Infrared Sensor and Amplifier for Blood Pressure Monitor

University of Minnesota
Department of Electrical Engineering
EE 4951 – Senior Design
Spring 2012

The Phoenix Senior Design Group:

Yan Qu
Daniel Kuha
Zhongyu He
Shams Faruque
Zi Huang

Advisors:

Larry Beaty
Doctor Emad Ebbini

Abstract: The Phoenix Project is developing an ambulatory blood-pressure monitor that is unobtrusive, inexpensive and easy-to-use. To meet these goals, a sensor must be developed that can be used to acquire accurate information about the blood pulse. Ideally, this sensor should deliver an electrical waveform that precisely represents that of the blood pulse through an artery. In this project, the Phoenix Senior Design Group explored the use of infrared technology in the implementation of this sensor. In particular, an infrared LED was used to emit photons into an artery, and a phototransistor was used to detect changes in the amount of radiation that was reflected. This approach was highly successful in acquiring the blood pulse waveform, and the technology appears to be a highly feasible solution, but we were unable to determine precisely how accurate the signal is, and some electrical problems remain to be solved.

Table of Contents

1 - Phoenix Senior Design Project Background

1.1 - Introduction

The Twin Cities IEEE Phoenix Project seeks to design a blood pressure monitor that is non-intrusive, inexpensive, and can be worn twenty-four hours a day for a week or more. By monitoring how a patient's blood pressure changes over an extended period of time, healthcare professionals will be able to identify, predict and diagnose various cardiovascular diseases in patients. Since traditional methods for measuring blood pressure, which require an inflatable cuff and air pump, are inconvenient for these purposes, our blood pressure monitor will utilize the idea that the blood pressure can be derived from the Pulse Transit Time (PPT), or the time it takes for a pulse to travel down the artery.

Currently, the central challenge in building this blood pressure monitor is the sensor itself, which must obtain an accurate electrical signal that represents the full pulse waveform from two locations on the body. A variety of sensors have been explored and achieved inadequate results. The central focus of the Spring 2012 Phoenix Senior Design Project was to investigate the use of an infrared LED as an emitter and an infrared phototransistor as a receiver to implement this sensor.

To test this technology, we assembled an amplifier prototype which featured eight channels. Each channel had its own sensor input, amplifier, and allowed for adjustable gain and input DC offset. The output of the amplifier channels were fed into a DAQ that performed an analog-to-digital conversion and fed the data to a PC. SignalExpress and MATLAB were then used to acquire, store, and process the data.

In addition to our design, several things need to be considered: the cost of the end device which must be globally inexpensive, the cost of our own prototype and monetary resources available, accuracy of the signal, power consumption and efficiency of the device, safety issues with tissue exposure to infrared radiation, and the overall feasibility of the design.

Our approach was successful in acquiring the full blood pulse waveform. We have also shown that signal processing techniques can be used to improve the quality of the signal. Further investigation of the signal needs to be made to ensure that all of the necessary frequency components of the blood pulse are preserved with this technique, and a few other problems regarding signal quality need to be solved before moving forward with this design, but we have found that this technology is very promising.

1.2 - Chronobiology Background

Halberg Chronobiology Center is trying to obtain an Ambulatory Blood Pressure Monitor suitable for long term use, encourage its use on a large scale to monitor health in patients around the world, and to encourage the development of diagnostic, prevention and treatment techniques.[1] They believe that changes in blood pressure cycles can be used to prevent and treat hypertension, heart attack, stroke, kidney disease, retinopathy, and other severe or even fatal diseases. Measurements of blood pressure cycles can be analyzed if they are continued for at least 7 days with automatic ambulatory monitoring that is easily available for everyone. This will enable people to receive treatment who would never be treated, reduce the debilitating side-effects of unnecessary medication, make visible critical symptoms that do not occur during physician visits, detect the onset of the vascular diseases which often do not have easily visible symptoms, and greatly reduce the enormous healthcare cost of catastrophic events by preventing them.[1]

1.3 - Objectives of the Phoenix Project

In general, the Phoenix Project expects the Senior Design group to carry out investigation on the sensor that is to be used in the monitor. The Phoenix Project is in need of an effective sensor circuit design that receives usable signals from the human body, relevant data and analytical sensor criteria.

The Phoenix Project's objectives on development of the monitor can be listed as follows:

- **Inexpensive**

The blood pressure monitor should be inexpensive on a global scale so that patients in impoverished or developing nations have access to it. The end-product should cost no more than $50, and ideally The Phoenix Project would like it to be $10 or less.[1]

With this in mind, our prototype, which is essentially a testing device, should cost no more than $100 for all materials and components.

- **Unobtrusive**

The blood pressure monitor needs to be worn day and night for several days with little or no significant effect on the patient's life. It should be no more encumbering that a wrist watch, a Band-Aid or a piece of jewelry, and it should be able to be used wherever the patient is, such as at home or at work when allowed, and while they are sleeping.[1]

The Phoenix Senior Design group will make effort on sizing the final sensor design into a reasonable scale to meet this requirement. Battery power will be used.

- **Easy to Use**

The monitor should be easier to use than current devices relying on the blood pressure cuff while providing measurements of equal accuracy. The patient should be able to ignore it, but it is desirable for them to be able to determine that it is functioning normally and observe a blood pressure and heart rate measurement if they wish. It should be automatic, so that measurements will be taken regardless of patient behavior. Also, it should allow manually initiated measurements.[1]

For this objective, the Phoenix Senior Design Group will design the sensor placement scheme so that its placement is straightforward and unambiguous.

- **Week of Blood Pressure Measurements**

The monitor should record measurements at least every half hour for at least 7 days. The Project wants to measure systolic and diastolic blood pressure, and heart rate. Additionally, The Project would like to measure physical activity to determine if vigorous body movement, such as physical exercise, influenced the blood pressure measurement; and we would like to measure blood flow.[1]

For the measurements for both systolic and diastolic blood pressure, a complete pulse wave form must be obtained by the sensor circuit. The Senior Design group will make this requirement the major goal. Power consumption is also an important consideration because the end product will be powered by a battery.

1.4 - Previous Work

From the report of the previous works in Phoenix Project, we learned that we can use PWTT to calculation the pressure. PWTT includes PEP (Pre-Ejection Period, which won't be used in our project) and a-PWTT (Pulse Wave Transit Time in the Artery). The Senior Design Group has been given the equation that can calculate the blood pressure via PWTT from the Chen Patent[2]

$$P = a + b \ln(T)$$

where a and b are constants that can be determined through measurements.

In order to get the PWTT, we have to record the full waveform of blood pressure pulses.

The previous group tested various kinds of sensors and decided to use magnetic sensor, which targets to the ferri ions in the blood, to detect the waveform of blood pressure pulses. But they failed to get a good result for that.

Engineers in Phoenix Project developed a circuit with IR sensor to detect the waveform and got inspiring results. However, the bottom half of the full waveform was missed for reasons unknown. Nonetheless the results were encouraging and provided merit to our decision to use an IR sensor.

1.5 - Initial Project Objectives

The most important part of the blood pressure sensor is the heartbeat monitor. For developing a prototype heartbeat monitor, the following can be achieved:

- A PCB to house the prototype circuit.
- An amplifier and filter for the heartbeat signal.
- Switchable filters.
- A modular device with multiple channels for input.
- Sensor connectors for the purposes of switching them in and out.
- What range of IR emitters are the most effective.
- Information on how safe IR emitters are on the skin.
- Whether an array of IR sensors is more effective than a single sensor.
- Placement of the sensors on the skin.
- Device must utilize voltages that can be obtained by a battery.
- Document ways to reduce manufacturing costs of the overall design.

Outside this specific device, the Phoenix Project will accept any contribution that helps them meet any number of other objectives.

- DAQ, measurement, and testing procedures.
- How well the current DAQ unit is working.
- Research on super capacitors as a possible source of power for the blood pressure monitor.
- Safety information about our chosen Infrared emitter to which human tissue will be exposed.

2 - Design Approach

2.1 Design Overview

Figure 2.1 outlines the basic design of how our prototype was implemented and tested. The sensor system is attached to some area on the body where a pulse waveform can be obtained. Various configurations of the sensor system were tested until we found an unobtrusive sensor that delivers the full waveform. The PCB had eight channels—with one of the channels being shown in Figure 2.1—each with terminal blocks to provide modularity. The Data Acquisition module is a commercial product from National Instruments, which interfaced with a SignalExpress on the PC.

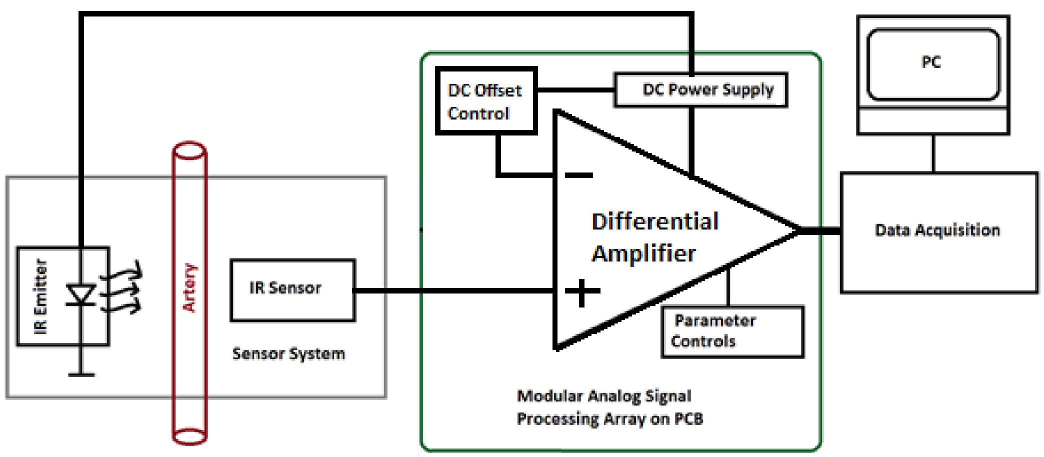


Figure 2.1

2.2 Initial Design Specifications

- Develop a non-intrusive sensor using an Infrared emitter and sensor to generate an analog representation of the blood pulse.
- The full blood pulse waveform is necessary to calculate diastolic and systolic blood pressure.
- Test within a wavelength range of 650nm to 950nm.
- Sensor (at least 4 sensors for each measuring position) array to accommodate the positioning issue.
- Blood pulse must be accurate enough to calculate blood pressure within 3mm Hg.
- Amplifier is an active low-pass filter with a cutoff frequency of 30 Hz.
- Amplifier circuit has an array of eight channels each with amplifiers so that multiple sensors can be processed.
- Amplifier circuit is modular so that a variety of sensors can be configured with it.
- Passband gain and DC offset must be adjustable so that the full pulse can exist within the 5V of head room regardless of the sensor we are using.
- The final sensor and amplifier prototype must cost no more than $100.00 in materials.
- Be able to measure the power consumption of the entire circuit.
- The amplifier will be powered with a 5V Power Supply.

2.3 - Sensor Design

Our design approach calls for a device which shines infrared radiation into the tissue. This infrared emission is reflected back from the tissue in quantities related to the quantity of blood currently in the artery. An infrared diode is used to generate the emission, while a phototransistor is used to “sense” the emission which is reflected back.

We tested a variety of infrared diodes with phototransistors, and ultimately settled on the TCRT1000 pictured below because it contained both of these devices in a single package. This device, shown in Figure 2.2a, is very small with dimensions of 7 x 4 x 2.5 mm. The emitter wavelength is very close to visible light in the infrared spectrum at 950nm. Collector current of the active phototransistor is typically 0.5 mA. It is also very inexpensive with a unit price of $0.04.

Figure 2.2a

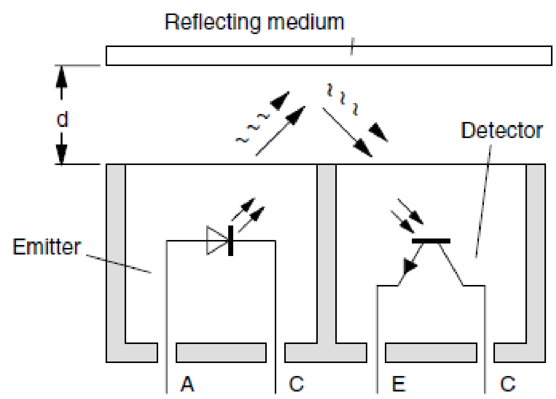


Figure 1.2b

Figure 2.2b shows the internal operation of the emitter and phototransistor. The reflecting medium in this case is the tissue into which the infrared photons are emitted. It should be noted that the bulk of the photons received at the base of the phototransistor are not reflected from the blood pulse at all, but from other chemicals and tissues. This results in a DC offset that is highly dependent on the pressure with which the sensor is placed on the skin and has been a major issue in our design. This is discussed in greater detail in section 3.4.

Wires were soldered to the pins and connected to an amplifier circuit.

2.4 - Sensor Placement

We tested the sensor in four different locations: fingertips, wrist, the forearm close to the elbow, and the earlobe. The quality of the pulse signal is highly dependent on the proximity of the artery with the surface of the skin. The most effective locations were the finger and, to a lesser extent, the wrist.

2.5 - Amplifier Design

To improve the quality of the signal received from the sensor, we developed a simple amplifier, shown in Figure 2.3. Initially this amplifier was to be configured as an active low-pass filter, but this was removed when we decided to use digital filtering.

The amplifier is a single-stage differential amplifier which uses two TL082 Wideband JFET Op Amps on a single chip. It uses simple a simple non-inverting feedback configuration through R3 and R4. These two resistors dictate the gain of the amplifier with the following equation:

$$V_{out} = V_{in}\left(1 + \frac{R_4}{R_3}\right)$$

One of the op-amps, U2A, is configured as a unity-gain buffer in the feedback network. This circuit receives an input from a potentiometer that is used to adjust the DC Offset.

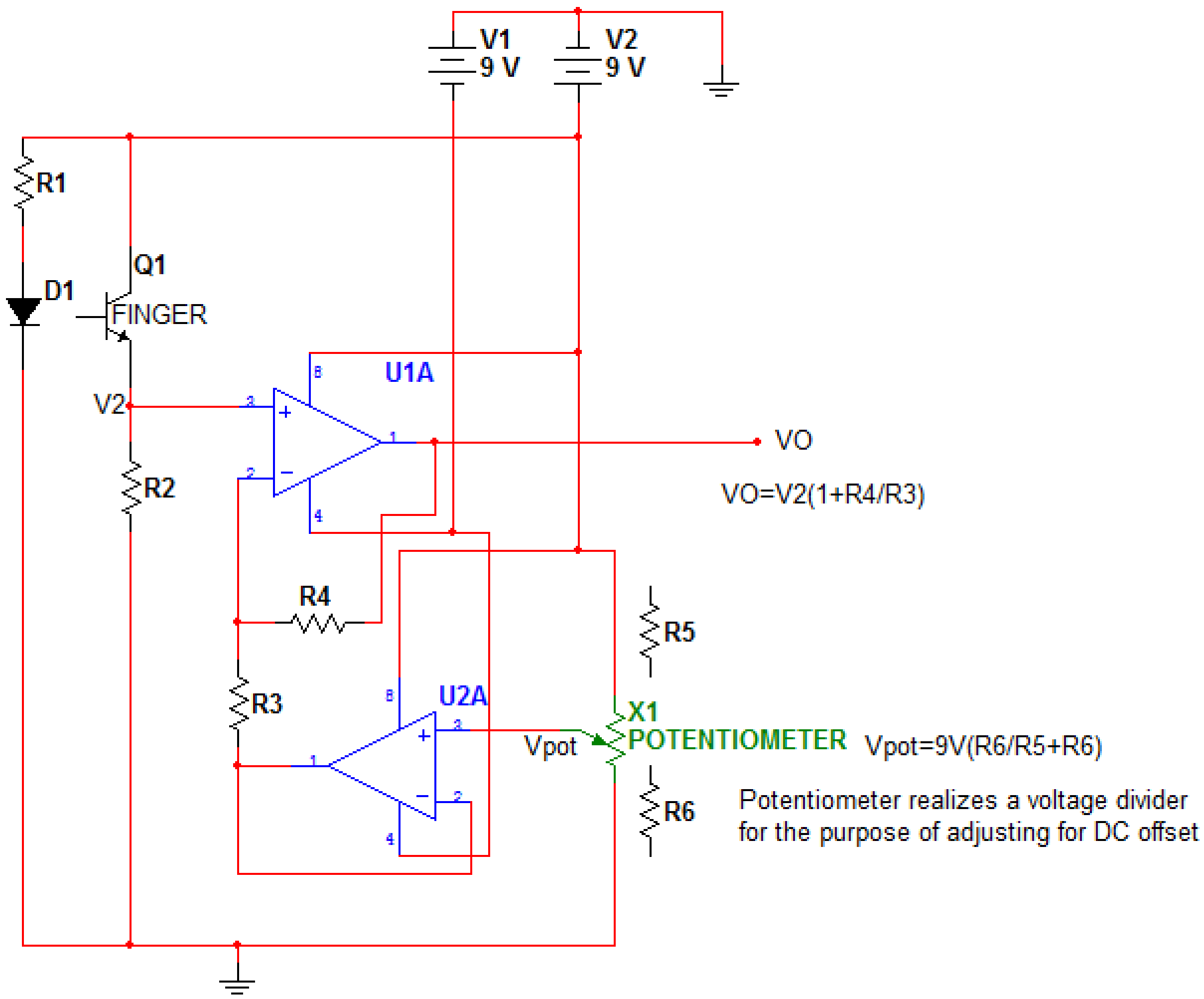


Figure 2.3

2.6 - Eight-Channel Prototype

Our prototype features eight channels, each with its own amplifier. The resistors R4 and R3, which dictate the gain of the amplifier, are replaced with a thumbwheel potentiometer so that the gain is adjustable.

Due to the nature of The DC-Offset is adjusted with a large sliding potentiometer.

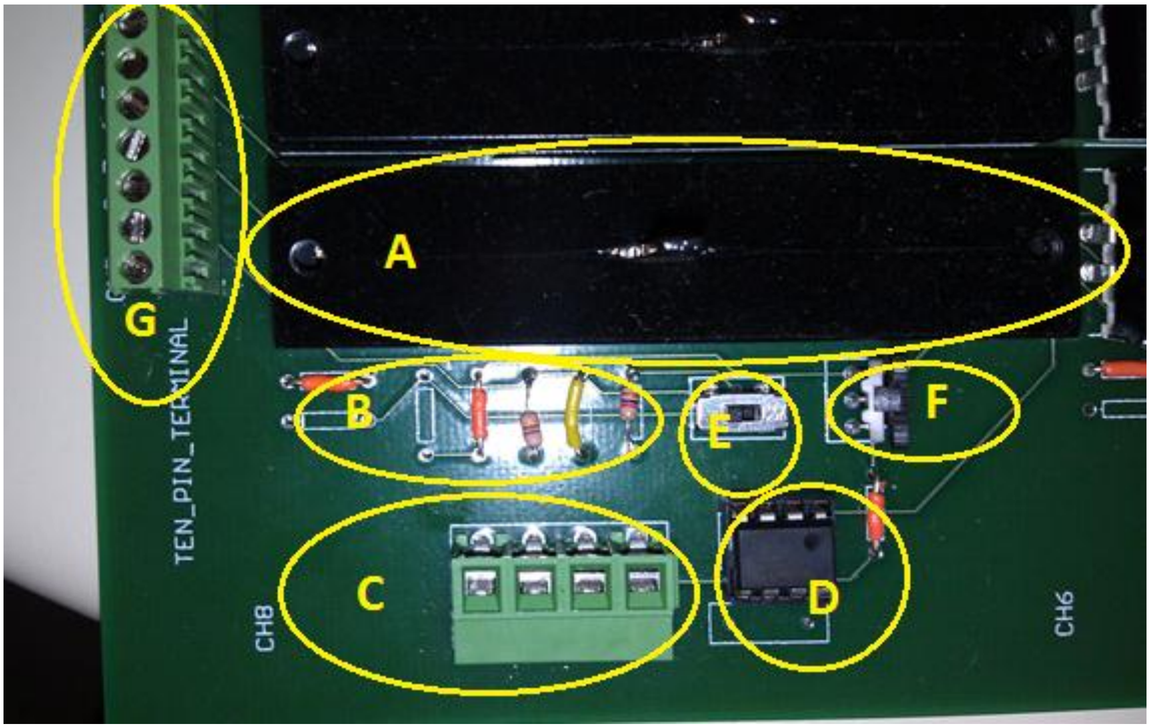


Figure 2.4

Figure 2.4 shows a single channel with letters labeling prominent devices corresponding to the following:

- **A.** Sliding potentiometer used to adjust DC Offset. It is very large to make it easy to precisely adjust the highly sensitive DC Offset.
- **B.** Through-hole ports used for biasing resistors in the sensor circuit, given by R1 and R2, and jumper wires to bring power to the sensor.
- **C.** Terminal Block to which the sensor is attacked.
- **D.** TL082 op amp to amplify the signal. Two JFET op-amps in a single chip.
- **E.** Switch which used to turn on a channel.
- **F.** Thumbwheel potentiometer which adjusts the gain of the amplifier.
- **G.** Terminal block which contains the output signals of all eight channels.

2. 7 - Data Acquisition and Digital Conversion

The DAQ we used in this project is National Instrument USB-6210, which has 16 digital Input /Output pins and 16 analog input pins. The voltage range of the analog input is ±10V. Any overvoltage input may damage the device permanently, which should be noted.

In order to use the DAQ, a sub-program of Labview called Signal Express is needed (not working for Mac OS). In our project, we only needed to use those analog input pins to transfer the analog signal from the PCB broad to digital data to be processed in computers.

With the Signal Express installed in the computer, we do A/D transformation with the following procedures.

1) Connect the NI USB-6210 to the computer via USB cable.
2) Start a new project in Signal Express
3) Add a new analog data acquisition in Signal Express to acquire to analog signal from the device. (Note: the pins labeled 16-31 on the device are correspondingly ai-00 – ai15 in Signal Express)
4) Set up the pins into differential data acquisition mode by selecting the ground pin first, then hold the 'control' button and select the signal pin, then change the mode to differential mode.
5) Set the sample rate to 1k. (Note: sample rate determine the accuracy of the signal. The higher might be the better as long as the device support, but it also would take a significant longer time to deal with the much larger amount of data. And due to the Nyquist Law, the sample rate should be no lower than the highest frequency of the signal you want.)
6) Set to "samples to read" to 10k. (Note: this means 10s sampling time, which is 10k/1k. The larger means the longer sampling time for a particular sample rate. And also this is the only amount of samples you can export or save)
7) Go to the data view, and add the signal you want to observe.
8) Run the program. (Note: If you want to observe the data for a long period, you can choose to run continuously. If you want to save or export the data, you'd better run only a little longer than the sampling time, which in our case, run for 12s)
9) Export the data to clip board or Excel (Valid license of Excel needed)

We also tested the older DAQ. It's still working basically in the same way. However, when we tested it with function generator, a significantly large DC offset was seen. The results is still linear corresponding to a linearly changing input. We do believe that the DC offset can be dealt with by software.

2. 8 - Digital Signal Processing

After acquiring data from the DAQ, we implemented digital filters using Matlab to deal with noise as well as the fluctuation in DC offset.

Figure 2.5 shows a fast Fourier analysis of the original data acquired. The frequency components are mainly distributed within the range from 0 Hz (DC) to approximately 20 Hz. We treat signals with frequency higher than 25 Hz as noise, and signals with frequency lower than 0.1 Hz as unwanted DC offset. This means ultimately we need a band pass filter with a pass band starting from 0.1 Hz to 25 Hz.

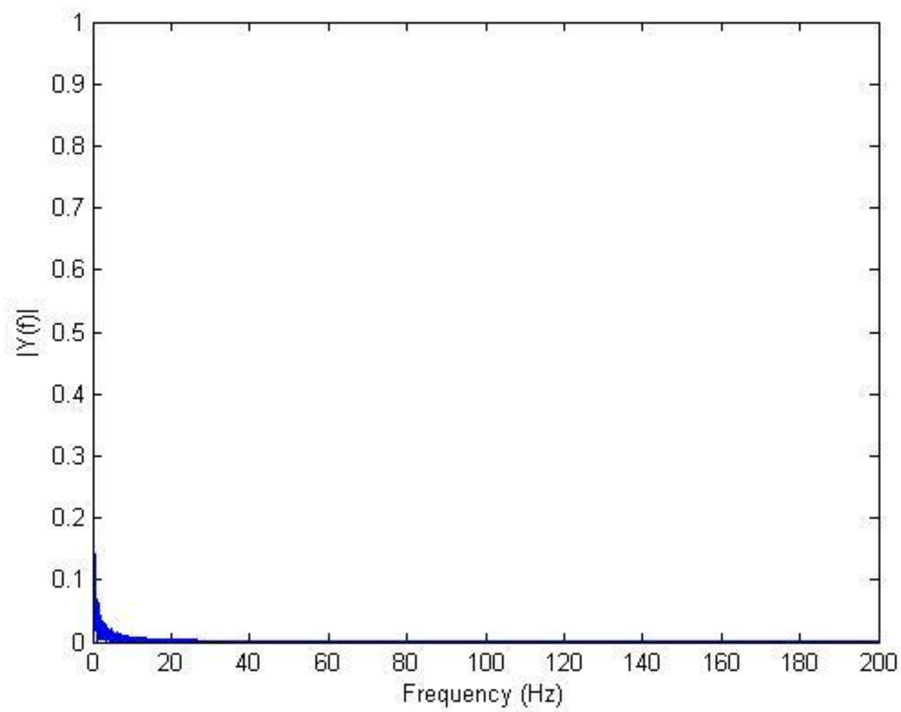


Figure 2.5: Fast Fourier Transform of Unfiltered Data (Shams Faruque; Index Finger)

We designed a two-stage filter. The first stage is a 4th-order Butterworth band pass filter with cut off frequencies 0.1 Hz and 200 Hz. Fig. 2.6 shows the frequency response of this filter. Notice there is a steep slope near 0 Hz.

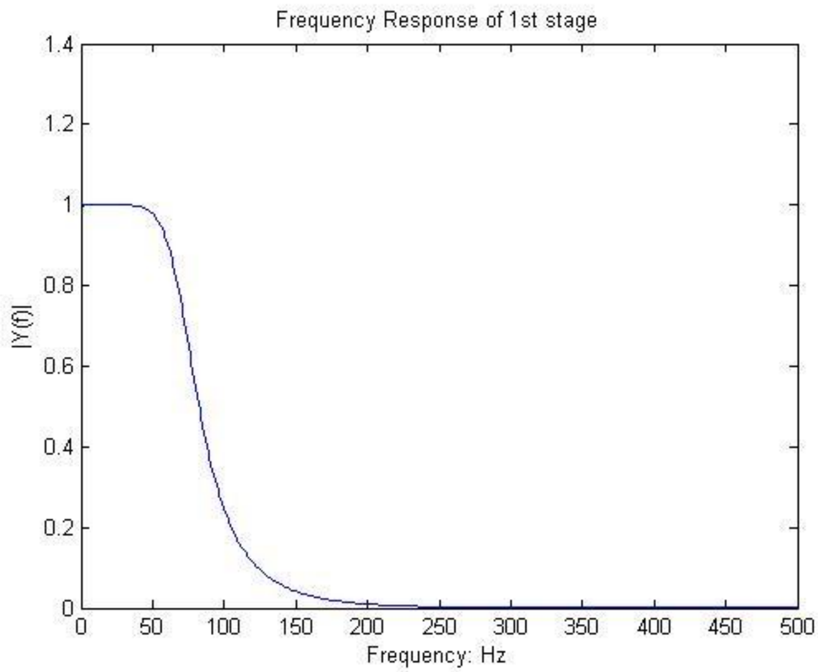


Figure 2.6: Frequency Response of the 1st stage filter

This filter takes care of the changing DC off set (0 to 0.1 Hz), and filters part of the high frequency noise. The fast Fourier analysis of the signal filtered by this first stage is below along with a time domain waveform:

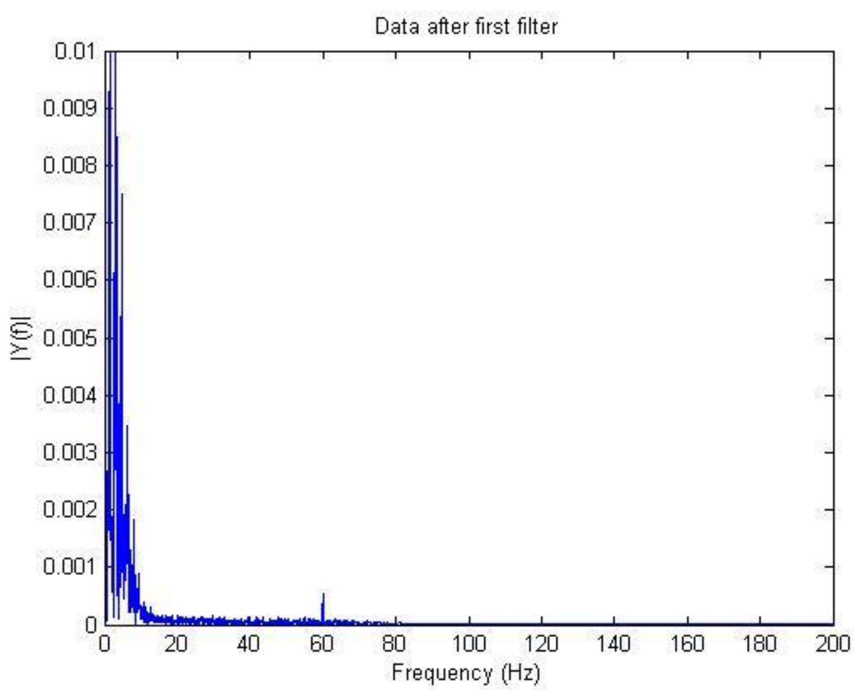


Figure 2.7

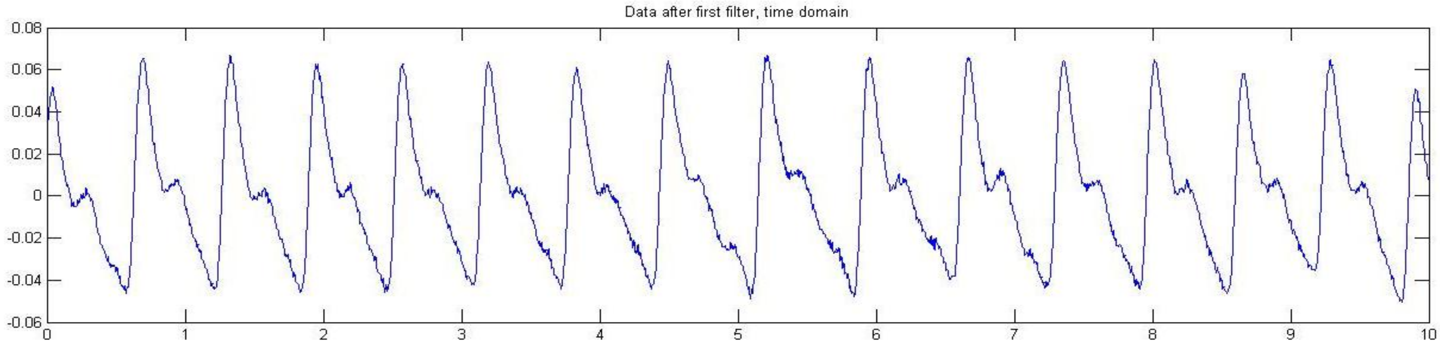


Figure 2.8

We can see that the DC offset and most of the high frequency noise is filtered out, leaving us some of the lower frequency noise. Also, we can see there is a small spike at 60 Hz, which is due to the interference from the AC power supply.

The second stage is a 10th-order Chebyshev II low pass filter, with cutoff frequency of 25 Hz. The frequency response is plotted below.

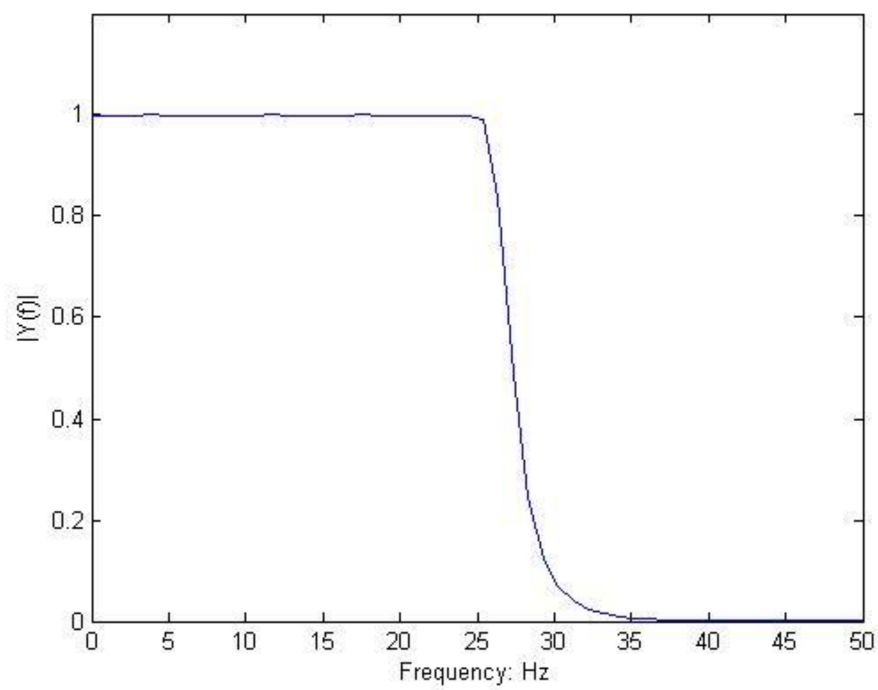


Figure 2.9

The 2nd stage filter mainly gets rid of the 60 Hz noise. The final filtered waveform is shown below:

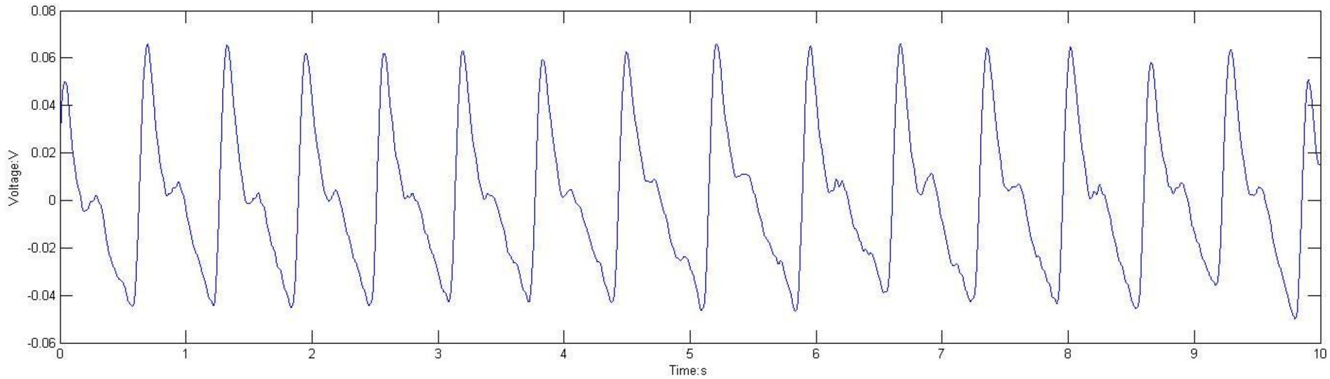


Figure 2.10

The digital filters we implemented are still somewhat basic, and we haven't been able to verify whether our filter blocks any signal that should have been kept. And it is possible that there is still some very low frequency noise left. To solve these problems, more advanced DSP algorithms can be implemented in the future, and it can be done with a microcontroller or a DSP chip in the final blood monitor product.

2. 9 - Risk Assessment and Management

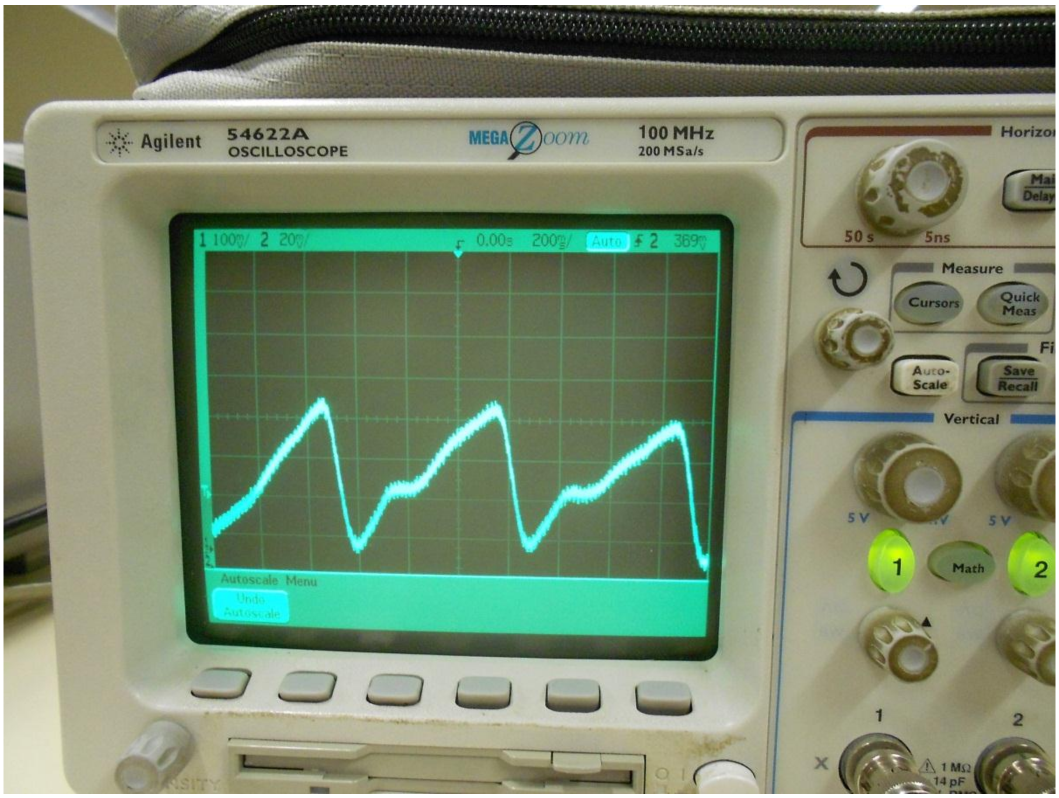
We anticipated several risks with our design process. Our major concerns are listed below, along with how we will mitigate them.

- Errors in the PCB can cause significant delays due to the time it takes for a PCB to be delivered.
    - Design PCB quickly to allow adequate time to order additional corrected PCBs.
    - Errors on the PCB can be corrected by slicing out traces and soldering in jumper wires.
- Faulty components burnt components.
    - Components are typically cheap enough that we can order extra components in preparation for this scenario.
- Scheduling conflicts such as midterms, traveling,
    - Anticipate conflicts in the timeline.
- Not working at the design show.
    - Extra components will also allow us to have a backup prototype for demonstration. Worst case scenario will be to use our breadboard prototype for demonstration.
- Not able to obtain complete pulse waveforms.
    - To mitigate this, we will conduct a comprehensive investigation to test a wide variety of sensors, emitters, and sensor placement configurations in various locations on the body.
- It is possible that we may exhaust our monetary resources available through the ECE Depot.
    - We anticipate certain expenses and allow a cushion of $100.00 for miscellaneous and unforeseen expenses, as outlined in the budget plan below.

3 - Project Results

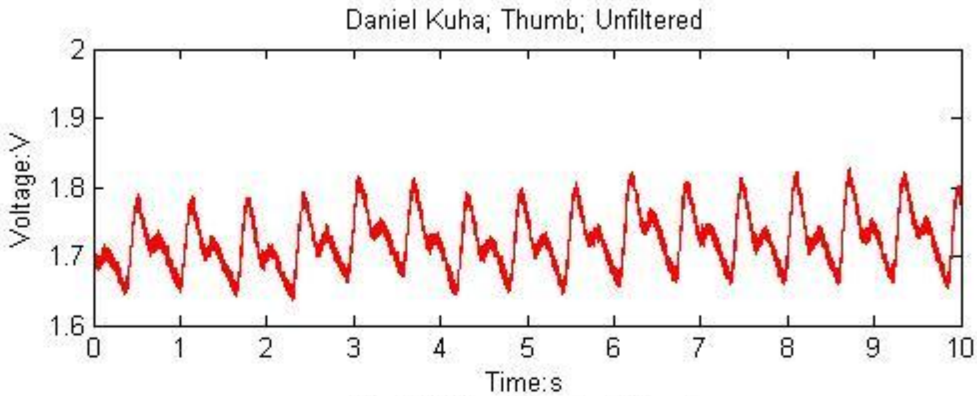
3. 1 Design Results

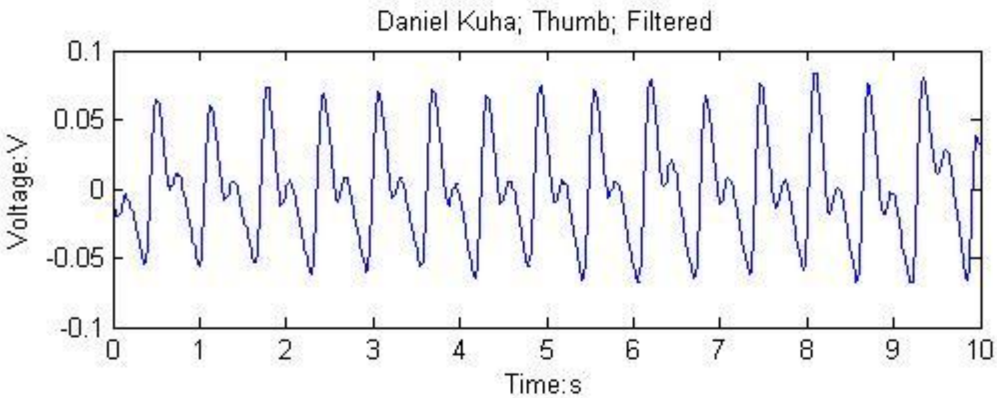
We were very successful in obtaining the blood pulse in a few different locations on the body. Very basic digital filtering has proven successful in removing both high-frequency and low-frequency noise from the signal, which tells us that more sophisticated noise filtering should prove very effective in delivering a high-quality signal.

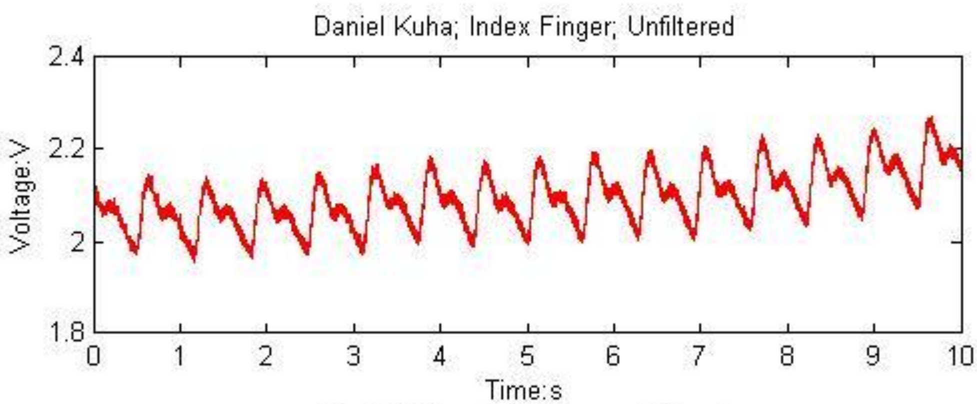


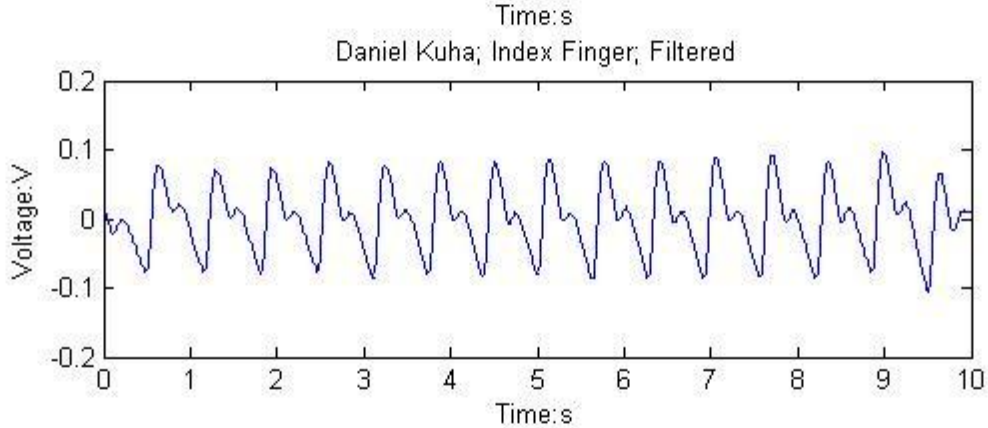
3.2 – Sample Data

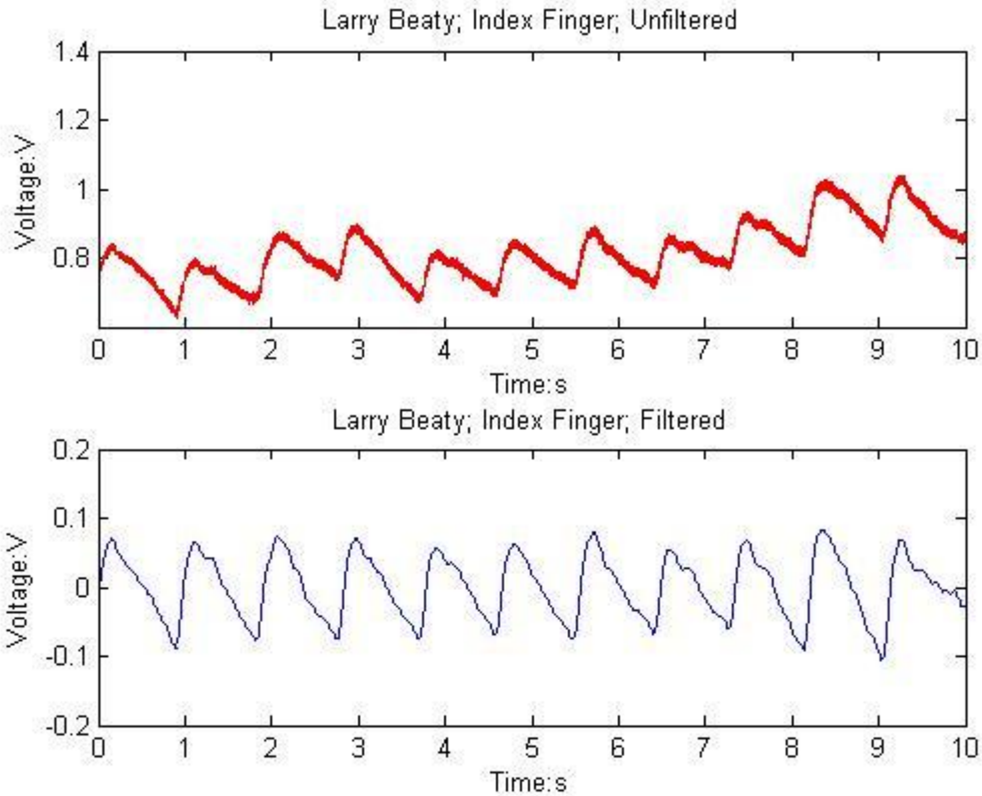
The following pages in this section contain a large amount of notable sample data and tests results. Samples were taken from all group members, as well as the project advisor, in locations including the various fingers, the wrist, and the earlobe. These images illustrate the effectiveness of the sensor in obtaining the signal and the use of simple digital filtering to eliminate high and low-frequency noise.

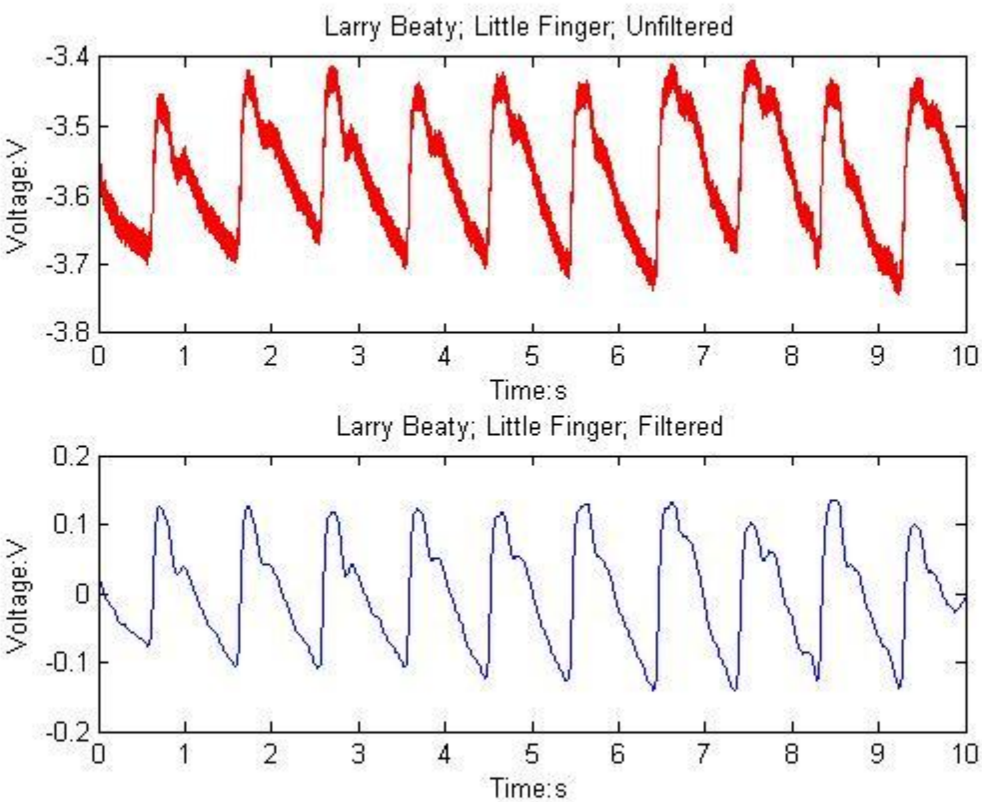

Daniel Kuha; Thumb; Unfiltered
Voltage:V
Time:s

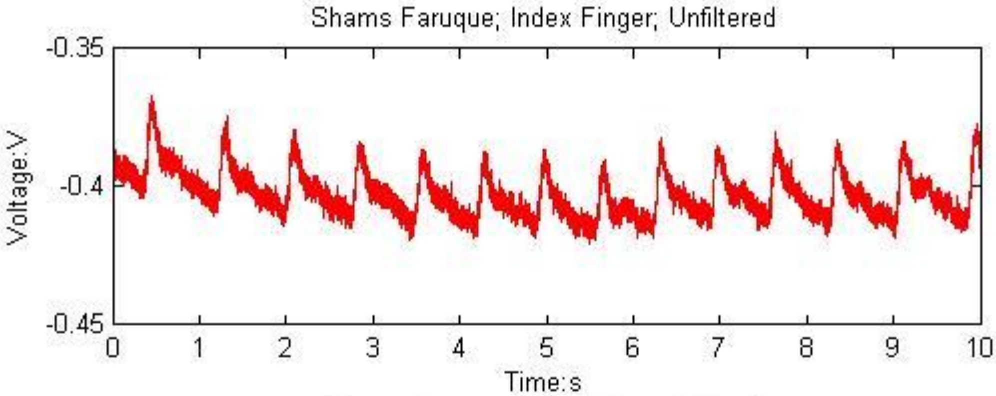

Daniel Kuha; Thumb; Filtered
Voltage:V
Time:s

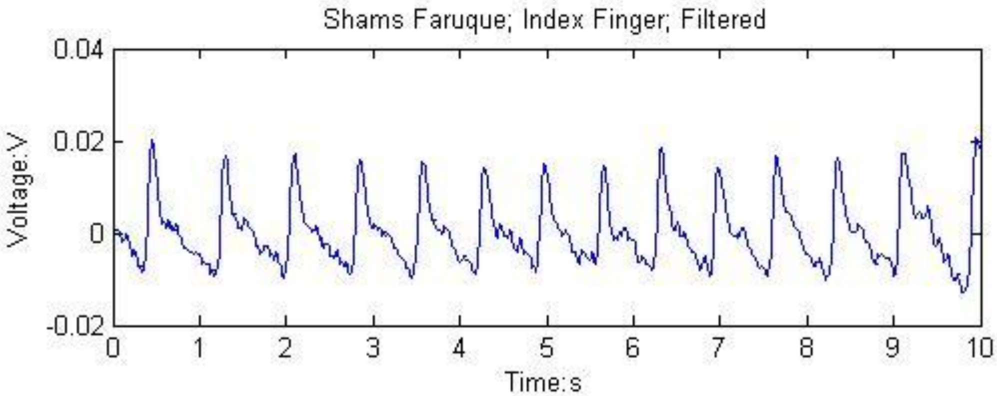

Daniel Kuha; Index Finger; Unfiltered
Voltage:V
Time:s

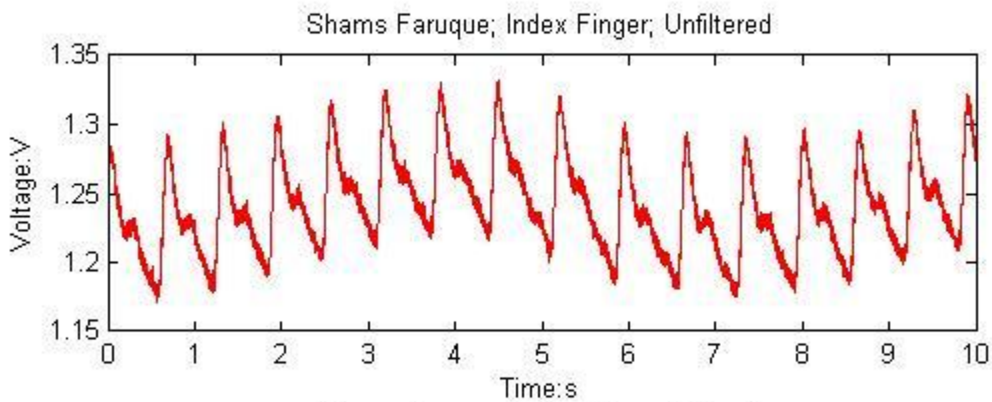

Daniel Kuha; Index Finger; Filtered
Voltage:V
Time:s

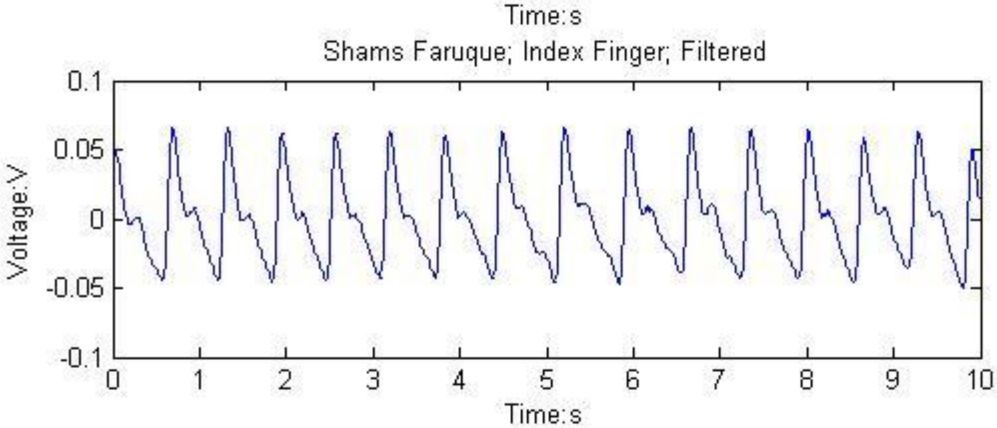

Larry Beaty; Index Finger; Unfiltered
Voltage:V
Time:s
Larry Beaty; Index Finger; Filtered
Voltage:V
Time:s

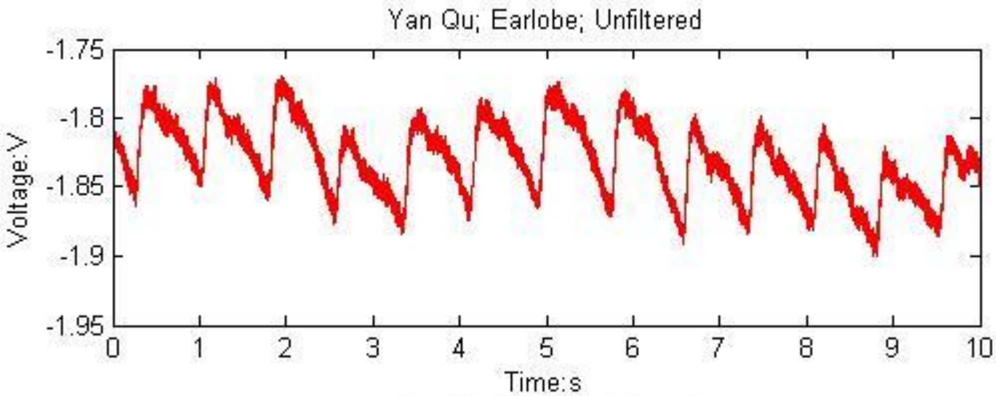

Larry Beaty; Little Finger; Unfiltered
Voltage:V
Time:s
Larry Beaty; Little Finger; Filtered
Voltage:V
Time:s

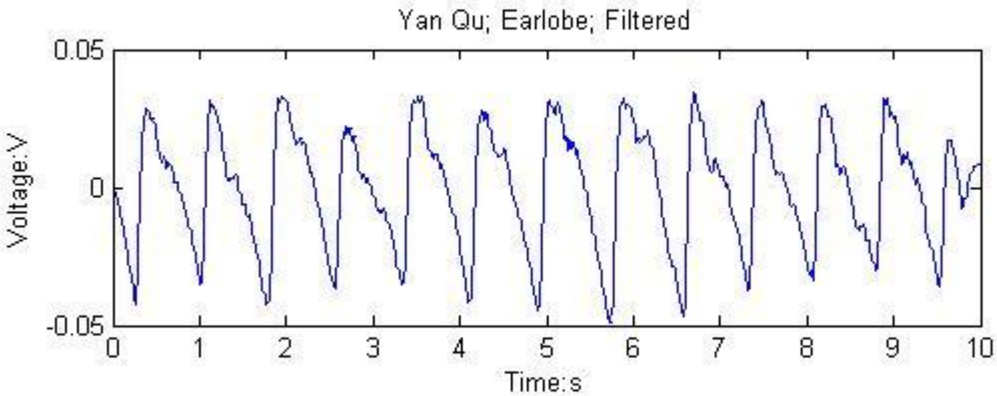

Shams Faruque; Index Finger; Unfiltered
Voltage:V
-0.35
-0.4
-0.45
0
1
2
3
4
5
6
7
8
9
10
Time:s

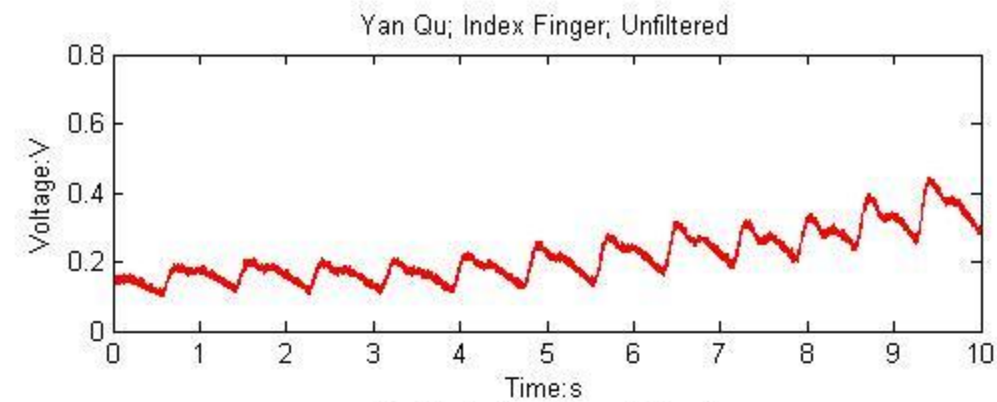

Shams Faruque; Index Finger; Filtered
Voltage:V
0.04
0.02
0
-0.02
0
1
2
3
4
5
6
7
8
9
10
Time:s

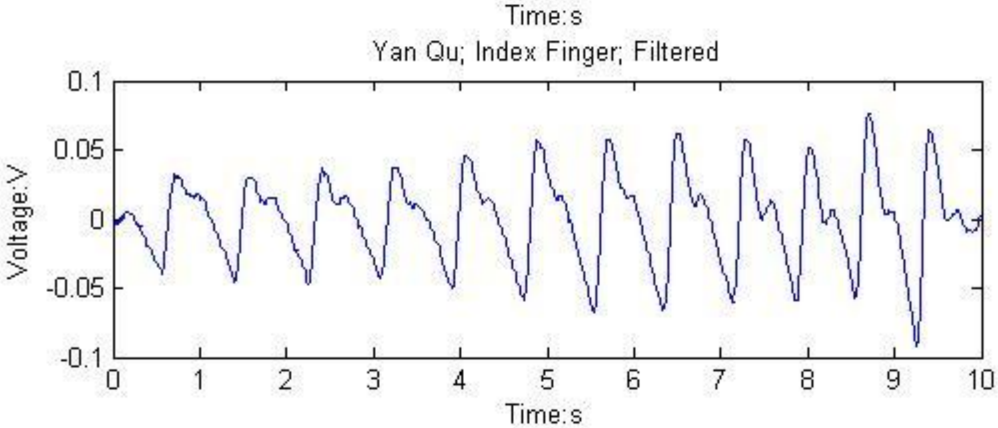

Shams Faruque; Index Finger; Unfiltered
Voltage:V
1.35
1.3
1.25
1.2
1.15
0
1
2
3
4
5
6
7
8
9
10
Time:s

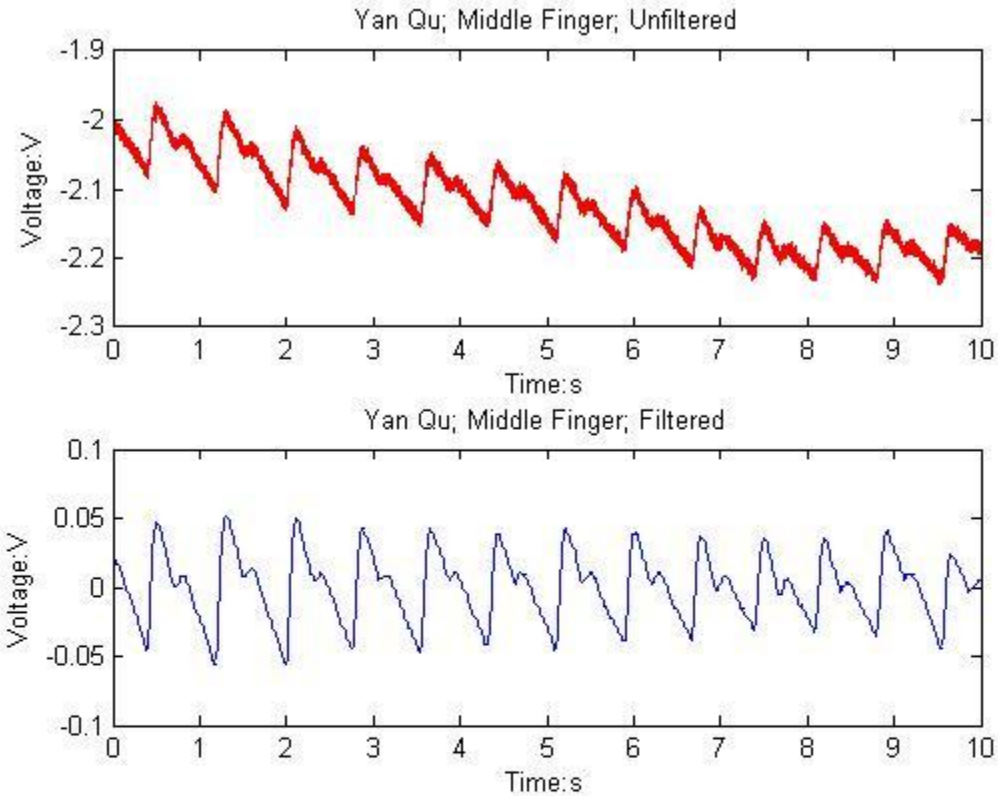

Shams Faruque; Index Finger; Filtered
Voltage:V
0.1
0.05
0
-0.05
-0.1
0
1
2
3
4
5
6
7
8
9
10
Time:s

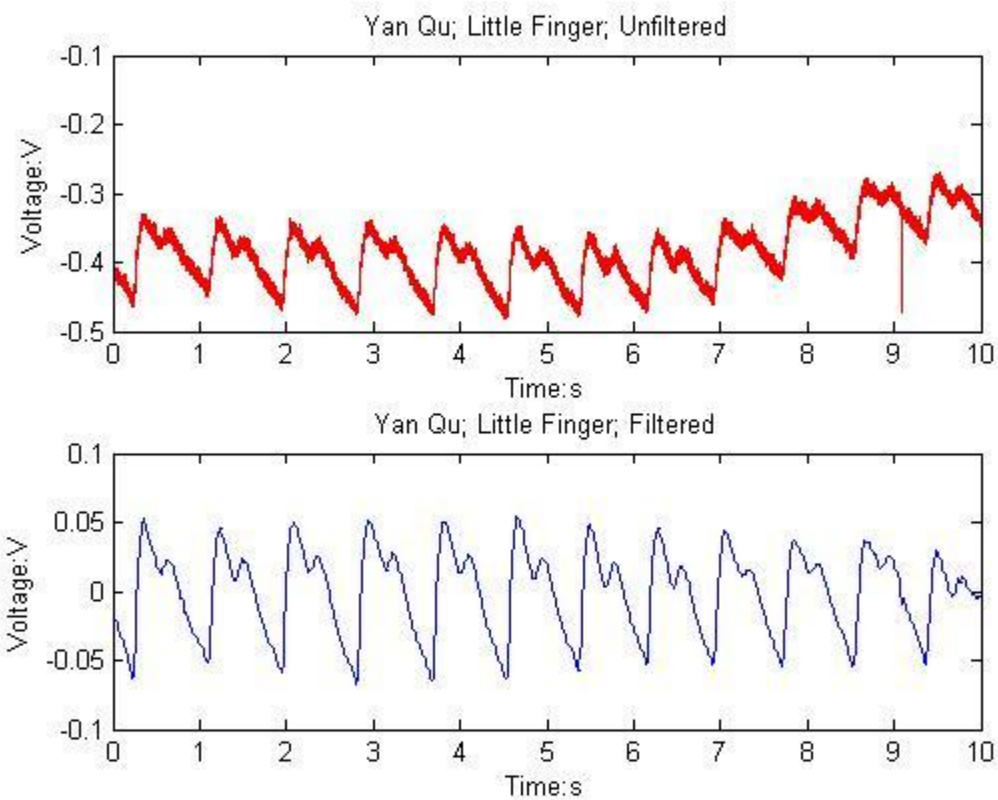

Yan Qu; Earlobe; Unfiltered
-1.75
-1.8
-1.85
-1.9
-1.95
Voltage:V
0
1
2
3
4
5
6
7
8
9
10
Time:s

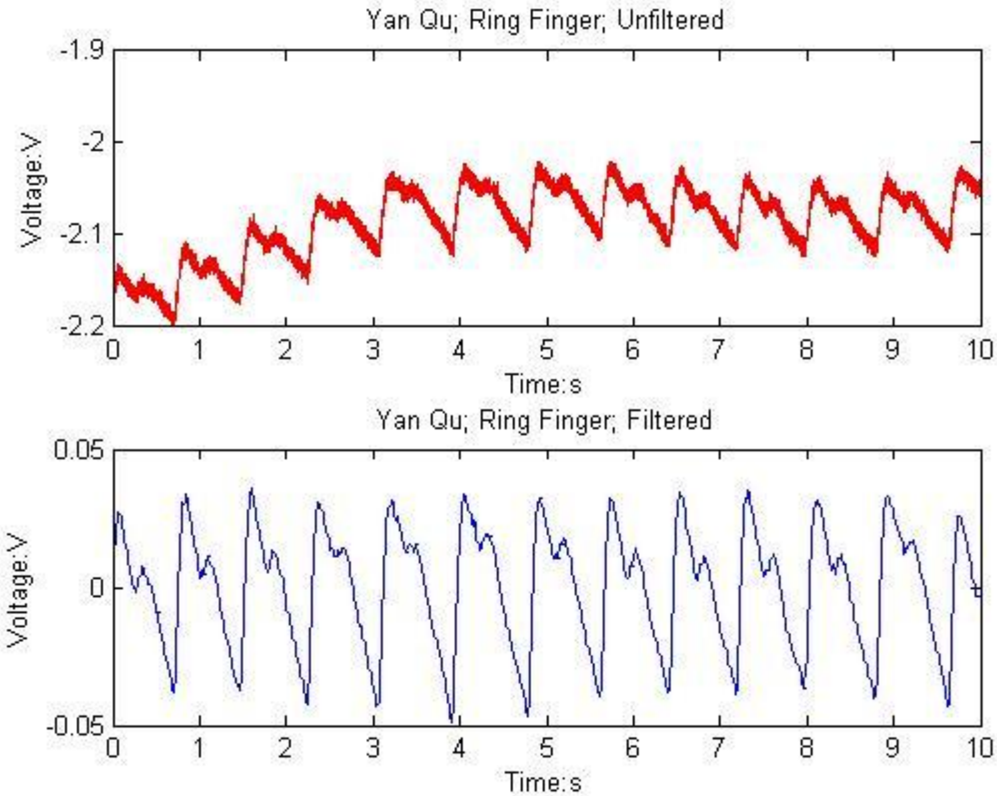

Yan Qu; Earlobe; Filtered
0.05
0
-0.05
Voltage:V
0
1
2
3
4
5
6
7
8
9
10
Time:s

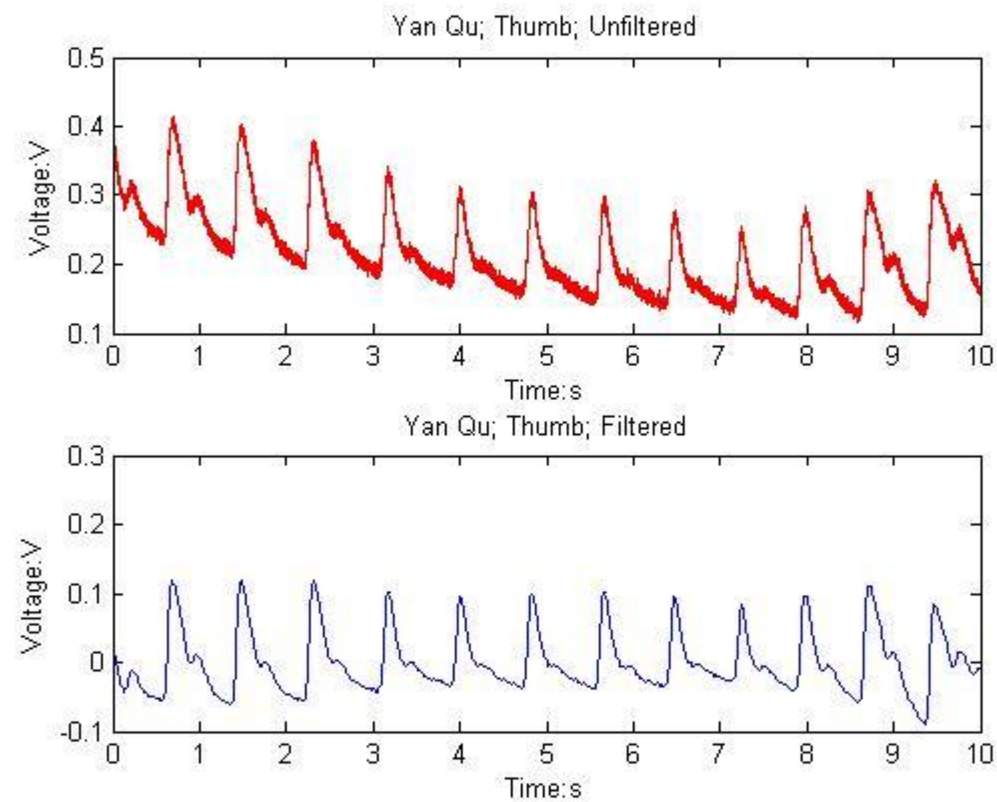

Yan Qu; Index Finger; Unfiltered
0.8
0.6
0.4
0.2
0
Voltage:V
0
1
2
3
4
5
6
7
8
9
10
Time:s

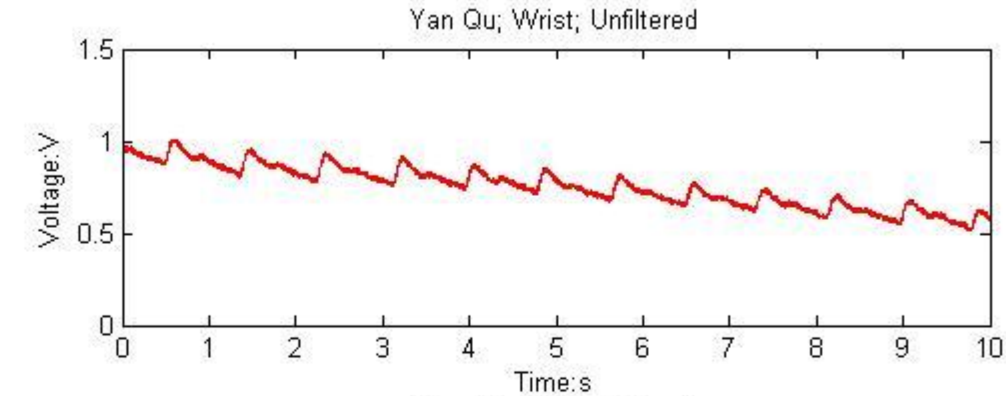

Yan Qu; Index Finger; Filtered
0.1
0.05
0
-0.05
-0.1
Voltage:V
0
1
2
3
4
5
6
7
8
9
10
Time:s

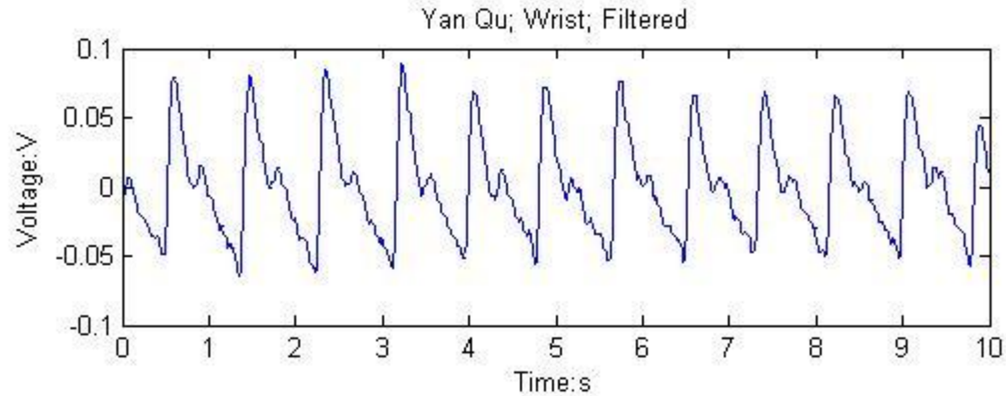

Yan Qu; Middle Finger; Unfiltered
-1.9
-2
-2.1
-2.2
-2.3
Voltage:V
0 1 2 3 4 5 6 7 8 9 10
Time:s
Yan Qu; Middle Finger; Filtered
0.1
0.05
0
-0.05
-0.1
Voltage:V
0 1 2 3 4 5 6 7 8 9 10
Time:s

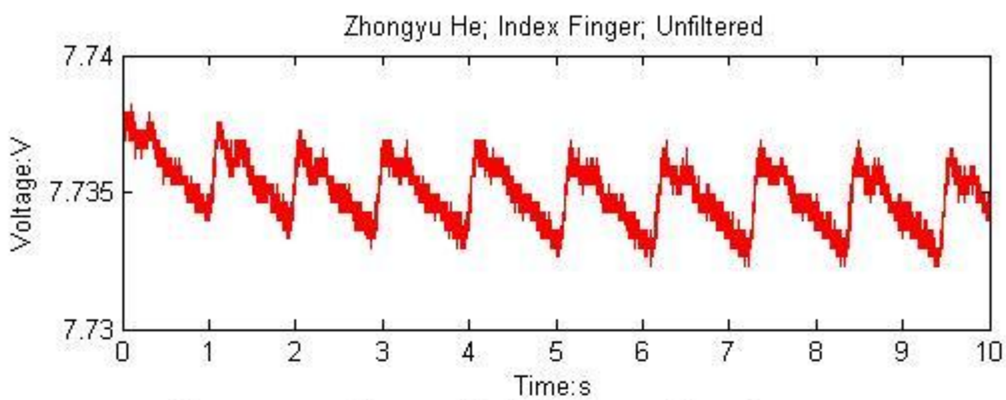

Yan Qu; Little Finger; Unfiltered
-0.1
-0.2
-0.3
-0.4
-0.5
Voltage:V
0 1 2 3 4 5 6 7 8 9 10
Time:s
Yan Qu; Little Finger; Filtered
0.1
0.05
0
-0.05
-0.1
Voltage:V
0 1 2 3 4 5 6 7 8 9 10
Time:s

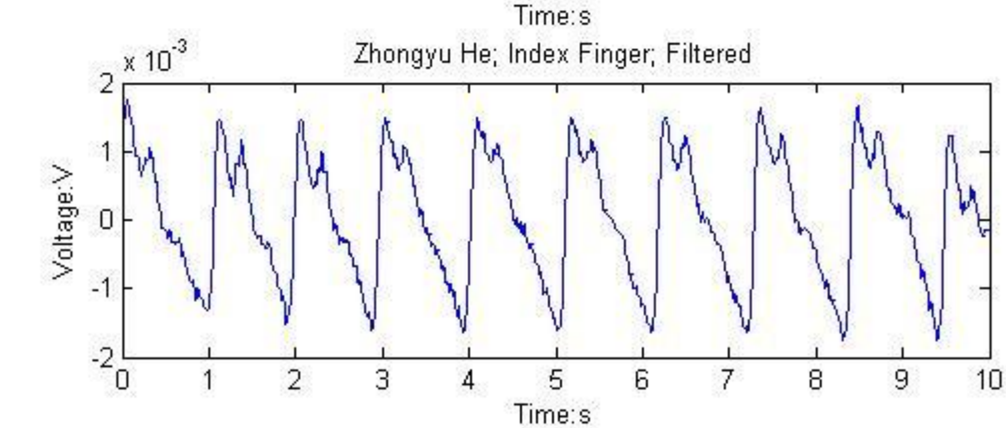

Yan Qu; Ring Finger; Unfiltered
Voltage:V
Time:s
Yan Qu; Ring Finger; Filtered
Voltage:V
Time:s

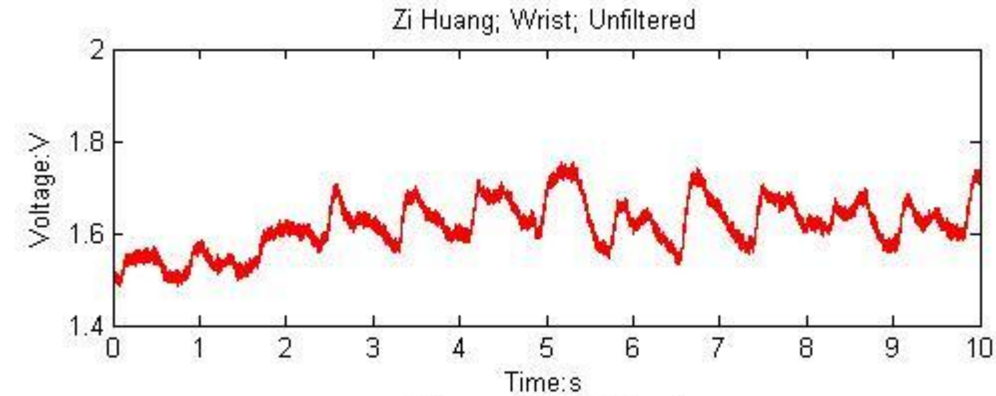

Yan Qu; Thumb; Unfiltered
Voltage:V
Time:s
Yan Qu; Thumb; Filtered
Voltage:V
Time:s

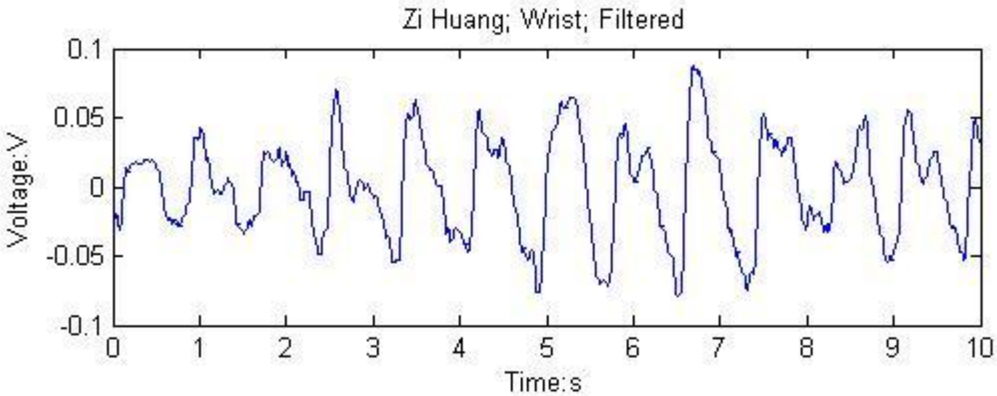

Yan Qu; Wrist; Unfiltered
Voltage:V
Time:s

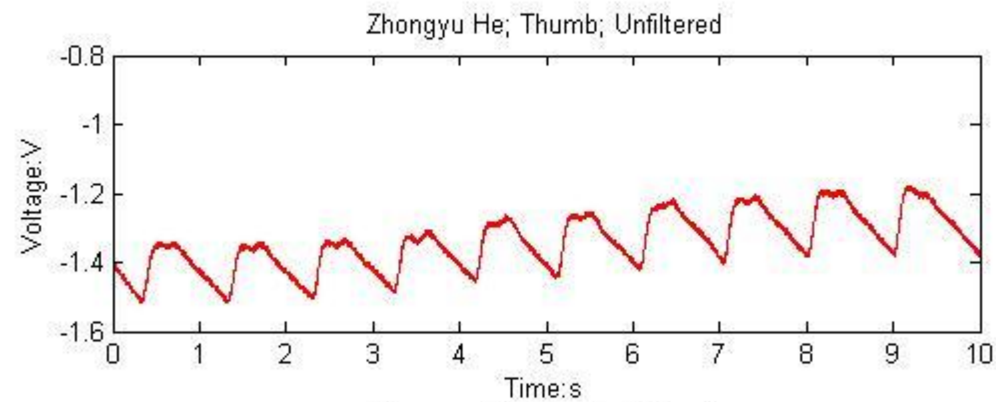

Yan Qu; Wrist; Filtered
Voltage:V
Time:s

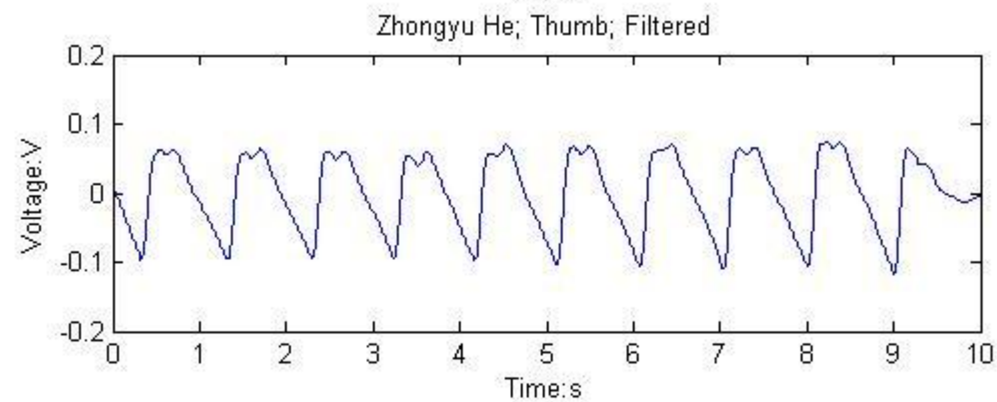

Zhongyu He; Index Finger; Unfiltered
Voltage:V
Time:s

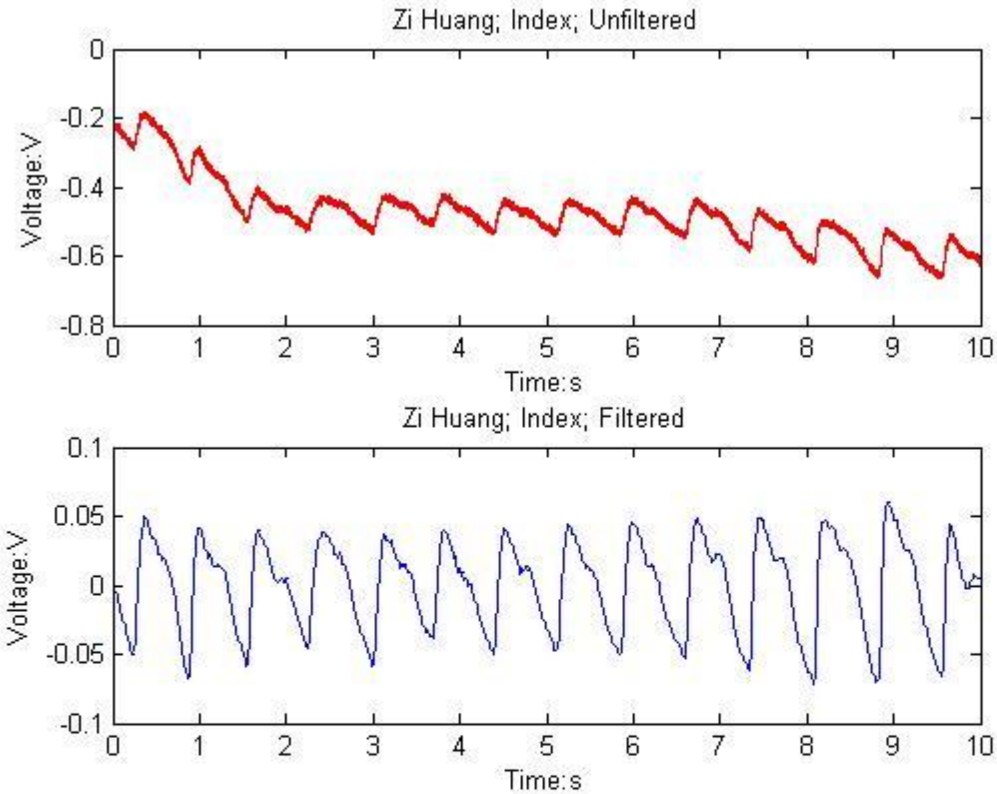

Zhongyu He; Index Finger; Filtered
x 10^-3
Voltage:V
Time:s

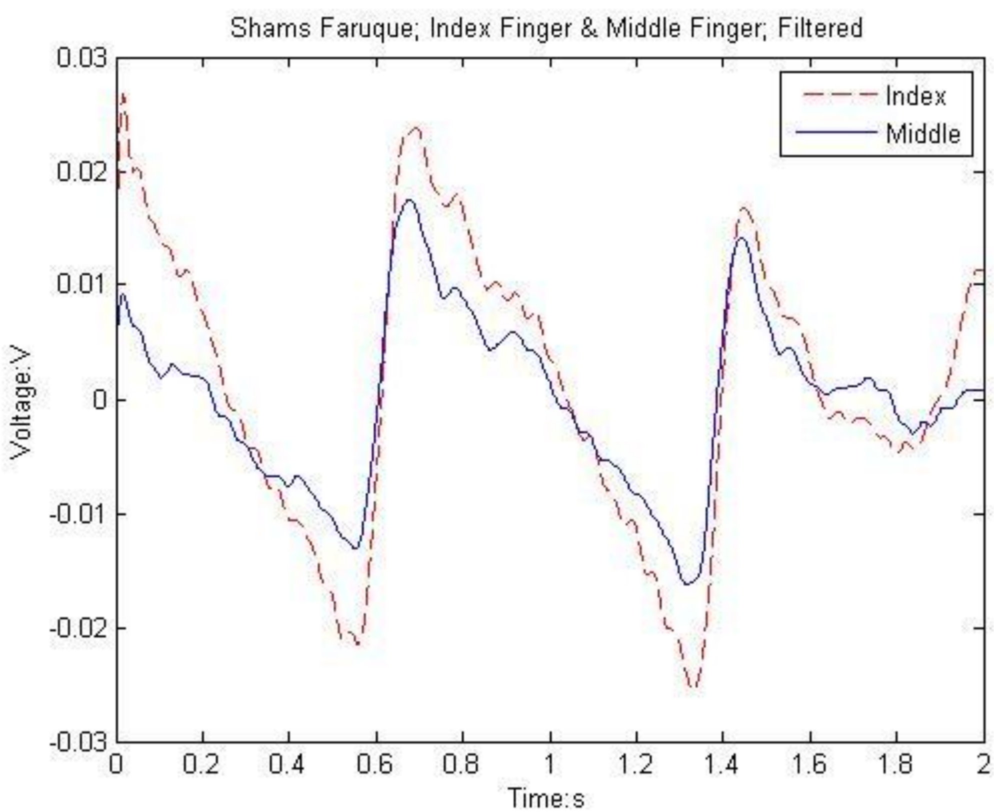

Zi Huang; Wrist; Unfiltered
Voltage:V
Time:s
2
1.8
1.6
1.4
0
1
2
3
4
5
6
7
8
9
10


Zi Huang; Wrist; Filtered
Voltage:V
Time:s
0.1
0.05
0
-0.05
-0.1
0
1
2
3
4
5
6
7
8
9
10


Zhongyu He; Thumb; Unfiltered
Voltage:V
Time:s
-0.8
-1
-1.2
-1.4
-1.6
0
1
2
3
4
5
6
7
8
9
10


Zhongyu He; Thumb; Filtered
Voltage:V
Time:s
0.2
0.1
0
-0.1
-0.2
0
1
2
3
4
5
6
7
8
9
10


Zi Huang; Index; Unfiltered
Voltage:V
Time:s
Zi Huang; Index; Filtered
Voltage:V
Time:s


Shams Faruque; Index Finger & Middle Finger; Filtered
Index
Middle
Voltage:V
Time:s

3.3 - Project Status

Here we discuss the status of our objectives. Most of them were accomplished successfully, but in light of various issues that came up, some were no longer feasible.

- A PCB to house the prototype circuit.
  - Success.
- An amplifier and filter for the heartbeat signal.
  - Success. Filter was implemented digitally.
- Switchable filters.
  - Not applicable. Filtering was performed digitally, so no filter circuit existed. Gain and input DC offset were still
- A modular device with multiple channels for input.
  - Success.
- Sensor connectors for the purposes of switching them in and out.
  - Success. Terminal blocks were used instead of connectors, however.
- What range of IR emitters are the most effective.
  - Hemoglobin has a high absorption rate with red light at 650 nm, which drops off at lower frequencies of infrared radiation.
- Information on how safe IR emitters are on the skin.
  - Outlined in section 4.2.
- Whether an array of IR sensors is more effective than a single sensor.
  - We found that it was never necessary to use more than one sensor to get our signal.
- Placement of the sensors on the skin.
  - Finger and wrist had the best results. Noisy result from earlobe, and no result from upper forearm.
- Device must utilize voltages that can be obtained by a battery.
  - We used two 9V batteries, but were unable to obtain a good signal with lower voltages because of the lack of head room. This issue is discussed in greater detail in section 3.4.
- Document ways to reduce manufacturing costs of the overall design.
  - Discussed in budget breakdown.
- DAQ, measurement, and testing procedures.
  - Utilized TI DAQ, SignalExpress and MATLAB.
- How well the current DAQ unit is working.
  - Zhongyu determined that all channels were operational, but the DAQ has a DC offset of 2.5V.
- Research on super capacitors as a possible source of power for the blood pressure monitor.
  - Zi Huang is investigating this.

3.4 - Unsolved Problems

The biggest electrical issue with the current circuit is the low-frequency component that results from movement of the patient on which the sensor is placed. The sensor is heavily sensitive to changes in the pressure with which the sensor is applied. This results in a DC offset that is unpredictable.

To understand this problem, it is important to note that the output voltage swing of the amplifier is limited to the DC power source with which it is biased. Thus, if the input DC offset voltage is amplified to a level that exceeds this voltage, the signal will essentially be destroyed. These conditions can be defined with

$$V_{CC} < \left|AV_{dc,input}\right|$$

where V_{cc} is the DC voltage powering the amplifier, A is the gain of the amplifier, and $V_{dc,input}$ is the input DC offset. Naturally, this becomes a much greater problem if we wish to reduce V_{cc} to levels which can be powered by rechargeable batteries, which will greatly reduce the headroom in which the signal can exist. It is also desirable to increase the gain A to increase the quality of the signal before digital conversion.

It is very difficult to remove this with a high-pass analog filter, because the large RC time constants that are necessary can distort the frequencies that correspond to that of the blood pulse. The DC offset *is* easy to remove digitally, but DSP on the signal is not typically performed until after some form of analog pre-amplification has occurred.

We eliminated the DC offset using an adjustable sliding potentiometer in the differential inputs of the amplifier. This, however, is not an acceptable solution, because the blood pressure monitor must be easy to use.

One possible solution to this problem is to use a DSP to sample the low-frequency DC component at the non-inverting input of the amplifier and feed it into the inverting input. In this way, the DC component would be subtracted from the input.

A fully-differential amplifier can also be used to increase the amount of headroom allowed at the output. Fully-differential amplifiers have differential outputs as well as differential inputs, so the signal is referenced with respect to the complement of the output, and the headroom is essentially doubled.

The other major issue is that we do not have a quantitative understanding of how accurate our blood pulse waveforms really are and if they contain all of the information needed to calculate the blood pressure. The Phoenix Senior Design Group believes that Fourier Analysis should be performed on real blood pulse data on a large sample of patients and identify precisely what frequency components need to be present in the waveform. This information should be accurate enough so that it can be used to accurately define design specifications for the development of the blood pulse monitor.

3.5 - Budget

The prototype cost much more than the final product would. Many more components were purchased than were necessary in case some components were broken or burnt out, which did indeed happen in our case. A few components we ended up not using.

We were never given a price for the PCB, so it is estimated to be around $40.

Components differ in price depending on quantity bought, and some components changed in price over time. Every single purchase made is listed below separately even if the same component was bought again.

The resistors and wires we used in our circuit were from lab kits from previous classes and labs, so we did not pay for them. Their total cost is negligible.

Item	Item Code (DigiKey)	Quantity	Price Each ($)	Total Price ($)	Date received
TCRT 1010	DK-751-1032-ND	3	0.94	2.82	2/14/2012
940 NM IR EMITTER	DK-160-1063-ND	3	0.46	1.38	2/14/2012
875 NM IR EMITTER	DK-516-1262-ND	3	0.85	2.55	2/14/2012
900 NM PHOTO DIODE	DK-PNZ331F-ND	3	7.28	21.84	2/14/2012
IR PHOTOTRANSISTOR	DK-160-1065-ND	3	0.44	1.32	2/14/2012
INSTR AMP	DK-INA2126PA-ND	1	3.86	3.86	3/5/2012
SLIDE POT 10K	DK-987-1401-ND	10	2.593	25.93	4/9/2012
THUMBWHEEL POT 10K	Dk-3352W-103LF-ND	10	1.186	11.86	4/9/2012
CONN IC SOCKET	DK-A100204-ND	10	0.152	1.52	4/9/2012
TERM BLOCK 4POS	DK-98370-ND	10	0.916	9.16	4/9/2012
TERM BLOCK 10POS	DK-A98164-ND	1	5.13	5.13	4/9/2012
SWITCH SLDE	DK-401-2001-ND	10	0.4	4	4/9/2012
TL082CP AMP	DK-296-1780-5-ND	10	0.176	1.76	4/9/2012
TCRT 1010	DK-751-1032-ND	15	0.825	12.38	4/11/2012
IR PHOTOTRANSISTOR	DK-160-1065-ND	15	0.313	4.7	4/11/2012
SOLDER LEAD FREE	733-1002	1	5.71	5.71	4/12/2012
1/16" HEAT SHRINK	720-1013	1	1.43	1.43	4/12/2012
1/8" HEAT SHRINK	720-1007	4	0.03321	0.13	4/12/2012
TCRT 1010	DK-751-1032-ND	15	0.825	12.38	4/13/2012
HOOKUP	540-1084	5	0.1278	0.64	4/19/2012
HOOKUP	540-1086	5	0.285	1.43	4/19/2012
HOOKUP	540-1135	5	0.285	1.43	4/19/2012
HOOKUP	540-1064	5	0.2	1	4/19/2012
WIRE MEAS/CUT CHARGE	WIRE MEAS/CUT CHARGE	4	3.24	12.96	4/19/2012

6V BATTERY	740-1008	1	3.79	3.79	4/19/2012
9V BATTERY	740-1000	8	1.43	11.44	4/19/2012
TL082CP AMP	DK-296-1780-5-ND	100	0.124	12.4	4/20/2012
1/16" HEAT SHRINK	720-1013	8	0.0325	0.26	4/26/2012
PCB		1	AROUND $40	AROUND $40	4/13/2012
			TOTAL PRICE	215.21	

Expenses Table

4 - Miscellaneous Information

4.1 - Power Consumption and Energy Considerations

Each individual channel, when on, was found to draw 10 mA from the 9V batteries: 6 mA were drawn from the positive Vcc supply, and 4 mA from the negative Vee supply. At 9V, this translates to a total power consumption of 0.09W for each channel that is switched on.

Alkaline batteries are specified to hold their charge for 565mAh. This means that a battery powering a single channel will last for 56.5 hours of constant operation.

It should be noted that, if the blood pressure monitor is only required to take a measurement once every half hour, then the sensor and amplifier circuitry need not be operational in between measurements. By switching them off, they will only draw power for the short time that is needed to take a measurement. This would effectively make the power consumption of the sensor and amplifier nearly negligible.

Feasibility of supercapacitor power supply was investigated. Typically a supercapacitor can supply a voltage at 2.5 V to 3.5 V. This will be sufficient for the final monitor. Supercapacitors for low power applications are inexpensive, and they have faster charge rate and longer product lifetime which are both good for a low cost design. Supercapacotors can easily cope with peak power load that happens a measurement is taken. However, between measurements, even though the sensor circuits are off, there will be other control units that still draw static power. The performance of supercapacitors under these circumstances still requires some further investigations.

4.2 - Safety Considerations

One of our goals was to investigate how safe infrared radiation is for use in a medical device such as this. Our wavelength of 950 nm is very close to visible light and we do not expect it to be any more dangerous than red light. In fact, the body generates infrared radiation by generating heat.

However, during testing, one of our team members held his finger on the sensor for over twenty minutes and felt a tingling in the finger. We are unsure why this occurred or if it will be a major issue when the sensor is on for a short period of time every half hour.

4.3 - Phoenix Senior Design Group: Knowledge and Experience

As senior students in electrical engineering, the Phoenix Senior Design Group is well-equipped with knowledge, talent, and experiences in electronics design and problem solving.

Daniel Kuha is a senior in the University of Minnesota's electrical engineering program and has worked on a variety of projects in both industry and academia. He has had relevant coursework in analog design, optics and wave mechanics, and signal processing. His experience includes hands-on tasks such as soldering and assembling circuit boards, PCB design, firmware design, and programming various data acquisition systems. Currently he is a part-time intern at 3M where he is independently developing an embedded wireless data acquisition system for environmental testing.

Shams Faruque has participated in research involving infrared laser communication for use on UAV's, funded by the Department of Defense. In addition to his relevant coursework in electronics at the University of Minnesota, he also designed a specialized filter and amplifier for the purpose of isolating a hidden signal.

Zhongyu He has worked on power cable malfunction locating device design (Programming and PCB layout). He won first prize in a high level SOPC programming and circuit design competition. Designed and built a radio for a specific frequency.

Yan Qu and Zi Huang both designed and built a Voice Amplifier device with regulator circuit. They also took multiple advanced electronics courses (EE 3115, EE 3161 EE 5323 etc.). They are currently designing a music tuner with LED display using PIC4550 microcontroller.

5 - Conclusion

Infrared sensor technology appears to be very promising. We were able to obtain what appears to be the full blood pulse waveform. Additionally, the sensor we used is very inexpensive and very small, qualities which are highly advantageous for the purposes of the Phoenix Project. While it is unlikely that this exact sensor would be used in the final product, our research indicates that infrared technology is a highly feasible solution to the Phoenix Project's sensor problem.

However, while we have the full waveform, we cannot quantitatively state how accurate it is and further investigation needs to be made by comparing it to real blood pulse data from medically certified instrumentation. The signal is also highly sensitive and subject to other mechanical forces and vibrations coming from the patient. Much of this can be filtered digitally, but not all of it can be accounted for because of the unpredictable nature of these forces, which could certainly exist within the desirable frequency components found in the blood pulse.

The primary electrical challenge we faced is overcoming the DC Offset discussed in section 3.4. Reductions in voltages and an increase in gain, both of which are desirable qualities sought in the final product, will make this an even greater problem, because a strong output signal and lower headroom makes it more likely to damage the signal. Our solution to the problem is temporary and certainly not acceptable for the goals of the Phoenix Project, because the device must be easy to use.

Ultimately, further research needs to be done, and some problems still exist with the technology, but this could be a promising direction in which to take the Phoenix Project.

6 - Resources

IEEE Student Laboratory; Labview; NI USB-6009 DAQ device; Senior Design Laboratory; CSE Labs; Altium; ECE Depot with expense account; Digi-Key catalogue

Reference

[1] "Objectives." Home Page. Web. 14 Feb. 2012.<http://www.phoenix.tc-ieee.org/000_Background/Phoenix_Objectives.htm.

[2] **Lab notes for previous works**: http://www.phoenix.tc-ieee.org/023_Data_Acquisition_Prototype/OptoElectronicSensor/20091121LabNotes.html

[3] **Chen patent for transient time and blood pressure calculation**: http://www.phoenix.tc -ieee.org/023_Data_Acquisition_Prototype/InvestigateChenPatentHardware/20060629pete_Chen%27s%20Patent_US06599251%28B2%29.pdf