

BME88A: EKG Preliminary Design Proposal

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March 10, 2015

1 Overview

An electrocardiogram, also known as EKG or ECG, is a noninvasive device that monitors electrical activity produced by the natural electrical system caused by the contraction of heart muscle. This process of depolarization and repolarization causes allows the heart to pump blood through the body. The electrical impulses generated by each heartbeat are registered by the EKG's electrodes and translated by the device into a waveform. Analysis of this waveform by personnel with requisite training can be used to assess heart condition.

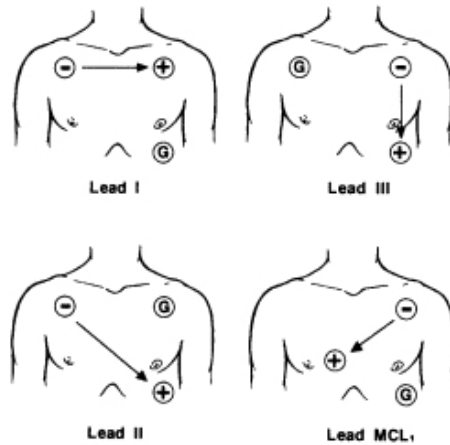


Figure 1: Various positions for 3-lead EKG electrodes. Observe that the ground is not along the path of the electrical signal between the two charged electrodes. [1] Image copied from RTBoard, *Electrocardiography Devices*.

Our design uses three electrodes to measure the electrical activity produced by the heart. By positioning two of the electrodes across the heart and the remaining one elsewhere on the body (not in between the two measuring electrodes) as a reference ground, we can generate a voltage across the skin over the heart. The resulting difference will be small, however, so we need an instrumentation amplifier to provide gain to render the signal

interpretable. This amplified signal will be sent to an Arduino (Sparkfun Redboard). When connected to a computer, the Arduino's serial input can be recorded and graphed.

2 PQRS

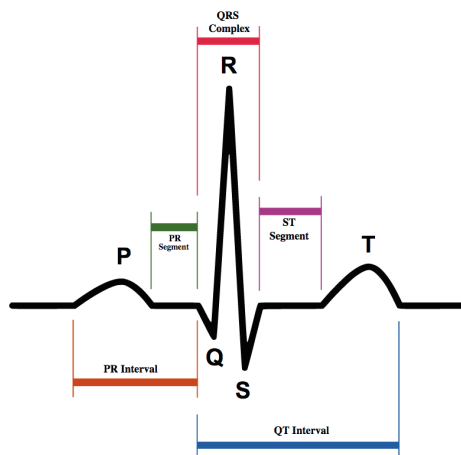


Figure 2: Schematic representation of an EKG reading. The QRS complex represents the ventricular depolarization and contraction of the heart chambers. [2] Image copied from Wikipedia article on Electrocardiography.

For this design we are looking to record the electrical signal of the heartbeat's QRS complex. The QRS complex is the combination of the three main graphical deflections observed on the electrocardiogram produced after the P and T wave. The P wave is the first short upward spike recorded in an ECG, and indicates the contraction of atria that pump blood into the ventricles. The QRS represents the ventricular depolarization and contraction, and it is graphed as a downward deflection, Q; a high upward deflection, spike R, and another downward S wave. Physiologically normal interval durations within the PQRS process happen quickly, in the order of tens of milliseconds. We expect a normal QRS interval to last around 60ms. Overall, we are looking for various contractions that occur in the heart and produce an electrical signal around 0.5mV. [5]

The baseline of the electrocardiogram is measured by the V_{ref} terminal of the instrumentation amplifier. Due to variability in the baseline as a direct result of autonomous muscle contractions, however, we must process the baseline with a bandpass filter. Doing this in software will require post-processing (filtering the data after it has been collected), which we are currently achieving using the scipython bandpass filter module and the scipython notch filter. A bandpass filter is designed to remove any frequencies above frequency B (f_B) and below frequency A (f_A) where $f_A < f_B$. For the EKG, a bandwidth of ~ 2.2

Hz from 0.8 to 3.0 Hz is optimal, as those parameters represent the normal range of the human heartbeat frequency (48 bpm to 180 bpm respectively), though we expect the signal to mostly consist of the 0.85 to 1.15 Hz bandwidth. The notch filter is an inversion of the bandpass filter in that it will filter out any frequencies between f_A and f_B . In the EKG this filter will be used to remove the 60Hz noise produced by inductive capacitance of the surrounding (mains-level) electronics. Both filters will be imported from the SciPython module [7]

The final data set will be fed into a graphing program, which will then output data to two modules, the Graphic User Interface (GUI) Module and the Diagnostic Reader Module (DRM). The DRM will also then output to the GUI. The GUI will be a highly simplified interface that will allow the user to change some of the parameters of the program to improve usability, possibly including bandpass filter parameter alterations and changing the DRM to better serve the needs of the user.

3 Design Problems

Anything we may have encountered...

Parts:

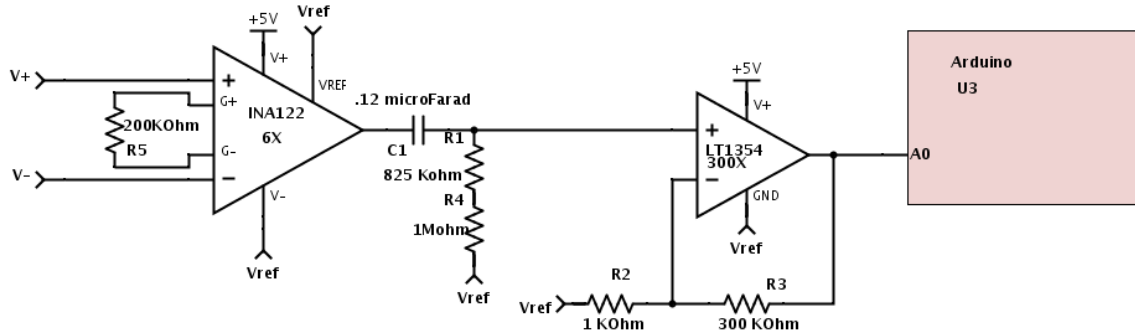
- Universal ECG EKG Electrodes Electrodes
- Sparkfun Redboard Arduino
- INA122 Instrumentation Amplifier
- CF14JT200K Resistor (R5)
- LT1354 Operational Amplifier
- CF14JT1K00 Resistor (R2)
- PR01000103003JR500 Resistor (R3)
- DC Filter
- C330C124KCR5TA Capacitor (C1)
- MRS25000C8253FRP00 Resistor (R1)
- HVR2500001004FR500 Resistor (R4)
- Wires

- Software Modules
- Registration Module
- Serial system in Arduino
- Pairing Module
- Noise Filter
- Bandpass Filter
- Notch Filter
- Grapher Module
- export to GNUplot
- Diagnostic Readout Module
- Heart Rate
- Peak Intervals
- GUI Module

Education:

- Complex Impedance basics
- DC Filtering (High pass filtering?)

4 Circuit Design



Hardware Modules:

Human: Only prerequisite is a beating heart (and consent).

Instrumentation Amplifier: Voltage fluctuations may be lower than the Arduino's resolution ($\geq 5\text{mV}$), so we must use the amplifier to boost the signal to a level we can monitor. Since the signal will be approximately 0.5 mV , however, even small fluctuations at required gain ($\sim 5000\text{x}$) could produced DC noise as high as 300 mV . [5] Therefore, any significant gain on the voltage in the instrumentation amplifier runs the risk of saturating (and thus overloading) it. As such, the primary purpose of the instrumentation amplifier will be to generate a differential signal, rather than to boost the voltage.

Arduino: Converts analog input to digital output for Laptop using a serial output.

Computer: Runs software/code and displays data.

Software Modules:

Register: Generates a list of differential values and time recorded, pairing the two values.

Noise Filters:

Bandpass Filter: Removes noisy frequencies higher and lower than the target bandwidth, imported from SciPython. [7]

Notch Filter: Removes 60 Hz noise generated by surrounding electronics. Grapher: Plots all data points and connects to generate EKG waveform, imported from matplotlib [8]

GUI: Basic interface with ability to change graphing options and potentially activate/disable diagnostic screening or change diagnostic parameters manually.

Hypothetical Software Module:

Diagnostic: Determines average distance between waveform peaks, possibly other diagnostically relevant information as well.

5 Current Design Plans

We plan on using a Texas Instruments INA122PA-ND instrumentation amplifier to find the differential signal from our electrodes, as mentioned above the gain will be minimized to 6X in order to not saturate the INA122. [6] The LT1254 Operational amplifier will provide most of the voltage gain at approximately 300X voltage gain. Because the signal will be inverted, we will need to manipulate the signal further in software.

- Gain from INA122PA-ND is adjusted by changing shunt from gain resistor terminal to ground. AS mentioned above

6 Cost

These are the fiscal costs associated with this project, not including man hours. The following assumes that a USB cable and a laptop is available to the reader.

Sparkfun Redboard:	\$20
Breadboard TW-E40-1020:	\$8.98
Wires:	\$4.95
Texas Instruments INA122PA-ND:	\$6.35 (3X)
LT1354 Operational Amplifier:	\$4.27 (3X)
Capacitor:	\$2.64 (3X)
MRS25000C8253FRP00 Resistor:	\$0.44 (3X)
HVR2500001004FR500 Resistor:	\$0.47 (3X)
CF14JT1K00 Resistor:	\$0.10 (3X)
PR01000103003JR500 Resistor:	\$0.37 (3X)
CF14JT200K Resistor:	\$0.10
Electrodes: Provided by Dr. Karplus	\$0.00

Total Cost:	Including Shipping/Markup: \$59.61
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7 Code

```
'''
Created on Mar 10, 2015

@author: Henry Hinton, Pavle Jeremic, Eduardo Hirata
'''

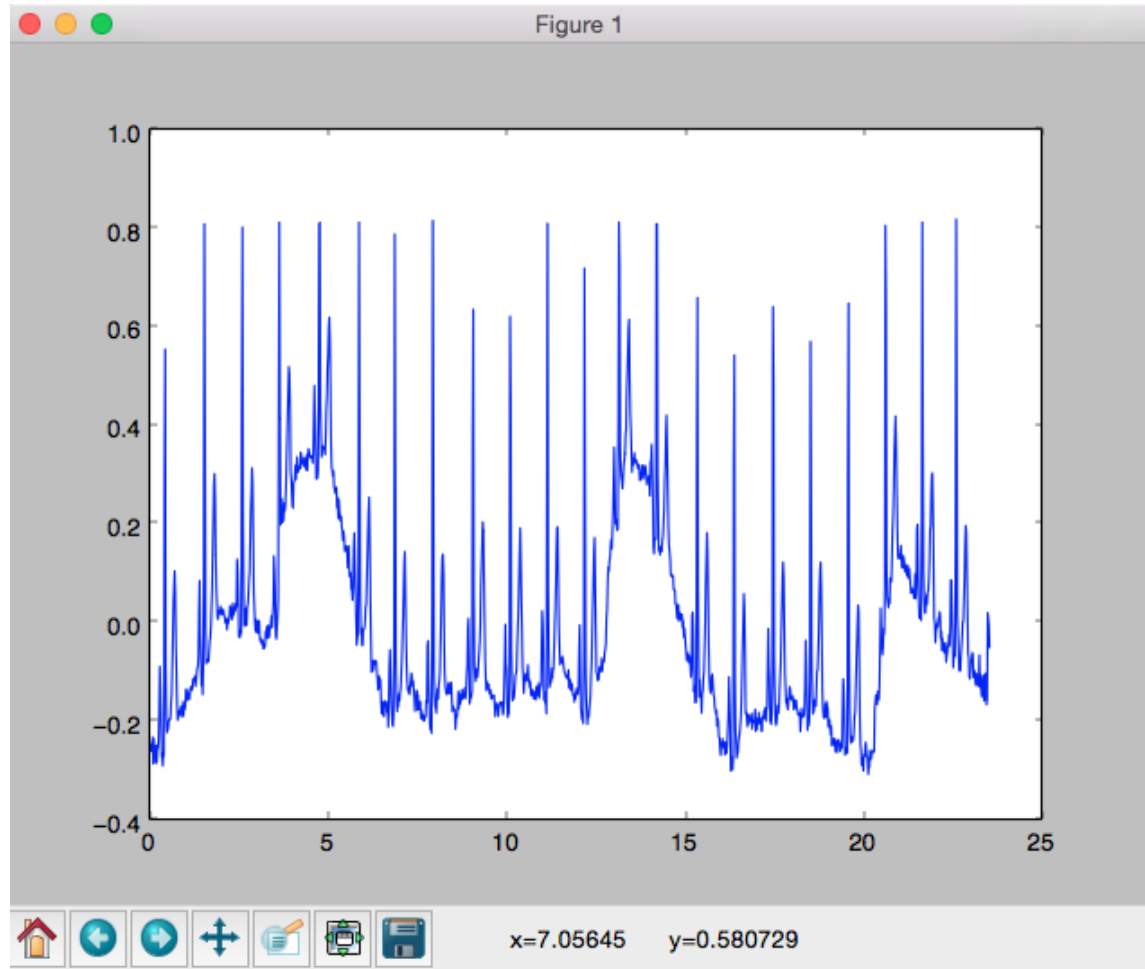
from sys import argv
import numpy
import scipy
import matplotlib.pyplot as plt

filename = argv[1]
raw = []
time, vdiff = [], []
# print('Using file: ' + filename)

with open(filename, 'r') as txt: #open file
    for line in txt:
        if line.startswith('#'): #skip commented lines in header
            continue
        raw.append(line.rstrip('\n')) #strip newline delimiter
print("Using %d points." % len(raw)) #verify data
for index, x in enumerate(raw):
    rows = x.split('\t') #split raw lines into time & vdif values
    print("%d, %s, %s" % (index, rows[0], rows[1])) #print values to console
    time.append(float(rows[0]))
    vdiff.append(float(rows[1]))

plt.plot(time, vdiff) #plot points
plt.show() #display points
```

The above code is our current graphing module that has successfully converted the example data [9] provided by Dr. Karplus [5] and generated a waveform (below). In the next two days we will implement the bandpass and notch filters from scipy. Immediately afterwards we plan on completing the Diagnostic Module and a GUI.



References

- [1] "Electrocardiography Devices." Electrocardiography Devices. N.p., n.d. Web. 24 Feb. 2015.
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- [2] Cardiac Waveform. Digital image. Electrocardiogram. *Wikipedia*, n.d. Web. 24 Feb. 2015.
http://en.wikipedia.org/wiki/Electrocardiography#mediaviewer/File:QRS_complex.png.
- [3] "How to Read an Electrocardiogram (ECG). Part One: Basic Principles of the ECG. The Normal ECG." N.p., n.d. Web. 24 Feb. 2015.
<http://www.southsudanmedicaljournal.com/archive/may-2010/how-to-read-an-electrocardiogram-ecg.-part-one-basic-principles-of-the-ecg.-the-normal-ecg.html>.
- [4] Karplus, Kevin. "Two-Stage EKG." Web log post. Gasstationwithoutpumps. Wordpress, 14 July 2012. Web. 17 Feb. 2015.
<https://gasstationwithoutpumps.wordpress.com/2012/07/14/two-stage-ekg/>.
- [5] Personal communication with Dr. Karplus regarding typical EKG sensor output.
- [6] Data sheet for Texas Instruments INA122PA-ND instrumentation amplifier. Web. March 1, 2015.
<http://www.ti.com/lit/ds/symlink/ina122.pdf>
- [7] Eric Jones and Travis Oliphant and Pearu Peterson and others. SciPy: Open source scientific tools for Python, 2001-present. March 1, 2015
<http://www.scipy.org/>
- [8] Hunter, J. D. Matplotlib: A 2D graphics environment. Computing in Science & Engineering vol.9 #3 pg. 90-95 publisher: IEEE Computer Society, 2007.
<http://matplotlib.org/index.html>
- [9] Demo code and data given by Dr. Karplus. https://users.soe.ucsc.edu/~karplus/bme88a/w15/EKG_demo/