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Development of a Modular Biopotential Amplifier Trainer for Biomedical Instrumentation Laboratory Experiments

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Abstract: This paper presents the design, development and implementation of a reconfigurable low-cost biopotential amplifier trainer module (RTR module) and quantitative analysis of the students' compatibility with the trainer module. The trainer module can measure Electrocardiogram (ECG), Electroencephalogram (EEG) and Electromyogram (EMG) biopotential signals by reconfiguring the module using the basic circuit and filtering blocks. Given hand on experience, the module is designed and implemented in such reconfigurable manner that the students can avoid, disconnect and add any filtering blocks to understand the effect of these filters to the biopotential signals. The laboratory experience is an important component of the learning process. The RTR module is a low cost and compact educational tool. With this RTR module, the students should be able to recognize the biopotential signals and the acquisition methods in an intuitive and easy way, allowing them to improve their skills of designing biomedical instrumentation.

Keywords: Biopotential, Electrocardiogram, Biomedical Instrumentation

1. Introduction

All manuscripts must be in English. These guidelines include in medical electronics and bio-signal engineering biopotential is an unavoidable factor. Biopotentials are electric potentials that is measured in living cells, tissues and organisms, which accompanies biochemical process [1]. There are different types of biopotentials in different parts of human body which are responsible for cardiac function, brain function, muscle movement, eye movement, sensory function and many other events in the body. Different biopotentials are ECG, EEG, EMG, EOG, AAP etc. Among all other biopotentials Electrocardiogram (ECG), Electroencephalogram (EEG) and Electromyogram (EMG) are the most important as they are representing cardiac activity, neural activity of brain and muscle construction respectively. Depending on their physiological nature, different biopotential signals have distinct amplitude and frequency characteristics. The distribution of this commonly used biopotential signals span more than four decades both in amplitude, from 1μV to 10 mV, and in frequency, from 1 Hz to 10 kHz. [2].

These biopotential signals contaminated with various noise such as ambient noise, motion artifacts and inherent instability of signal [3, 4]. The amplification of biopotential signals and these noises can be eliminated through different design or filtering techniques such as instrumentation amplifier, right leg driven circuit, high pass filter, low pass filter and notch filter.

In engineering and technical education, the laboratorial experiment is an important component of the learning process. The proposed universal modular biopotential amplifier trainer named RTR module is developed with a view to develop the students learning enhancement and clearing their knowledge about biopotential signals and their acquiring instrumentation. Reconfigurable design of the RTR module given the students freedom to add or avoid different filtering and basic circuit blocks during measurement of the biopotential signals, and to realize their effects practically.

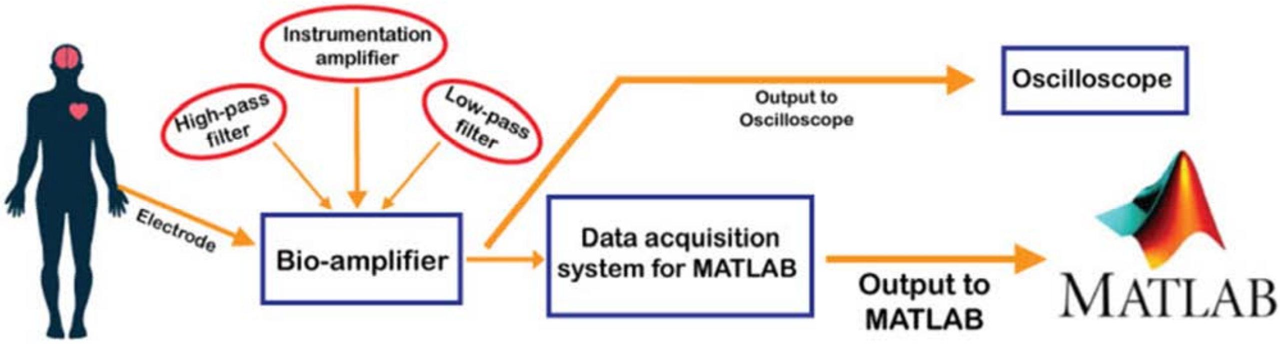


Figure 1. *Methodology for achieving goal of the proposed RTR MODULE.*

Comparatively biomedical educational devices are very costly. The proposed RTR module is a cost-effective alternative for the students and reconfigurable design of the RTR module leads them to the improvement of their skills, providing hand-on and work-based designing abilities of biomedical instrumentation.

2. RTR Module

2.1. Method and Functional Blocks

The main challenge of Acquiring biopotential signals is, biopotential signals are usually in millivolts or less in amplitude and have specific frequency ranges for different [2]. Amplitude of voltage and frequency of the ECG, EEG and EMG shown in Table 1. Measurement of biopotential signals may use amplifier which can deal with voltages at low level or high source impedances. Moreover, it is also important to reject the field coupling from the power line and to reject noise from the electric system and environment.

The proposed RTR module is capable of measuring the ECG, EEG and EMG signals. RTR module is developed following the Bipolar 3 lead configuration [2]. Three electrodes are used, including two measurement electrodes (Ea and Eb) and a reference electrode (Eref). Passive AgCl patch electrodes are used.

Amplifiers with different gains and different filtering blocks are required as these biopotentials signals are different in both voltage and frequency ranges shown in Table 1.

Table 1. *Amplitude and Frequencies of biopotential signals.*

Source	Amplitude	Frequency
ECG	0.5mV - 1mV	0.2Hz – 50Hz
EEG	100μV - 2mV	3Hz – 50Hz
EMG	100μV - 90mV	5Hz – 150Hz

RTR Module is developed and implemented with reconfigurable design. RTR module consists Instrumentation amplifiers with different gains, right leg driven circuit, high pass filters, low pass filters, filters of higher orders, and notch filters. Acquiring the different biopotential signals different instrumentation amplifiers can be used with different gains. Reconfiguring design of the RTR module allows the student to select suitable high and low pass filters blocks as well as the higher order filters according to their required ranges. Each and every fundamental circuits and filtering blocks have separate input and output pins. Using this input-output pins student can add or remove any circuit/ filter blocks and realize it's effect.

Figure 2, Figure 3 and Figure 4 representing the configuration of the RTR module functional block diagrams for the measurement of ECG, EEG and EMG signals respectively

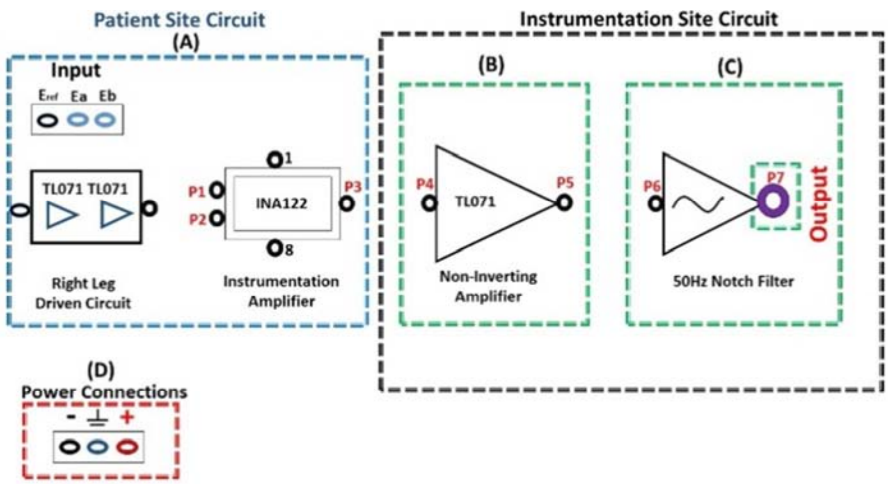


Figure 2. *Functional block diagram of ECG measurement configuration.*

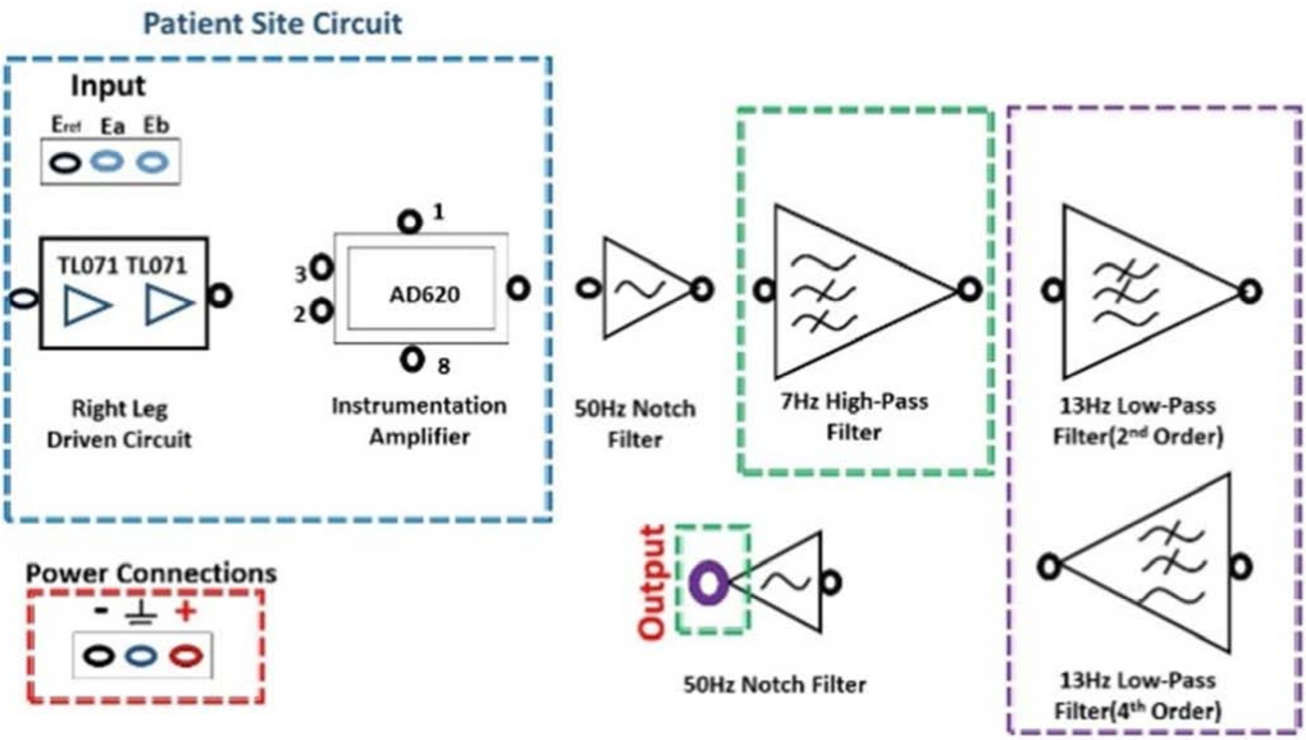


Figure 3. *Functional block diagram of EEG measurement configuration.*

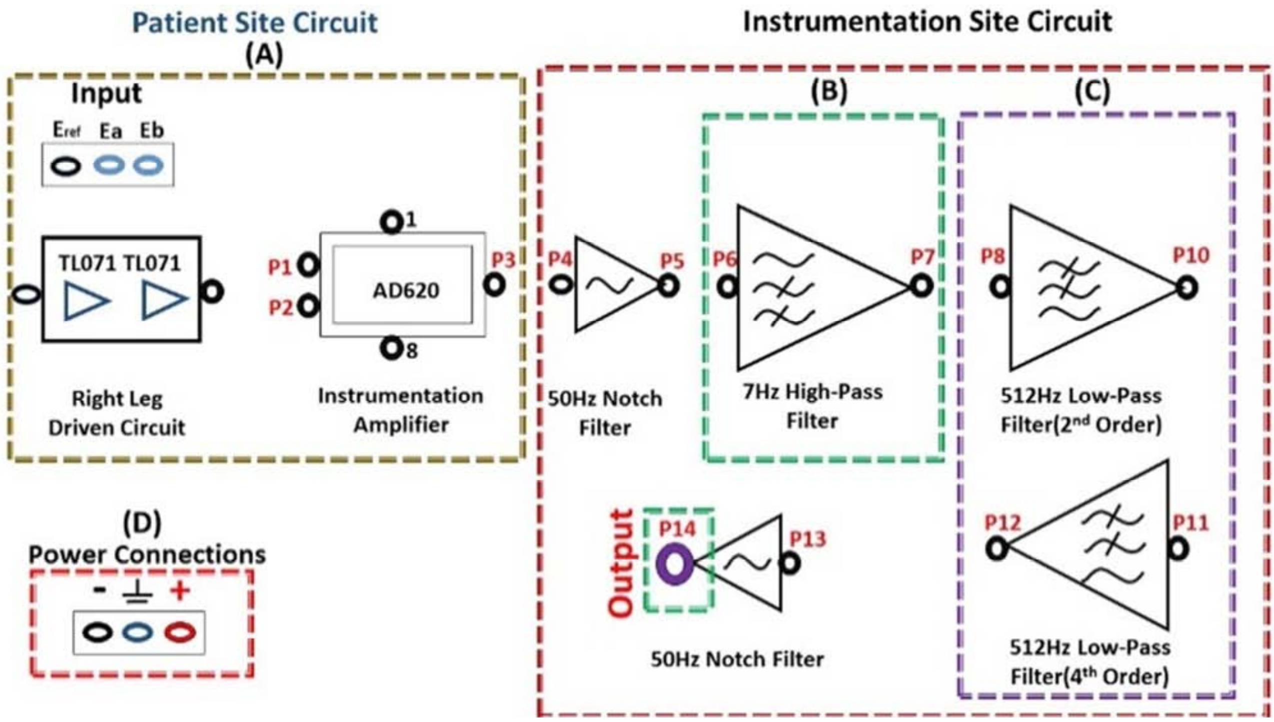


Figure 4. *Functional block diagram of EMG measurement configuration.*

By flexibly connecting the pin connections shown in the Figure 2, Figure 3 and Figure 4 the RTR Module can be configured to measure the ECG, EEG and EMG signals respectively. Besides this configuration the student can add additional filtering blocks and can remove the blocks from the configuration to understand its effect.

2.2. Equations

The RTR module composed of several fundamental circuit blocks that are generally used in biopotential amplifiers, including three instrumentation amplifiers with different gains, right leg driven circuit, notch filter, 7Hz high pass filter, 13Hz low pass filter (2nd and 4th order) and 512Hz low pass filter (2nd and 4th order).

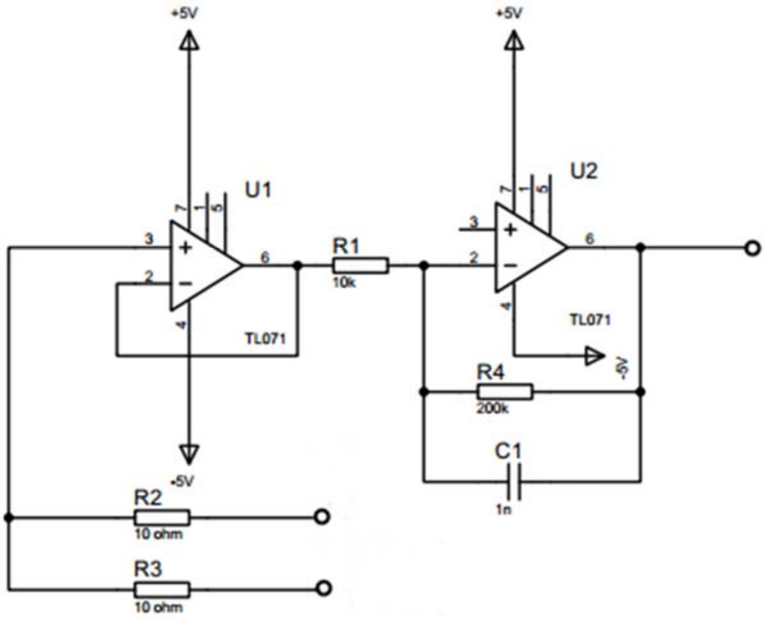


Figure 5. *Circuit diagram of Right leg driven circuit module.*

Common mode rejection or CMR, is one of the most important parameters for biopotential signal applications [7]. During measurements, a large amount of electromagnetic interference is coupled to the patients' body through the skin.

To reduce the CMR interference right leg driven circuit was made up. TL071 was used for the right leg driven circuit with unity gain. Figure 5 shown the circuit module of right leg driven circuit.

Instrumentation amplifiers have been broadly used in biopotential recording applications because of the high input impedance and the easy gain and offset adjustments through resistors [5]. Voltage ranges of ECG, EEG and EMG are in Micro-Volt to Mile-Volt ranges. To make these signals readable for the other blocks of module a great deal of amplification is used to employ high gain. We have used 3 different instrumentations amplifier as these biopotential signals need different gains and interconnected the instrumentation amplifier and right leg driven circuit internally to reject CMR so student not have the freedom to disconnect the right leg driven circuit.

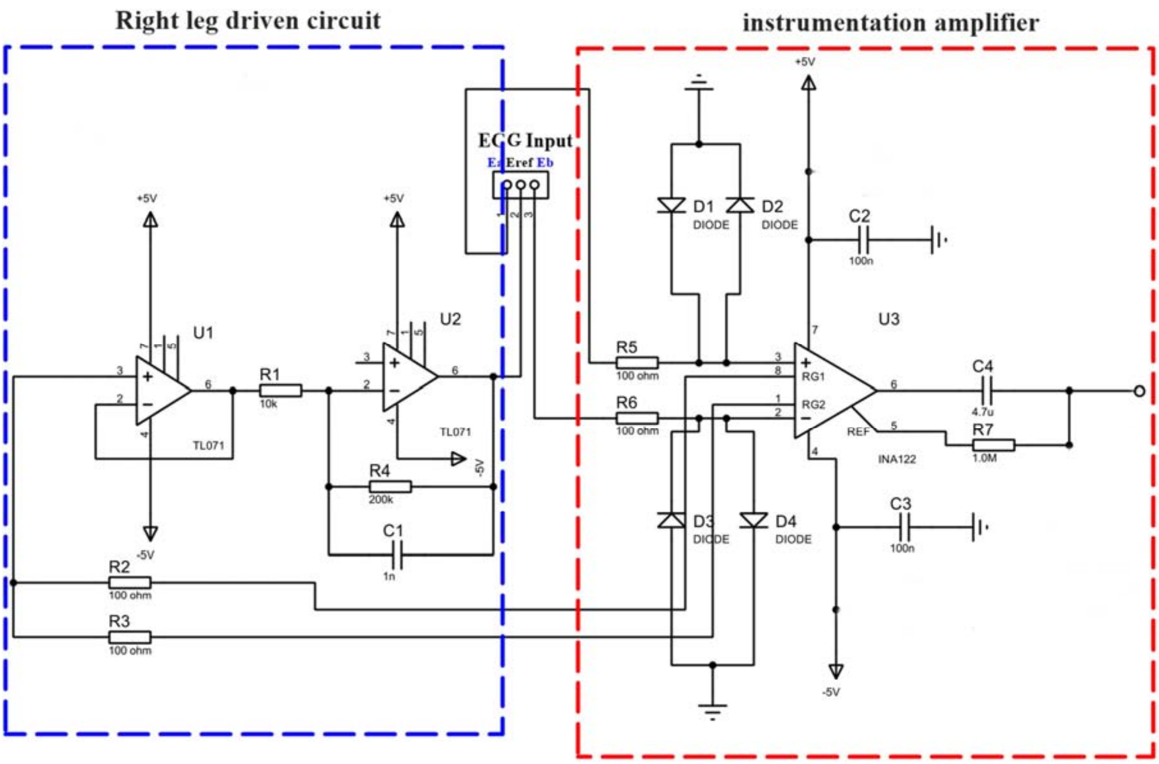


Figure 6. *Instrumentation amplifier circuit module of ECG measurement.*

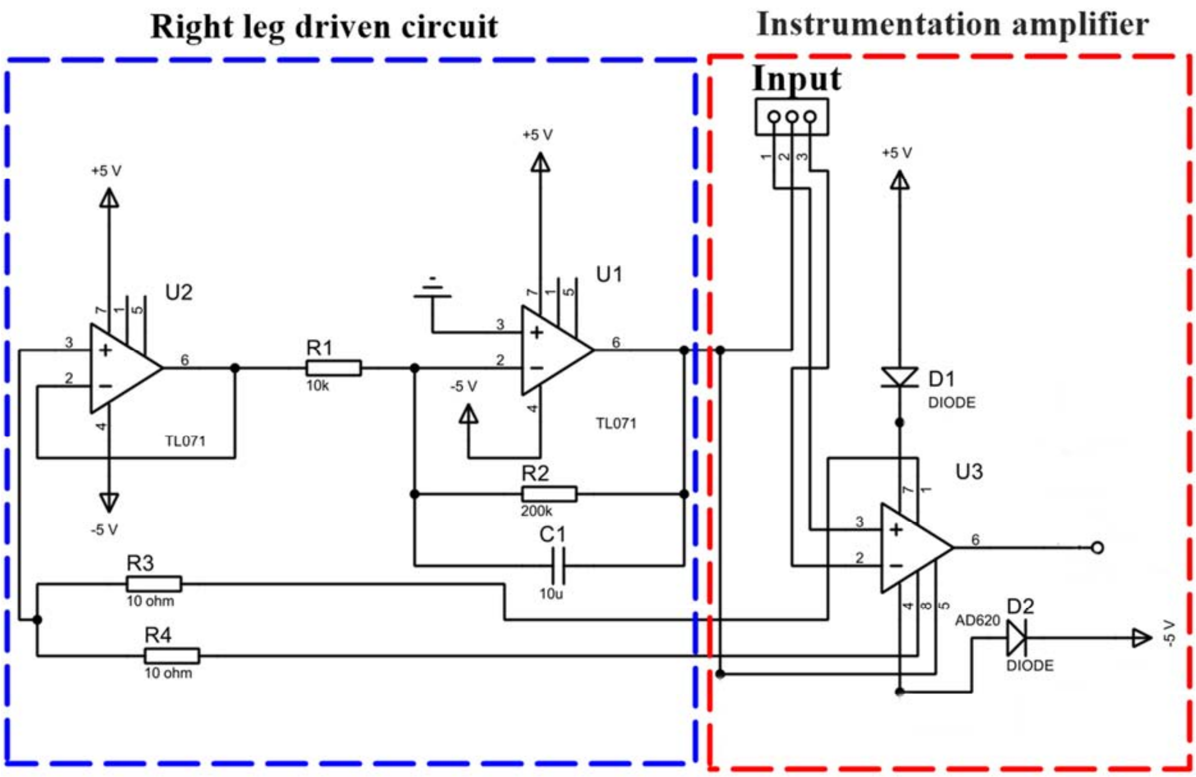


Figure 7. *Instrumentation amplifier circuit module of EEG and EMG measurement.*

Figure 6 shown the instrumentation amplifier circuit module of the ECG measurement. INA122 is used as an instrumentation amplifier for ECG measurement. The calculation of gain can be obtained from equation (1). Figure 7 Shown the Instrumentation amplifier circuit module for both the EEG and EMG amplifier as they required almost same amount of gain. AD620 is used as instrumentation amplifier in this case. The calculation of the gain can be obtained from equation (2). Table 2 shows all the amplifiers gain.

$$Gain = 5 + \frac{200K}{R_G} \tag{1}$$

$$Gain = 1 + \frac{49.4K}{R_G} \tag{2}$$

Fig. 2 shown there is non-inverting amplifier added after the instrumentation amplifier in ECG measurement configuration. The amplitude of the ECG signal decreased due to the active filtering. The main goal of designing a non-inverting amplifier is to saturate the ECG signals and converted them into an amplified waveform. TL071 is used as non-inverting amplifier and its gain can be calculated from equation (3). Figure 8 (a) shown the non-inverting amplifiers' circuit module.

$$Gain = 1 + \frac{R_1}{R_2} \tag{3}$$

Table 2. *Gains of different amplifiers.*

Biopotential Signals	Instrumentation amplifier GAIN		Non- Inverting amplifier GAIN		TOTAL GAIN
	Name	Gain	Name	Gain	
ECG	AN122	10.88	TL071	100	1088
EEG	AD620	989	X	X	989
EMG	AD620	989	X	X	989

After amplification it's very important to select the proper filtering options as these biopotential signals have different frequency ranges shown in Table 1. In Figure 2, Figure 3 and Figure 4 shown that in every configuration of the output biopotential signals is taken from the notch filters output. In EEG and EMG configuration before adding high pass and low pass filter a notch filter is added. Figure 8 (b) shown a notch filter circuit module.

In every IC, there is a noise from a power source which is generated from the power line. This noise has the same frequency as the power supply line. This noise can interface with the desired signal [10]. To avoid and nullify this power line noise 50 hz notch filter is used. The center rejection frequency of this circuit is determined by equation (4).

$$f = \frac{1}{2\pi}\sqrt{\frac{1}{C2*C3*R3*(R1+R2)}} \tag{4}$$

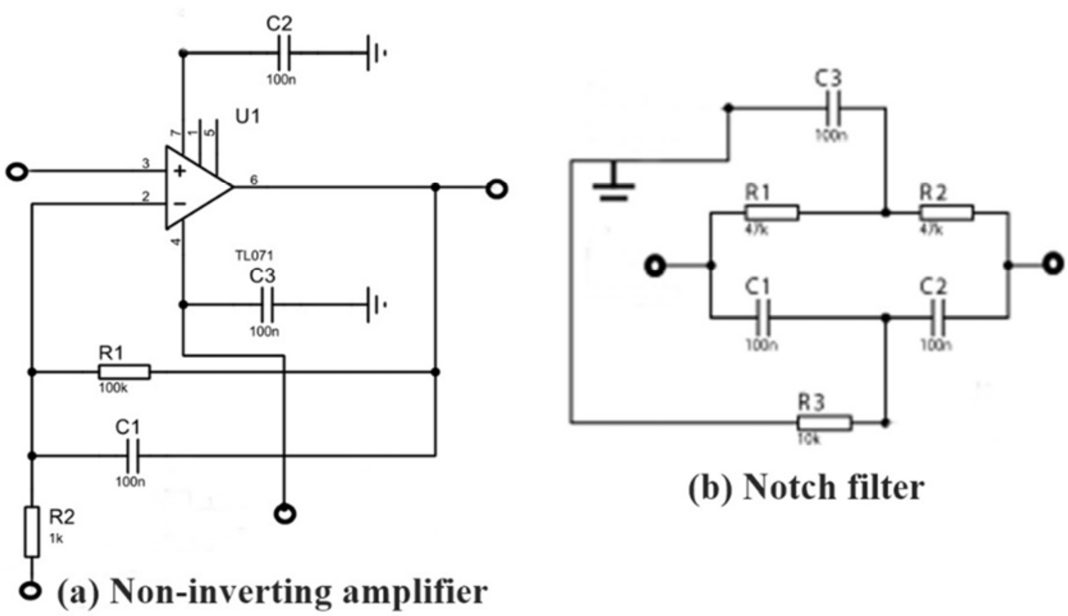


Figure 8. *(a) Non-inverting amplifier Circuit module. (b) Notch filter circuit module.*

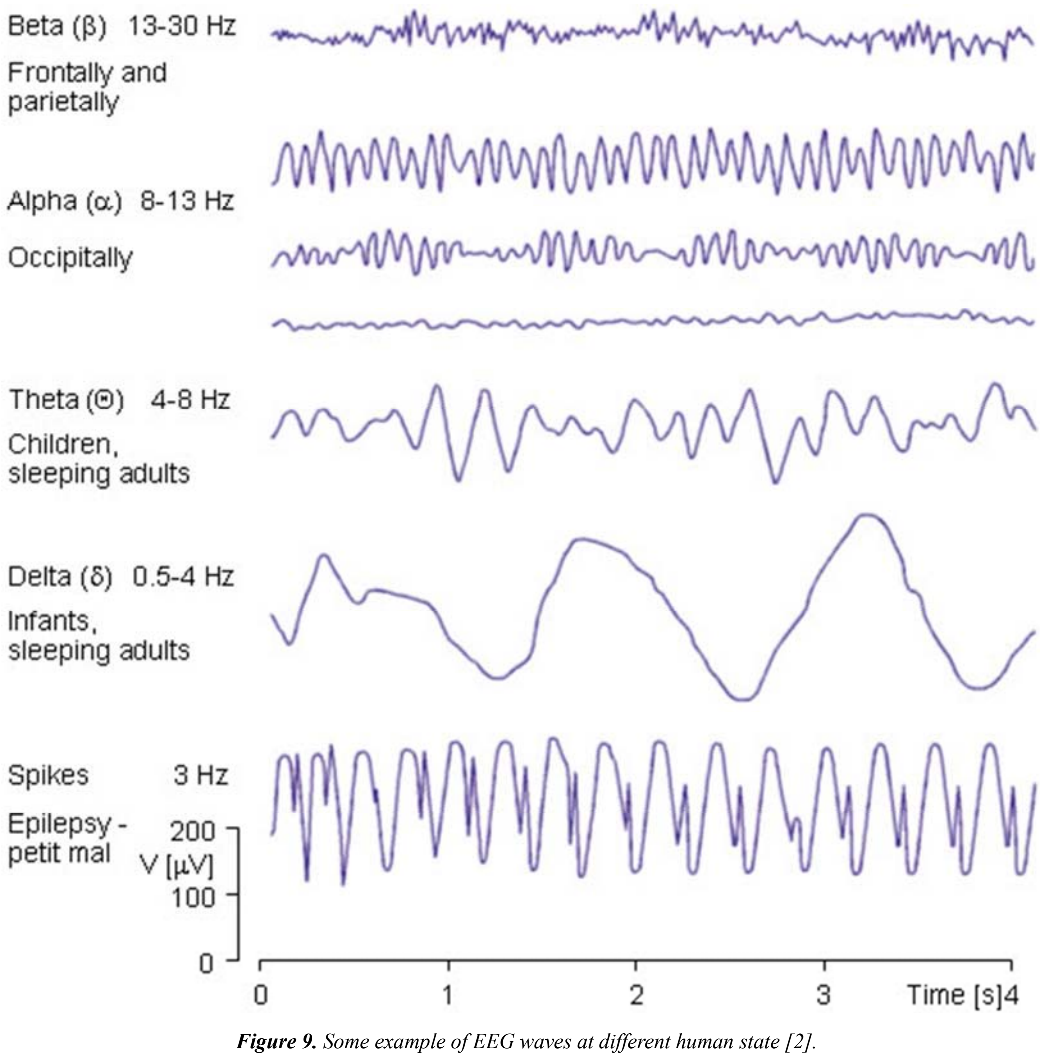


Figure 9. *Some example of EEG waves at different human state [2].*

EEG signal is quite complex to measure and it has different frequency componeent in different human state. Figure 9 shows some example of EEC waves. For making it easy in this module, we wanted to capture the alpha range of the EEG signal only and preset our filters according to that. Figure 9 explains the frequency range of Alpha signal which is between 8 to 12 Hz. To cut of the delta and theta waves, which have frequencies below 7Hz, so a 7Hz high pass filter was need. A 7Hz 2nd order multiple-feedback high pass filter was used to cutoff those unwanted signals. Since the frequency of the alpha wave is 8-12 Hz. A low pass filter circuit is needed that will cut off any frequency above 12 Hz. In the ideal case, the cut-off frequency of the low-pass filter would be 12 Hz. But in the practical scenario, the gain starts to drop quite before the cut-off frequency. In that case using a 12 Hz low pass filter would cause a data loss. That is why a 13 Hz low pass filter was chosen so that there is less attenuation in an alpha wave.

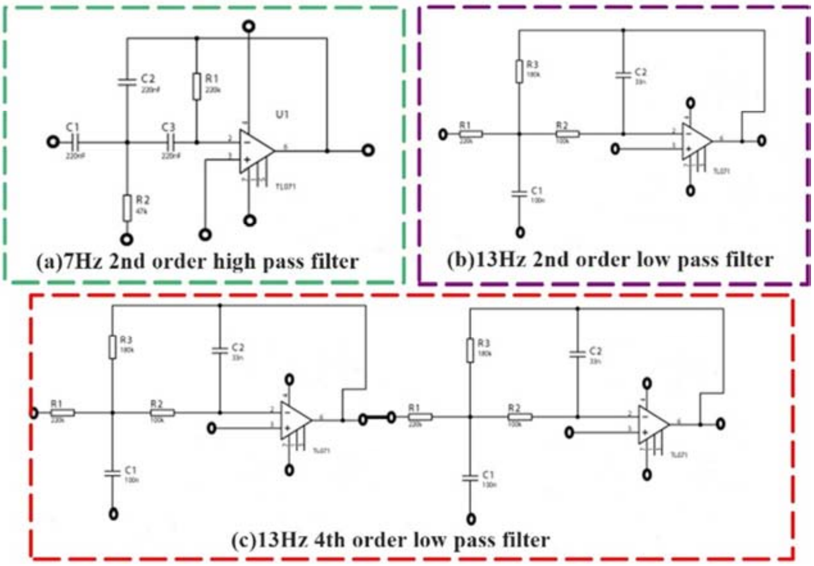


Figure 10. *(a) 7Hz 2nd order high pass filter circuit module. (b) 13Hz 2nd order high pass filter circuit module. (c) 13Hz 4th order high pass filter circuit module.*

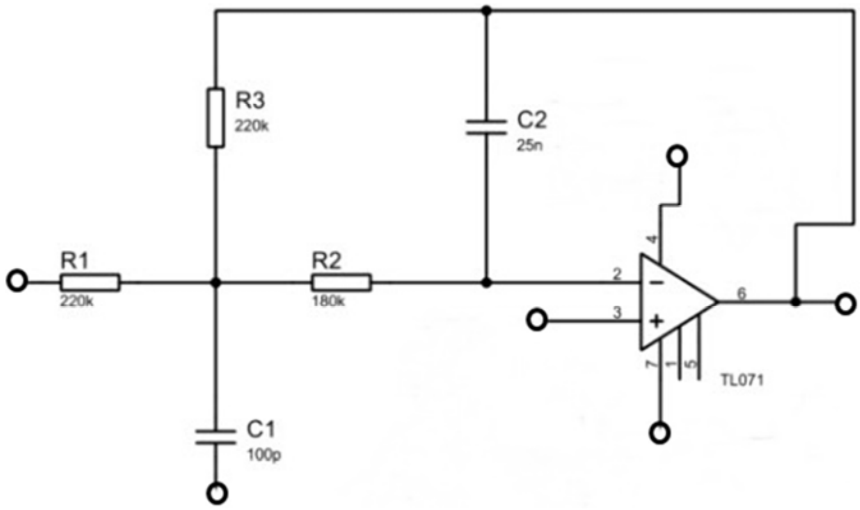


Figure 11. *512 Hz 2nd order low pass filter.*

Figure 10 (c) shows 13 Hz 4th order circuit module used for the reason to attenuate the signals above 12 Hz more so that the output at the end of the full circuit does not contain any signals above 12 Hz. The cutoff frequencies f_{HP} and f_{LP} was calculated using the following equation in eqn. 4 and 5. And resistors and capacitors were selected accordingly.

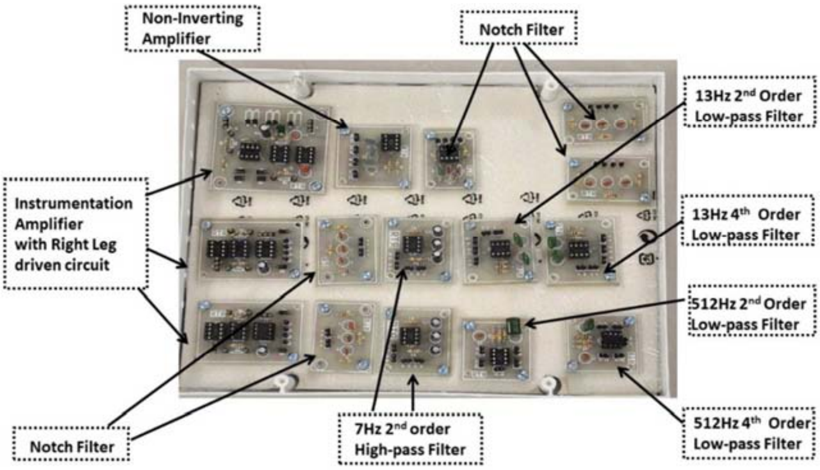
$$f_{HP} = \frac{1}{2\pi}\sqrt{\frac{1}{C2*C3*R3*(R1+R2)}} \quad (4)$$

$$f_{LP} = \frac{1}{2\pi}\sqrt{\frac{1}{C2*C3*R3*(R1+R2)}} \quad (5)$$

Figure 4 shows the EMG measurement reconfiguration of the RTR module. EMG module almost has the configuration of the ECG module, the only difference is in the filtering options. Table 1 shows the frequency range of the EMG signals. A 7 Hz high pass filter is used and to reject the higher unwanted frequencies two 512 Hz low pass filters were used (2nd &4th order). Figure 11 shown the circuit module of the 512 Hz 2nd order low pass filter. 512 Hz 4th order low pass filter is designed by cascading two 512 Hz 2nd order low pass filters.

2.3. Implementation and Display

Proposed module gives output wave shapes that can be observed directly using a cathode ray oscilloscope (CRO) or a digital one. However, data acquisition system can also be employed to see the real-time ECG, EEG and EMG output on a personal computer or even in MATLAB so that students can further work with the collected data.



(a)

(b)

(c)

Figure 12. *Designed prototype of RTR module. (a) Inner circuit blocks; (b) Side view. (c) Top view.*

A simple proposed data acquisition system can be achieved using a microcontroller unit and MATLAB for software interfacing; the proposed block setup is shown in Figure 13.

The analog outputs from the module are to be converted into a digital data through an ADC for the computer to rea and display. A microcontroller can be configured and programmed to do the operation.

For interfacing or build up the communication between the hardware part to the computer we had used the serial communication of the PC and finally using the serial communication facility of MATLAB environment we succeed to show the Real-time data on MATLAB.

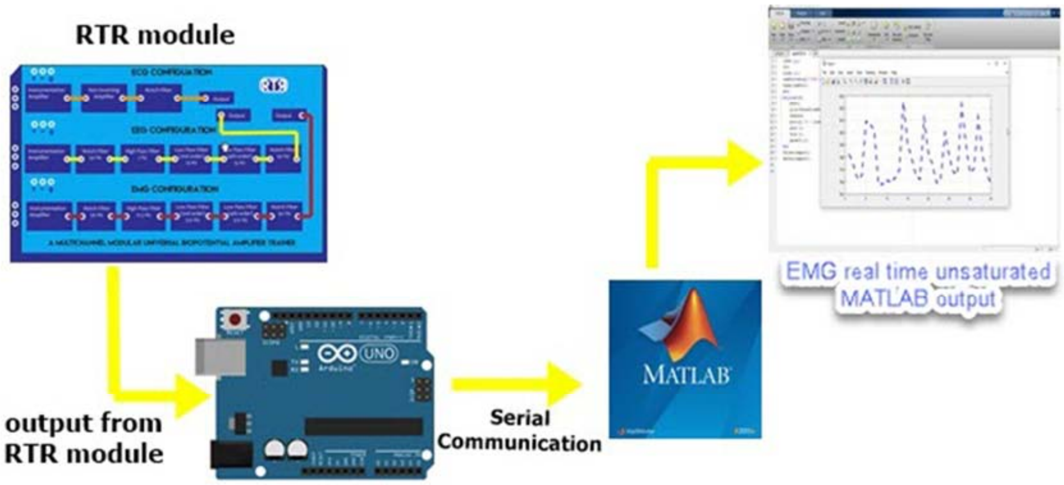
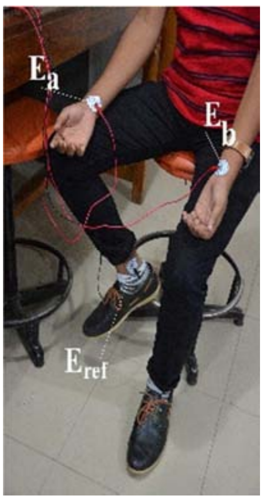


Figure 13. *Proposed block setup of data acquisition system.*

3. Results

Define The experiment with the human body biopotential signal measurements Ag/AgCl surface electrodes were used and RTR module was reconfigured according to the configuration shown is Figure 2 Figure 3 and Figure 3 for the measurement of ECG, EEG and EMG respectfully.

With the human body experiments, first, we discussed the ECG experiment. For the placement of the lead, bipolar lead configuration was used [9], where two measurement electrodes are attached to the right (E_a) and left (E_b) arms, respectively. The reference electrode (E_{ref}) is placed in the right leg. The placement of electrodes and experimental result are shown in Figure 14 (a).



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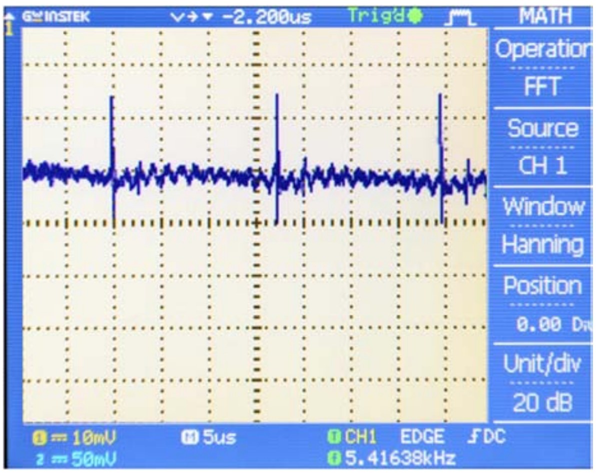

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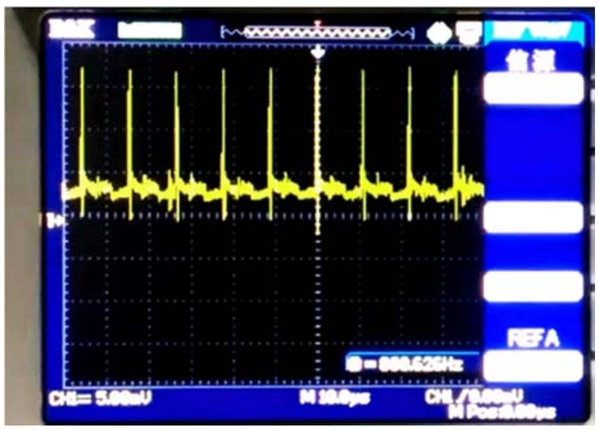
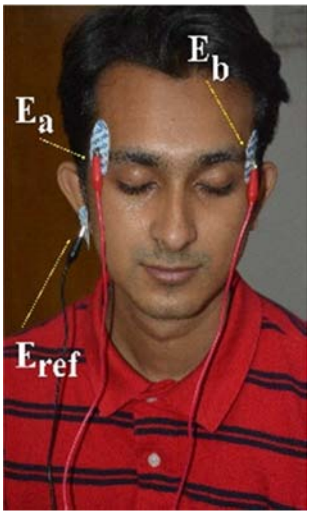


(c)

(d)

Figure 14. *ECG measurement. (a) Electrode placement: E_b on the left and E_a on the right wrist and E_{ref} on the right foot; to observe lead I (potential difference between LA & RA) of Einthoven triangle. (b) ECG in digital oscilloscope (colour inverted to omit black background) (c) & (d) ECG using Notch filter.*



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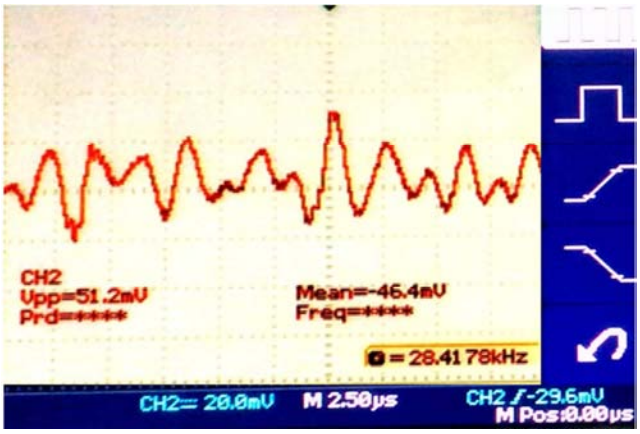
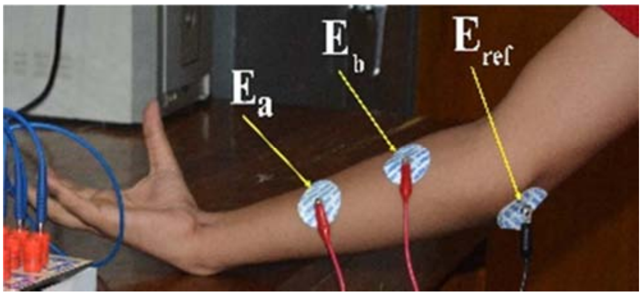


(b)

Figure 15. *EEG measurement. (a) Electrode placement: E_b on the left and E_a on the right, while E_{ref} on the ear lobe to ensure a reference point. (b) Output in digital oscilloscope (color inverted to omit black background).*

For the EEG measurement experiment, the module connection configuration is given in Figure 8. Our EEG module was designed to acquire the alpha range of the EEG signal which can be absorbed with the eyes closed [8] in figure 15 (b). Two measurement electrodes were placed on the right and left side of forehead, standard temporal electrodes to record the infra- and suprasylvian regions which lie over the Sylvian fissure. The placement of the electrodes and experimental result are shown in Figure 15.



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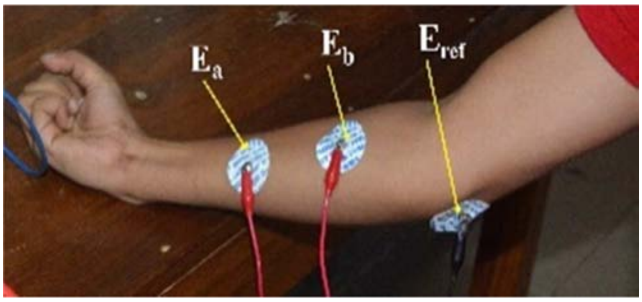

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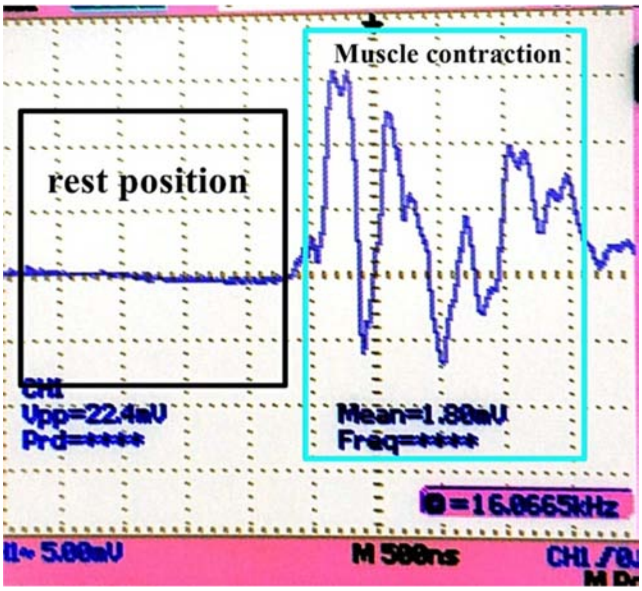


(c)

Figure 16. *EMG measurement. (a) Electrode placement: electrode E_a and E_b placed on the fore arm muscle and E_{ref} on the elbow to ensure reference point (b) Output in digital oscilloscope (color inverted to omit black background).*

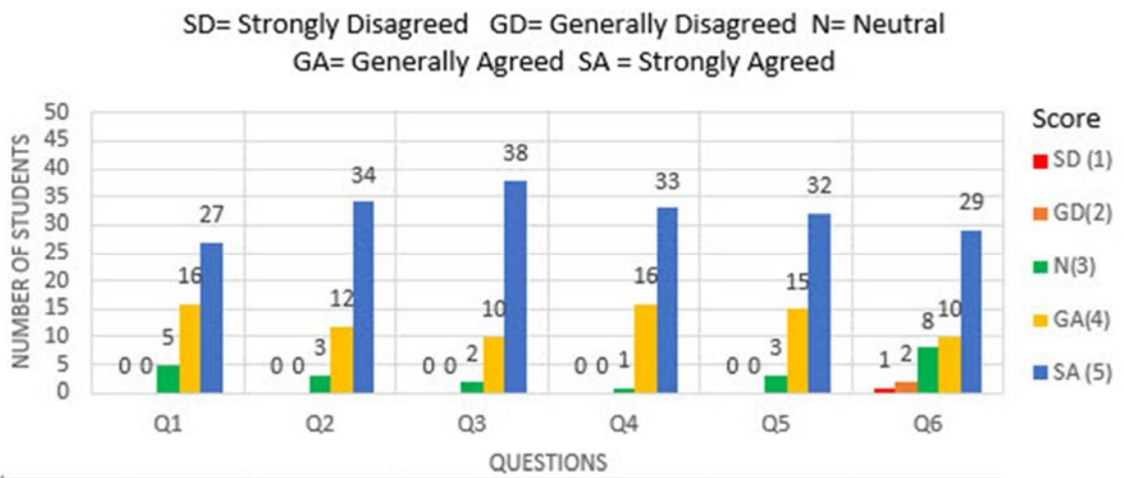
Finally, the EMG measurement experiment was done. For measuring the EMG signal the bioamplifier module connection configuration is shown in Figure 16. For the EMG measurement electrodes are placed on the skin surface of the forearm flexor muscle, and the reference electrode was placed on the elbow to ensure a reference point because there is no muscle which can give rise to a potential. The placement of the electrodes and experimental result are shown in Figure 16 (a, b).

4. Survey

The purpose of developing RTR module is the improvement of the students' skills, providing hand-on and work-based designing abilities of biomedical instrumentation. The RTR module developed as an education tool for the biomedical instrumentation laboratory experiments. At the end of the use of biomedical instrumentations laboratory measurement using RTR module, the students were asked to feedback opinion with six questionnaire items, shown in Table 3.

Table 3. *Student Survey Questions.*

#	Description
Q1	The "RTR Module" will improve medical instrumentation knowledge when compared to traditional lecture courses.
Q2	This "RTR Module" provides more practical knowledge and technologies for medical instrumentation.
Q3	You can relate the RTR Modules instrumentation with your theoretical knowledge.
Q4	RTR Modules step by step filtering options give you more clear ideas about bio-amplification and filtering.
Q5	RTR Module is giving more improved in hands-on skills of medical instrument design.
Q6	This "RTR module" will make you pay more affords on this course.



Mean	4.44	4.62	4.72	4.64	4.58	4.28
Standard Deviation	0.6681	0.5963	0.5307	0.52	0.6029	1.0008

Figure 17. *Student survey answers.*

The feedback survey was done from 50 students, and they were asked to answer the questionnaires. Each question score ranging from 1 to 5, as shown in Figure 17, and a chart for showing he distribution of all answers is summarized. The statistical analysis for the mean and standard deviation was calculated on the students' feedback the results are shown in the bottom of the chart. In summary most of the students provided their positive feedback on the RTR module, especially for the reconfigurable designing features of the RTR module. They also expressed their interests on designing medical instrumentation.

5. Conclusion

The proposed Universal biopotential amplifier trainer aimed to be a compact educational tool for the students and laboratory experiments. We designed the board in a manner that the students can configure the board to develop hands-on skills and learn step by step procedure of biopotential amplifier design. The developed trainer is a cost effective compact educational tool with limited features to get basic biopotential signals of ECG, EEG, and EMG. In the future, this educational Universal biopotential amplifier trainer board can be improved for measurements of other biopotential activities by adding more gain option and filtering blocks. A data acquisition system can be integrated as well to ensure a complete learning module for laboratory experiments.

References

[1] L. A. K, "The web's where you study in!," 2008. [Online]. Available:http://www.ustudy.in/node/5029. Accessed: Jul. 24, 2016.

[2] Nelson CV, Geselowitz DB (eds.) (1976): "The Theoretical Basis of Electrocardiology", 544 pp. Oxford University Press, Oxford.

[3] Carlo J. De Luca, Surface Electromyography: Detection and Recording. Delsys Incorporated, 2002.

[4] M. B. I. Raez, M. S. Hussain and F. Mohd-Yasin, “Techniques of EMG signal analysis: detection, processing, classification and applications,”Biol. Proced. Online 2006; 8 (1):11-35.doi:10.1251/bpo115 March 23, 2006.

[5] M. S. J. Steyaert and W. M. C. Sansen, “A micropower low-noise monolithic instrumentation amplifier for medical purposes,” *IEEE J. Solid-State Circuits*, vol. 22, no. 6, pp. 1163–1168, 1987.

[6] J. G. Webster, “Implementing guided design in a medical instrumentation course,” IEEE Transactions on Education, vol. 22, no. 2, pp. 110 – 116, 1979.

[7] M. Guermandi, A. Bigucci, E. F. Scarselli and R. Guerrieri, "EEG acquisition system based on active electrodes with common-mode interference suppression by Driving Right Leg circuit," 2015 37th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC), Milan, 2015, pp. 3169-3172. doi: 10.1109/EMBC.2015.7319065.

[8] B. Vermani, N. Hooda and N. Kumar, "Parametric evaluation of EEG signal during Eyes Close and Eyes Open state," 2015 Annual IEEE India Conference (INDICON), New Delhi, 2015, pp. 1-5.doi: 10.1109/INDICON.2015.7443754.

[9] M. H. Fan, M. H. Guan, Q. C. Chen and L. H. Wang, "Three-lead ECG detection system based on an analog front-end circuit ADS1293," 2017 IEEE International Conference on Consumer Electronics - Taiwan (ICCE-TW), Taipei, 2017, pp. 107-108.doi: 10.1109/ICCE-China.2017.7991018.

[10] U. Biswas and M. Maniruzzaman, "Removing power line interference from ECG signal using adaptive filter and notch filter," 2014 International Conference on Electrical Engineering and Information & Communication Technology, Dhaka, 2014, pp. 1-4.doi: 10.1109/ICEEICT.2014.6919072.