maxim – Dallas Semiconductor). Two of them are used for multiplexing 4 input channels to 8 filter inputs and the other two are used to de-multiplex analog data from 8 filter outputs to 4 isolation circuit inputs. It should be noted that 4 such ICs actually provide the ability to multiplex/de-multiplex up to 6 channels (only 4 channels were used in this case).

Below the signal amplifiers and the filters, sits a third amplifier circuit pointing the other way, sending a signal to the patient. This is the ‘right-leg’ driver. It got its name for historical reasons. The driver was previously only used by ECG meters, which measure the electrical activity in the heart. During ECG sessions, the driver (also abbreviated DRL, for Driven Right Leg) is attached to the right leg, as far away from the heart as possible [16]. The purpose of the DRL is to reduce common-mode signals such as 50/60Hz mains hum, by cancelling them out. It can attenuate mains hum up to 100 times more than the instrumentation amplifier can do by itself [17], [18]. The electrode attached to the DRL can also be attached to the patient’s arm.

After the amplification and filtering, the bio-signals are ready for acquisition by the USB-6259. The interface circuit is electrically isolated from the USB-6259 as well as external power sources using opto-couplers and a DC-DC converter. Not shown in the diagram is the power supply section which powers the entire system.

The USB-6259 prominently features as many as 32 analog input terminals, 4 analog output terminals, 32 digital pins, 16-bit A-D converters and two 32-bit counters [19]. 8 of the analog input terminals are used for connecting to the interface circuit (2 sets of 4 channel circuits). 8 digital output pins are also connected to the interface circuit to control the working mode (SEMG or EEG) of each channel. The acquisition of signals and control of the circuit is handled through programs written in the LabView software. The USB-6259 communicates with a PC running LabView 8.0 through a Universal Serial Bus (USB) cable. The signals acquired are then displayed and analyzed through LabView.

Fig. 2 shows the physical representation of the interface circuit development.

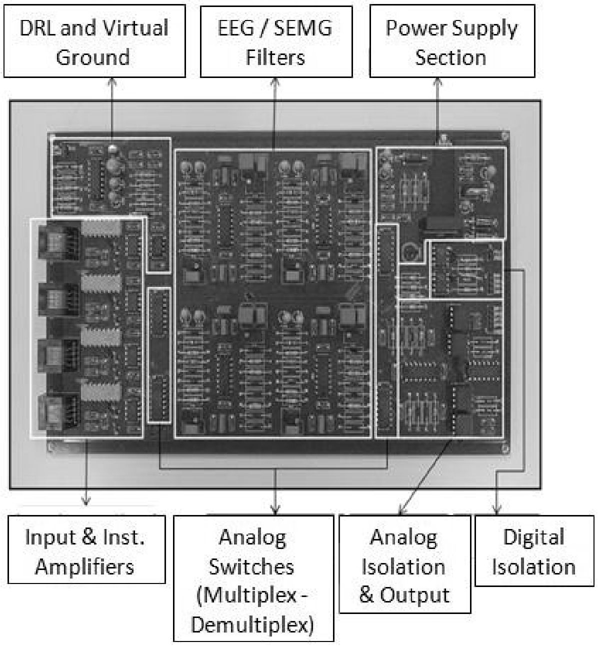


Fig. 2. EEG/SEMG interface circuit PCB

## III. RESULTS

A trial experiment was conducted by generating signal in LabView 8.0 (running on Windows XP, Pentium 4 PC with 1.5 GB RAM) and give input to the circuit through the Analog Outputs of the USB-6259. The frequency of this signal was varied over a range which covers the expected range of SEMG signals. The outputs from the circuit were measured and gain calculations were made in LabView. The frequency response of the circuit boards was then plotted in LabView (Fig. 3).

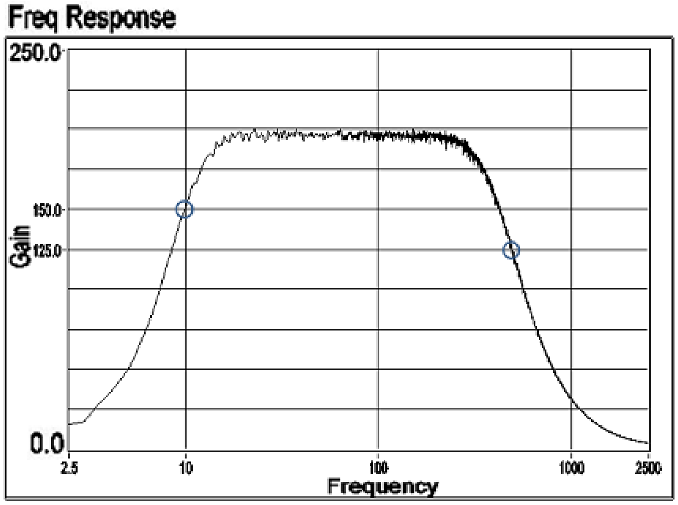


Fig. 3. Frequency response of actual PCB in SEMG mode

A negligible amount of distortion was observed in the curve, due to the effects of real-world measurement conditions like sampling noise of DAC in the 6259 and random environmental noise.

The cut-off frequencies are indicated by the circles on the graph. The gain at the lower cut-off frequency (10 Hz) is approximately *150*, while at the higher cut-off frequency (500 Hz) it is about *125*. Between them, which is the expected range whereby the SEMG signal would present (10Hz – 500 Hz), gain of the system is approximately *200*. This is an acceptable performance for SEMG measurements [20].

The EEG mode of the circuit would have to be tested by scaling down the analog output test signal generated by the USB-6259 into the µV range. We chose not to directly generate output in µV signal for stability purpose. A 1/1000 Voltage divider circuit was added to the USB-6259 Analog test signal. This arrangement would provide µV signals from mV signals.

This was observed in a short test in which the signal generated by the USB-6259 was 100 mV, 20 Hz signal and theoretically the voltage divider should have given a 100 µV, 20 Hz. Practically, the following figures illustrate the effects of noise on the µV test signal. Fig. 4 shows the mV signal given to the voltage divider circuit, while fig. 5 shows the actual noise affected signal that is fed to the circuit operating in EEG mode.

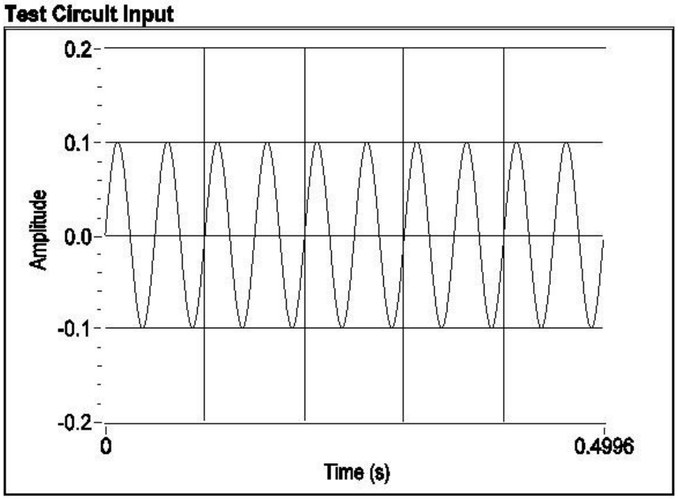


Fig. 4. Input to 1/1000 voltage divider circuit for EEG Circuit test

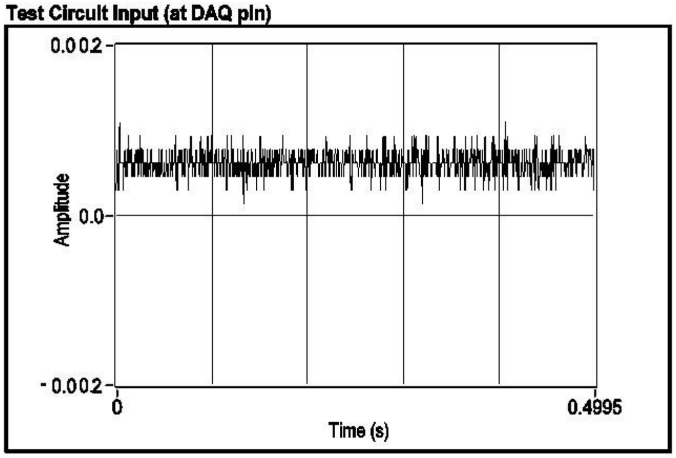


Fig. 5. Noise affected output of 1/1000 voltage divider

The distortion due to noise is clearly eminent on the output of the voltage divider. This variability and uncertainty in input makes it difficult for designing an automated test routine (as in the SEMG case).

In spite of this critical issue, the EEG performance of the circuit could still be approximated by analyzing its amplified and filtered output. In the wider “Active” orthosis project for which the sub-system is being designed, the use of quantitative EEG analysis is significant for detection of triggers and condition of the patient [21], [22], [23]. In most quantitative EEG applications, the frequency content of the signals is the most important parameter of interest. Hence, even if the EEG circuit could detect the main frequency contents of the test signal satisfactorily, there would be some degree of success achieved in the test procedure.

Fig. 5 shows that in spite of the high noise distortion in the input signal, the designed circuit is able to adequately reproduce the main frequency contents (20 Hz in this case) of the signal which lies in its pass-band (0.16 to 59 Hz). The power spectrum shows a sharp peak at 20 Hz indicating that noise in other frequencies is rejected by the EEG circuit. There are very small bumps at 40 Hz (as it is the harmonic content from the 20 Hz signal) and at 50 Hz (power line frequency). These results do indicate that the EEG circuit did perform it main function in a satisfactory manner.

Fig. 6 shows the amplified and filtered signal from the designed circuit operating in EEG mode, while fig. 7 shows the power spectrum of this signal. This is useful for detecting the frequency contents of the signal.

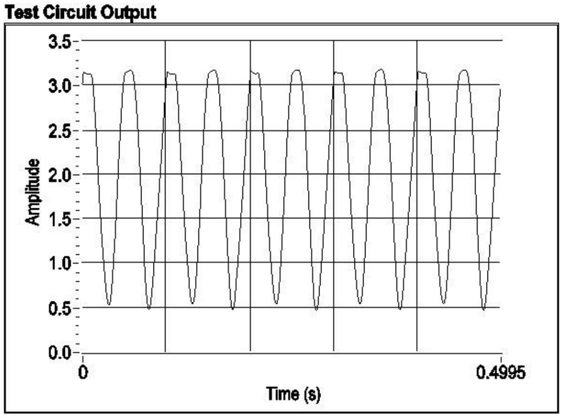


Fig. 6. Test Output from circuit operating in EEG Mode

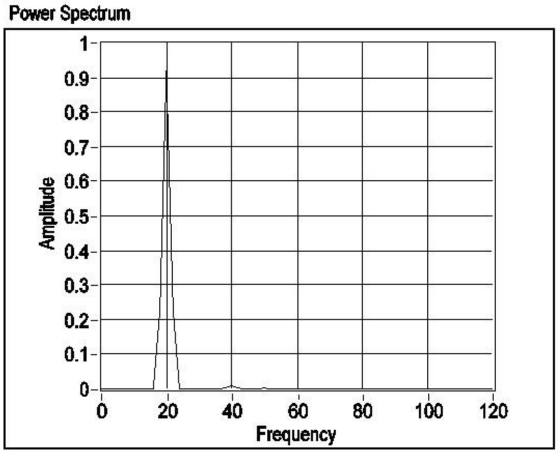


Fig. 7. Power spectrum of test output for circuit operating in EEG Mode

For the verification of the performance of the proposed prototype to conclusively prove the viability of making this low-cost system, it was decided to measure the SEMG response of 4 sets of left hand finger flexions on both systems and compare the results. The electrode positions for measuring finger flexion were carried out as suggested in [10]. These positions are shown in fig. 8.

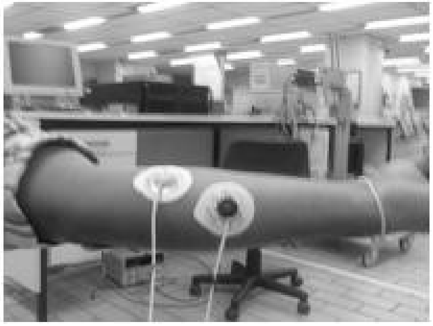


Fig. 8. SEMG Electrode positions for finger flexion

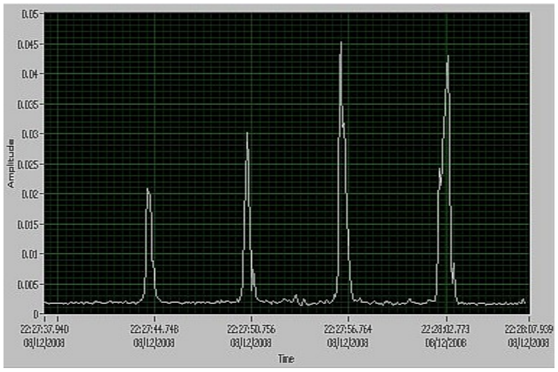
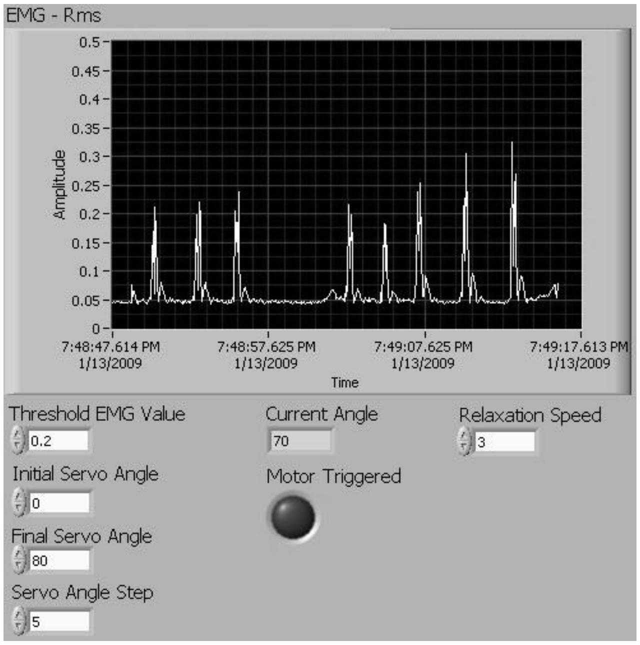


Fig. 9. SEMG (RMS) on the proposed system for 4 sets of left hand finger flexion

Fig. 9 shows the SEMG response measured by 9V battery operated version of the proposed prototype. LabView program was used for SEMG signal processing. It can be clearly seen from the above results that the proposed system can produce results which are stable and sensitive.

The motor can be programmed to rotate a certain degree after SEMG signal above threshold value is detected. This we call Active Mode rehabilitation, since the motor needs a trigger from SEMG signal before it rotates. The threshold varies depending on the subject and muscle group. The USB-6259 will trigger the motor whenever the average RMS value rises beyond specified threshold value.

Fig. 10 shows the Average RMS Value for the SEMG signal and settings for motor rotation. The angle through which the wrist joint moves can be easily set by the therapist. The speed with which the orthosis returns back to its original position can be adjusted, as well as the SEMG threshold value. Fig. 10 is the recommended front panel to be used by the therapist. A simpler 'patient version' will be developed in the future.



Threshold EMG Value: 0.2
Initial Servo Angle: 0
Final Servo Angle: 80
Servo Angle Step: 5
Current Angle: 70
Relaxation Speed: 3

Fig. 10. Front panel of LabView Program for Active Mode Rehabilitation

## IV. CONCLUSION

The world is facing an alarming number of major stroke occurrences. The bulk of this is occurring in developing countries and threatening to overwhelm the health resources of these low to middle-income nations [24]. The result is that there is a pressing need worldwide for robotic rehabilitation devices that fulfill clinical requirements. Such devices should be cheap, modular, versatile, compatible, as well as easy to set up and monitor.

The primary objectives of versatility, low-cost and portability for the 8-channel EEG-SEMG system were satisfied by the developed prototype. This is an important milestone towards effective home-based rehabilitation. Automated tests with LabView were used to verify the proper operation of the circuit in the intended frequency ranges. SEMG signals from five healthy persons have been measured, and it has been found that the performance of the system is stable and sensitive enough to detect even small isometric contractions.

This system can also be used in early therapy in acute phase of stroke, by using an arm glove with SEMG electrodes. Even when the patient is lying down, he can start therapy and the system described above will act as a bio-feedback platform to boost functional return of hand movement as well as patient morale.

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