Testing a Heart Rate Monitor for use in Noisy Signal Analysis

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Abstract

When a heart beats, it sends an electrical pulse through the body. Studying this electrical pulse can help determine if the heart is pumping enough blood and help diagnose health problems. An effective way to get this information is through an electrocardiogram (ECG). An ECG is a plot of the heart's voltage vs time. Originally, the purpose of this project was to design, build and code a system that creates an ECG. To accomplish this, an Arduino Uno microprocessor, SparkFun heart-rate monitor, and three sensor pads were used with success. Currently, the focus is to refine the process of data collection and remove noise from the signal. As an ECG is known for its complex behavior (such as being nonstationary and nonlinear), an analysis technique that is appropriate for dealing with such characteristics is needed. Empirical Mode Decomposition is being used to decompose the signal into frequency components so that high-frequency noise can be identified and attenuated.

Background

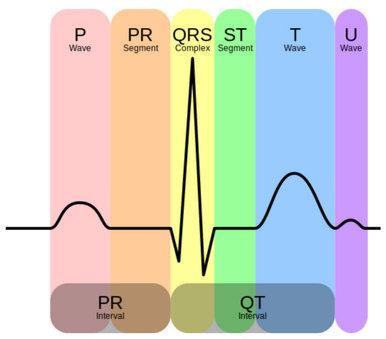
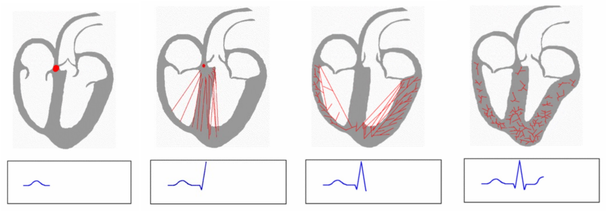


Figure 1: To the left is an example of an ECG illustrating the individual waves and intervals. The PR interval includes the P wave and the PR segment. The QT interval includes the QRS complex, the ST segment, and the T wave.

Credit Wikipedia.org

An ECG is a graph that shows the electrical activity of a heart over time. Analyzing these graphs can help determine if a heart is functioning properly. There are multiple waves recorded for a heartbeat signal (Figure 1). "The PR interval is the initial wave generated by an electrical impulse traveling from the right atrium to the left." [1] The atrium is the part of the heart that receives the blood and pumps it into the ventricle. Figure 2 shows the blood flow of a healthy heart with the corresponding to the ECG. The normal time for a PR interval to be completed ranges from 0.14s to 0.20s. If a PR interval is over 0.20s, there is a possibility of a heart block in the subject. [2]



Credit Wikipedia.org

Figure 2: This figure shows a heart beating over a cycle with the corresponding parts of the ECG. The red lines show the blood flow.

The QT interval (Figure 1) varies depending on the heart rate, there is not a specific time range. A normal QT interval depends on age and gender. An examination of both the PR and QT intervals can identify abnormalities and help to effectively diagnose a heart issue.

System Setup

In order to collect data, an Uno, a SparkFun Single Lead Heart Rate Monitor, and sensors were used, which were powered by an external supply. The output of the heart rate monitor was connected to the Uno for data recording (Figure 3). The Uno takes in data from the sensor pads and generates an output.

The heart rate monitor contains an Analog Devices signal conditioner that receives, filters, and amplifies the ECG signal. "It is designed to optimize biopotential transmissions in noisy environments". [1]

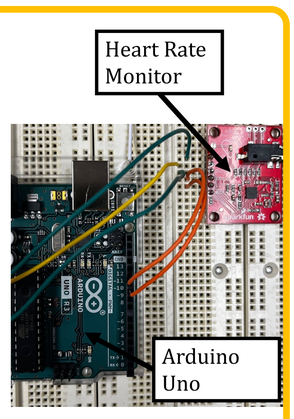


Figure 3: Above the Arduino Uno connected to the Heart Rate Monitor is shown.

Data

To collect the heart rate three electrode sensors were used. The patient needs to stand/ sit still when the data are being collected because the movement can cause noise in the output. Data were collected from a female patient (Figure 4).

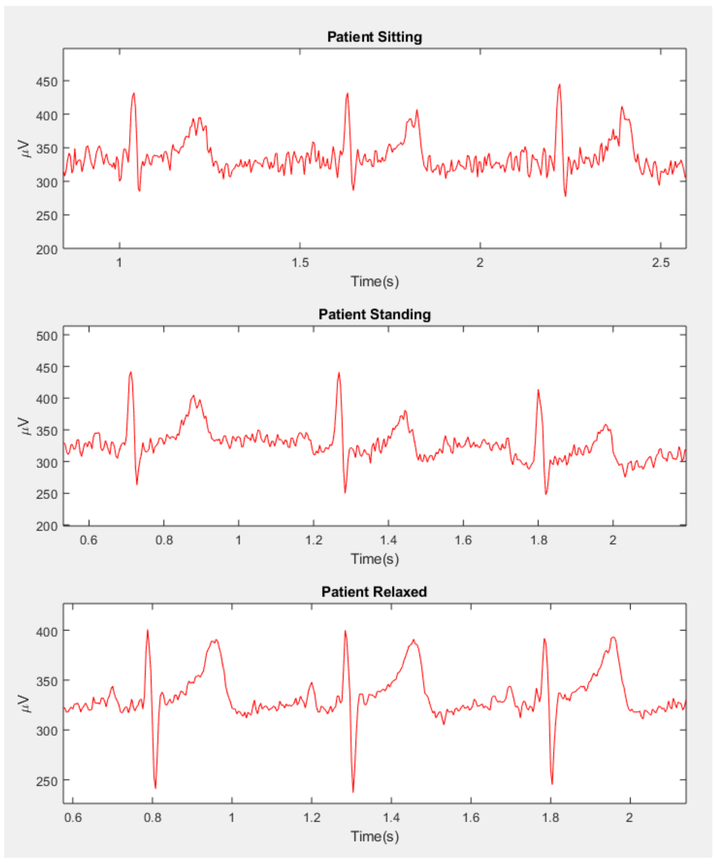


Figure 4: Three ECG's from a female patient are shown. In the top graph the patient was sitting, in the middle graph the patient was standing, and in the bottom graph the patient was standing with relaxed arms. In each graph you can see three cycles of the heartbeat.

Comparing Figure 4, the experimental data, to Figure 1, the expected data, it is clear that the system is picking up background noise. To remove this noise, multiple methods were examined.

Empirical Mode Decomposition

Empirical mode decomposition (EMD) has been proven effective for denoising non-stationary data such as an ECG. [3] An EMD takes non-stationary data and breaks it into stationary components with different frequencies. These different components are known as intrinsic mode functions (imf's). When these functions are added together you get the original function back. [3]

In Figure 5 the imf's are shown. The purpose of the EMD is to create stationary data that can be used to identify important frequencies.

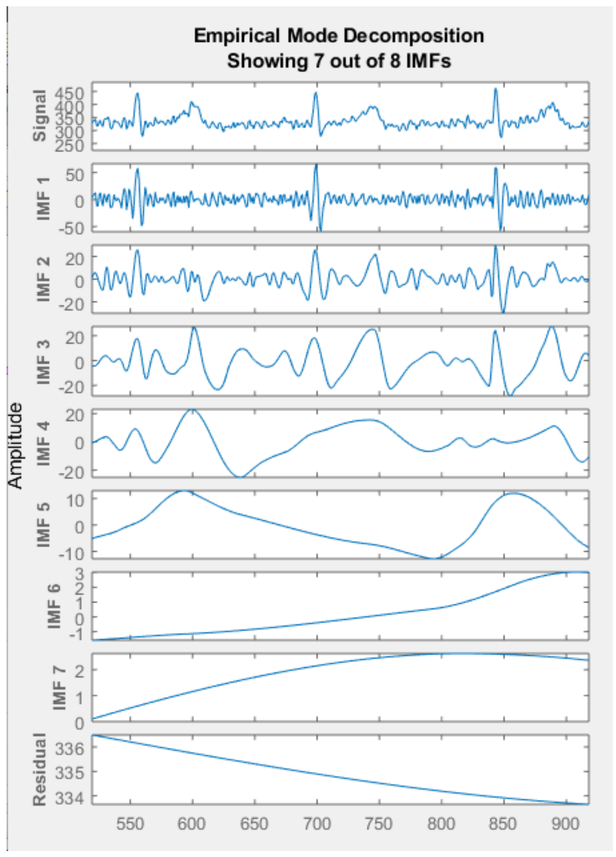
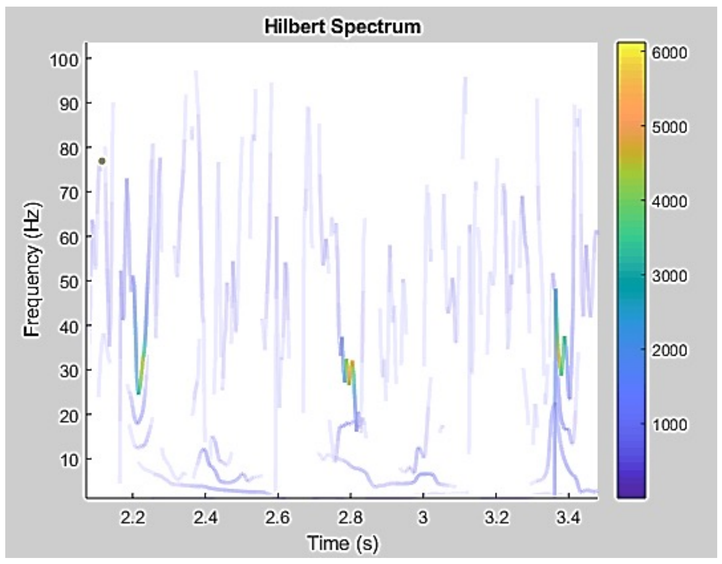


Figure 5: An EMD is shown for three cycles of a heartbeat. Note the frequency change through the successive components.

DeNoising

Using the stationary components, a Hilbert Spectrum can be created. This is generated by taking a fast Fourier transform of each of the imf's. [3] From the Hilbert Spectrum shown in Figure 6 it is clear the high frequencies do not contribute much power to the signal. Therefore, applying a low pass filter should be an effective way to denoise the data. Figure 7 shows the data after the filter with a cutoff frequency of 40Hz is applied. The integrity of the signal is not affected but the noise is mostly removed.



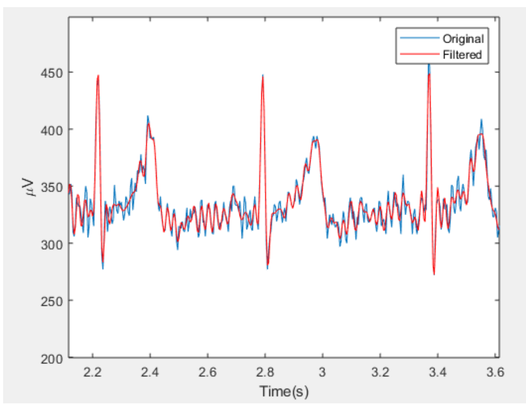


Figure 6: Shown above is the Hilbert spectrum of the collective imf data. The colors indicate the relative power. Note that the most powerful points correlate to the QRS complex.

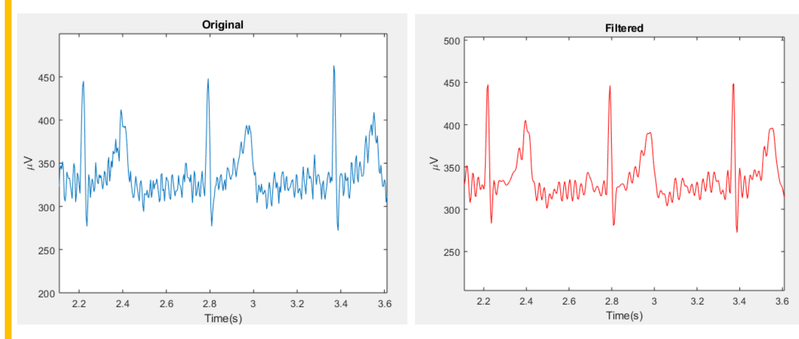


Figure 7: The original signal is overlaid with the filtered signal.

Future Research

We have shown that data from an ECG can be denoised using a low pass filter. An alternative approach would be to subtract the first imf and rebuild the signal from the remaining imf's. However, this would remove key features of the QRS complex. As an intermediate step, one could perform the EMD in regions that do not include the QRS complex, remove the first imf, and then rebuild the entire signal with the QRS complex added back in. This will be attempted in the next phase of the project.

Acknowledgments

I would like to thank Barbra Sobhani and Bernadette Garcia of COSGC/NASA. Also, thanks to Casey Kuhns for his design of the sensor while at SparkFun.

References

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[3] Blanco-Velasco, M., Weng, B., & Barner, K. E. (2008). ECG signal denoising and baseline wander correction based on the empirical mode decomposition. Computers in Biology and Medicine, 38(1), 1–13. https://doi.org/10.1016/j.compbiomed.2007.06.003