More than Meets the Eye

A Portable System to Track and Map Eye Movements to a User Defined Language

18-551 Final Report
Spring 2000

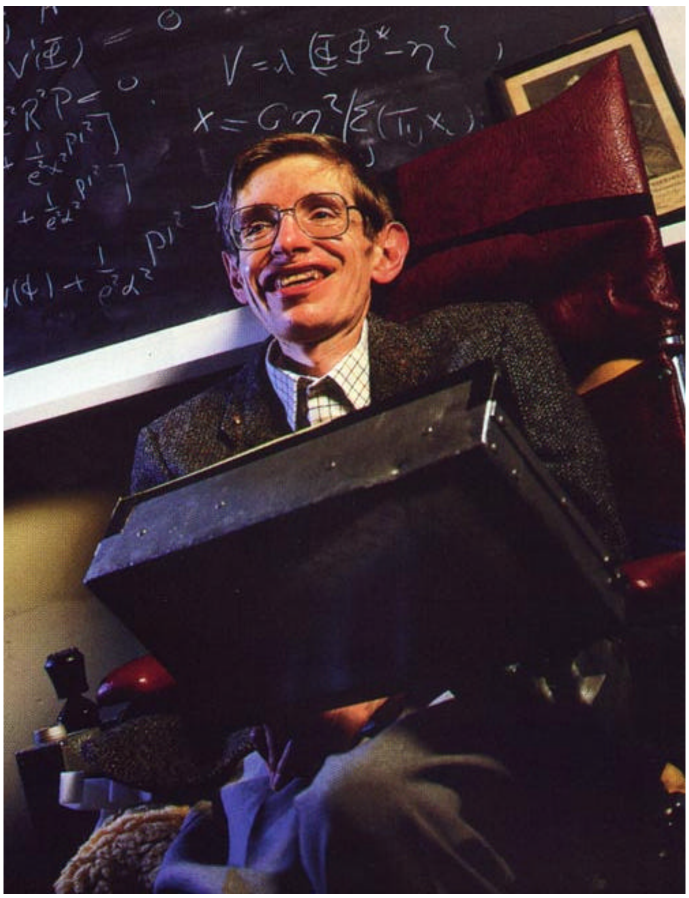

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TABLE OF CONTENTS

Abstract

This report discusses a project that was recently developed and completed as part of the ECE capstone design class, 18-551: Digital Communication and Signals Processing. The title of this project is "More Than Meets The Eye," and its goal was to create a portable and affordable eye-movement communication system for the hundreds of thousands of paralyzed people in America today.

The following account discusses the project's background, as well as its overall goals and impressions of the project. In addition, details concerning the data flow path and algorithm are included.

Applying new technology to such an interdisciplinary field as biomedical engineering was an exciting and exhaustive effort for our group; still, we hope that our success in this project leads others to choose projects that likewise widen the scope of DSP applications.

1.0 Summary of Report

1.1 Statement of Purpose or Problem

Hundreds of thousands of Americans today live with afflictions that render them with little to no control of their muscles. These afflictions – including Lou Gehrig's disease and stroke – can leave a person mentally sound but with no viable method of communication with his/her world. Among the variety of situations and diseases that paralyze people, eye movements remain the most common and lasting areas of movement that are controllable well enough to communicate.

While there exist several promising products and areas of research concerning eye movement communication devices, a simple, portable, and financially viable device remains underdeveloped. Most eye movement communication devices involve moving a mouse on a computer screen; this method requires not only a heavy computer monitor but also an overly challenging precision in movement and signal processing.

Keeping this problem in mind, our 18-551 group's decided purpose was to design an in-depth signal processing application, using the TI C67 processor, that would enable paralyzed people to communicate with their eyes in a more portable and simple manner than current options that involve bulkier and more expensive equipment.

After research in the area of different eye movement detection methods, our group aimed to read in the EOG (electro-oculogram) type of eye movement signal, using electrodes attached to the face. The purpose of our design became to first amplify and then filter this EOG signal such that it could be mapped to a given vocabulary for simple and portable communication. Given the success of our 18-551 design, a final product for paralyzed people would need only non-intrusive electrodes, our biomedical instrumentation amplifier, an EVM board, and speakers.

1.2 Summary of Findings

Our final product design has proven successful in processing the above-mentioned EOG signal in a manner that would enable a paralyzed user to communicate with relatively minimal effort and cost. The final design used five silver-silver chloride electrodes, an instrumentation amplifier, EVM, DSP, and a PC. Our successful demo of our solution involved outputting eye movements to the screen from which they can be mapped to a set vocabulary.

1.3 Summary of Recommendations

Applying real-time biomedical signals to this ECE course's signals processing setup presented an aspect somewhat different from most 18-551 design projects. In addition to adjusting for the wildly varying aspects of the biological signal itself, we found it unexpectedly challenging to read in any sort of reliable signal to process. We would recommend that future projects involving real-time biomedical signals acquisition treat this data capture matter with considerable gravity.

While the EVM board is not necessarily geared towards low-frequency biomedical signal acquisition, we still would recommend this type of biomedical signals processing project to future 18-551 groups. From our research and work in lab, we have unanimously concluded that there remains a great amount of work to do before new technology has been completely introduced to biomedical signals processing efforts. It is our hope that 18-551 students continue to apply DSP technology to fields such as this one.

2.0 Background to Problem

2.1 Introduction

In America today, paralyzing disabilities prevent hundreds of thousands of people from communicating with the outside world. Paralysis affects people of all ages through neurological disorders such as cerebral palsy and ALS (Lou Gehrig's disease), as well as strokes, spinal cord injuries, and age-related disabilities[1].

Although the majority of people with incapacitating conditions are mentally coherent, they often cannot form words through voice, hand motions, or writing. Generally, however, they still have motor control of their eyes.

2.2 Current devices

Several designs already exist that enable a person to "talk" with his/her eyes. These existing devices fall into two or three categories. Many of them are based upon refracting light; the nature of these systems leaves them prone to interference from other light sources. The remaining designs use expensive amplifiers, bulky headsets and processing equipment to decode and filter low-voltage electro-oculogram (EOG) signals found in the eyes.

[1] The Facts About Spinal Cord Injury and CNS Disorders. 1999. *The University of Alabama National Spinal Cord Injury Statistical Center* http://www.apacure.com/

2.3 The Next Step

While there exist several promising products and areas of research concerning eye movement communication devices, a simple, portable, and financially viable device remains underdeveloped. All current eye movement communication devices involve moving a mouse on a computer screen; this method requires not only a heavy computer monitor but also an overly challenging precision in movement and signal processing.

Keeping this problem in mind, our 18-551 group's decided purpose was to design an in-depth signal processing application, using the TI C67 processor, that would enable paralyzed people to communicate with their eyes in a more portable and simple manner than current options that involve bulkier and more expensive equipment.

3.0 Literature Search

3.1 Prior 551 work

We were not able to find many examples of prior 18-551 project work in the area of biomedical signals. The only one we found that could be considered a biomedical signals processing project was "A Real Time System for the Detection of Cerebral Ischemia from EEG Data" (S96: Badelt, Cardhana, Schultz).

While this paper was very helpful to us in brainstorming, we faced considerably different challenges because our data capture was in real-time and not from a database. To the best of our knowledge, no project of this type has been taken on by an 18-551 group.

3.2 Current EOG communication devices

EOG: A Background

The eye actually contains electric potential, or voltage. The cornea is positively charged while the retina is negatively charged. When the eye is looking straight ahead, electrodes equally spaced from the eye will be at right angles to the eye's electric field, resulting in an output of zero. However, when the eye moves, there is a direct current voltage shift which is referenced with the straight ahead position. For every degree of change in eye orientation in either horizontal or vertical direction, there is a change in voltage of about 1uV[2]. This voltage shift due to eye movement is known as an electro-oculogram (EOG) signal. Due to motor constraints, EOG signals are also not very high frequency signals.

Research tells us that here are four general types of eye movement: vestibular, optokinetic, saccadic, and pursuit[3]. Vestibular and optokinetic eye movements are mostly involuntary, while saccadic eye movements are used to jump from one focus point to another. Pursuit eye movements are when the eye is used to remain fixated on a moving object. Most eye movement detection systems primarily detect saccadic eye movements and occasionally pursuit eye movements for use with communications with the physically impaired and/or virtual gaming.

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[2] Kaufman, Arie A. "US5360971: Apparatus and method for eye tracking interface." US Patent Application. IBM Intellectual Property Network (http://www.patents.ibm.com, accessed 2/27/00)
[3] Webster, J.G. 1999. The measurement, instrumentation, and sensors handbook. Boca Raton, FL: CRC Press. 74-10 – 74-20.

4.0 Approach, Method, and Materials

4.1 Overall approach

Our group's overall approach to designing our system was to read in the EOG signal, amplify it, and then allow the EVM to digitally process it and identify the given movement to a corresponding word or letter in the vocabulary.

We started our work by researching what had been accomplished already in the field of EOG detection, and by ordering the necessary hardware. In addition, we acquired sample EOG data from UPMC's Vestibular Lab.

After we had acquired the necessary hardware, we began to work on amplifying our own EOG signals. After this was accomplished, our next challenge was to get our signal into the EVM, despite the signal's inherently large DC component and the AC coupling on the CODEC.

This being successfully accomplished, we implemented the algorithms that we had found in our research for eye movement pattern recognition.

4.2 Method

Figure 1, which shows our high level signal flow, describes the method in which our EOG signal travels through the system we designed. The three main components of the high-level signal flow are the analog amplifier, the EVM/DSP, and the PC. There are two channels: horizontal and vertical.

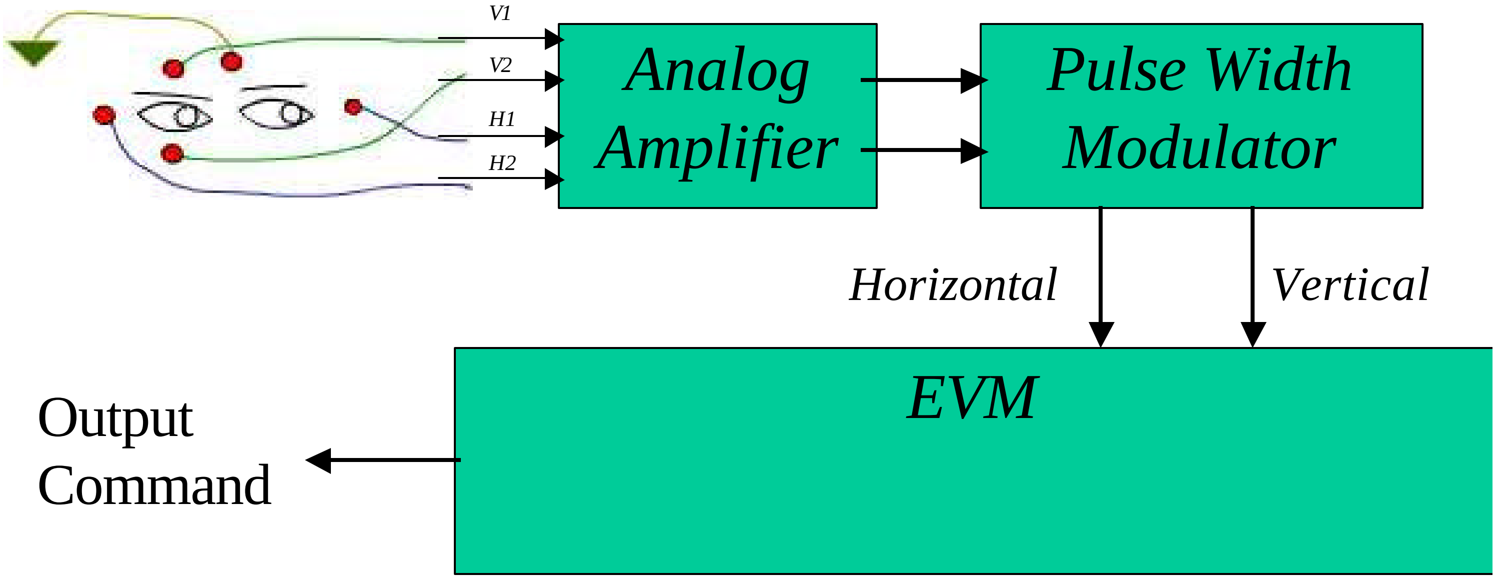

Figure 1: Our Design's High Level Signal Flow

4.3 Materials

We initially acquired materials for the instrumentation amplifier through Tech-Electronics. The approximate cost of the instrumentation amplifiers needed to process both the horizontal and vertical eye movement components is $20. We obtained 8 mm diameter silver-silver chloride electrodes for EOG recording from In Vivo Technologies. At a price of $20 each, the total of five electrodes will approximate be $100.

	Price	Amount	Subtotal
Circuit Components	$20.00	1	$20.00
Electrodes	$20.00	5	$100.00
Total			$120.00

Table 1: Expenses

5.0 The Design Process

5.1 Introduction

Over this past semester we have researched and explored countless options concerning EOG detection. Research in biomedical signal (and, in particular, EOG signal) processing is not widespread; in fact, all of our references and data were difficult to find and piece together. The following account of our design process details some of the major steps we've gone through to create a viable solution for our project.

5.2 Analog Circuitry

Detecting and amplifying biomedical signals requires much more precision and complexity than most other signal applications. Case in point, the EOG signal exists at only a few milliAmps and varies on the order of microVolts. In addition, interference from the skin, facial muscles, and EEG (Electro Encephalogram) creates a large voltage drift that can cause amplifiers to saturate and become useless. An exhaustive search for previous EOG detection systems showed that there has been no completely successful solution for a completely robust and affordable amplifier. Even the most expensive amplifiers, which can cost over $3000 each, do not work for the entire population of users[4].

In building this circuit, we went through several major changes and a countless number of adjustments. One large challenge was finding a reasonably priced yet stable amplifier to isolate and detect the EOG signal. Not knowing much about specific requirements, we built our first circuit using standard components from Tech Electronics. Unfortunately, the low quality and precision of these components led to an unsatisfactory output. To

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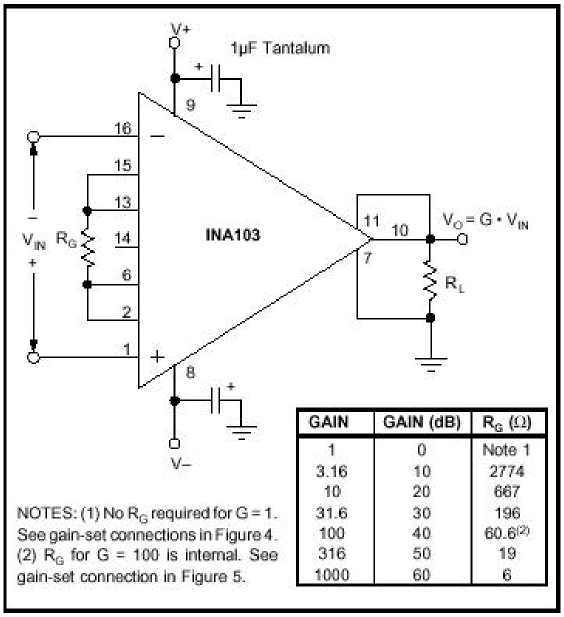
[4] Gips, J. and P Olivieri. Eagle Eyes: An eye control system for persons with disabilities. The Eleventh International Conference on Technology and Persons with Disabilities, Los Angeles, March 1996.

solve this problem we researched extensively before finding an IC Chip called the Burr-Brown INA103 Precision Instrumentation Amplifier. This chip can amplify the difference between two inputs up to 1000 times with excellent stability[5].



GAIN	GAIN (dB)	R_G (Ω)
1	0	Note 1
3.16	10	2774
10	20	667
31.6	30	196
100	40	60.6[(2)]
316	50	19
1000	60	6

Figure 2: INA103 Amplifier

For the voltage drift issue we used an active high pass filter with cutoff at 0.16 Hz to remove the DC component, which otherwise might cause the the amplifier to saturate. In addition, our active low pass filter also amplified the AC component even further.

The final hurdle we faced concerning analog circuitry was getting the EOG signal into the EVM via the Analog to Digital Converter. In order to do this we added offset to the EOG signal and tried Amplitude Modulating it using a simple oscillator circuit. This was not a very effective approach, as it was difficult to extract the original signal due to noise and the A-D. Instead, we used a Pulse Width Modulator circuit using a 555 timing chip. This circuit varies the width of a square wave at 1.5 kHz, and has input voltage from the amplifier circuit.

[5] INA103 Product Folder. http://www.burr-brown.com (3 April 2000).

The analog amplifier uses the electrodes to detect the real-time EOG signal around the eye. This signal is approximately 1 mV with a large DC component. The signal is first amplified and then AC coupled, which removes the DC component. Following that, the amplifier circuit recreates the DC component to add the DC back in.[6] Then the signal becomes pulse width modulated and it is ready to go to the EVM.

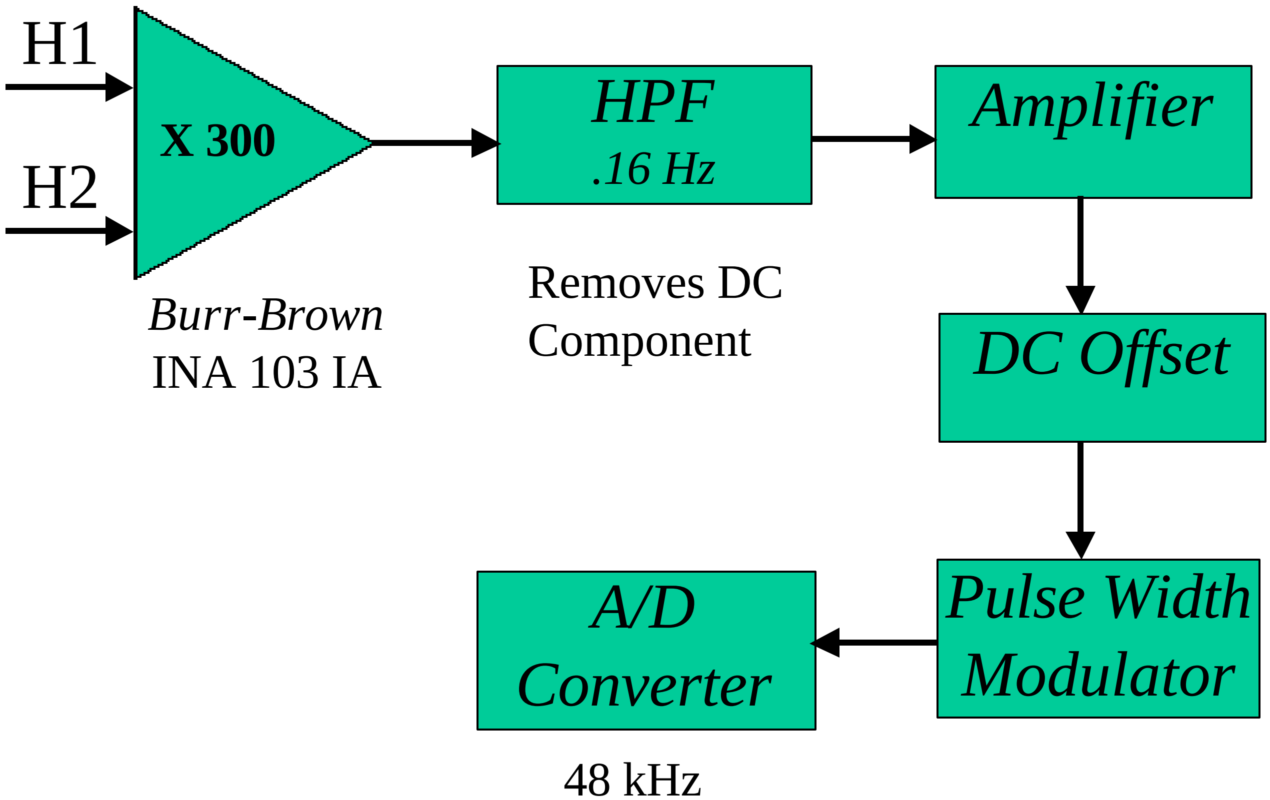


Figure 3: Analog Data Flow

[6] Webster, J.G. 1999. The measurement, instrumentation, and sensors handbook. Boca Raton, FL: CRC Press. 74-10 – 74-20.

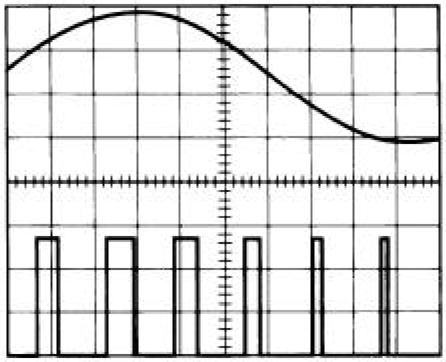


Figure 4: Pulse Width Modulation

5.3 EVM

At the EVM, our design has the A-D sampling at 48 KHz to detect the maximum resolution of the pulse width modulated signal. An algorithm we wrote in the EVM then demodulates the signal to 1.5 KHz, with the intention being to restore it to its original state.

When passing the signal through the CODEC, the right channel corresponds to the horizontal component, while the left channel corresponds to the vertical component. Both signals, having been demodulated at 1.5 kHz, are then Low Pass Filtered using a FIR Filter, which has a cutoff at 50 Hz. This eliminates the majority of noise and other signals, which do not correspond to the EOG signal.

In determining the algorithms and code for processing the EOG signal, our group learned a lot about the nature of biomedical signals themselves. EOG, like most biomedical signals, varies greatly from person to person, and can look very different from other EOG data due to a myriad of different factors. In fact, when we compared our read-in data to the sample EOG data that UPMC's Vestibular Lab gave us, we found that they were markedly different due to variations in capture technique.

Initially our group was using a more complex algorithm, using adaptive filtering to detect eye movements[7]. However, we learned this method only worked for saccadic eye movements, and so decided to use a self-designed adaptive algorithm instead.

Our final, working algorithm determines an eye movement by using dynamic thresholds on time and amplitude for each of the possible eye movements. These thresholds are established initially at the beginning and are adjusted up or down depending on whether a certain derivative threshold is met and a signal is detected or not. It does this by adjusting them when certain thresholds are met on the derivative. This is a fairly simple and accurate method, which gives us results just as effective as the complex adaptive filtering, which only detects saccades. As we have noted, one of the biggest difficulties with identifying eye movements through EOG signals is that every human has a different EOG signal. Therefore our algorithm adapts the thresholds it uses to identify specific eye movements. These identified eye movements are then transmitted to the PC.

We sample our incoming signal at 48 KHz; this is only necessary because we are using a pulse width modulated signal and need to gain the highest resolution possible. With better hardware more specified for our application, this would not be needed. Our code running on the EVM is not very computationally intensive and easily runs in real time. If this system were implemented for commercial use, this would allow cost to drop greatly as it could be implemented on a much slower DSP that only handled integers. Additionally the memory requirements are so low that all data can be handled in on chip memory.

Average	Maximum	Minimum
3.046e-4	1.336e-5	2.450e-3

Table 2: Run Times (in seconds)

7 Juhola, M., V. Jantti, I. Pyyko, M. Magnuson, L. Schlalen, and M. Akesson. 1985. Detection of saccadic eye movements using a non-recursive adaptive digital filter. Computer methods and programs in biomedicine 21 (1985) 81-88.

5.4 PC and Vocabulary Mapping

Once our read-in eye movements are identified by the EVM, the PC receives them and a very simple program corresponds the detected eye movements to the corresponding text or commands and outputs them to the screen. This allows the user to communicate. In future applications, this output to the screen would be replaced by a simple voice generator.

6.0 Conclusion

We were by far most successful in detecting a right saccade, a left saccade, and a blink. These three aspects we demonstrated in lab, with the output to our computer screen representing our language output.

The challenges we faced with the vertical component detection were due directly to the freedom of movement of the eye: the vertical range of motion is significantly less than the horizontal (about one third). In addition, accurately performing pursuit motions identifiable by our system turned out to be out of the range of human capability (our eyes would have difficulty performing a "true" pursuit motion without any tiny saccadic jumps). While these issues were pressing enough that we did not include vertical or pursuit motion in our final product, we feel that further work in these areas might lead to their inclusion at a later date.

As stated by the syllabus, the purpose of this course was to "provide the student with a rich, in-depth design and application hardware project experience in the areas of digital communications and/or signal processing systems"[8]. While we are still addressing issues with the vertical and pursuit components of our proposed system, we feel that we've achieved success in producing a viable communication system and, perhaps more importantly, in learning invaluable lessons about the signals processing design process.

7.0 Recommendations

Applying real-time biomedical signals to this ECE course's signals processing setup presented an aspect somewhat different from most 18-551 design projects. In addition to adjusting for the wildly varying aspects of the biological signal itself, we found it unexpectedly challenging to read in any sort of reliable signal to process. We would recommend that future projects involving real-time biomedical signals acquisition treat this data capture matter with considerable gravity.

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[8] Casasent, David. 18-551: Digital Communications and Signal Processing Systems Design http://www.ece.cmu.edu/~ee551 (Jan 2000).

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