MODULE III.2 BIOINSTRUMENTATION

Kiarra Lavache, Adi Shastry, Logan Smith
Group 3

12/20/2020

INTRODUCTION

Bioinstrumentation is a very important and growing field. Because most biological signals are small or contain a lot of noise due to interactions with other signals, electronic instruments and electrical principles must be used to get a clear picture of what is going on in the body. When measuring a biological signal, there are three main components that must be present: sensors, processors, and receivers/outputs. Receivers are instruments like microphones, photodetectors, and accelerometers. They take in the signal that is to be measured. Processors are instruments like amplifiers, filters, voltage dividers. They help to remove unwanted noise and make the signal of interest easier to read. Lastly, receivers/outputs are instruments like speakers, monitors, and LED lights. They present the final version of our original signal after it has been modified during the previous steps.

New developments in the field of bioinstrumentation are significant to the field of biomedical engineering as whole in many ways. More advanced bioinstrumentation devices can lead to improved diagnosis time and accuracy for patients. It can also lead to more accurate and detailed readings of parameters such as heart rate, steps taken, and skin temperature taken on devices like Apple watches and FitBits, which may someday aid in patient diagnosis and general health monitoring as well.

In this lab, the basic components of electrical circuits were used along with Arduino software to design devices that could measure and quantify different biological signals such as the ECG and EMG. Throughout the procedure, consideration was given to different aspects of the circuit such as the gain of the amplifiers and the bandwidth of the measurements. Appropriate changes in the circuit design were made to alter these aspects and obtain the desired results. Ultimately, the ECG and EMG were measured using these different circuit designs.

RESULTS

The following procedures serve as a basic introduction to the circuitry involved in measuring not only the ECG but other biosignals such as the EMG. Once initial measurements were made, the data informed alterations to the measurement circuit such that the data collected was more in line with what was necessary for analysis.

Statistical Methodology

These procedures were conducted in such a way that there was no need for any statistical analysis techniques. Most of the analysis was done qualitatively simply by looking at the graphs of the measurements taken.

Build Measurement Circuit

The initial ECG measurement circuit was constructed using an instrumentation amplifier and a second stage amplifier. Similar to the heart rate monitor breakout board used during the last lab, this circuit was able to measure the ECG and display it onto a computer screen through the Arduino acquisition stage.

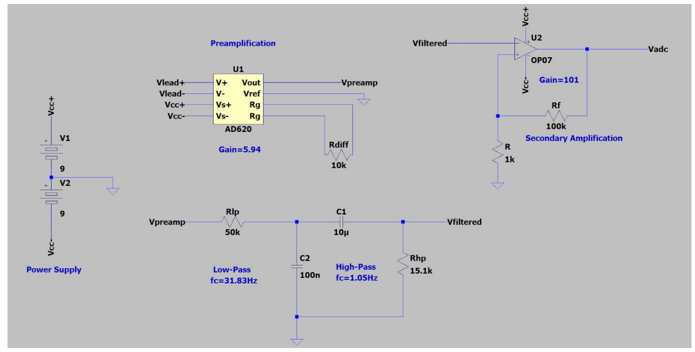

Figure 1: This is a schematic of the original measurement circuit. This was used to make preliminary measurements of the ECG signals and will be used to inform design adjustments.

Although the ECG signal acquired did contain a lot of noise, the individual ECG cycles were able to be detected fairly clearly. The maximum value obtained from this circuit was around 2.6V.

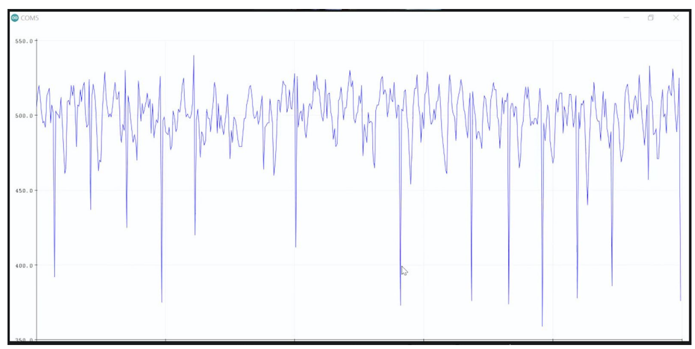

Figure 2. Image of ECG detected using the Measurement Circuit. Notice the scale of the peak value is around 540(this was not converted to Volts and represents the decimal representation of the data stored in registers ADLAR1 and ADLAR2[1]). In volts this would be a measurement of about 2.6V

Gain Alteration of Measurement Circuit

As can be seen in Figure 2, the maximum measurement the circuit was measuring was about 2.6V. This is with a gain of 101 in the post filtering amplification portion of the circuit and pre-filtered gain of 5.94. To ensure that the full dynamic range of the Atmega328p microcontroller is utilized, the gain of the measurement circuit was adjusted as can be seen in Figure 3.

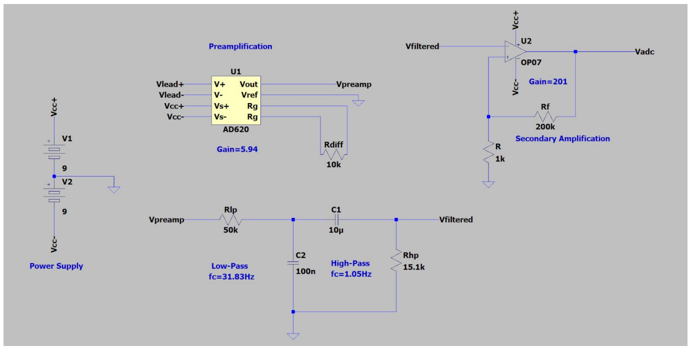

Figure 3: The adjusted measurement circuit to allow for the utilization of the dynamic range of the ADC of the ATmega 328P microcontroller.

The gain of the pre-filtered portion was not adjusted because this would simply result in the dissipation of energy when the signals not included in the bandwidth we want the circuit to pass, are attenuated. As a result, the post-filtering signal is amplified. The gain necessary was calculated to be about 200, this was informed by the maximum measurement seen in figure 2 and is further explained in the Appendix section. The result of this adjustment to the circuitry can be seen in Figure 4.

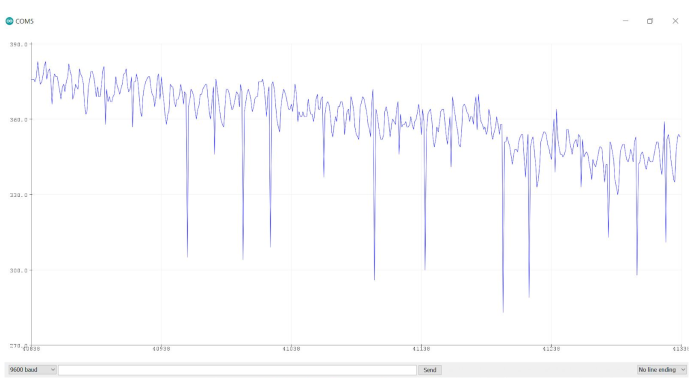

Figure 4: Shows the ECG signal measured with the circuit shown in Figure 3. As can be seen, the measurements are still not utilizing the entire dynamic range of the Atmega328p.

Bandwidth of Measurement Circuit

The next alteration made to the circuit would be to effectively filter out the P and T waves, the rationale for doing so will be explained in the discussion section. The frequencies of the P and T waves were determined to be 5-30Hz and 0-10Hz respectively[2]. According to the literature on the subject, the QRS waves are between 8-50 Hz, with the actual frequency being on the higher end for individuals without abnormal ventricular conduction[2]. Therefore, the cut off frequencies were determined to be 10-30Hz, this should attenuate the T and P waves while retaining the QRS waves. The updated circuitry can be seen in Figure 5.

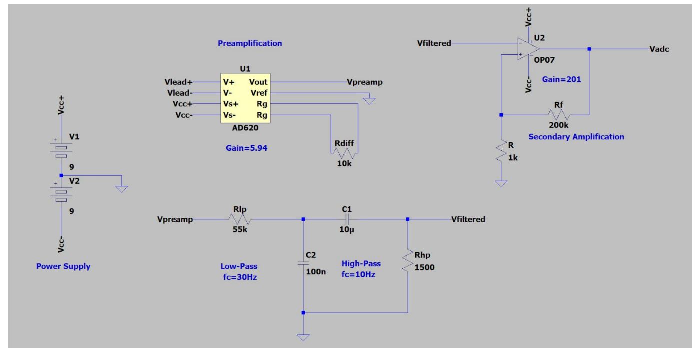

Figure 5: This is the adjusted circuitry built to attenuate the P and T waves from the ECG measurements taken.

The gain was left unchanged from the previous alteration since the output is expected to be roughly the same in terms of amplitude and thus would require the same amplification in the post filtering stage of the circuit. The measurement of the QRS waves can be seen in Figure 6.

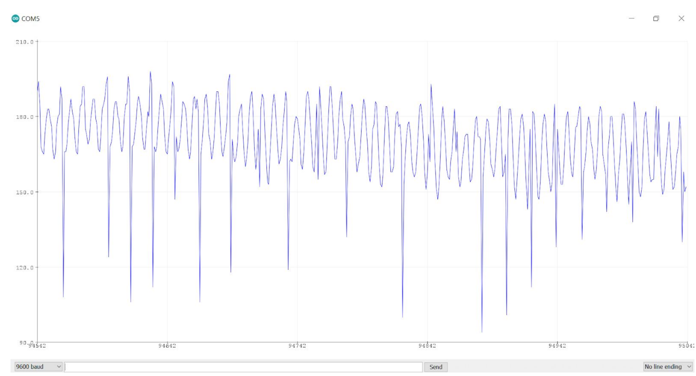

Figure 6: This is the output of the circuit shown in Figure 5. the graph seems to be picking up only peaks, however there is quite a bit of noise. Notice that the signal is further attenuated.

Electromyography Measurement

The EMG is a measurement of the electrical activity of muscle fibers in the body. In order to design a measurement circuit to detect these electrical impulses and only these impulses, the electrical circuits from previous procedures were augmented to pick out a frequency bandwidth of 10-450Hz[4]. The pre and post filtering gain were also augmented to ensure that the output of the measurement circuit was able to utilize the entire dynamic range of the ADC on the ATmega328p microcontroller[3]. Figure 7 shows the schematic for the EMG measurement circuit.

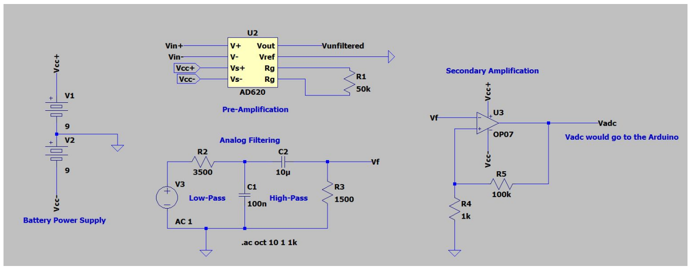

Figure 7:This is the schematic for the EMG circuit. Please note that the voltage source V1 is actually equal to the output of the AD620 IC, Vunfiltered. The voltage source was put in to ensure the correct bandwidth was being passed in the bandpass filter.

The output of the measurement circuit is shown in figure 8.

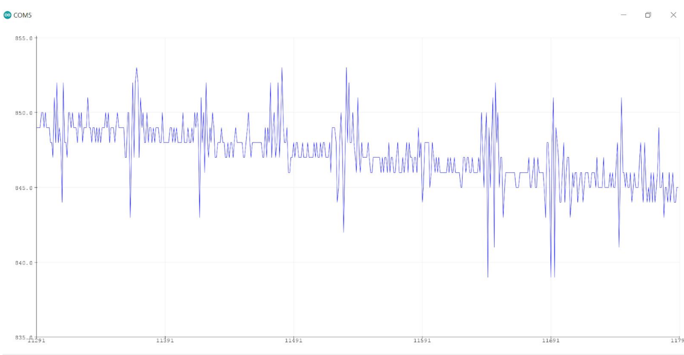

Figure 8: This is the output of the EMG circuit when the positive and negative nodes were connected to the bicep muscles.

When the muscle was flexed , the amplitude of the signal fluctuated significantly indicating that there was some electrical activity taking place. In Fig. 8, each "cycle" represents one flex and release of the bicep.

DISCUSSION

In this procedure an electrical circuit was designed and built to measure the ECG. After the initial measurements were taken, changes were made to the circuit in order to alter the gain on the first amplifier and alter the bandwidth on the second amplifier. The necessary gain was changed to 200 and the bandwidth to 10-30 Hz. Lastly, an electrical circuit was designed and built to measure EMG and measurements were recorded.

In discussing the outcomes of this procedure, it is important to address the topic of electrical isolation. Electrical isolation is defined as the separation of the non-ideal effect of a circuit from all of the other parts. This is essential because without electrical isolation, the potential for electrical hazards increases significantly and puts the users of any electrical circuits at an extreme risk.

Build Measurement Circuit

As seen in Fig. 1, the ECG was able to be successfully measured with the designed circuit. However, the signal did include a lot of noise and was not as accurate as the signal from the previous procedure in which the heart rate breakout board was used to measure ECG. While the -QRS wave was quite prominent in each of the ECG cycles, the -P and -T waves were a little more difficult to see because of the surrounding noise.

Gain Alteration of Measurement Circuit

As seen in figure 4 the gain adjustment did not have a substantial impact on the actual usage of the dynamic range of the ADC. The ECG sensors used have proven to be incredibly sensitive to even the smallest changes in placement, movement of the subject, moisture on the surface of the skin the sensors come into contact with, among other things. This is the most likely explanation for the deviation between what was expected and what was actually detected on the serial plotter.

Bandwidth of Measurement Circuit

As mentioned in the results section, there are some particular use cases where attenuating the P and T waves would prove to be useful. One such case is trying to detect a heartbeat. Here by removing the P and T waves, the actual heartbeat can be more precisely measured. This comes as a result of not having to deal with multiple peaks normally detected without such an attenuation, allowing for easier processing on the programming side and easier adaptability in terms of detecting peaks in the measurement for different subjects.

As can be seen in figure 6, while the graph is only picking up the peaks of the ECG signal, there seems to be a lot of noise that has carried over from the other measurements taken using the sensors, this was already discussed earlier. Also, as mentioned in the figure, it is also important to point out that the signal is utilizing the dynamic range of the ADC to a much lesser extent than what the theoretical gain should be. This will also be explained in the error analysis section.

Electromyography Measurement

Similar to the ECG signal, there was some noise already present in the output before the desired signal was measured. Despite this noise, the EMG measurements could still be seen very clearly. When the bicep was flexed, the amplitude of the signal increased significantly from when the bicep was relaxed. The magnitude of the increase in amplitude was also observed to be proportional to how hard the muscle was flexed. Large muscles flexes resulted in larger changes in amplitude and small muscles flexes resulted in smaller changes in amplitude.

Error Analysis

There are two major parts sources of error present in the measurements taken as a part of the procedures completed in these procedures: the attenuation of the signals even with the amplification portions of the measurement circuit and the noise associated with the measurements.

The noise associated with the circuit was already discussed in an earlier section, however it is critical to mention it again. The sensors used are highly sensitive and thus are affected by even the slightest change. Since measurements were made on different days, there are numerous external factors that probably affected the precision of the measurements made when compared to one another. This is the most likely explanation for the discrepancies seen throughout this report in terms of the noise seen.

The final thing to recognise is the fact that the measurements made in this report show very attenuated signals that do not in fact utilize the full 0-5V range of the Atmega328p's ADLAR registry where the ADC readings are stored[1]. This is a result of how close the cornering frequencies are for the bandpass filters used throughout these procedures. Having such narrow filtering bandpass filters will eventually attenuate the entire frequency spectrum in a fashion that the circuit was not intended for. To correct this, active bandpass filters can be utilized. Using such methods will allow the signal to remain, but also attenuate frequencies not needed for further analysis.

Summary and Future Work

This procedure gave a brief overview of bioinstrumentation and some of its uses. Through circuit design and application, we were able to measure the ECG and subsequently alter the circuit to generate our desired output. The EMG was also measured. Results and outcomes of this experiment could be useful in measuring other signals such as the photoplethysmogram (PPG). This work could also be further developed by figuring out what other electrical components could make the signal acquisition easier and clearer for both the ECG and EMG.

REFERENCES

[1]Atmel. (n.d.). *ATmega328P*. 8-bit AVRMicrocontroller with 32K Bytes In-SystemProgrammable Flash. RetrievedNovember18,2020,fromhttps://ww1.microchip.com/downloads/en/DeviceDoc/Atmel-7810-Automotive-Microcontrollers-ATmega328P_Datasheet.pdf

[2]Tereshchenko, L. G., & Josephson, M. E. (2015). Frequency content and characteristics of ventricular conduction. *Journal of electrocardiology*, *48*(6), 933–937. https://doi.org/10.1016/j.jelectrocard.2015.08.034

[3]Hernández-Ochoa, E.O., Schneider, M.F. Voltage sensing mechanism in skeletal muscle excitation-contraction coupling: coming of age or midlife crisis?. Skeletal Muscle 8, 22 (2018). https://doi.org/10.1186/s13395-018-0167-9

[4]Rose, W. (2019, October 24). Electromyogram analysis. Retrieved November 30, 2020, from https://www1.udel.edu/biology/rosewc/kaap686/notes/EMG%20analysis.pdf

APPENDIX

Appendix I: Gain Alteration Calculation

As described in the results section, the gain of the original circuit was about 101 and the highest voltage output was about 2.6V. To adjust the circuit for this the following calculation was made.

$$V_{\text{Original without Gain}} = \frac{2.6V}{101} = 0.026$$

$$\text{Adjusted Gain} = \frac{5V}{0.026V} = 192$$

$$\text{Adjusted Gain} \approx 200$$

To achieve this, a 200K and 1K Ohm resistor was used as can be seen in Figure 3 in the results section.

Appendix II: Analog Data Collection

The code used for this initial analog data collection is shown below.

1. void setup() {
2. // put your setup code here, to run once:
3. Serial.begin(9600);//This will turn on serial communication between the arduino and the computer
4. }
5. void loop() {
6. // put your main code here, to run repeatedly:
7. int v = analogRead(A0);//Reads the Input from Pin A0
8. delay(10);//Delay for 250ms in order to allow for data acquisition
9.
10.
11. Serial.println(v);//The arduino will send the data to the computer, and the computer will plot it
12. }