Detecting Heart Irregularities Through ECG Sonification

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Introduction

The primary cause of death in the US is heart disease, responsible for about 697,000 deaths in 2020 [1]. To detect heart diseases such as arrhythmia, electrocardiography (ECGs) provides a simple and non-invasive test. ECGs detect the potential difference between heart cells, capturing the heart's rhythm. The heart's depolarization is represented as the PQRST waves within ECGs. P waves depict atrial depolarization, the QRS complexes portray ventricular depolarization, and the T wave demonstrates ventricular repolarization. Thus, ECGs can detect abnormalities within PQRST waves to diagnose heart irregularities such as atrial fibrillation [2]. As such, ECGs allow for the earlier detection and monitoring of heart diseases, such as arrhythmias, coronary heart disease, heart attacks, and cardiomyopathy, preventing future health complications [3].

ECG signals can be represented not only visually but also sonically. Through sonification—the process of conveying information within audio—users can hear ECG data to auditorily monitor patients' heart rhythms. The main advantage of ECG sonification over visualization is the flexibility that allows users to visually focus on one task while simultaneously sonically monitoring a patient's heart rhythm for irregularities.

Previous research on ECG sonification has focused on parameter-mapping ECG features. Various approaches have included the ECG amplitude, mean amplitude difference, slope, and ST-segment elevation, to control various sonification parameters such as frequency, volume, timbre, and even added sounds of water droplets or real heartbeats [4]. For this research, the ECG amplitude, mean amplitude difference, and RR intervals were selected to represent the sonification frequency, volume, and morpholoy, respectively. The ECG data utilized was from the MIT-BIH Arrhythmia database [5,6] as well as self-collected ECGs.

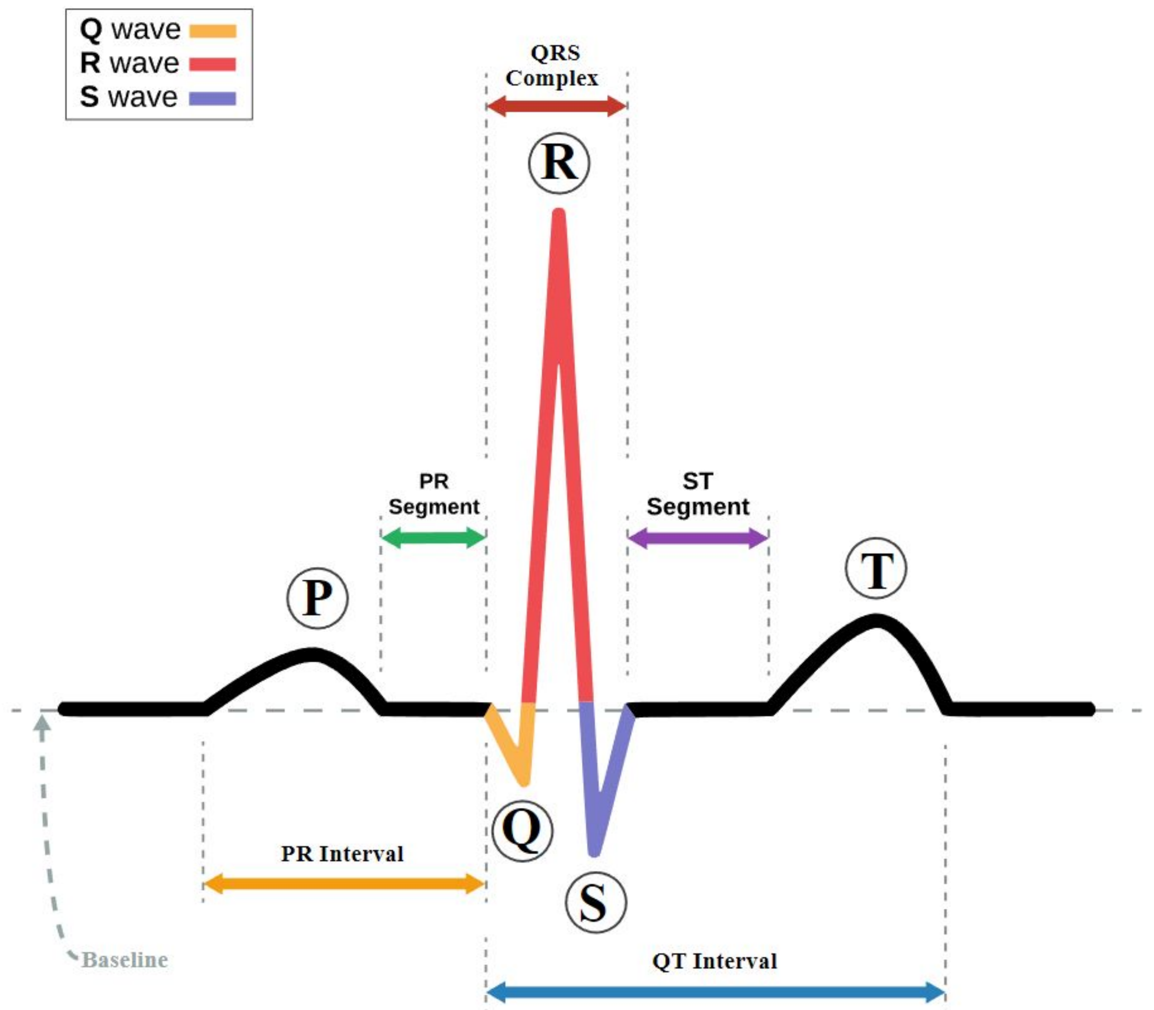

Figure 1. The PQRST wave that portrays heart depolarization within ECGs
Source: Created by Agateller (Anthony Atkielski), converted to svg by atom., Public domain, via Wikimedia Commons

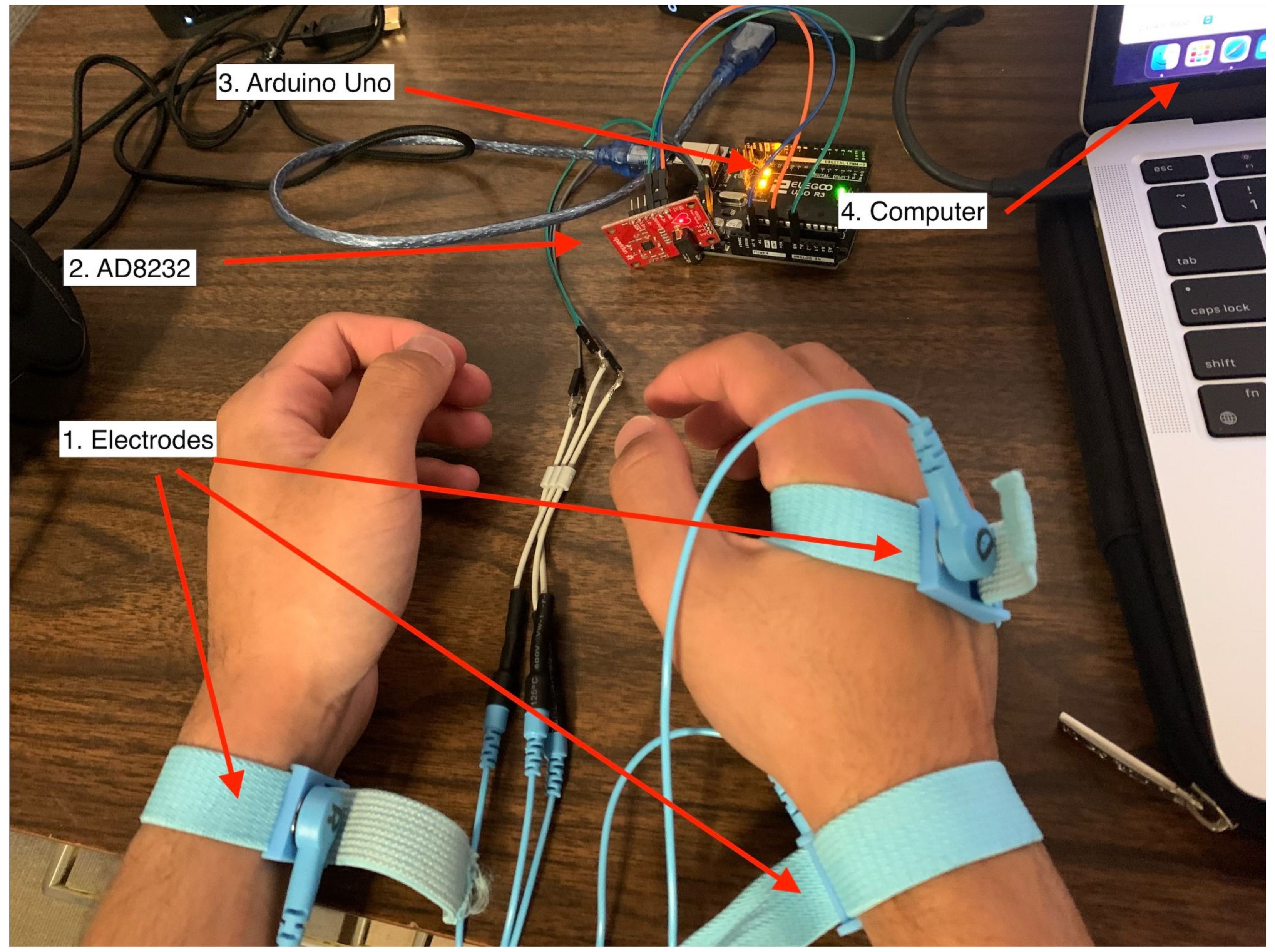

Figure 2. Electrodes (**1.**) placed on my palms and wrist record ECG signals to the sensor AD8232 (**2.**) sent to the microcontroller Arduino Uno (**3.**) sent to my computer (**4.**).

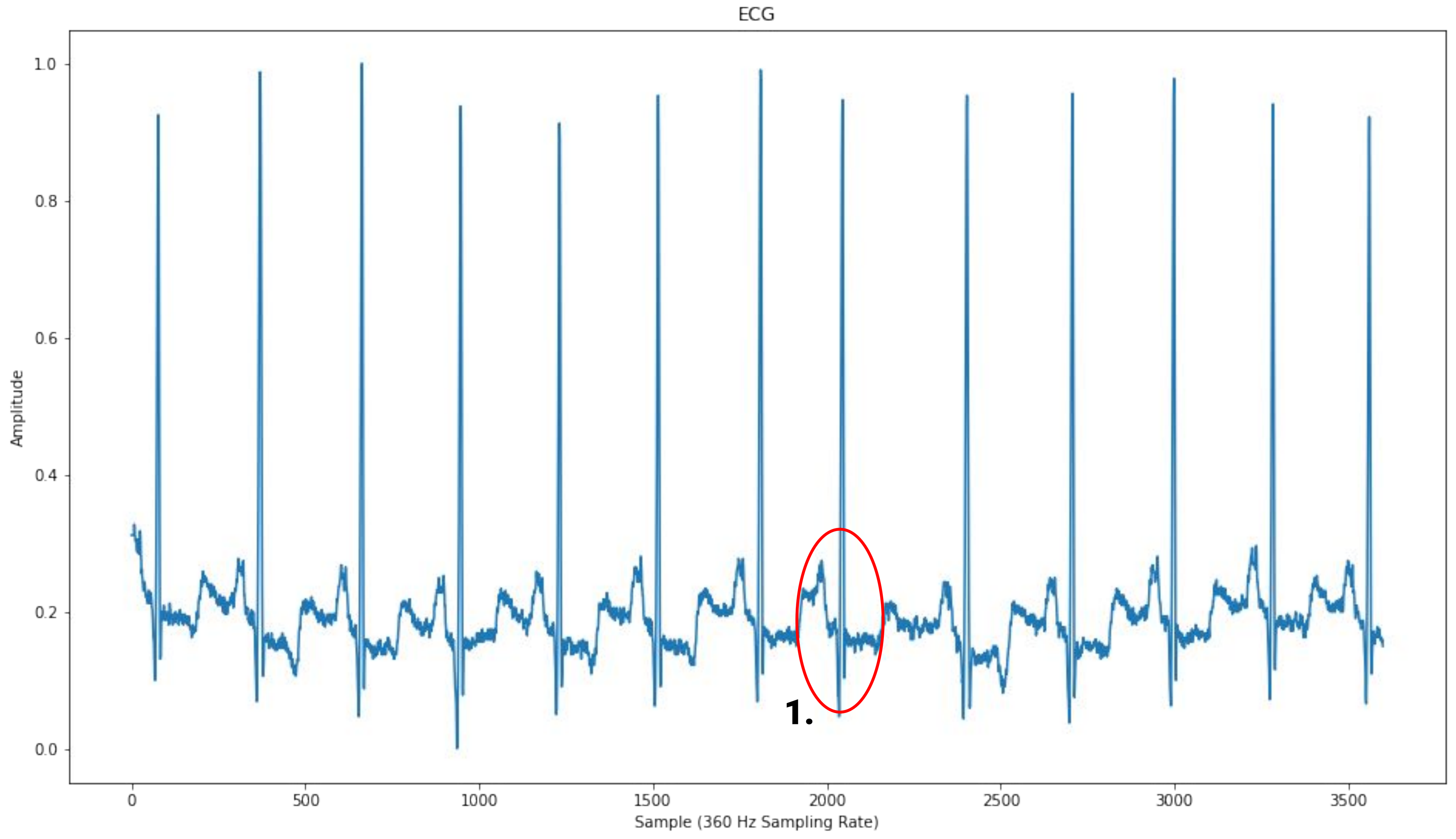

Figure 3. The first 10 seconds of MIT-BIH Arrhythmia Patient 100's ECG from the MLII lead. Atrial premature beat (**1.**)

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Denoising

Step 1: Fourier Transform Filter

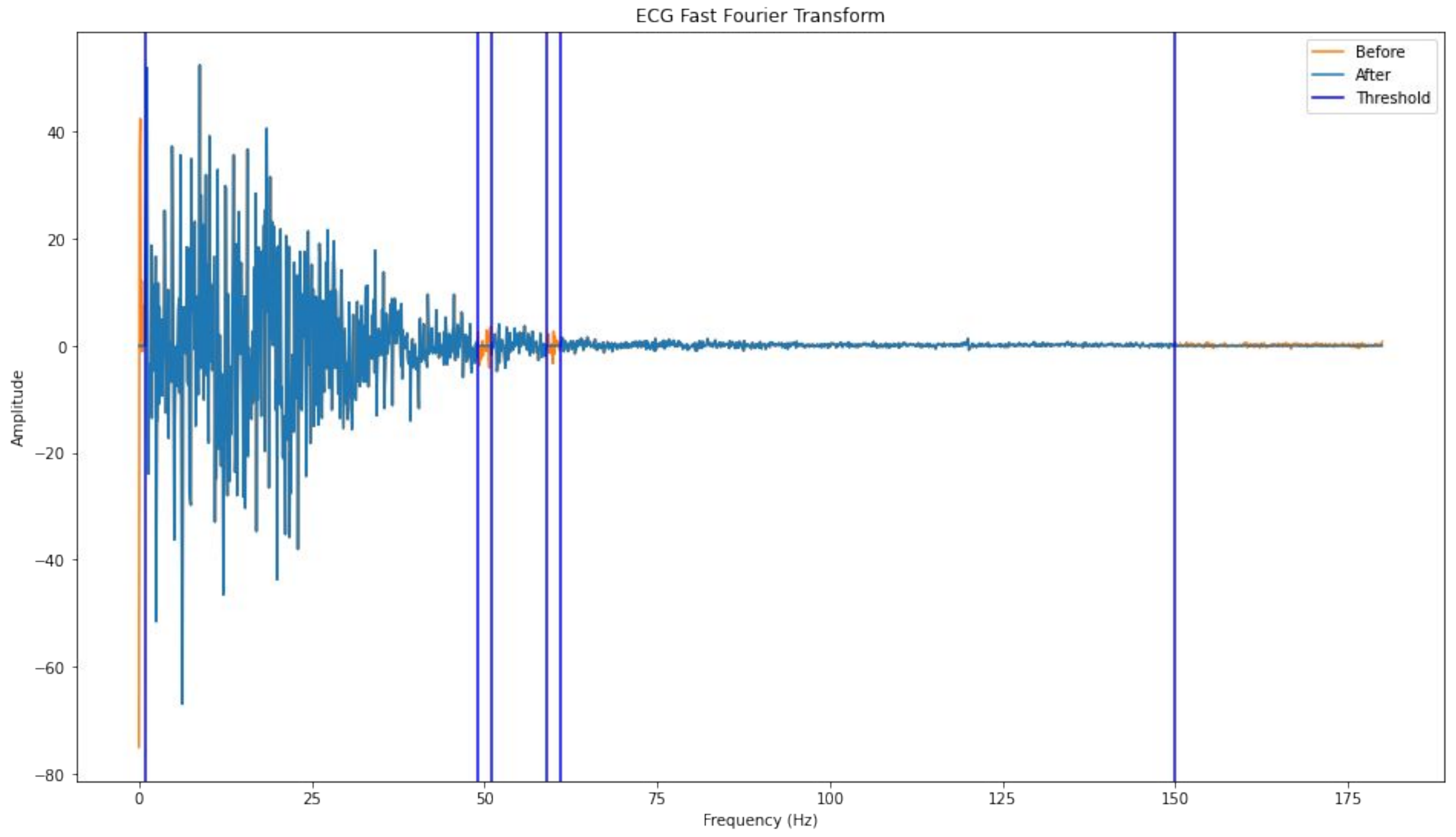

Figure 4. The Fast Fourier Transform converts the time-domain ECG signal into the frequency-domain. Notch filters from 49-51 Hz and 59-61 Hz are applied to remove power line interference, and Band Pass filters from 1-150 Hz are applied to remove low frequency baseline wander and high frequency muscle artifacts. An inverse Fast Fourier Transform converts the frequency-domain ECG signal back into the time-domain.

Step 3: Moving Average Filter

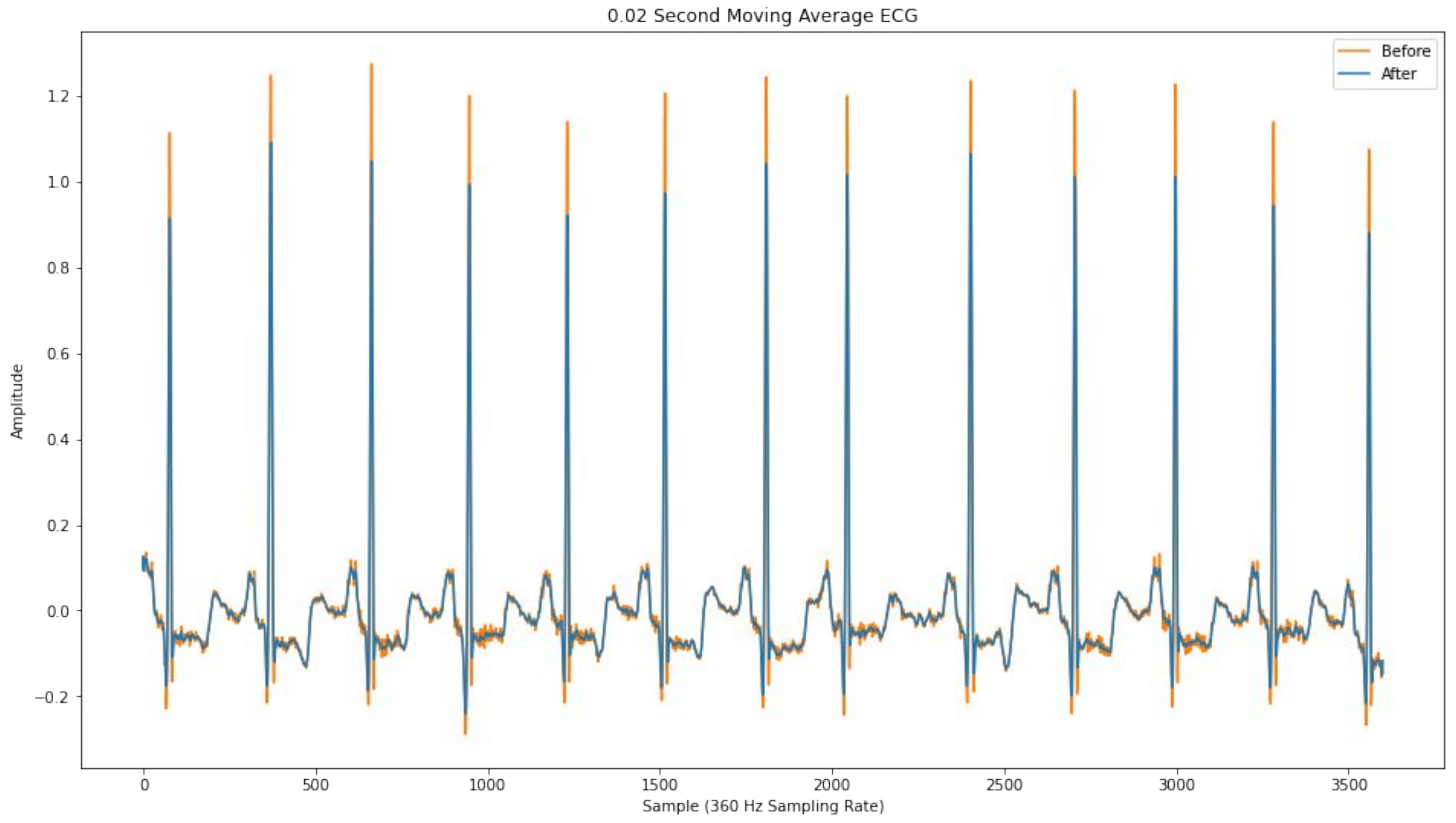

Figure 9. A moving average filter of 0.02 seconds smooths out the ECG signal to eliminate further noise.

Step 2: Wavelet Transform Filter

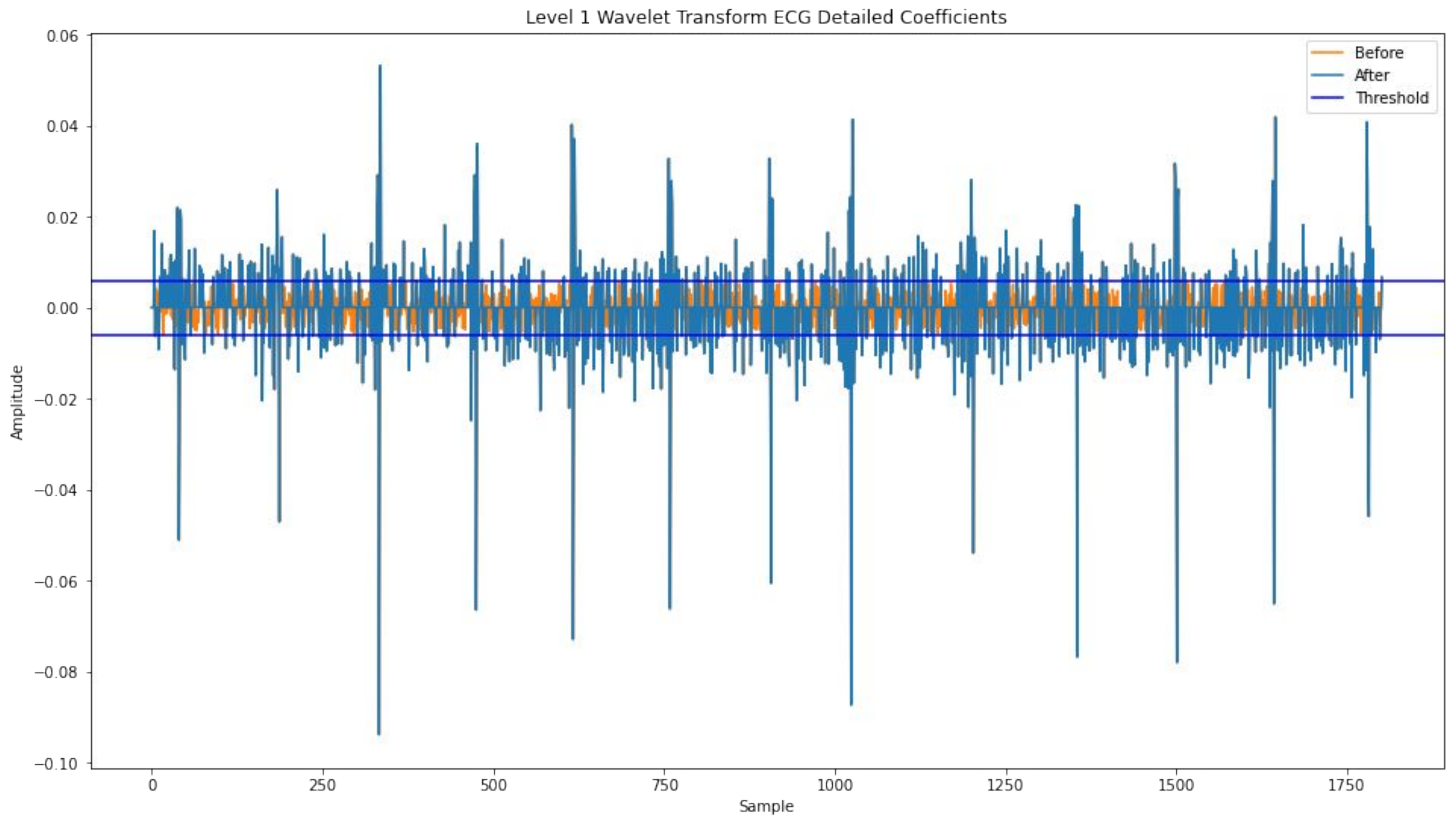

Figure 7. The Level 1 Wavelet Transform of the ECG signal captures signal frequencies from 90-180 Hz while remaining in the time-domain. A threshold is calculated based upon the wavelet coefficients standard deviation to eliminate high-frequency noise while not affecting the R waves. The inverse Wavelet Transform reconstructs the ECG signal.

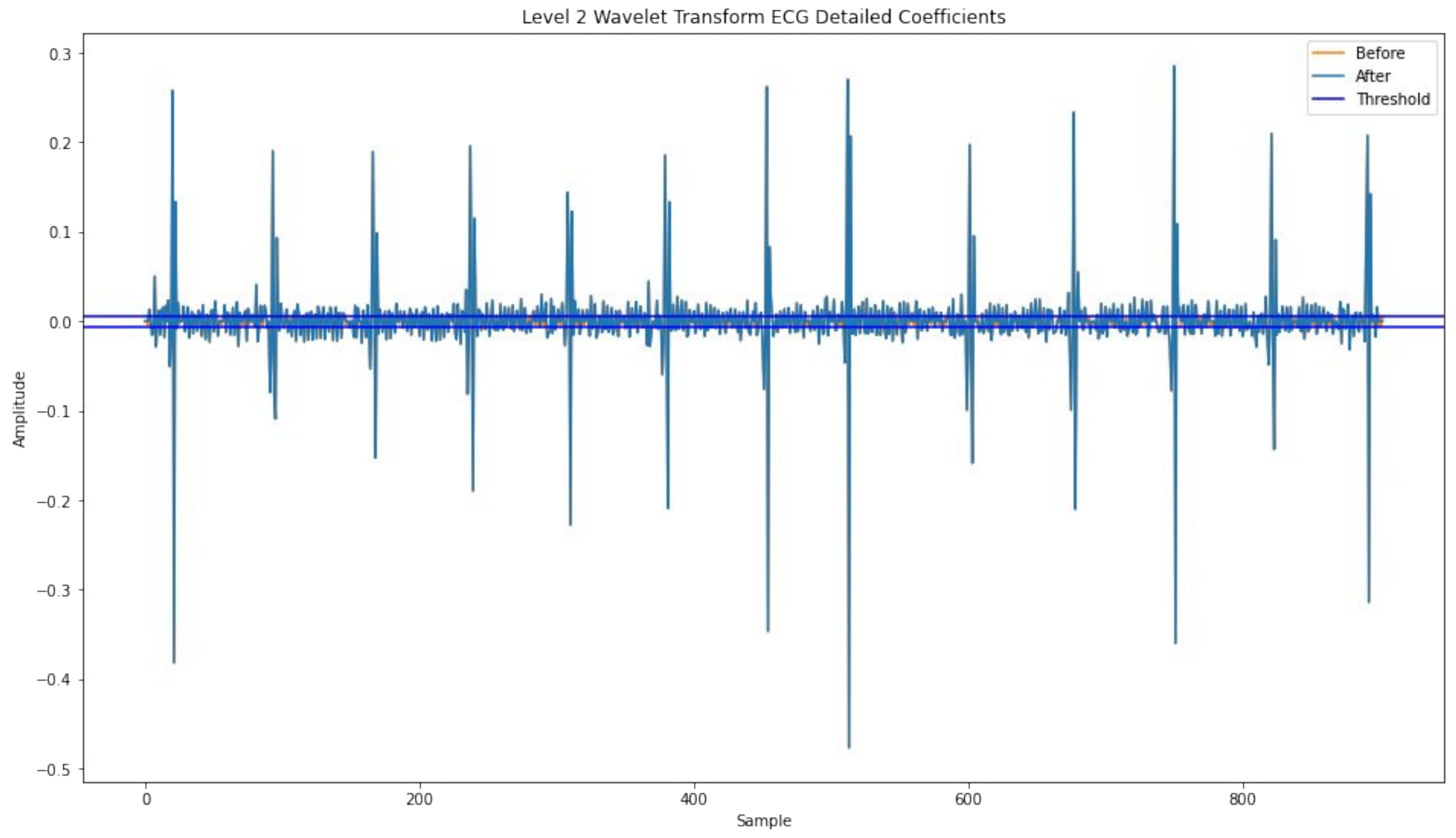

Figure 8. The Level 2 Wavelet Transform of the ECG signal captures signal frequencies from 45-90 Hz while remaining in the time-domain. A threshold is calculated based upon the wavelet coefficients standard deviation to eliminate high-frequency noise while not affecting the R waves. The inverse Wavelet Transform reconstructs the ECG signal.

Results

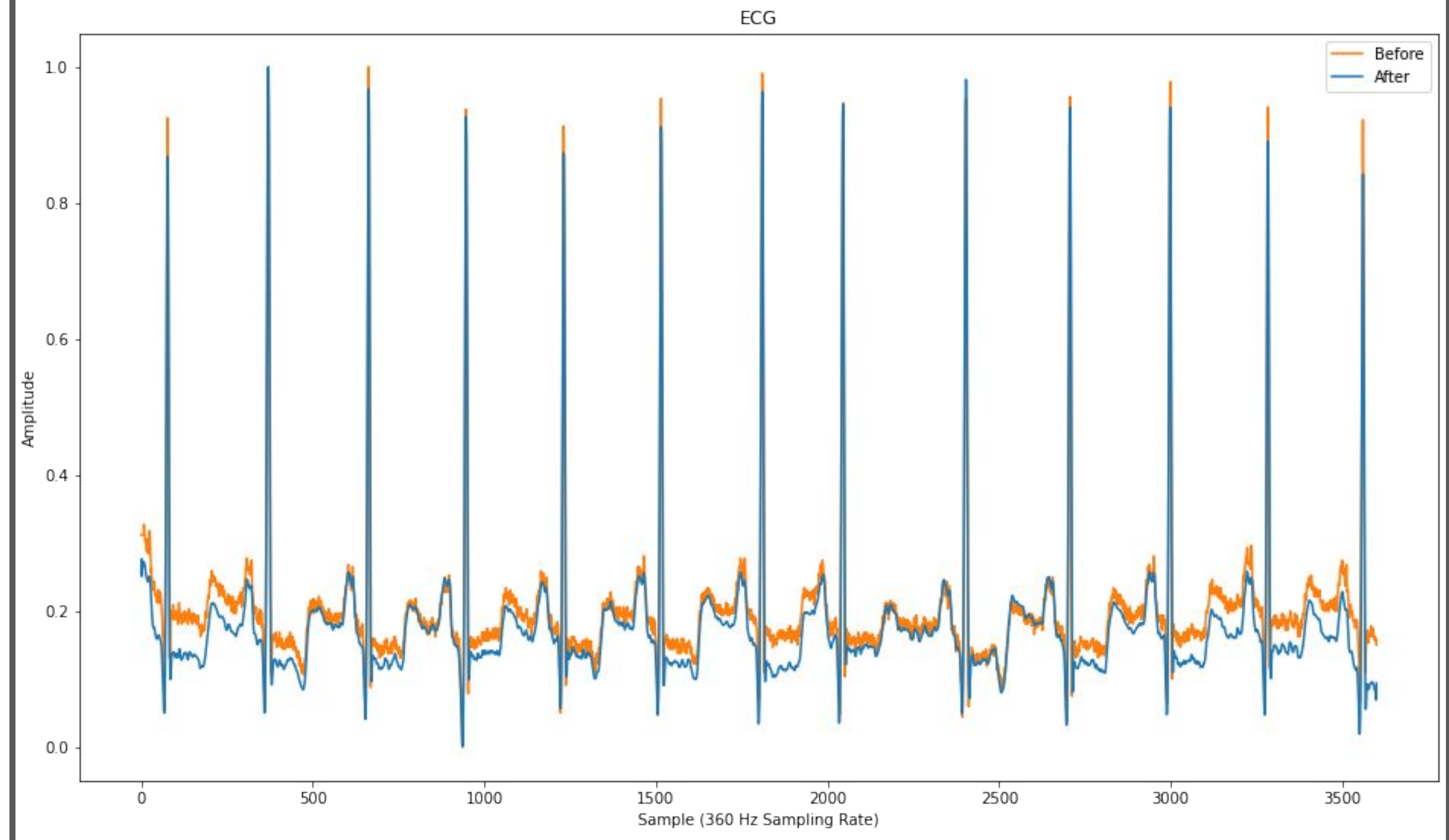

Figure 10. The results of denoising the first 10 seconds of MIT-BIH Arrhythmia Patient 100's ECG.

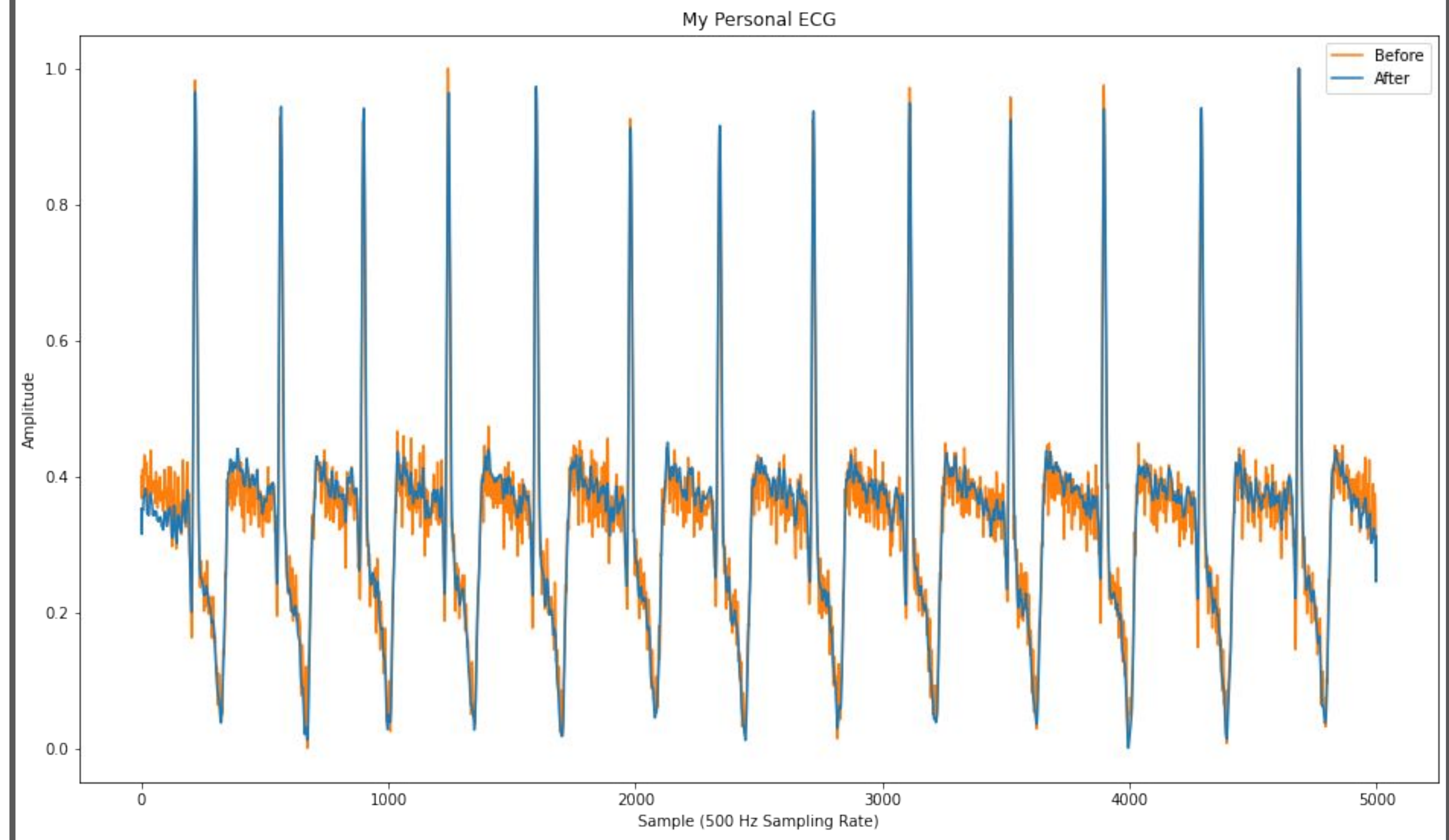

Figure 11. The results of denoising 10 seconds of my heart's own ECG.

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Sonification

Frequency Mapping

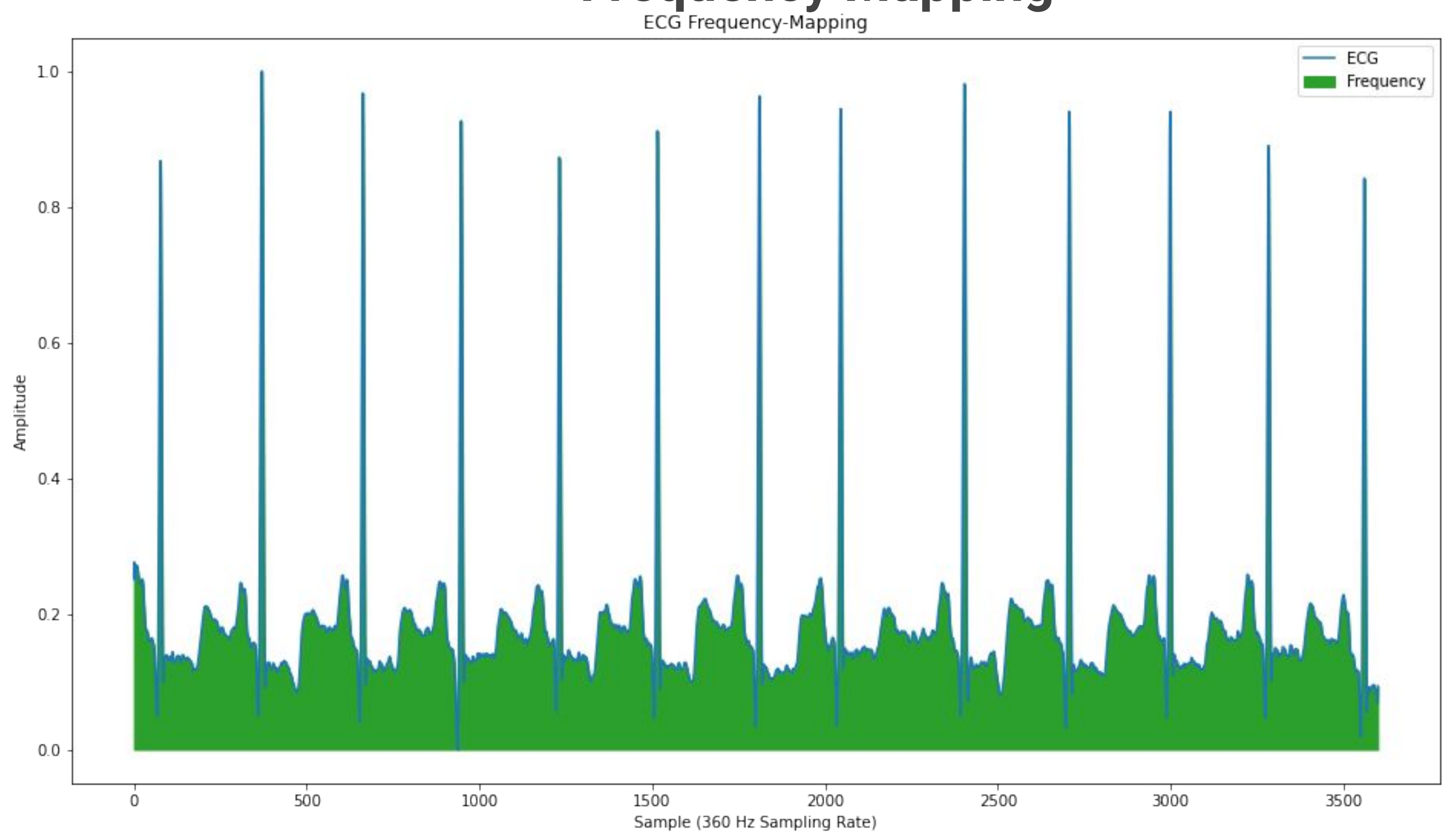

Figure 12. The ECG amplitude is mapped to the sonification frequency, normalized to a frequency range from 110 Hz to 880 Hz.

Volume Mapping

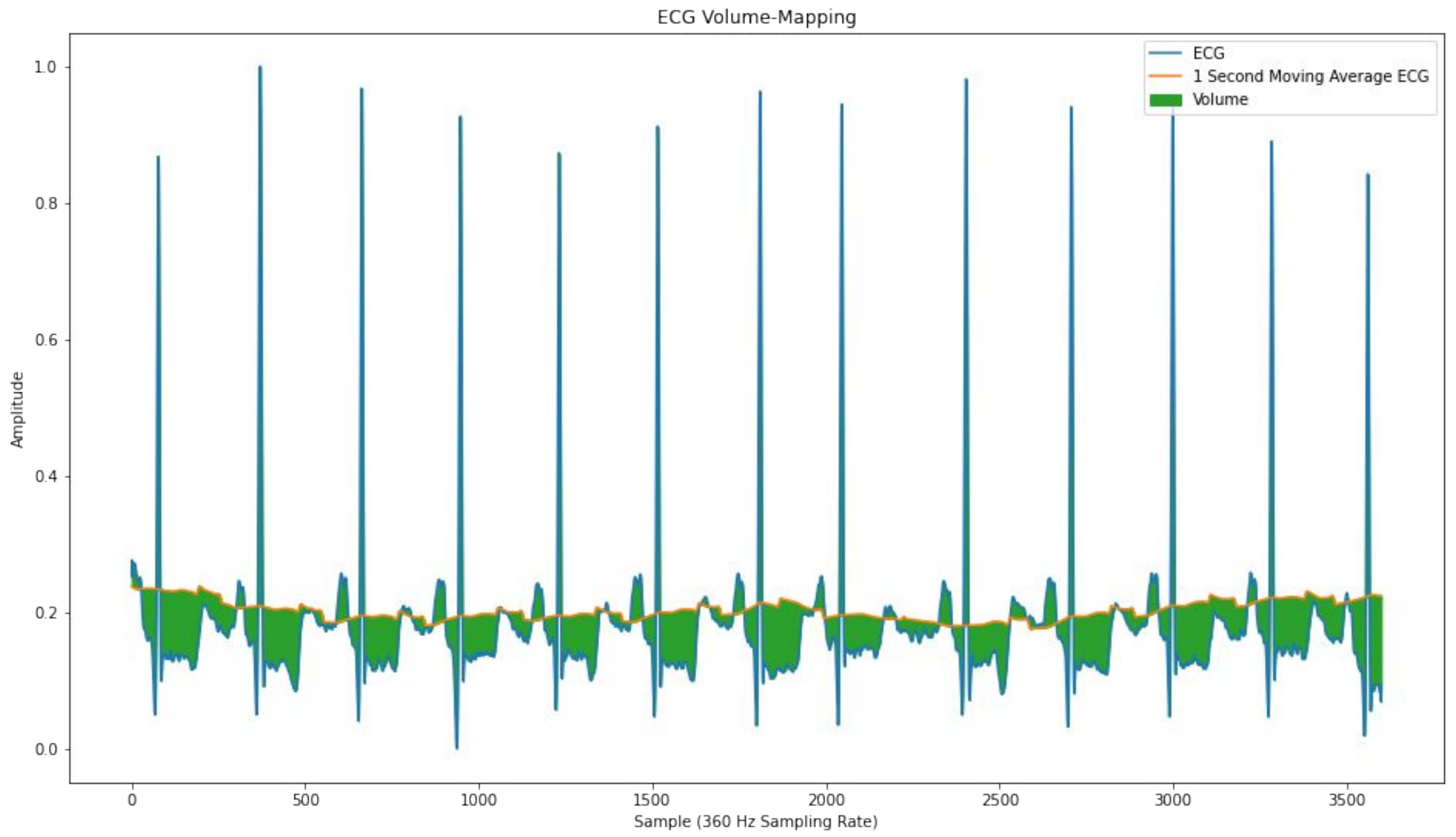

Figure 12. The ECG amplitude difference from the 1 second moving average ECG is mapped to the sonification volume, normalized to the volume range of 16-bit audio.

Morphology Mapping

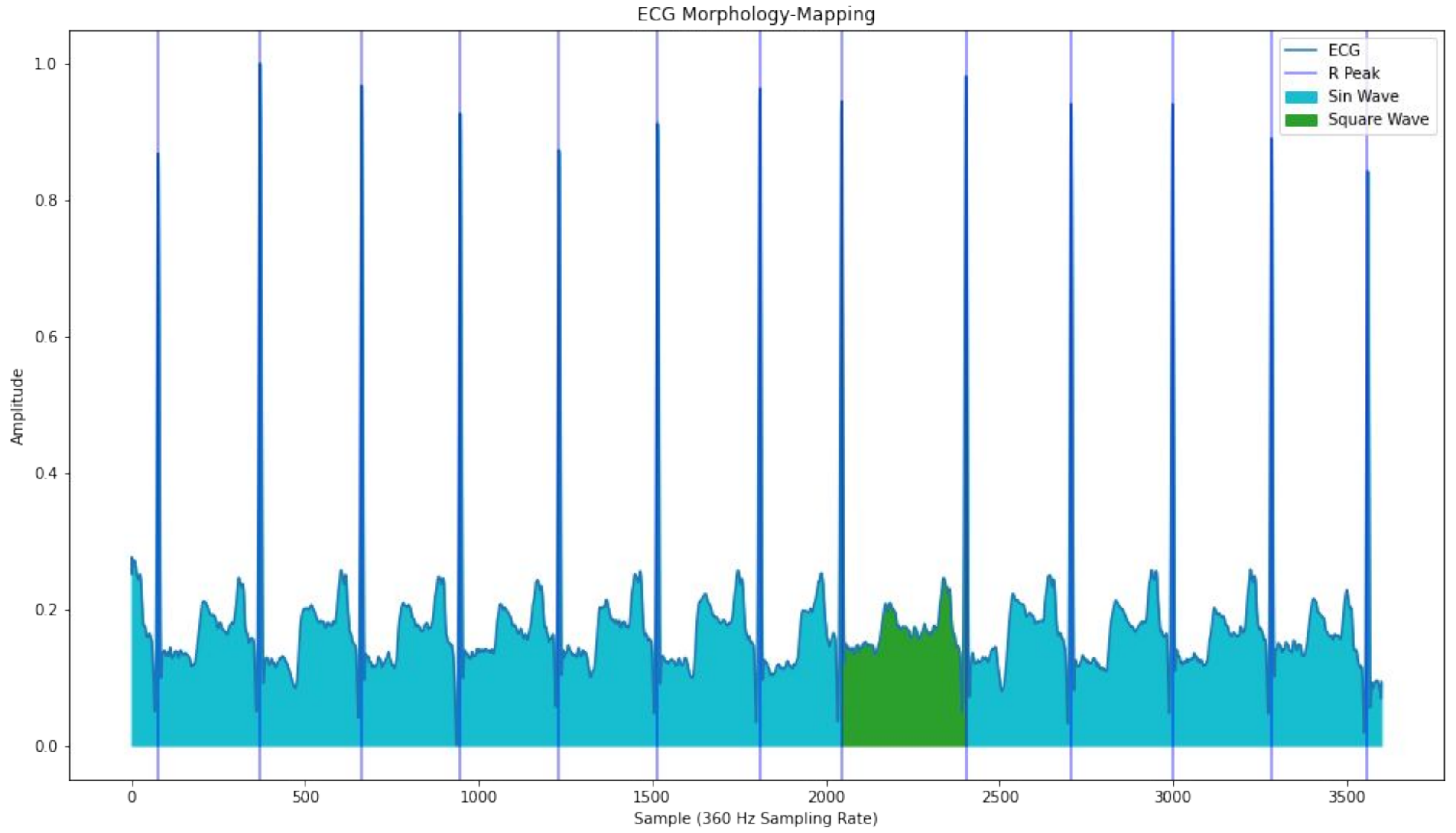

Figure 13. When the ECG RR-Interval is detected as 2 standard deviations beyond the mean RR-interval of the surrounding 10 RR-intervals, the corresponding sonification utilizes a square wave with 6 terms, instead of a pure sine wave.

Results

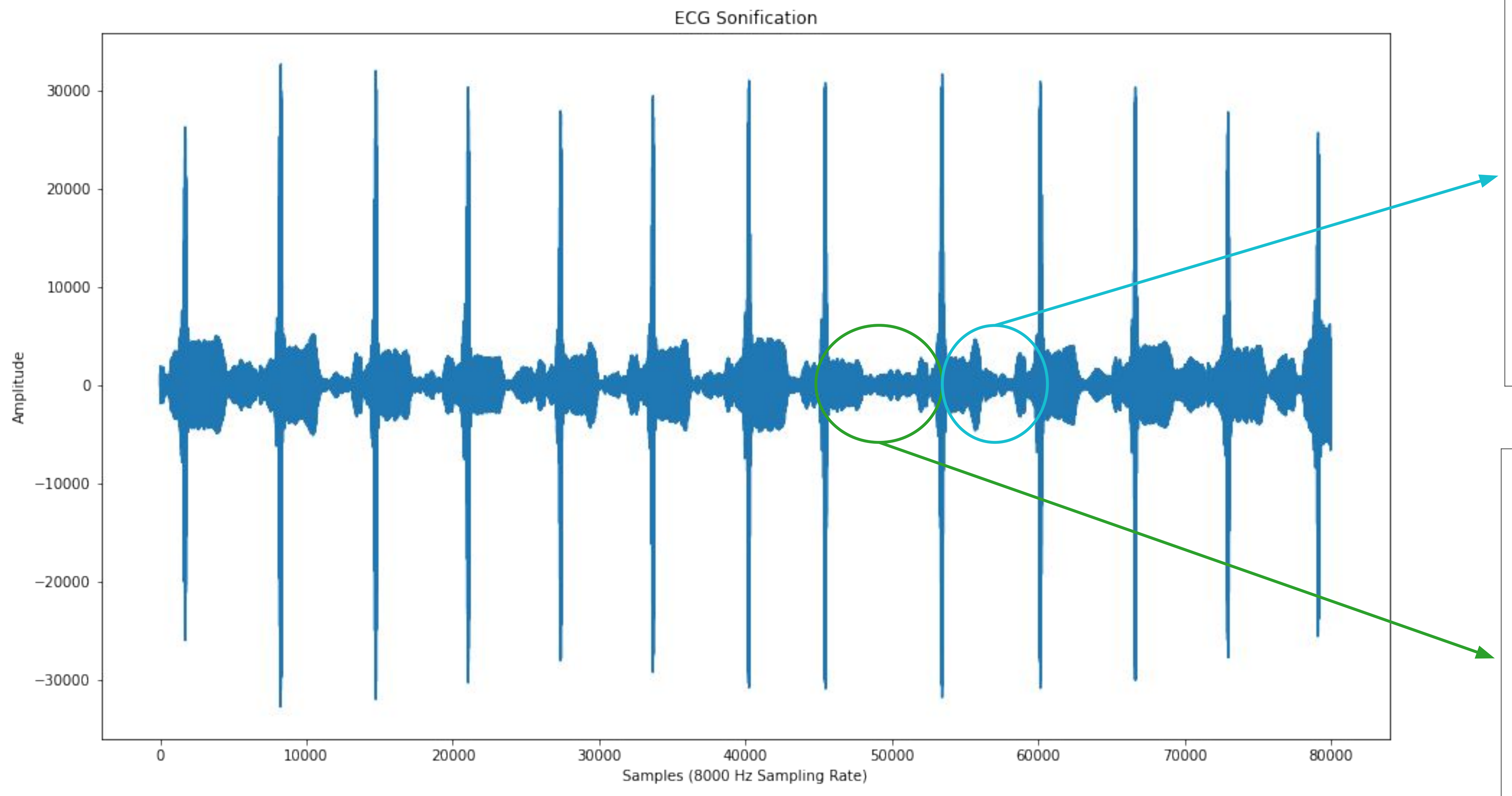

Figure 14. The results of sonifying the first 10 seconds of MIT-BIH Arrhythmia Patient 100's ECG.

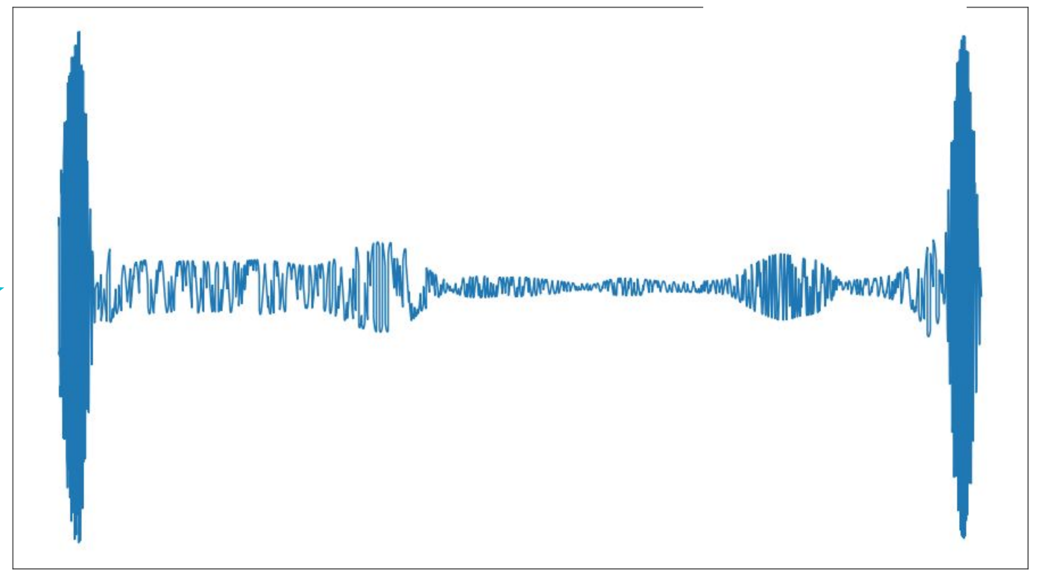

Figure 15. The sine wave sonification

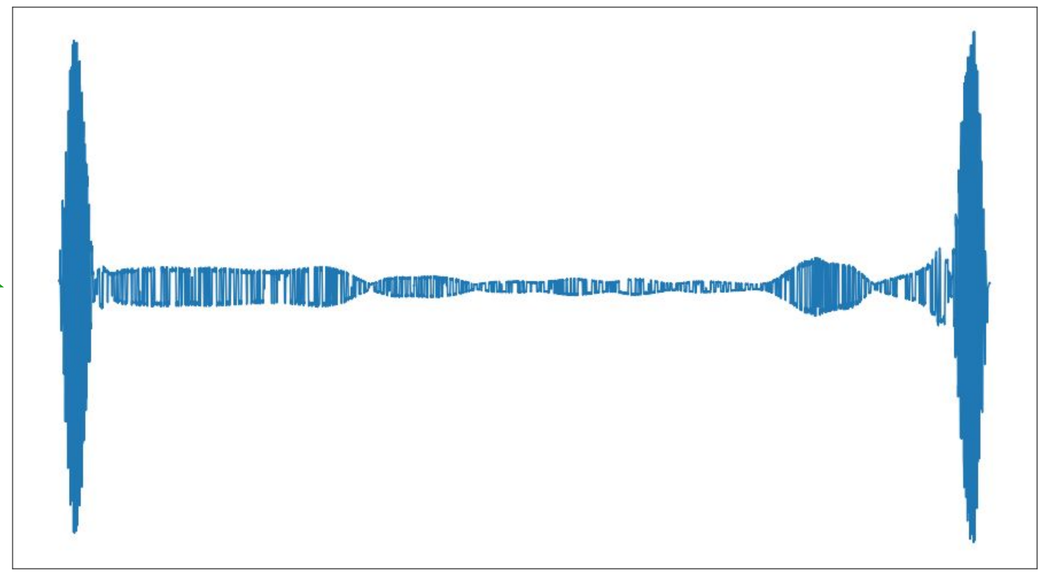

Figure 16. The square wave sonification

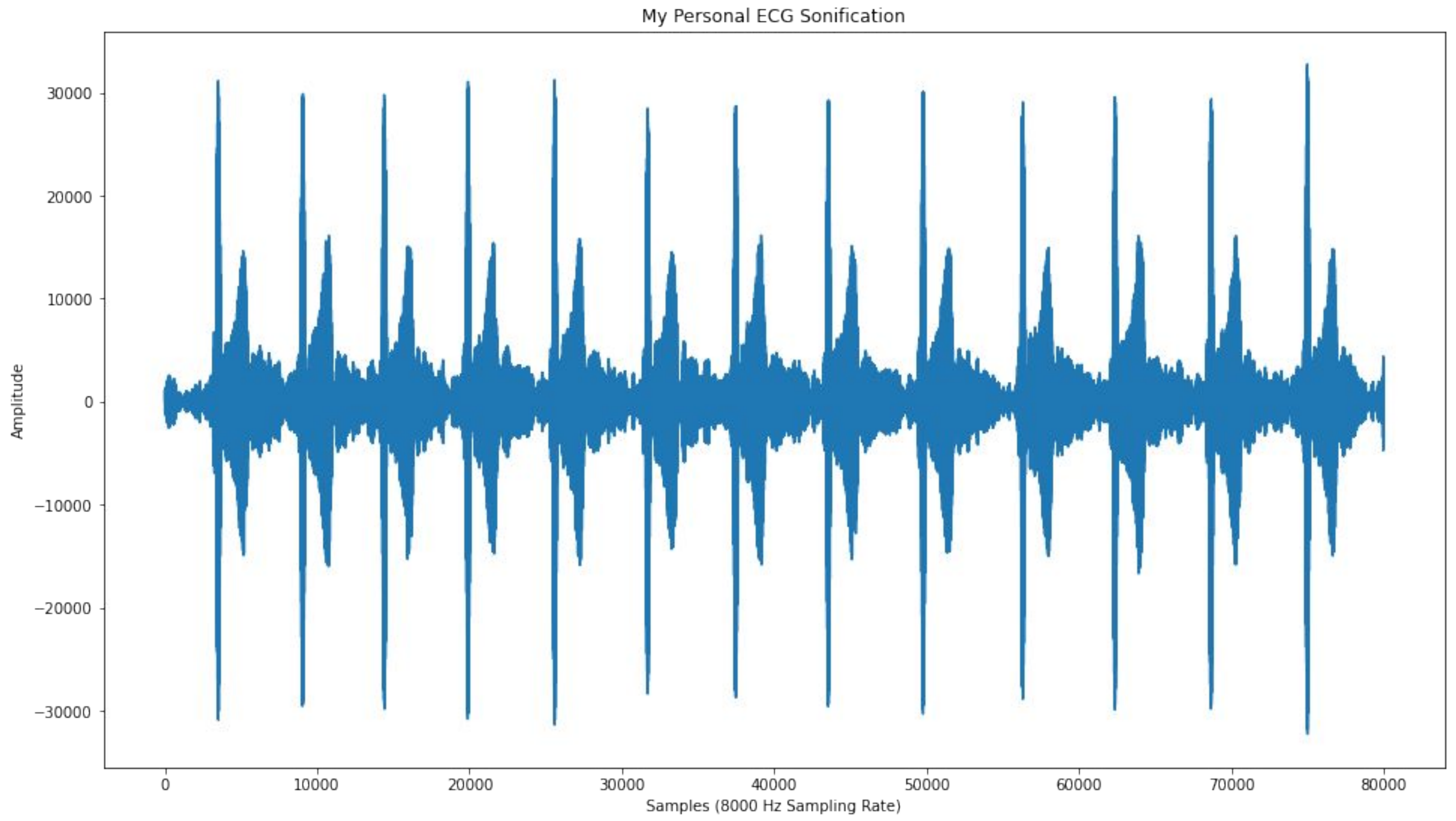

Figure 14. The results of sonifying 10 seconds of my heart's own ECG.

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References

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2. A. E. A. N. J; "Cardiology explained," National Center for Biotechnology Information. [Online]. Available: https://pubmed.ncbi.nlm.nih.gov/20821845/. [Accessed: 29-Oct-2022].
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Acknowledgements

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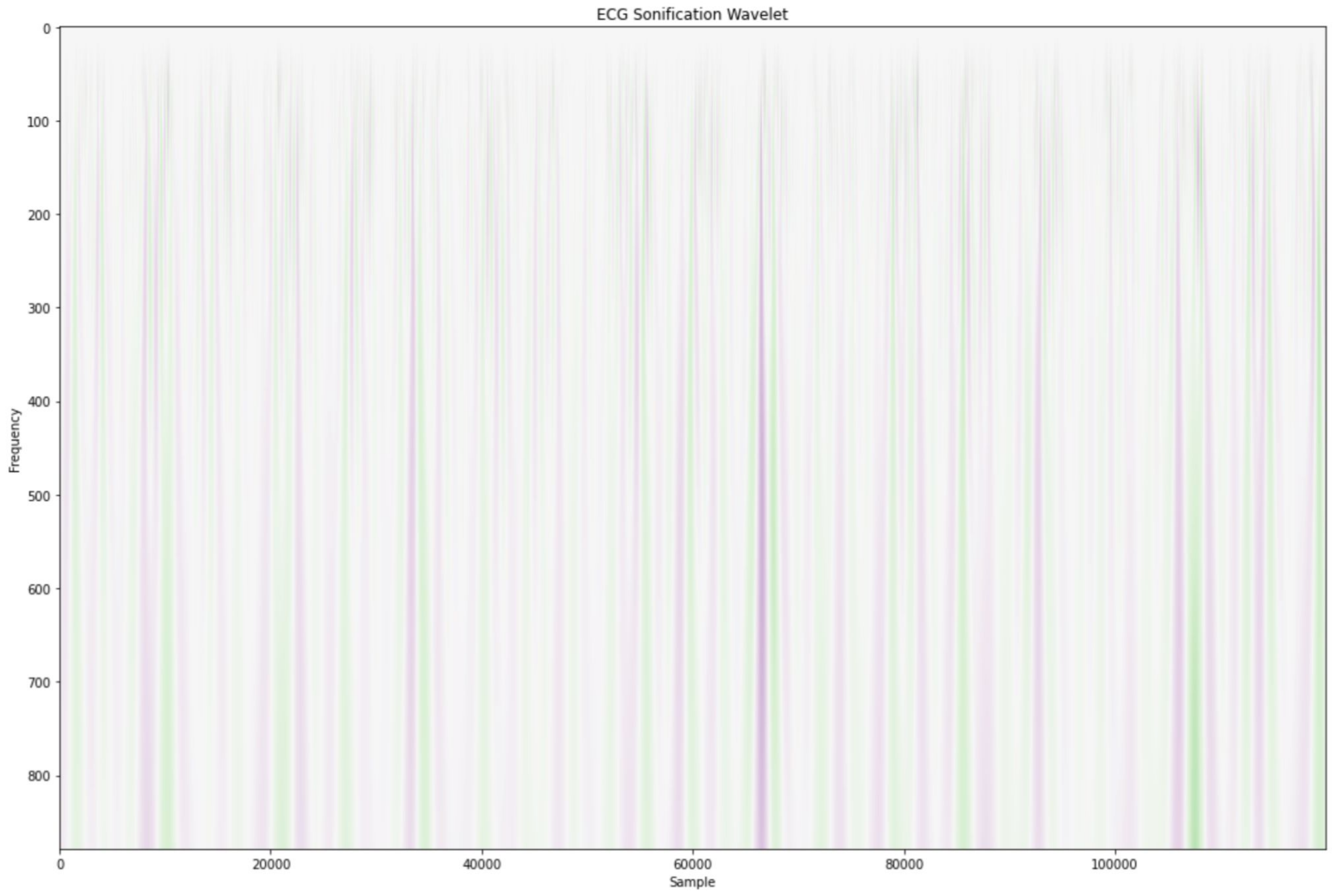
Future Work

- Applying a machine learning neural network classification model to classify ECG sonification samples as normal sinus rhythm or as arrhythmic. Utilizing wavelet transformations to convert the ECG Sonification to time-frequency to apply a 2D Convolutional Neural Network.



- Incorporate a user interface.
- Host application on a web server to allow uploading of ECG signals to be sonified.