High Quality Acquisition of Surface Electromyography – Conditioning Circuit Design

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Abstract: The acquisition of Surface Electromyography (SEMG) signals is used for many applications including the diagnosis of neuromuscular diseases, and prosthesis control. The diagnostic quality of the SEMG signal is highly dependent on the conditioning circuit of the SEMG acquisition system. This paper presents the design of an SEMG conditioning circuit that can guarantee to collect high quality signal with high SNR such that it is immune to environmental noise. The conditioning circuit consists of four stages; consisting of an instrumentation amplifier that is used with a gain of around 250; 4th order band pass filter in the 20-500Hz frequency range as the two initial stages. The third stage is an amplifier with adjustable gain using a variable resistance; the gain could be changed from 1000 to 50000. In the final stage the signal is translated to meet the input requirements of data acquisition device or the ADC. Acquisition of accurate signals allows it to be analyzed for extracting the required characteristic features for medical and clinical applications. According to the experimental results, the value of SNR for collected signal is 52.4 dB which is higher than the commercial system, the power spectrum density (PSD) graph is also presented and it shows that the filter has eliminated the noise below 20 Hz.

1. Introduction
The acquisition of SEMG signals during contractions is used for many applications including the diagnosis of neuromuscular diseases, prosthesis control as such signals could prove to be a diagnostic tool for estimating muscle fatigue or for evaluating patients with neuromuscular diseases, low backache, and disorders of motor control [1-5].

SEMG acquisition quality is influenced by different parameters including inter-electrode distance (IED), EMG electrodes position and electrodes configurations. The effect of variation such parameters is studied in [6-7]. Moreover, different methods of crosstalk quantification and reduction are discussed in [8] and suggestions for better electrode locations are presented in [9] to face up the cross talk issue.

SEMG signal quality can be represented by calculating signal to noise ratio (SNR), to increase the SNR, the measurement system must include special electronics for the signal filtering and processing. Surface EMG measurement system with high SNR is presented in [10], however, a notch filter used in the system can delete some useful components from EMG signals.

Some EMG measurement systems in previous mentioned works suffers from noise interference related issues either due to non-use of low pass filter or of sampling the signals with rate less than the needed, these probably the factors lead to reduce accuracy of the results. Further, using notch filters

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could not remove unwanted frequency components alone without washing some useful frequency component along side, once again at the cost of poor quality signals.

The SEMG signals have a very low amplitude and low frequency contents. The quality of such signals is highly dependent on the conditioning circuit design. This paper presents a design of SEMG conditioning circuit that can guarantee the high quality signal acquisition and immune the environmental noise. The SNR is calculated and compared to the other works, and the PSD graph for the SEMG signal is presented.

2. The SEMG measurement system
As shown in Fig. 1 the SEMG system consists of surface electrodes, leads, conditioning circuit, data acquisition device (DAD) and a computer.

![](image)

Figure 1: SEMG measurements system.

The electrodes attached to biceps muscle and connected to the conditioning circuit using the leads. In order to get the signal for analysis and storing we need to convert it to a digital form using DAD, then the signal can be transferred to the computer using USB connection.

3. The conditioning circuit
The goals of the signal conditioning are noise reduction, signal strengthening, removing unwanted signal component and signal translation fulfill the requirements of the next stage for further processing.

3.1 Amplifier:
A differential amplifier is used with bipolar SEMG electrodes. Since the signals have low amplitude a large gain is required. As shown in Fig.2, we choose the INA 2128 instrumentation amplifier due to its high CMRR at high gain, the CMRR of the INA2128 is about 120 dB which is sufficient for the design. Moreover, the effect of 50Hz power supply interference will be removed. This amplifier has a high input impedance to limit the attenuation from electrode-skin interference. Also, it shows that the high CMRR can improve the signal to noise ratio as in equation 1 as below:

\[
U = K(v_{e1} - v_{e2}) + \frac{K}{\text{CMRR}} v_{\text{common}} \quad (1)
\]

\[
R_G = \frac{50K}{G-1} \quad (2)
\]

To calculate the resistance for a certain gain, Equation 2 can be used, where G is the gain. For this stage of amplification a gain of 250 is sufficient, and the value of RG = 200 Ω.
The reference electrode used is mono-polar and this is to add stability during measurement of signals to correct these signals level. The body reference circuit used is taken from the INA129P instrumentation amplifier datasheet as suggested.

### 3.2 Band pass active filter (4-th order)

The band pass filter input is the output of the instrumentation amplifier. It’s used to eliminate the unwanted frequency component that is outside the typical SEMG signal frequency range 20-500Hz. High-pass filtering is used to remove movement artifacts and DC components (<10Hz). And low pass filtering is desirable to remove high frequency content above 500Hz to avoid signal aliasing, the filter structure is shown in fig.3.

To find high cut-off frequency $f_{c1}$ and $f_{c2}$ we assume that $R=1k$ and solving the equations 4, 5, 6 and 7 for $C1$, $C2$, $R1$ and $R2$. The frequency response for the filter is given in Equation 3, and the response shown in Fig. 4 by Pspice simulation.

$$H(s) = \frac{\frac{1}{R^2C_1C_2}}{\frac{1}{R^2C_1C_2} + \left(\frac{2}{RC_1}\right)s + s^2} + \frac{s^2}{\frac{1}{C^2R_2R_2} + \left(\frac{2}{CR_2}\right)s + s^2}$$

$$W_{c1} = \sqrt{\frac{1}{R^2C_1C_2}}$$
3.3 Gain adjustment and signal translation.
Since we have used a 250 gain for the instrumentation amplifier to avoid the saturation, a second stage of amplifier is needed to bring the voltage level up to meet the analogue to digital converter or data acquisition device requirement. The amplifier circuit is shown in fig. 5.
We use Equation 8 to calculate the gain, when we made changes of $R_4$ values from 0-50k the gain changed from 1 to 51 at this stage.

$$G = 1 + \frac{R_4}{R_1} \quad (8)$$

The output of gain adjustment will be ±10 V single ended. Interfacing this output to the ADC requires attenuation and a level shift, the circuit shown in figure converts the ±10 V single ended to +5V signal can connected to ADC in differential configuration for more noise rejection.

4. Experimental Procedures
The conditioning circuit is used to collect signals form biceps muscle, it is connected to the PicoLog 1012 device and the signal is recorded using PicoLog recorder software, the sampling rate used is 2 kHz. The duration for collected signal is 10s, during the 10s two isometric contractions is recorded. Signal-to-noise ratio is defined as the power ratio between a signal (meaningful information) and the background noise (unwanted signal):

$$SNR = \frac{P_{signal}}{P_{noise}} \quad (9)$$
Which could be written using amplitude ratios as:

\[ SNR_{\text{dB}} = 20 \log_{10} \left( \frac{A_{\text{signal}}}{A_{\text{noise}}} \right) \]  \hspace{1cm} (10)

5. Results and Discussion

The raw EMG data is imported to excel and the plots shown in fig. 7. While the PSD graph is shown in Fig. 8. The plots shows that the filter has successfully eliminate the signal components below 20Hz. These components mostly generated by cables movement or electrode displacement.

![Figure 7: Raw EMG signal during isometric contraction of biceps muscles.](image1)

![Figure 8: PSD for the collected SEMG signal.](image2)

The SNR ratio can be calculated using the amplitude relation as in equation 10. The SNR calculated for this study is 52.39 dB which is better than the SNR for commercial system (42dB) that is calculated according to results presented in [10], and it is still less than the SNR for the system proposed in the same paper (59dB). However, the system in [10] uses a notch filter which may lead to lose some useful frequency components.
6. Conclusion
The characteristics for the medical and clinical application can be obtained by acquisition of accurate signals. The design of an SEMG conditioning circuit presented in this paper guarantees the collection of high quality signal with high SNR that is immune to environmental aberrations. Experimental results show that the value of SNR for collected signal is 52.4 dB which is higher than the commercial system. The power spectrum density (PSD) graph is presented as well which shows that the filter has the capability to eliminate the noise below 20 Hz.

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