Project 1 – 2 Report

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Introduction

This project uses a bandpass filter to detect heart rate from the noisy BVP (Blood Volume Pulse) signal. The input signals are acquired from 2 students using the BVP (Blood Volume Pulse) device. A PPG (Photoplethysmography) sensor recorded data with 128 samples per second. Total time 100 seconds. The maximum amplitude range of the device is from -100 [mV] to +100 [mV], and the resolution is 24 [bit].

Data and Results – Student A

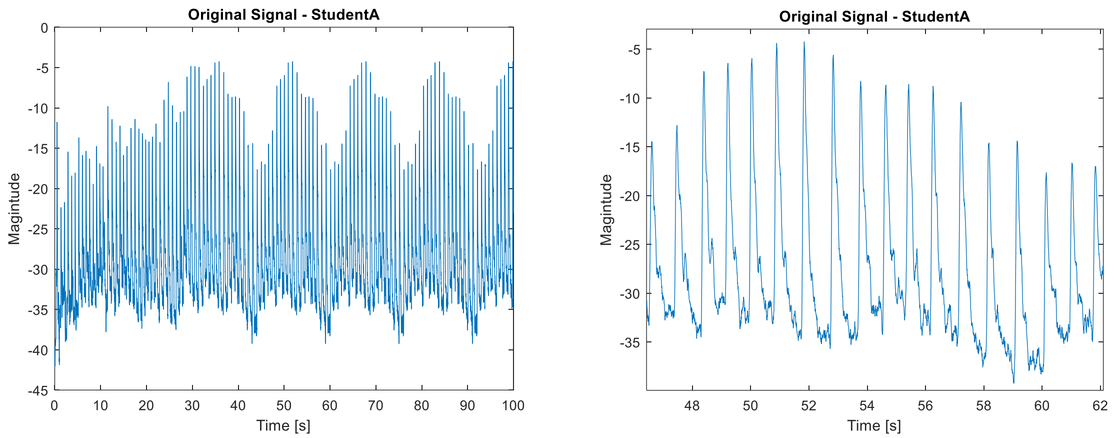

Figure A_1
Original student A's heart rate data from PPG

Figure A_1 (left) is the original signal of 100 seconds of a student A, and Figure A_1 (right) is part of the signal.

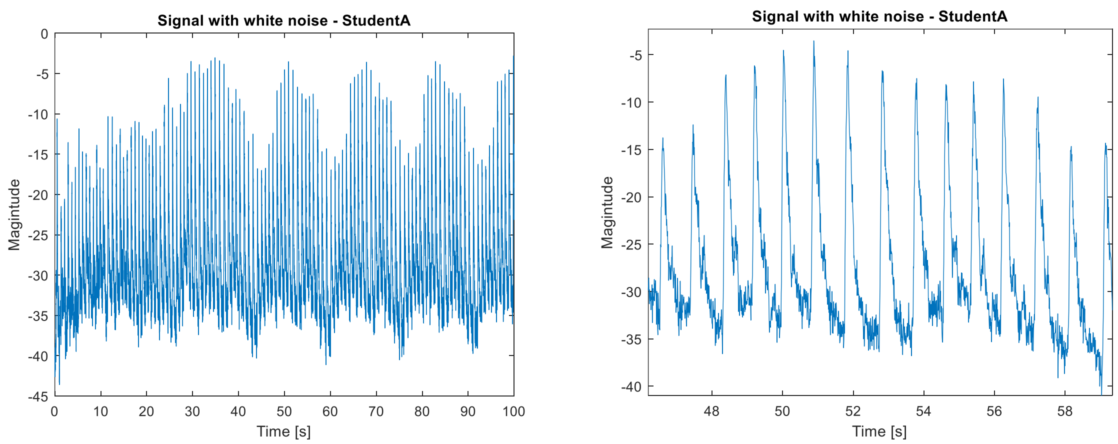

Figure A_2
White noise added to student A's heart data

Generated random white noise with MATLAB and added it to the original data.

Bandwidth

The bandwidth of the signal is 1Hz. Though this is very low bandwidth, this makes sense because the signal we are measuring is a heartbeat signal, and the heartbeat is generally around 60 ~ 160 beats per minute which convert to 1 ~ 2.67 [Hz] (60/60 - 160/60), and our signal represents around 140 beats per minute which convert to 2.4 [Hz], so we designed a filter that has a bandwidth of 1 [Hz] from 1.7 [Hz] to 2.7 [Hz] (BW = 2.7-1.7 = 1 [Hz])

Filtering

We chose the Butterworth Bandpass filter for this project. Heart rates taken at normal conditions have a relatively constant frequency. After performing FFT on noised signal, we obtain a general range of the heart rate. Then design the bandpass filter by selecting the cutoff frequencies containing the heart rate.

Order: 6. Cutoff 1st: 2 [Hz]. Cutoff 2nd: 2.5 [Hz]. Heartrate: (2.4~2.6 [Hz]), this range may vary with different patients' data. 2.4~2.6 [Hz] is the range of the two testing students' heart rates.

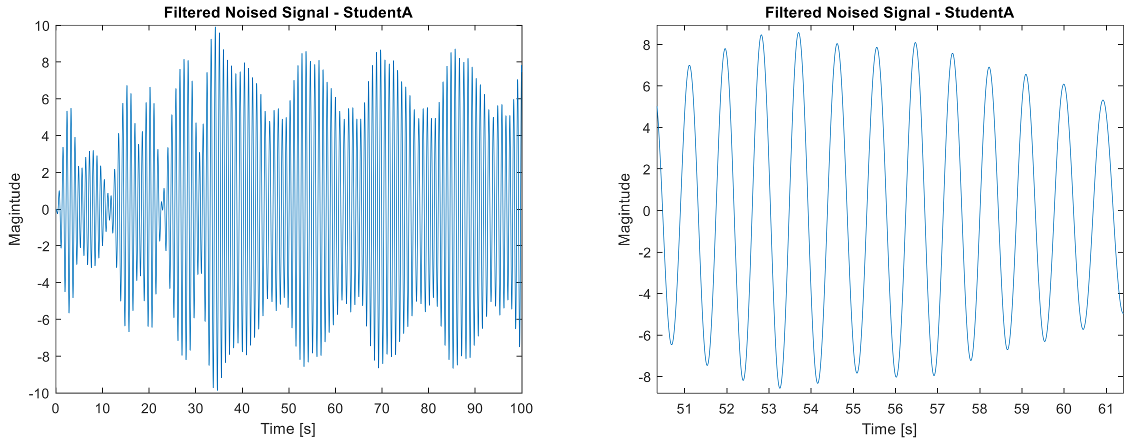

Figure A_3
Filtered noise signal, recovered heart rate signal

Figure A_3 shows that the heart rate signal was successfully recovered with the key interest on heart rate with peak-to-peak frequency. The result is a smooth and periodic sinusoidal signal.

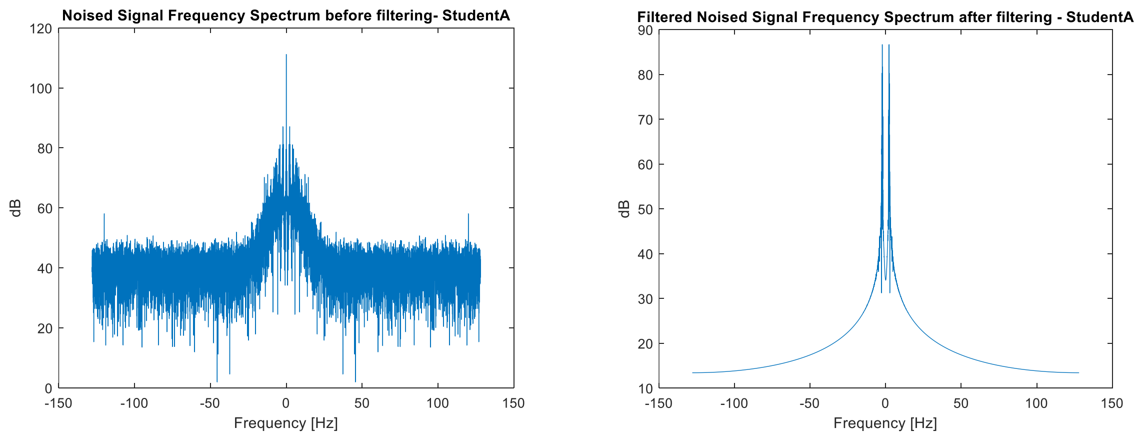

Figure A_4
dB plot of the frequency spectrum

Figure A_4 (left) shows the frequency spectrum of a noise-added signal. Figure A_4 (right) is the frequency spectrum of the filtered signal. We represent the spectrums in the dB scale because the original FFT spectrum is dominated by some large amplitudes, making it hard to observe the details of all frequency ranges. Before filtering the signal, in Figure A_4 (left), we can see the noise components in the frequency spectrum. After filtering the signal, there is no noise signal but only one component of the signal we want to detect.

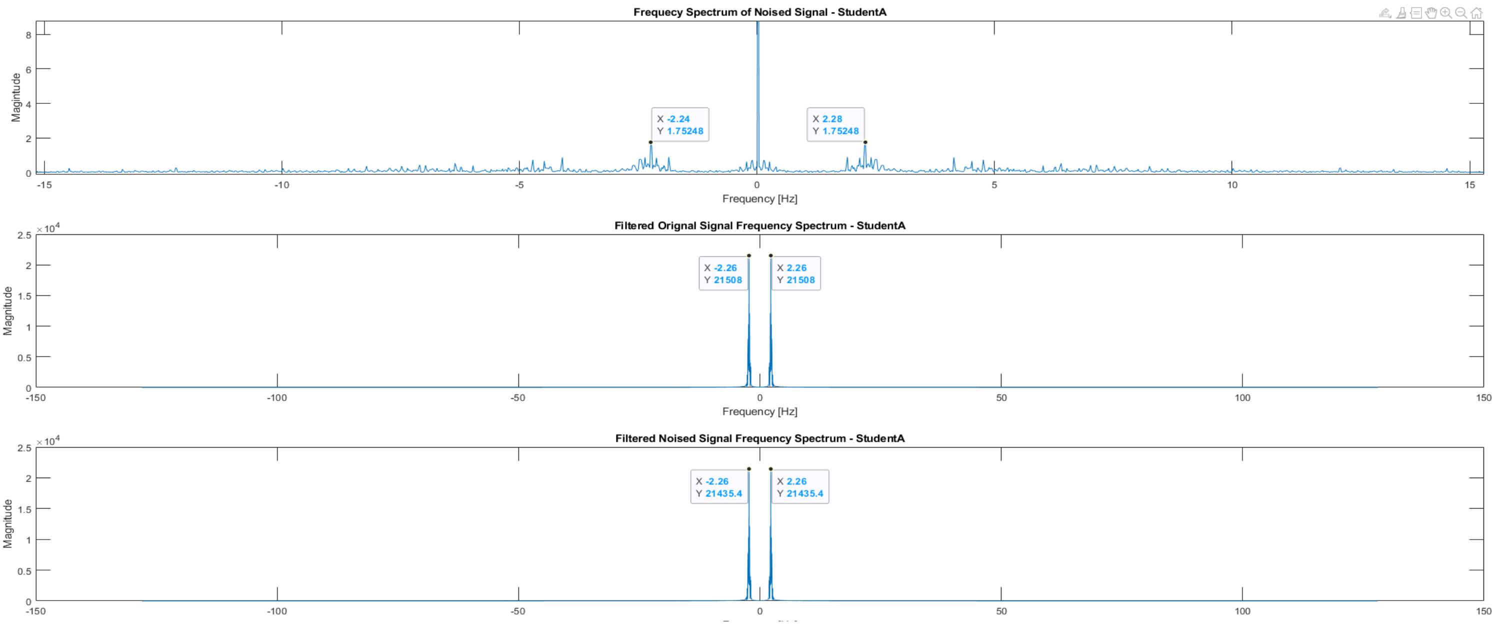

Figure A_5
Frequency spectrum of the noised signal, filtered original signal, and filtered noised signal

Figure A_5 shows the complete progress in the frequency domain. First, in Figure A_5 (top), we obtained the frequency spectrum of the noise signal. We have a general heart rate range between 2.24 to 2.26 [Hz] and used this range for filter designs. Then, in Figure A_5 (middle) and (bottom), we showed the frequency spectrums of the filtered original signal and noise signal, and both spectrums gave the agreeing number of 2.26 [Hz]. Thus, it proves that the filter was correctly designed.

$$Heartrate = 2.26\,Hz \times 60\,seconds = 136\,BPM \text{ (Beats per minute, participant A)}$$

Data and Results – Student B

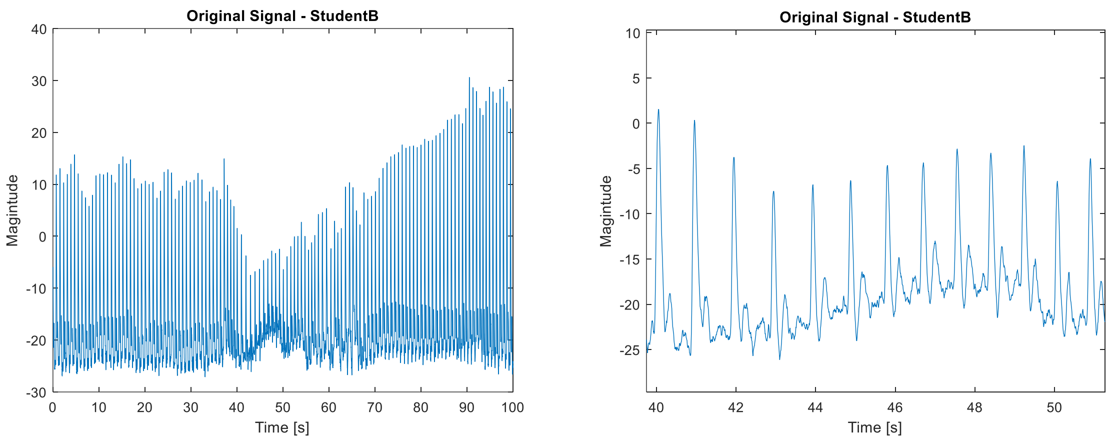

Figure B_1
Original student B's heart rate data from PPG

A PPG sensor recorded data with 128 samples per second. Total time 100 seconds.

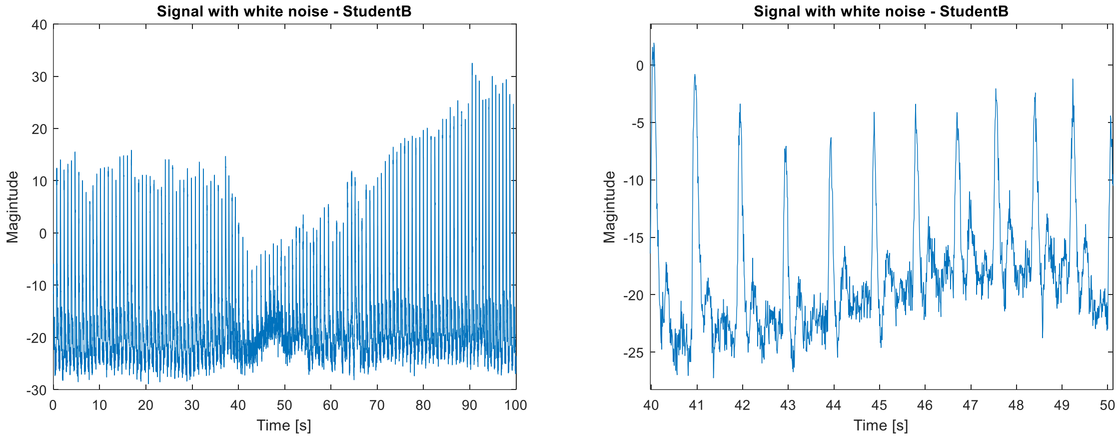

Figure B_2
White noise added to student B's heart data

Generated random white noise with MATLAB and added it to the original data.

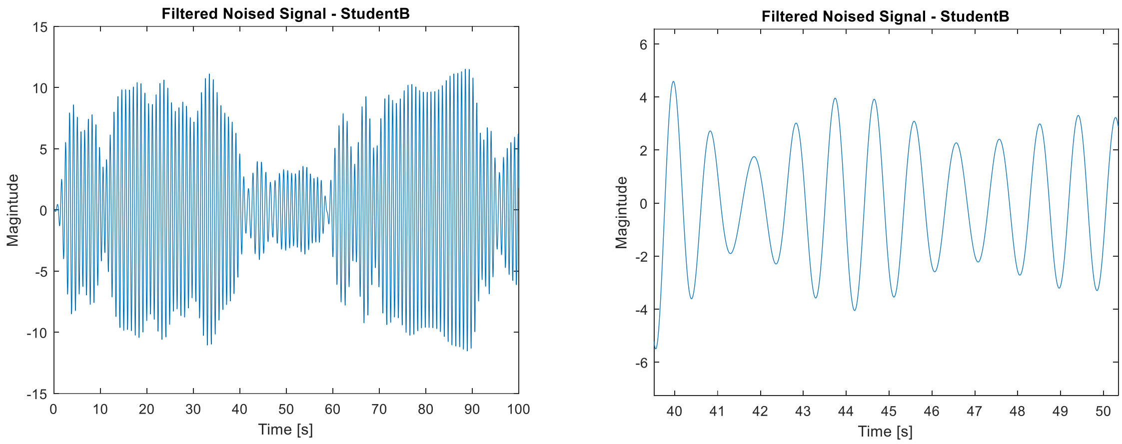

Figure B_3
Filtered noise signal, recovered heart rate signal

Figure B_3 shows that the heart rate signal was successfully recovered with the key interest on heart rate with peak-to-peak frequency. The result is a smooth and periodic sinusoidal signal.

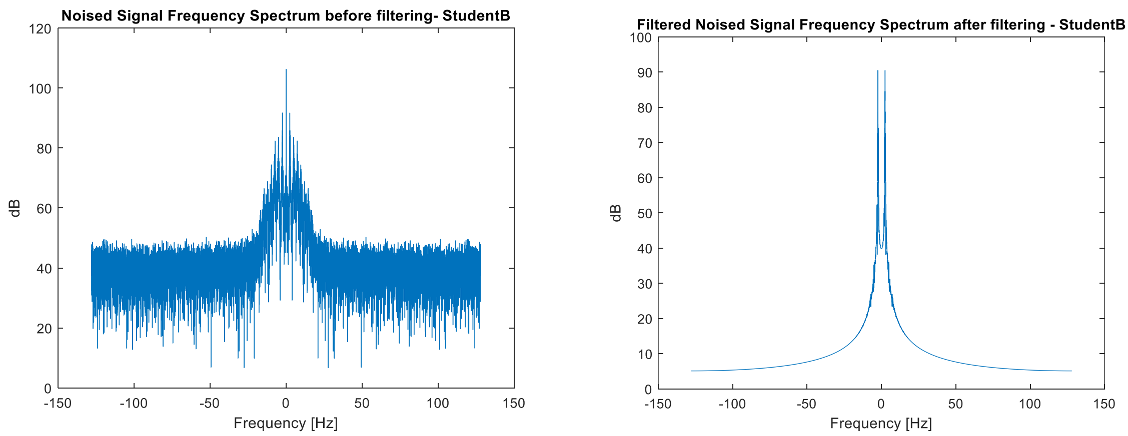

Figure B_4
dB plot of the frequency spectrum – Details explained at Figure A_4

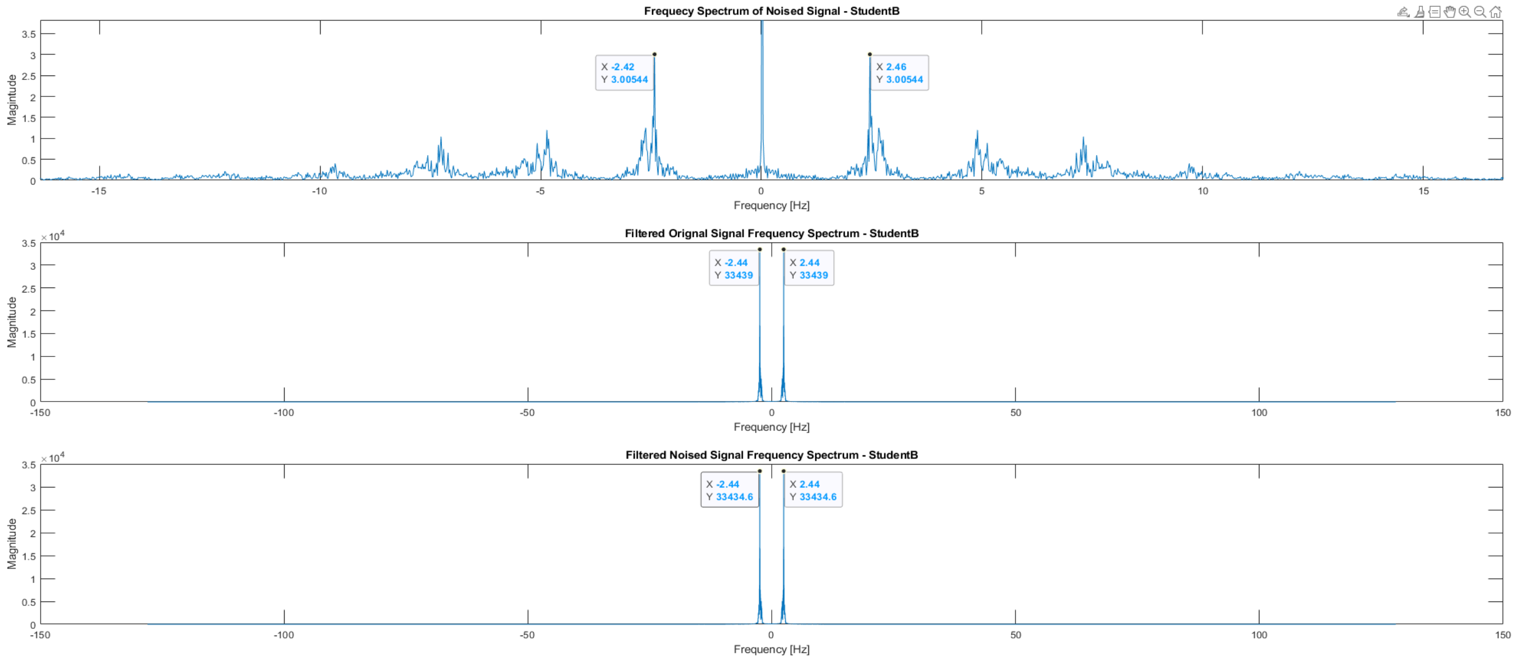

Figure B_5
Frequency spectrum of the noised signal, filtered original signal, and filtered noised signal

Figure B_5 shows the exact steps we took from student A. With different participants, the heart rate varied. The range is now between 2.42 to 2.46 Hz observed from the noise signal's frequency spectrum.

This range is used for the filter design parameters. The results from the filtered original signal and noised signal agreed at 2.44 Hz for student B.

$$Heartrate = 2.44\ Hz\ \times 60\ seconds =\ 146\ BPM \quad \text{(Beats per minute, participant B)}$$

Summary

- We detected heart rate from the noise signal acquired from the BVP device using a bandpass filter.
- We added the white noise to see if the filter suppressed the noise.
- Two input signals from two students are used to test the filter.
- We can assume the heart rates are constant since we measured data in their rest state without movement.
- We checked the FFT of the noise signal.
- We designed a Butterworth bandpass filter allowing both participants' heart rate frequencies.
- We observed the filter suppressed the noise and other components of the original signal to see only the heart rate signal.
- We compared the original signal and filtered signal, and we checked that the heart rate is corresponding each other.