Design and Development of Low-Cost EMG Amplifier for Assistive Technology

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***Abstract*— The importance of EMG signal is very widespread in many areas of biomedical application due to its distinct output characteristics. However, the small amplitude and noise vulnerability nature of EMG signal necessitates amplification and filtering through properly designed electronic circuitry. So far, a suitable design of an EMG amplifier with an optimum signal-to-noise ratio (SNR), and biosafety feature is a challenging issue. Besides, the high cost of a medical grade bioelectric amplifier also limits the open source approach to clinical research and development. Our work delineates a simple, affordable, but efficient method to design an EMG amplifier with a clinical safety feature of optical isolation compared to other standard bio amplifiers. In addition, the research also focuses on the development of an efficient signal processing algorithm for the post processing of the bio-signals which can be easily implemented into any embedded system dedicated for human-computer interaction.**

Keywords—EMG; bioelectric amplifier; assistive technology

I. INTRODUCTION

Electromyography (EMG) is a clinical technique to record and evaluate the electrical activities of skeletal muscle fibers [1]. The signal is recorded as electromyograph through measuring electric potential of skeletal muscles by placing surface electrodes in the skin or by inserting needle electrodes into the specific muscle's cell [2]. The axons of the motor neurons extend to the muscle fibers. During voluntary movement, the membrane potential of the cell goes above resting membrane potential (-70 mV) which generates action potential that propagates through particular motor nerve fiber. After that, the propagating electrical impulses resulting from ionic reaction in the motor neurons cause sensation to the associated muscle fiber. [3]

EMG signal has two main applications. Firstly, it is used by the clinicians for the diagnostic purposes like evaluating voluntary movement and muscle functionality. On the other hand, engineers use it for prosthetic purposes. For example, various assistive technologies like prosthetic hand and upper limb exoskeleton exploit the EMG signal for artificial physical maneuver. [4] [5]

Like other biosignals, EMG signal usually has low amplitudes and it is distorted by various noise sources mainly power line interference, contact impedance, and movement artifacts. Hence, the signal should be properly amplified, and conditioned using amplifier, and filters. Amplifiers are used to gather and increase the signal integrity of electrical activity for output. And filters are used to minimize the distortion of the signal with improved SNR. Ideally, an EMG amplifier should display relatively smooth signals and its amplitude should interpret the level of EMG signal present. While all of these features are already available in numerous electromyography technologies, however, they are still limited in terms of open-source design, cost, and efficiency. To address this issue, we have designed and developed a low-cost EMG amplifier that does not only have all these ideal features but also ensures medical grade safety feature like optical isolation and improved CMRR (80 dB) that is required for an ideal bioelectric amplifier.

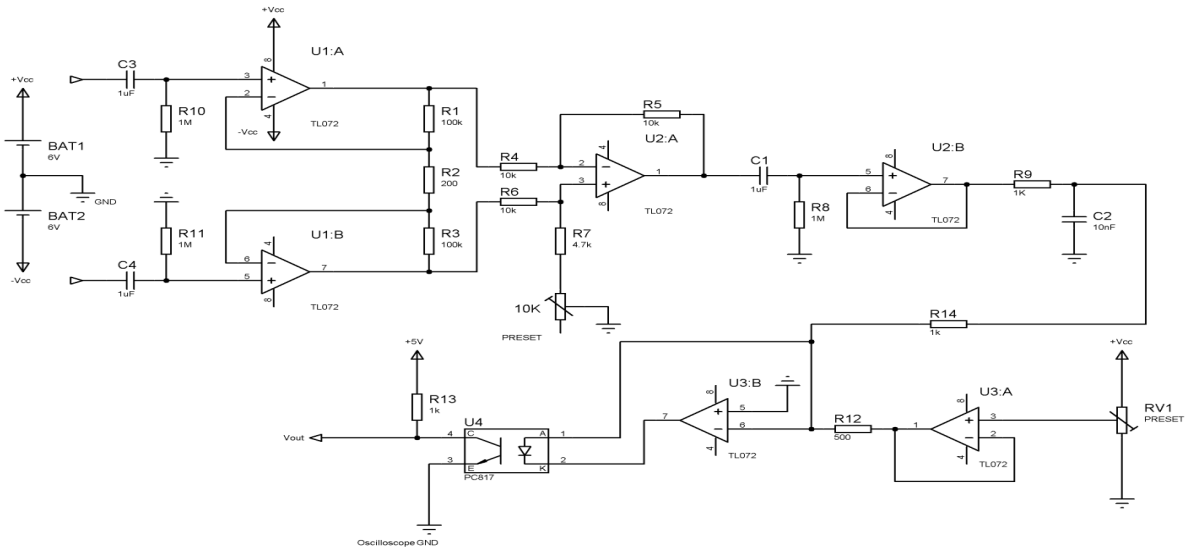

Fig. 1: Schematic diagram of the EMG amplifier circuit with the band-pass filter, and the optical isolation circuit

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II. Design and Circuit Analysis of the EMG Amplifier

In Fig. 1, the EMG amplifier circuit consists of an instrument amplifier with a gain of 1000 at the input section, a band pass filter with a cut-off frequency of 0.16 Hz to 16 KHz (typically, EMG signal ranges from 10 Hz to 5 kHz), and an optocoupler circuit with a quiescent point of 2.5 volt at the final output section of the whole assembly. The optocoupler circuit isolates the signal conditioning circuit from the output circuit in order to ensure the bio-safety issues of the subject. The instrumentation amplifier is electrically tuned to have a low common mode gain by varying the 10K trimmer at the amplifier circuit. There are two passive RC high pass filters with a cut-off frequency of 0.16 Hz at the inputs of the instrument amplifier to remove any kind of dc component from the bio signals. The band pass filter following the instrumentation amplifier is active in nature and consists of R-C networks, and a buffer to prevent the distortion of the conditioned signal after the high pass stage. Finally, the output signal from the band pass filter is fed with a current limiting resistor of 1K at the optocoupler circuit.

A. Design and Performance Analysis of Instrumentation Amplifier

The instrumentation amplifier consists of three operational amplifiers. It has two inputs $V_1$and V_2, and single output V_{out}; all referenced to ground or common (0 V). The amplifier has two stages. The 1st stage has a differential input and also has a differential output (double ended input and double ended output) while the 2nd stage has a differential input and single ended output.

Conventionally, for bioelectric amplifier, the two op-amps of the 1st stage should have exactly the same characteristics e.g. same input impedances. Therefore, these should be the part of same IC package (made on a single semiconductor chip). For maximum voltage transfer from the source to the amplifier, the input impedance of the amplifier should be large compared to the electrode impedance. For surface electrodes, the electrode impedance would be of the order of 10KΩ at low frequencies. Therefore, the input impedance of the op-amp should be about 100 times larger, i.e., about 1 MΩ. This can be achieved using op-amps with either BJT or FET at the inputs. However, for EMG equipment, provision for needle electrodes with much larger source impedance should be there, and therefore the use of FET input op-amps are necessary.

For bioelectric amplifier, CMRR should be large as possible. For an EMG amplifier, it should be greater than 60dB. In the 2nd stage of the amplifier, two ratio, R5/R4 and R7/R6, associated with the two inputs of the differential amplifier are assumed to be equal. This is essential to get a high value of CMRR. However, in practice it is almost impossible to have two exactly equal fixed resistors. This condition is achieved manually by introducing a 10K trimmer pot in series with R7 resistor. The advantage of the resistors is that their properties are slightly altered with change in temperature which can be negligible. On the other hand, the properties of the semiconductor devices vary with temperature and manufacturer. So the overall gain of the amplifier should depend largely on the resistors. This is achieved through negative feedback.

During performance study, the input voltage is kept low for differential configuration and is kept high for common mode reading. The input sensitivity of the oscilloscope is adjusted in a manner to have a better reading of the output.

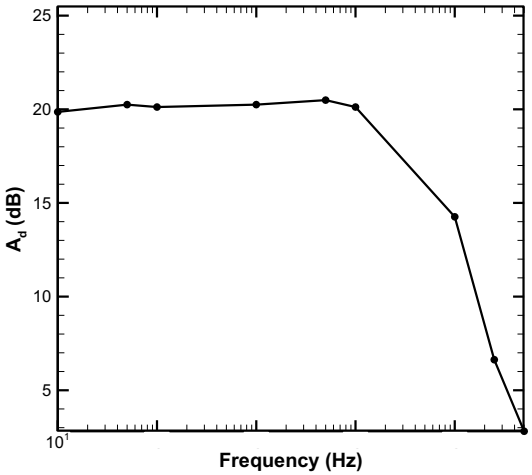

Fig. 2: Differential gain vs. Frequency

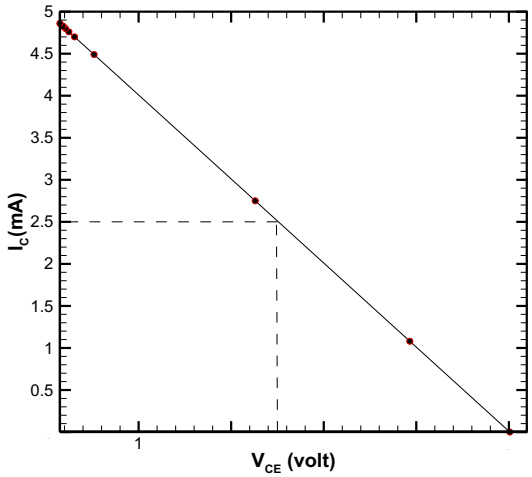

Fig. 4: I_C vs V_{CE} for R_C=1 K ohm

From Fig. 2 and Fig. 3, it can be observed that the differential gain (during tuning the instrumentation part, the differential gain is kept low such as 20 dB, however, for bio signal amplification and improved SNR, the gain is changed to 1000 after electrical tuning), and common mode rejection ratio drop sharply from a certain high frequency. An ideal operational amplifier has an infinite frequency response and can amplify any frequency signal from DC to the highest AC frequencies so it is therefore assumed to have an infinite bandwidth. With real op-amps, the bandwidth is limited by the Gain-Bandwidth product (GB), which is equal to the frequency where the amplifiers gain becomes unity. The op amp gain bandwidth product is constant for voltage feedback amplifiers.

$$\text{GBP} = A_v \times f_{\text{roll-off}} \quad (1)$$

At low frequency, the gain almost remained constant but with the logarithmic increment of the frequency of the input signal, the gain tends to decrease to unity in order to maintain the constant gain bandwidth product. This GBP

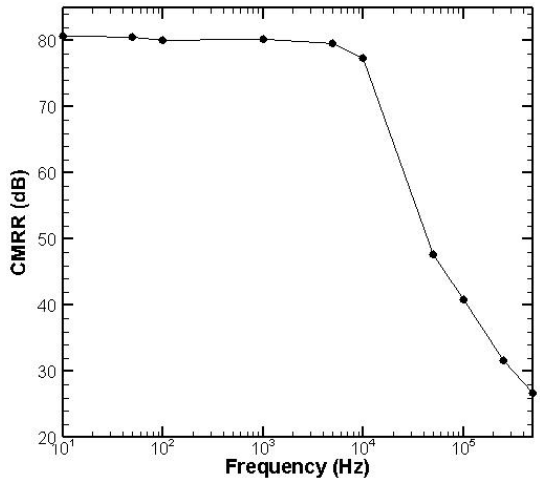

Fig. 3: CMRR vs. Frequency

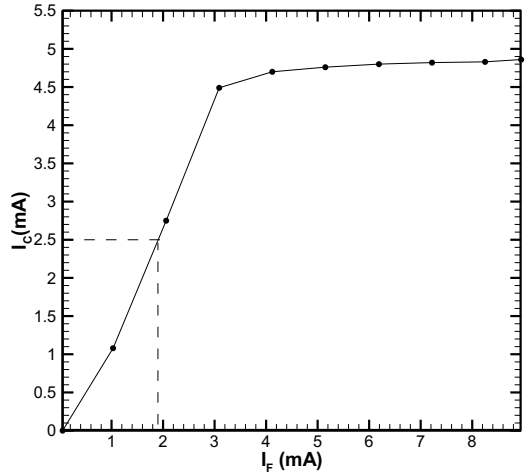

Fig. 5: I_C vs I_F for R_C=1 K ohm

constraint enables op-amp to be stable at high frequency

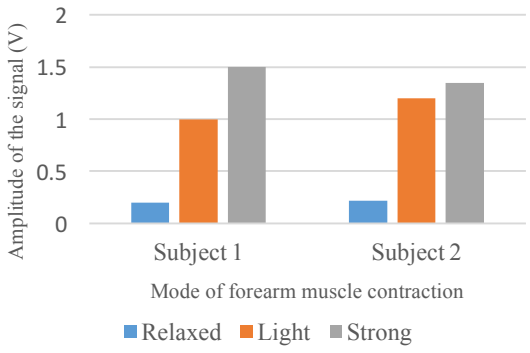

Fig. 6 EMG Signal Amplitude of Different Subjects

response.

B. Design and Performance Analysis of Optical Isolation Circuit

Optocoupler interconnects two electrical circuits by means of an optical interface. The basic design of an optocoupler consists of an IR led that emits infrared light and a photosensitive semiconductor to detect the incident infra-red rays.

In Fig. 1, the optical isolation circuit simply consists of two J-FET op-amps (U3) and an optocoupler. The first stage op-amp is a simple voltage follower and the second stage op-amp is a voltage to current follower to drive the LED of the optocoupler. The value of the RV1 is chosen to 10K to limit the current. This preset resistor is used as a voltage divider to vary the input voltage. The R12 is chosen to 500 ohm, and the current IC is measured at the output of the optocoupler for R13=1K.

In the design, we have set the Q point to 2.5 volt for R13= 1K. For bio signal amplifier, choice of appropriate Q-point is important because the complete acquisition of the entire bio signal depends extensively on it.

To limit the collector current for the optocoupler receiving unit we have chosen the R13 value of 1K. This choice of resistor can be determined from the I_C vs V_{CE} graph (Fig. 4) and I_C vs I_F graph (Fig. 5). From the graph, the value of $I_{C,Q}$ = 2.5 mA and $I_{F,Q}$ = 2 mA which are optimum for our designed circuit.

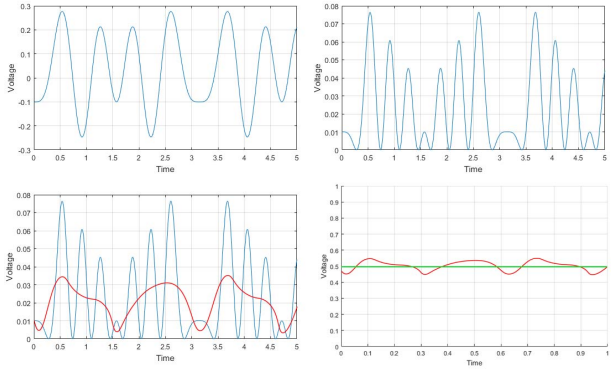

Fig. 7: Graphical illustration of the proposed signal processing algorithm for the post processing of the raw EMG signals.

III. RESULT

The EMG signals are recorded for three different voluntary movements of the subject's forearm muscles. From Fig. 8 and Fig. 6, the recorded signals reveal that the strong contraction provides the highest peak to peak amplitude. This means, the amplitude of the signal is proportional to the degree of muscle contraction irrespective of the subjects. However, the study also indicates that the pattern of the EMG signal is subjective depending on the biological condition of the nerve and muscle fiber of the

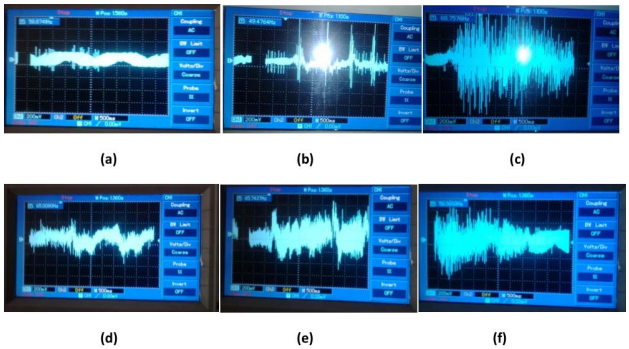

Fig. 8: EMG signals for (a) Relaxed (b) Moderate (c) Heavy contraction of subject 1 and EMG signals for (d) Relaxed (e) Moderate (f) Heavy contraction of subject 2

individuals.

For prosthetic purpose, the EMG signal has to be post processed for the digital control of the manipulator or, actuator of the assistive devices. In the current research, we have adapted the following signal processing algorithm (Fig. 9) to establish a threshold value for the moderate voluntary contraction of the forearm's muscle.

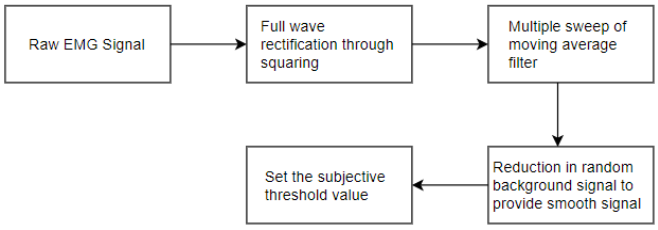

Fig. 9: Workflow of the proposed signal processing algorithm.

Fig.7 delineates the probable effect of above signal processing algorithm on a raw EMG signal.

IV. Conclusion

In summary, the work has demonstrated a simple and effective methodical approach to design and development of a low-cost EMG amplifier for assistive technology. Currently, the device has been tested on two subjects, and the results are significant enough to detect the mode of contraction of the forearm's muscle. It is likely that the post processing of the raw EMG signal can be further harnessed for controlling the prosthetic devices using minimum digital circuitry. Ultimately this work has the potential to produce a functional bioelectric amplifier that could be further exploited to study and manipulate other biosignals for clinical purpose.

Acknowledgment

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