Multipurpose Low Cost Bio-Daq System for Real Time Biomedical Applications

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***Abstract*—Bio-electric signals are all kinds of electrical signals that can be measured and monitored from biological beings. These signals are of low frequency and very low voltage and are often contaminated with surrounding noise. Hence the bio-electric signal acquisition system should provide very high input impedance, very high Common Mode Rejection ratio (CMRR), high voltage gain and high selectivity. To achieve these specifications, bio-electric acquisition systems are commonly designed using precision components. Use of precision components makes the design very expensive and occasionally availability constraints of these components in the local market, makes the design more difficult. The main objective of this work is to develop a compact and cost effective bio-electric signal acquisition system for real time biomedical applications. The proposed design employs general purpose electronic components which are commonly available in any electrical lab that makes the cost of prototype around $160. The system mainly consists of Op-Amp based bio-amplifier, data acquisition board and a laptop. Design examples are in the form of Electro Cardio Gram (ECG), Electro Myogram (EMG), Electroculogram (EOG) and Electro Encephalogram (EEG) acquisitions.**

Keywords— Acquisition; Bio-electric signal; CMRR; Op-amp; MATLAB; Notch filter;

I. INTRODUCTION

All animal tissues, such as muscles, nerves and bones are made up of individual cells. These cells consist of cell membrane that separates the intracellular fluid from extra cellular fluid. The cellular fluids are mostly water with various molecules, atoms and ions suspended. For an excitable cell (e.g. nerve cell, muscle cell) the cell membrane is selectively permeable to ions and organic molecules thereby controlling the movement of substances in and out of cells. When these cells are at resting state, equilibrium ionic concentration between intra cellular and extracellular fluids maintain a fixed potential across the membrane called resting potential [1], whose amplitude in the range of -60mV to -90 mV. When these cells are excited, cell membrane changes its ionic permeability and hence a transient potential called action potential is generated (Amplitude in the ranges of +20 mV to +40 mV). These bioelectric potentials are specific to a particular organ and have unique characteristics that provide vital information of its function.

Table 1 describes the origin of various bio-signals and their electrical characteristics [1] [2]. Common bio-electric signals are Electrocardiogram (ECG), Electromyogram (EMG), Electroencephalogram (EEG) and Electrooculogram (EOG).

TABLE I. BIO-ELECTRIC SIGNALS AND ITS CHARACTERISTICS

Bio–Electric signals and its origin	Amplitude	Frequency
ECG, Heart muscles	1 to 5 mV	0.05 – 100 Hz
EEG, Brain	0.001 to 0.01 mV	0.5 – 40 Hz
EMG, Muscles	1 to 10 mV	10 to 2000 Hz
EOG, Eye ball movement.	0.01 to 0.1 mV	DC to 10 Hz

II. ANATOMY OF BIO-ELECTRIC SIGNAL ACQUISITION SYSTEM

Figure 1 illustrates main sections of the bio-electric signal acquisition system [2]. It mainly consists of two modules; the bio-amplifier and the Data Acquisition (DAQ) board. The bio-amplifier is composed of the Instrumentation Amplifier (IA), the active Band pass filter (BPF), the active Notch filter (NF) and the output amplifier, which are explained in detail below.

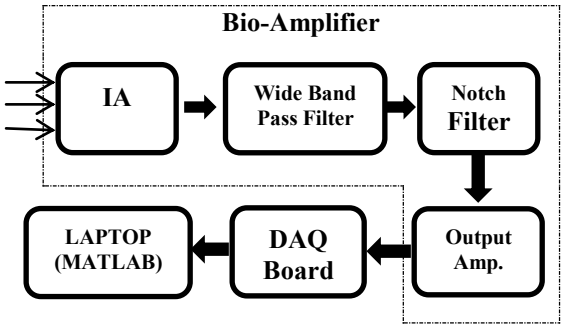


Fig. 1. Structure of Bio-electric signal Acquisition systems

A. Instrumentation Amplifier

IA acts as a differential amplifier [2] [3], which has the capability to amplify the difference of its input signals while attenuate the noise common to both input signals, thereby offering high common mode rejection ratio (CMRR).

IA can be built either by using general purpose operational amplifier (Op-amp) or by using precision built instrumentation amplifier (e.g. INA 121, AD 620). Op-amp TL072 (dual Op-

amp) have been used in our design because of its low cost, availability and relatively good frequency response.

Fig. 3 shows the circuit diagram of IA [2] [3] using three Op-amps A, B, C and seven resistors R1 to R4. U1 and U2 are the input terminals and U3 is the output terminal. Op-amps A and B used inverting amplifiers and Op-amp C is used as differential amplifier. 9V dual power supply have been used as the voltage source. Overall gain of IA is calculated by using (1).

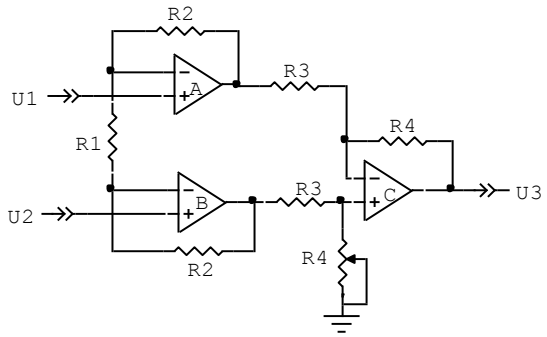


Fig. 2. Instrumentation Amplifier

$$(1+ (2R2/R1))* (R4/R3) \quad (1)$$

Overall gain of the IA can be adjusted by changing the value of the resistor R1. Considering the op-amp's gain – bandwidth constraint, overall gain of this stage was set to 250. The resistors used are R1 10K, R2 120K, R3 10K and R4 100K. Output of this stage (U3) is connected to the input terminal of the BPF.

B. Band Pass Filter (BPF)

This part consists of a cascade of two Sallen-Key [3] second order filter circuits shown in the fig. 3. First circuit is the high pass filter (HPF) with a cut off frequency (f_L) of 0.04 Hz, having a pass band gain (A_L) of 2 and provides roll-off of +40 dB/decade and the second circuit is the low pass filter (LPF) with a cut off frequency (f_U) of 500 Hz having a pass band gain (A_H) of 2, provides a roll off of -40dB/decade. Terminal U4 is the input and terminal U5 is the output. The Op-amps D and E wired as non- inverting amplifier. The bandwidth thus obtained (0.04 to 500 Hz) covers frequency ranges of most of the bio-electric signals (Refer Table I).

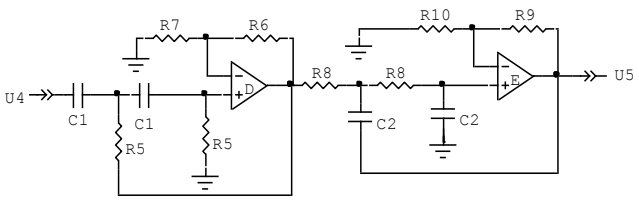


Fig. 3. Sallen-Key second order BPF

Capacitor 1 micro Farad (electrolytic) used as C1 and 0.1 micro Farad (ceramic disc) used as C2. Unknown resistors are calculated by using (2)-(5).

$$f_L = 1/(2*pi*R5*C1) \quad (2)$$

$$f_U = 1/(2*pi*R8*C2) \quad (3)$$

$$A_L = 1 + (R6/R5) \quad (4)$$

$$A_U = 1+ (R9/R10) \quad (5)$$

Resistors used for the BPF are R5 as 3.3 M, R6 and R7 as 10K, R8 as 3.6K, R9 and R10 as 10K. Output of this stage (U7) is connected to the notch filter.

Recording of bio-electric signals is normally done in an environment that is equipped with many electrical systems which produce strong electrical and magnetic fields [2]. These fields induce potential interference to the acquired bioelectric signal. Notch filter [4] is a band-reject filter with high Q factor that passes most frequencies unaltered, but attenuates 50 Hz power line noise to very low levels.

A unity gain notch filter based on twin T network [3] using capacitors (C3, C4) and resistors (R11, R12) as shown in the Fig. 4. Terminal U6 is the input and U7 is the output. Op-amps F and G are used as buffers and variable resistor R13 is used to adjust the notch depth. Equations (6) to (8) used to determine resistors R11 and R12.

$$C3 = C4 = C5/2 \quad (6)$$

$$R11 = 2 * R12 \quad (7)$$

$$f_N = 1/(2*pi*C3*R11) \quad (8)$$

Capacitor 270 pF (ceramic disc) used as C3 and 540 pF (parallel combination of two 270 pF capacitors) used as C4. Resistors used are R11 as 12M, R12 as 6M and R13 as 100K (variable).

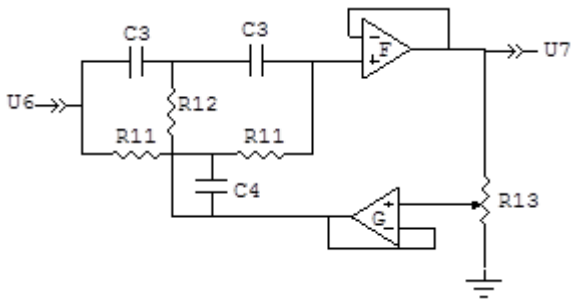


Fig. 4. Sallen-Key second order BPF

Notch filter not only restricts the 50 Hz signal but also attenuates neighbouring frequency components. Therefore the output of the notch filter should be amplified to the desired voltage. Output of the notch filter (U7) is amplifed by the output amplifier.

C. Output Amplifier

It is a non-inverting amplifier [3] with max gain of 101. As in Fig 5, the terminal U8 acts the input and the terminal U9 acts as the output. The resistors R15 (100K) and R16 (1K) are used to set the gain 101. The input voltage to this circuit is controlled by the variable resistor R14 (100K) that adjust the output voltage. Output of this stage (U9) is fed to the DAQ board for digitization and computer interfacing.

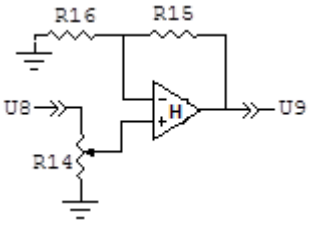


Fig. 5. Output Amplifier

D. DAQ BOARD

We have used NI-USB-6008 [4] as the DAQ board, which is USB powered, low cost, mini data acquisition card with 8 analog input and 2 analog outputs. This device is compatible with MATLAB software. A MATLAB program is used to acquire real time bio-electric signals from the human body. This program includes DC offset correction and band pass filter for the processing of the acquired data. Algorithm for the above program is described in the Fig. 6.

First pin of the analog port of the DAQ board was configured as the input channel and set the time of acquisition as desired. DC offset correction of the acquired signal is done by eliminating first term of the Fast Fourier Transform (FFT) [5]. Digital filter is implemented to realize butter-worth second order BPF [8]. The filter coefficients of the BPF [5] are determined from bandwidth of the desired bio-electric signal.

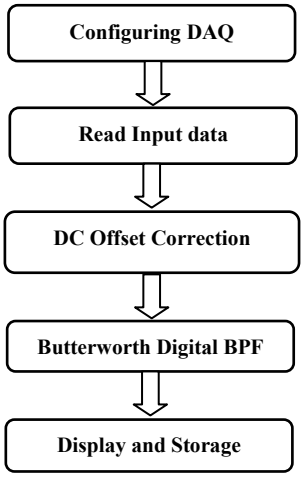


Fig. 6. Algorithm for the digital filter

III. RESULTS AND DISCUSSION

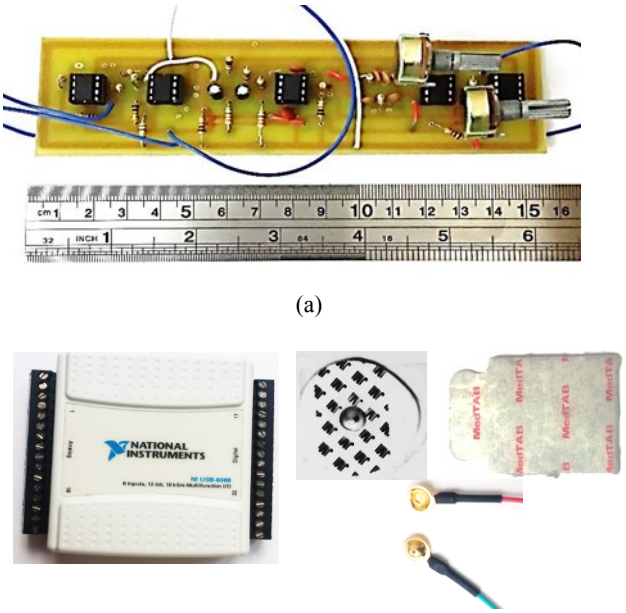
The proposed bio-amplifier was implemented on printed circuit board and interfaced to the laptop using NI DAQ board (PCB). A MATLAB program was designed to display and monitor the acquired data. Performance tests were carried out to monitor ECG, EMG, EOG and EEG signals.

Table II lists the electronic components used and cost of the proposed system. Cost of the bio-amplifier circuit was around USD 12 and total cost including the DAQ board was USD 160. This cost was significantly lower than that of the commercially available bio-electric signal acquisition system.

TABLE II. BIO-ELECTRIC SIGNALS AND ITS CHARACTERISTICS

Components & Description	Quantity	Unit Cost in USD	Total Cost in USD
Resistors - 0.5 Watts, Tolerance +/-5%	19	0.1	1.9
Capacitor – 0.1 micro Farad (Ceramic)	6	0.28	1.68
Capacitor – 1 micro Farad (Electrolytic)	2	0.3	0.6
IC Socket – 8 pin Plastic	5	0.02	0.1
Dual Op-amp TL 072	5	0.4	2
Bread board	1	5	5
Flexible wire	1	0.1	0.1
Cost of Bio-amplifier board			11.38
NI – USB 6008 DAQ board	1	149	149
Total Cost			160.38

Fig. 7 (a)-(c) displays the prototype of the proposed bio-amplifier and associated components. Fig. 7 (a) shows bio-amplifier on PCB, Fig. 7 (b) shows the NI-DAQ-6008 DAQ board and Fig. 7 (c) shows various electrodes used for testing.



(a) (b) (c)

Fig. 7. (a) –(c) Prototype of the proposed system and associated components

Disposable Ag-Ag Cl electrodes [1] were used for the ECG acquisition. Flexible Ag-Ag Cl electrodes [1] were used for EMG and EOG recording and gold plated metallic cup type electrodes [2] were used for EEG recording. Following section describes various tests procedures and the corresponding test results.

A. ECG Acquisition

Standard limb leads systems [1] were used for the ECG measurement. Four disposable Ag- Ag Cl electrodes were

placed in the four limbs; right arm (RA), left arm (LA), right leg (RL) and left leg (LL) as shown in the Fig. 8 (a). For lead I ECG, LA and RA to be connected U1 and U2 terminals of the IA. For lead II ECG, LL and RA to be connected, and for lead III ECG, LL and LA to be connected to the IA. RL must be grounded in the above three cases. Fig. 9 shows the acquired ECG (Lead II) signal.

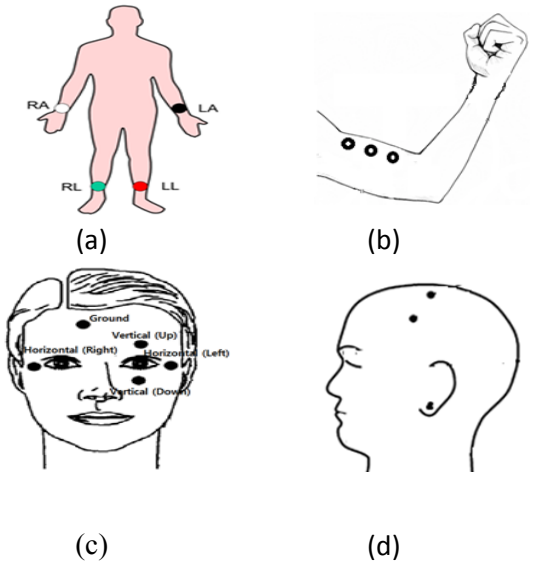


Fig. 8.(a)- (d) Placement of Electrodes

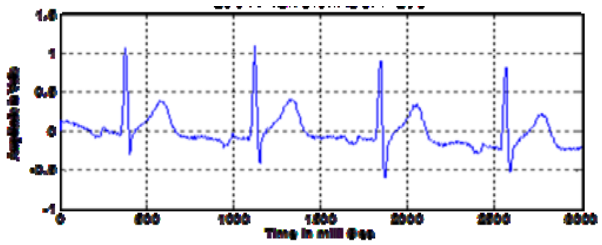


Fig. 9 Recorded ECG (Lead II) Signal

B. EMG Acquisition

Three flexible Ag-Ag Cl electrodes were attached to the biceps as shown in the Fig. 8 (b) to acquire the EMG signal. Upper and lower electrodes were attached to U1 and U2 pins of the IA and middle electrode was grounded. EMG was recorded by contracting and relaxing the muscles [1], [2]. Digitally filtered EMG signals were displayed and recorded in the laptop (Refer Fig. 10).

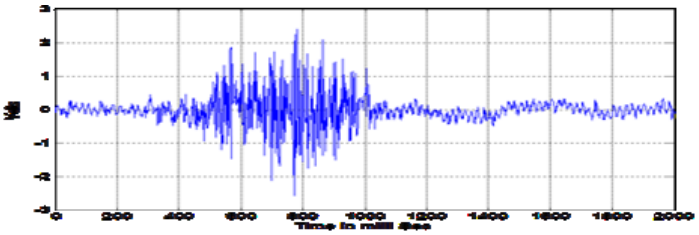


Fig. 10 Acquired EMG Signal

C. EOG Acquisition

Three flexible electrodes were placed above and below the eyes [2], [3] as indicated in the Fig. 8 (c). EOG signals were recorded by rotating the eyes in horizontal and vertical directions repeatedly. Figure 11 shows the EOG when the eyes were moving in the horizontal direction. First and third peak indicates the left to right movement of the eyes and the second peak indicates right to left movement of the eyes.

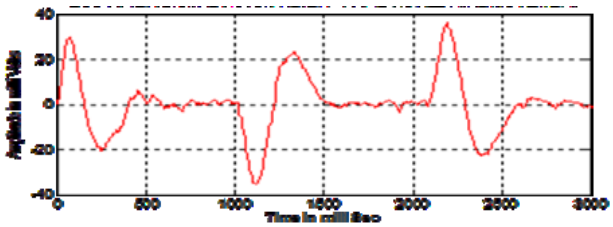


Fig. 11 Recorded EOG Signal

D. EEG Acquisition

Three metallic cup electrodes were attached the scalp using adhesive gel as shown in the Fig. 8 (d). Two electrodes attached to the scalp were connected to U1 and U2 terminals of IA and the electrode attached to ear (left or right) was grounded. EEG (beta wave) was acquired and recorded in the laptop. Fig. 12 displays recorded EEG signal.

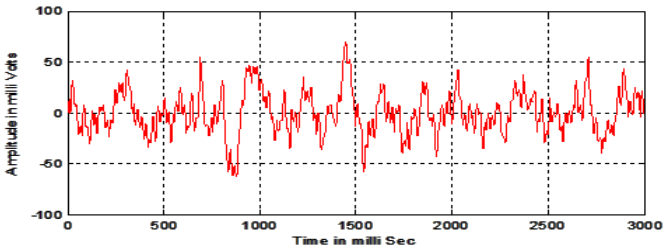


Fig. 12 Recorded EEG Signal

VI. Conclusion

The bio-electric signal acquisition system described in this paper was successfully developed. Performance tests have been carried out to acquire real time bio-electric signals from the human body. The morphology of the acquired bio-electric signals claims the efficiency of the developed system. This system can be effectively used to record bio-electric signals within the range of 0.05 Hz to 500 Hz. To provide additional safety to the patient, optical isolator may be used. SNR of the EEG signal can be improved by proper skin preparation, correct placement of electrodes and providing adequate shielding to the bio-amplifier.

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