Funky

An Unobtrusive Fingertip Health Tracker

ECE4012 Senior Design Project

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Executive Summary

We are designing an ultra low powered device that monitors visceral signals from the body for the presence of certain symptoms relating to common illnesses experienced in America today. The form of this device is a non-obtrusive fingertip clamp that is wireless-enabled and synced to transmit data to the user's smart phone or tablet. Information from the user's smart phone sensors (accelerometer, gyroscope, compass, and barometer) will be monitored in addition to the user's physiology in order to see the larger picture. Finger pulse oximeters exist today, but do not provide statistics and data trends in a manner that is easily understood by the common population. The aim of our device is to bridge this gap and make professional medical advice easily accessible and understood. Our device will monitor the user's blood oxygen saturation and finger pulse in combination with their cell phone statistics in order to alert the user when there are any signs of health concern or with suggestions to improve health and wellness. The diagnostic that our device provides is similar to that which a doctor would prescribe, saving the user the hassle of scheduling an appointment and traveling to an office. This device is not recommended as a substitute to visiting a doctor, but a supplement to give the user insightful information regarding their bodily health during the times a doctor is not accessible. Essentially, our device is a doctor's check-up right at your fingertips! The production cost of such a device is $115 per unit. The device could be sold at $150.00 per unit for a profit rate of 20%.

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Funky: An Unobtrusive Fingertip Health Tracker

1. Introduction

The aim of our design is to create a health monitoring system that records a history of the user's physiology and returns useful feedback such as overall health status, suggestions for treatment, and even recommended local doctors to go visit depending on which symptoms are monitored. Our team, JH3, requests $500.00 in order to develop our product.

1.1 Objective

Our overall object is to monitor the heart rate and blood oxygen level and transmit the data for display in real time. Our project will be an accessory to a smartphone.

1.2 Motivation

Cardiovascular disease is the number one cause of death in America and most people that will become affected are simply unaware of their condition. Some of these people may die at home alone due to stroke and some of them just cannot prevent the emergency from happening. A mobile heart rate monitoring device could become widely available and interface directly with popular devices like smart phones. Our device is intended to monitor the heart rate and blood oxygen saturation of users throughout the day and send updates to their smart phone via low powered Bluetooth technology. The convenience that our device offers is great because the user simply has to check their phone in order to receive useful information about the state of their heart and physiology. In case of emergency, the smart phone will automatically send an alert to local paramedics indicating the user's location and health status.

1.3 Background

The pulse meter allows the non-invasive measurement of heart rate with sensors placed on or near the skin with arterial blood flow. Oxygenated blood has a high content of oxyhemoglobin compared with deoxygenated blood that contains a high concentration of deoxyhemoglobin. Oxygenated blood is pumped from the heart to the body tissue through the arterial system [1].

The pulse meter technology relies on two principles of human physiology. One, a specific property of oxyhemoglobin: it reflects red light at approximately 660 nm. Deoxyhemoglobin absorbs more red light and thus reflects less red light [2, 3]. Thus a pulse meter utilizing red light waves will reflect more light during systole, when the left ventricle contracts, and oxyhemoglobin is in high concentration. Conversely, less red light will be reflected during diastole and deoxyhemoglobin is in high concentration, absorbing more red light. Second, blood volume increases during systole and decreases during diastole. More blood volume allows more red lights to be reflected during the contraction phase. These two principles can be leveraged to measure a distinct bio signal from the skin surface at approximately 1 Hz [2, 4].

The key to sensing a change in red light reflectance is a device design that interfaces closely with the surface of the skin. The typical design utilizes the transmission of light through a body extremity like the tip of a finger. A light emitting diode can be positioned near the skin surface to project light toward the skin. A photodetector diode is placed on the opposite side of the skin surface. This design creates a pathway for the light to be transmitted through the skin and detected on the opposite side by the photodetector. The transmitted light is converted to a current by the photodetector. The current is converted to a voltage by a transimpedance amplifier acting as a current to voltage converter. The circuit design can then filter and amplify this voltage to create a voltage signal of the pulse [5].

2. Project Description and Goals

<u>Project Goals</u>

We defined several project goals for the device design:

- Embed a heart rate monitor into an ring
- Monitor heart signal at the skin surface and transmit the signal through Bluetooth in real time
- Send the data to smartphone periodically or alert a doctor when there is an emergency.

These project goals allowed us to identify available resources for designing, building, and testing the device.

<u>Project Description</u>

We designed a block diagram to outline the device component functionality to meet the project goals (Figure 1). The device will first measure the heartbeat signal from the surface of the skin on a user's finger. Then it will transmit the signal through a Bluetooth chip. After receiving the signal, smartphones will process and display it to the user. We can also collect the data from the user to create a baseline for different conditions such as exercising, sitting and sleeping. We will send alert to user when the value exceeds a certain range. In extreme conditions, we will send alerts to doctors through cellular network. The circuit design incorporated an analog band pass filter through a cascade of a low pass and high pass filter.

3. Technical Specifications

3.1 Quantitative Specification

Item	Specification
Lowest Working Temperature	-40 C
Highest Working Temperature	100 C
Supply Voltage	5 V DC
Working per charge	24 Hours
Weight	200 g
Photodiode	Wavelength range 440nm-1000nm 9.5uA photocurrent output subjected to 1000 lux
Red LED	100% output at wavelength of 680 nm
Infra-Red	100% output at wavelength of 940 nm
UA741CP operational amplifier	0.5 V/us slew rate
Digilent Analog Discovery Kit	Output voltage signal
Nordic Max Interrupt time	7.5ms
Nordic Max ADC	256bit
Bluetooth Low Energy Protocol	>4.0
iOS Version	~7.0
Cocoapods	~0.36.0
Apple HealthKit	Compatible

Table 1 Device Specification

3.2 Demonstration Recorded Measurement

Type	Demonstration Recorded Measurement
Voltage Output	0-2 V
Frequency of the Output	1Hz - 1.69 Hz
Period of the Output	0.59 s - 1 s
FFT from Digilent kit	1Hz-1.50 Hz
Voltage Output (including motion artifact)	0-4 V
Frequency of the Output	0 Hz (a random signal)
Period of the Output	0 s (a random signal)
FFT from Digilent kit	Random Value (a random signal)

Table 2 Demonstration Recorded Measurement

3.3 Qualitative Specification

- Exceptional User Experience
- User Customizations
- Bluetooth Communication
- The big range of temperature in which the design functions properly is determined by overlapped working temperature range of all electronic components.
- USB port voltage determines 5V DC. (Charging method)

4. Design Approach and Details

4.1 Design Approach

4.1.1 Hardware

The Hardware of this design will be a custom-built IC. It includes a SFH 203 P visible Red LED diode, an IR204C Infrared LED, two UA741CP amplifiers, a microprocessor and communication parts. The capacitor and resistor values are chosen so that outputs will be in the range of the microprocessor without sacrificing the accuracy of the voltage output. There are a transimpedance circuit, two passive and one active filter. The cut off frequency of the transimpedance circuit is 125 Hz and the gain is 4.7M. The two low pass filters has cut off frequency 6 Hz and 4.8 Hz. The active low-pass filter has a cutoff frequency of 4.8Hz. The Hardware Assembly can be seen in the Figure 1. The final Circuit design can be seen in the Figure 2.

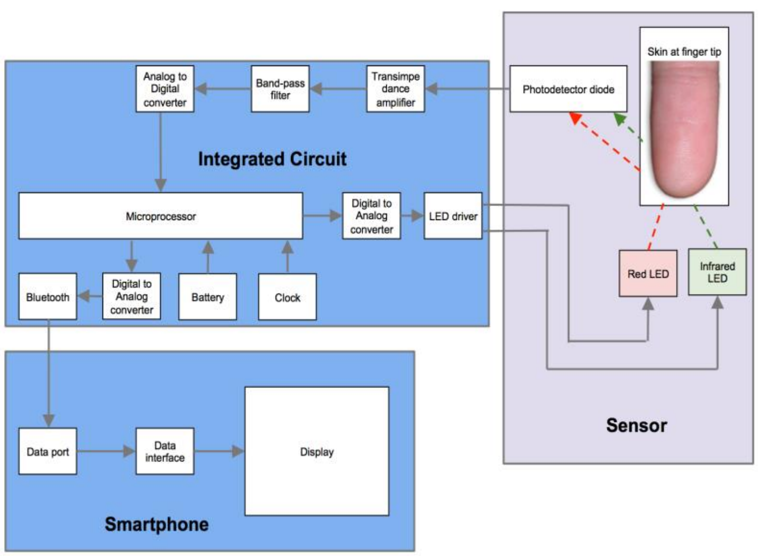


Figure 1 Hardware Diagram

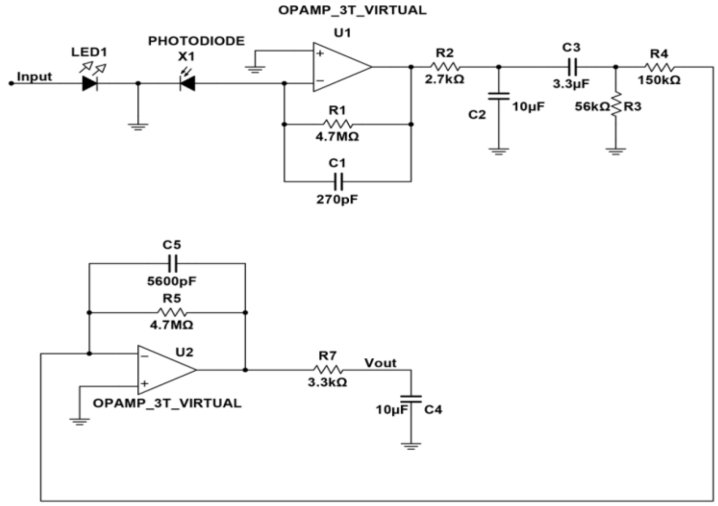
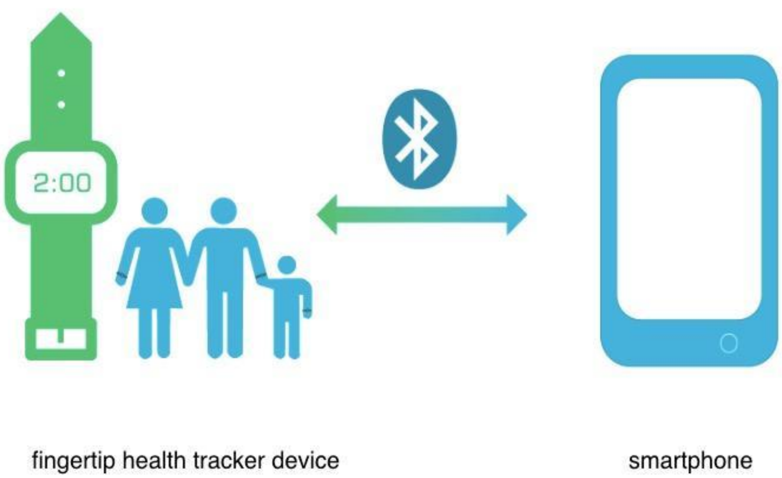


Figure 2 Preliminary Circuit Design

4.1.2 <u>Software</u>

4.1.3 In our software design, we separate the software into the device end code and smartphone end code



and they are connected by Bluetooth low power communication mechanism.

On our wireless-enabled passive fingertip health tracker device, instead of mbed OS approach we proposed, state machine that determine the proximity and timer is implemented. With a combination of scheduling mechanism, all program code is running directly at the chip memory. There is no operating system below this structure. In the manner, program need to implemented as simple as possible that avoid complicated scheduler problem.

The next part of the software design will be focusing on a smartphone application. This application will be implemented in the iOS platform because of its ease to develop, huge installed base and availability of various activity fitness sensors. [6] We will design our app following Model View Controller paradigm. In our Model, we will implement the functionality to establish the Bluetooth connection with fingertip health tracker device, exchange data with the tracker device only when the application is active in the phone foreground or the device initiate a emergent *wakeup call to the phone. The data will be stored into Apple's HealthKit store, which will be encrypted if the phone is locked by user's passcode or TouchID [7].

In our View, we display that a real time view when data comes in. In addition, we display a statistics and trends of collected data view. We will warn user if an abnormal data pattern appears. In our Controller, we will query the data from the device database and present the data in the View.

4.2 Codes and Standards

Bluetooth 4.0 will be used as the main data transmission mechanism between sensor and data processing unit (Phone) in an ultra-low power consumption situation.

FCC mark is a certification mark employed on electronic products manufactured or sold in The United States, which certified that the electromagnetic interference from the device is under limits approved by the federal communications commission.

4.3 Constraints, Alternatives, and Tradeoffs

Constrains.

The limited space in a ring constrains the size of the printed circuit board to be extremely small. Considering cost and time, this situation creates difficulty building a PCB for the prototype. The small space in the ring also limits the size of battery. As a result, the idle time of the product could be less than 30 hours. The pulse rate and blood oxidation value is greatly affected by motion artifacts. Implementing PWM and adaptive filter design could solve this problem.

The max sampling rate from the Nordic NDK-51 has been limited due to the hardware soft interrupt clock. The highest precision from the Nordic NDK-51 has been limited due to the hardware ADC size.

Alternatives

Apple watch (coming in February new year) can be considered as alternative products as it also provide heart rate information to users' cell phones. However, our design could provide the oxidation information for users, which makes our design competitive. Fitbit and Jawbone has similar product with heart rate monitor, but both of them design are focused on activity tracking, and display result for user is raw data of heart rate, which is not understandable for normal user.

Tradeoffs

Power consumption vs. better accuracy

Limited space vs. Battery life

Precision vs. Motion Artifact

Overloaded Information Vs. Intuitive UI Design

Signal Processing Vs. Hardware Capability

5. Schedule, Tasks, and Milestones

The Gantt chart in Appendix A shows a task breakdown that must be completed.

6. Project Demonstration

6.1 Actual Demonstration

6.1.1 Hardware Setup

For the hardware part, two breadboards were used. Each breadboard has a red LED and a photodiode to detect the pulse. The LED and the photodiode were covered by a black ring, which allows users to put fingers into. An analog discovery kit was used to visualize the waveform. Then, the data was transmitted to smartphone through Bluetooth in the MCU.

6.1.2 Software Setup

When the companion iOS app was launched on the paired smartphone, the recorded health data will be presented in the app. User authorizes sharing of the data to another person (doctor) from the iOS app. The other person will then launch an iOS app to view the data. User jumps up and down and deliberately to let Funky detect abnormal behaviors, the iOS app then should present an alert.

6.2 Result

Our Result from the analog discovery kit shows a clear heart pulse as shown in Figure x1.

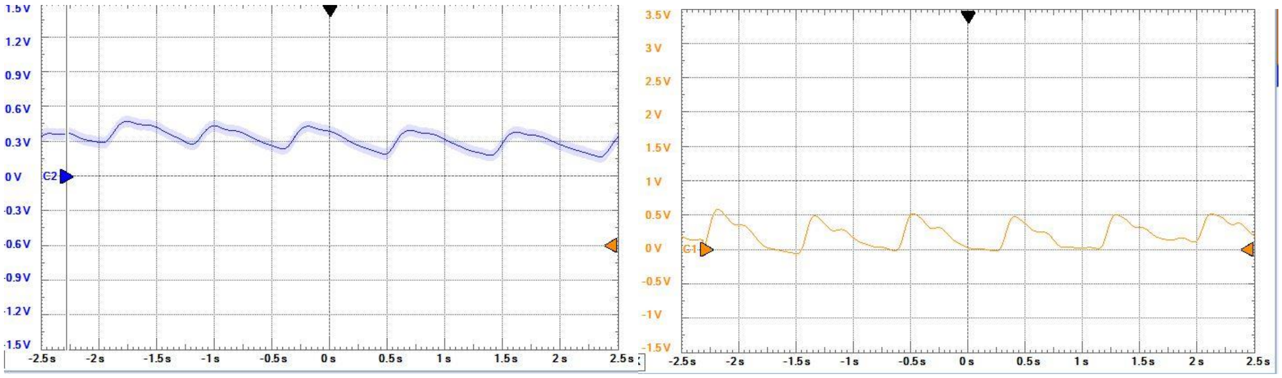


Figure 3 Waveform of heart pulse from analog discovery kit.

The heart rate after calculation in IOS APP as shown in Figure x2, with a summary view shown in Figure 4,

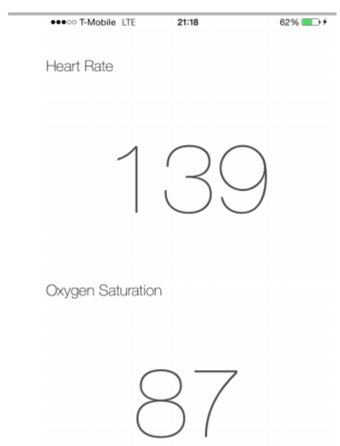


Figure 4 Heart rate shown in IOS App.

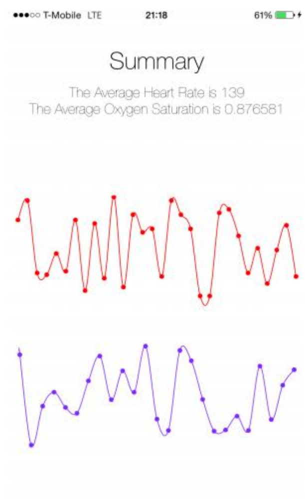


Figure 5 Heart rate summary view shown in IOS App.

6.2.1 Acceptance testing

We performed a lot of testing on our device and the results accuracy of over 80%, which is a very good number for a prototype device.

7. Marketing and Cost Analysis

7.1 Marketing Analysis

There is a lot of wearable activity tracking device in the market. Two of them use iOS and Android app to display user personal data. The cost of buying each of them is shown in Table 2.

	Fitbit Charge HR	Jawbone UP3
Feature	Tracks continuous heart rate Activity tracking	Heart rate monitor Activity tracking
Price	$ 149.95	$179.99

Table 3 Similar Products comparison

Both the Fitbit and Jawbone allow for heart beat monitor, but both of them only display the raw data, which is user current heartbeat on the smartphone. A major selling point for Funky will be the more accurate heart beat detection and analyzed data. The product show result to user in the experience they can understand.

7.2 Cost Analysis

Funky consists of an iOS app and a specially designed heart beat monitor. The cost of developing iOS app will be about 30 hours. The parts that are needed to implement heart beat rate monitor device are listed with prices in Table 3. In the design, Microcontroller needs to capable with Bluetooth 4.0 standards. The cost of battery, print circuit board and packaging are estimated based on digitkey's current catalog.

Item	Price
Capacitor EEA-GA1H1R0H [9]	0.35
MTE6800N2-UR Visible Emitters [10]	3.15
UA741CP Amplifiers [11]	1.68
SFH 203 P Photodiodes [12]	0.74
Nordic USB dongle Kit [13]	27.91
nRF 51 DK	59.95
PBC and Packaging	30.00
Total	86.78

Table 4 Development Phase Parts Cost

Task	Hours
Research & Meeting	30
Lecture	20
Hardware Design & Assembly	10
Software Development	10
Integration	3
Testing	5
Demonstration	1
Total	79

Table 5 Development Phase Labor Breakdown per Engineer

Five Engineers contribute to design and development of Device. It is assumed that a qualified engineer is paid $30 per hour in the team. The individual labor breakdown for this project is shown in Table 4, and the total labor cost for five engineers is $11850.00. Assuming 30% fringe benefits of labor and 120% overhead on materials, labor, and fringe benefits, Table 5 summarized the cost of development for the Device.

Item	Cost
Parts	86.78
Labor	11850
Fringe Benefits	3555
Subtotal	15491.78
Overhead	18590.20
Total	34081.98

Table 6 Development Cost Estimation

The Profit over one year of production of Device is given with assumptions. Based on Fitbit and Jawbone sales volume estimated, 2500 units are sold per year. [14] In the production period, the parts cost will reduce to $70.00 for buying in bulk. Additionally, there is a 10% sales expense and fringe benefits. Device is sold for $150.00 per unit. There is a $437500.00 profit over five years production and consider the development cost with $403419.00 net profit, which is about 20%. The selling price with $150.00 is higher than Fitbit activity tracker, but the more accurate and ease-to-use heart monitor is a major feature, which other competitor’s products is not focused.

Production Cost Item	Cost
Parts	70
Labor	10
Fringe Benefits	3
Subtotal	83
Overhead	100
Sales Expense	15
Total	115

Table 7 Product Cost in Production Phase

8. Conclusion

8.1 Current Status

We can successfully demo measuring SPO2 and display the data on the phone but we can't measure the Heart Rate correctly. Software solution can't detect the period of the heart rate sensor input after multiple algorithm tries, such as finding triggers and software FFT. As the desired PCB is extremely small, it was not printed due to cost and time factors. Design a circuit and implement it is not a simple task. There will be problems recurring in the process. The algorithm we designed worked for simulation data but not for actual data and we should design the algorithm after we get the actual data.

8.2 Future Work

If implementing pwm and adaptive filter, motion artifacts of the signal could be improved. We didn't predict the complicate signal behavior at the beginning, to implement digital signal processing module, a FFT module can implement with DSP chip that process the analog output before microcontroller unit read sensor value. To better calculate the pulse rate in the condition of noises, trigger level algorithm can be applied. At the end, an assembled print circuit board with electronics components can develop to make a better demonstration.

9. References

[1] E. Chan, M. Chan, and M. Chan, ‘Pulse oximetry: Understanding its basic principles facilitates appreciation of its limitations’, Respiratory Medicine, vol. 107, pp. 789–799, Mar. 2013.

[2] S. DeMeulenaere, ‘Pulse Oximetry: Uses and Limitations’, Journal for Nurse Practitioners, pp. 312–317, May 2007.

[3] D. Sears, ‘Overview of Hemoglobin’s Structure/Function Relationships’, 1999. [Online]. Available: http://mcdb-webarchive.mcdb.ucsb.edu/sears/biochemistry/pdf/hbn-overview.pdf. [Accessed: 21-Nov-2014].

[4] P. Jain and A. Tiwari, ‘Heart Monitoring systems - A review’, Computers in Biology and Medecine, vol. 54, pp. 1–13, Aug. 2014.

[5] S. Lopez, ‘Pulse Oximeter Fundamentals and Design’, Freescale Semiconductor, Inc, Revision 2, Nov. 2012.

[6] Arm, (2014, October 1). ARM Announces Device Platform and Free OS to Accelerate Internet of Things Deployment [Online]. Available: http://arm.com/about/newsroom/arm-announces-device-platform-and-free-os-to-accelerate-internet-of-things-deployment.php

[7] Apple, (2014, December 2). Technology [Online]. Available: https://www.apple.com/iphone-6/technology/

[8] Apple, (2014, December 2). Health, An entirely new way to use your health and fitness information [Online]. Available: https://www.apple.com/ios/whats-new/health/

[9] Digikey Corporation. (2014, December 2) Product Detail [Online]. Available: http://www.digikey.com/product-detail/en/SFH%20203%20P/475-2649-ND/1893875

[10] Digikey Corporation. (2014, December 2) Product Detail [Online]. Available: http://www.digikey.com/productsearch/en?pv40=53&FV=fff40008%2Cfff80028%2C1140050&k=led&mnonly=0&newproducts=0&ColumnSort=0&page=1&quantity=0&ptm=0&fid=0&pageSize=25

[11] Digikey Corporation. (2014, December 2) Product Detail [Online]. Available: http://www.digikey.com/product-detail/en/UA741CP/296-11107-5-ND/382197

[12] Digikey Corporation. (2014, December 2) Product Detail [Online]. Available: http://www.digikey.com/product-detail/en/EEA-GA1H1R0H/P15831CT-ND/3831198.

[13] RedBearLab. (2014, December 2) BLE Nano Kit [Online]. Available: http://store.redbearlab.com/products/blenano

[14] Terapeak. (2013, July 13) Fitbit, Nike Top the Market for Activity Trackers [Online]. Available: http://www.terapeak.com/blog/2013/07/31/fitbit-nike-top-the-market-for-activity-trackers/#.VH4iJjHF-tb

Appendix A

Table A1. Complete Task List with Duration, Dates, and Assignments

Task Name	Duration	Start	Finish	Status	Assigned To
Learn how to use this template					
Funky	102	12/04/14	04/24/15		
Task	23	12/04/14	01/05/15		
Proposal	23	12/04/14	01/05/15		
Proposal Due	23	12/04/14	01/05/15	Complete	All Members
School Break	21	01/06/15	02/03/15	Complete	All Members
	21	01/06/15	02/03/15		
Design	43	02/04/15	04/03/15		All Members
Hardware		02/04/15			
Design and Configure Sensor	38	02/04/15	03/27/15	Complete	Yang
Circuit Design	7	02/04/15	02/12/15	Complete	Chuyao
Microcontroller Choose	14	02/04/15	02/23/15	Complete	Ze Chen
Parts Order	11	02/04/15	02/18/15	Complete	Ze Chen
Hardware ordered pick up	1	02/19/15	02/19/15	Complete	Ze Chen
Software		02/04/15			
GUI Design	8	02/04/15	02/13/15	Complete	Zeheng Chen
Software Implementation	20	02/16/15	03/13/15	Complete	Zeheng Chen
Micro-Controller Software Implementation	1	02/20/15	02/20/15	Complete	Ze Chen
Software Testing	10	03/16/15	03/27/15	Complete	Zeheng Chen
Data interpreting	5	03/30/15	04/03/15	Complete	Ze Chen
Integration	14	04/06/15	04/23/15		
Signal Process	6	04/06/15	04/13/15	In Progress	Chuyao
Debug Signal and Data	8	04/14/15	04/23/15	Complete	All Members
PBC design	5	04/06/15	04/10/15	Complete	Chuyao
Component integration	14	04/06/15	04/23/15	In Progress	All Members
Demo	4	04/21/15	04/24/15		
Preparation	4	04/21/15	04/24/15	Complete	All Members
Final Demo	1	04/24/15	04/24/15	Complete	All Members

Figure A2. Project Gantt Chart