BME 544 Assignment 4

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Overview

The landmark chosen for this cardiac cycle tracking task is the QRS complex (more specifically, the R wave peak). The algorithm used to accomplish the tracking is based on the Pan-Tompkins algorithm [1], a widely used method for detecting QRS complexes in ECG signals. The algorithm works by enhancing the QRS complex while suppressing noise and other components through the following steps:

1. Bandpass Filtering: Removes baseline wander and high-frequency noise using a 5-15 Hz bandpass filter to focus on QRS frequencies.
2. Differentiation: Highlights rapid changes in the signal by emphasizing the slope of the QRS complex.
3. Squaring: Amplifying large values and suppressing small ones will make the QRS complex more prominent.
4. Moving Window Integration (Averaging): Smooths the signal to create a waveform representing QRS energy over time.
5. Thresholding & Peak Detection: Adaptive thresholds are used to detect QRS complexes while accounting for variability in amplitude and RR intervals.

Flow Chart

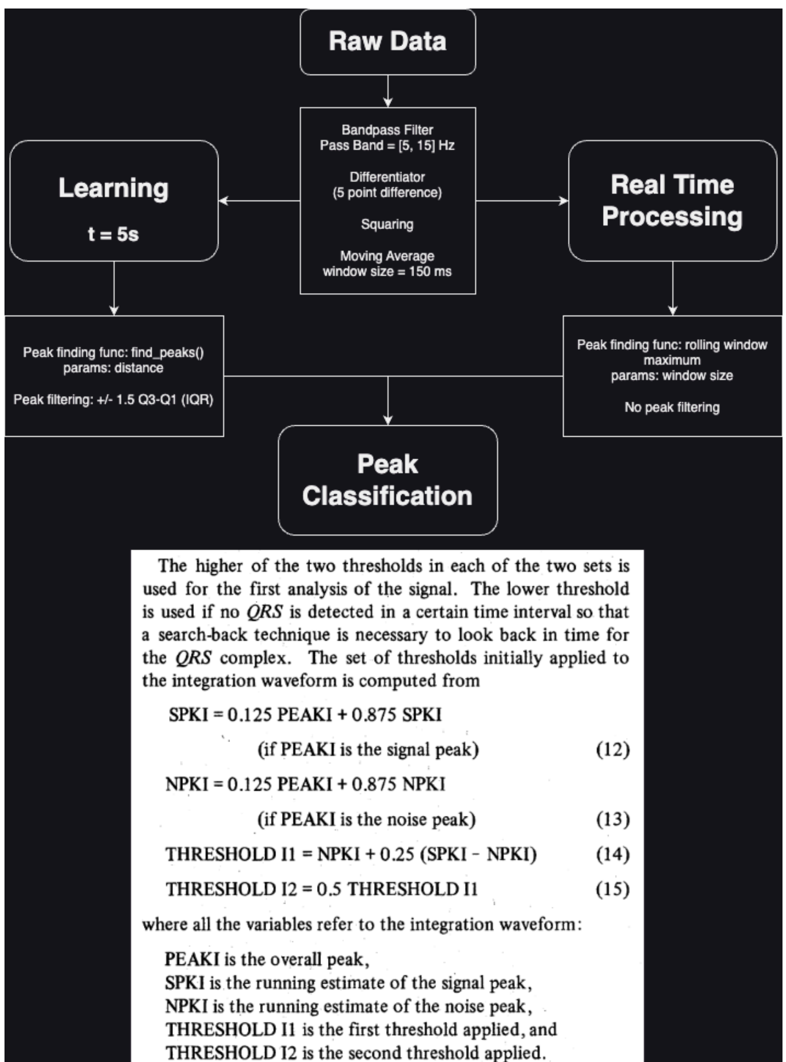
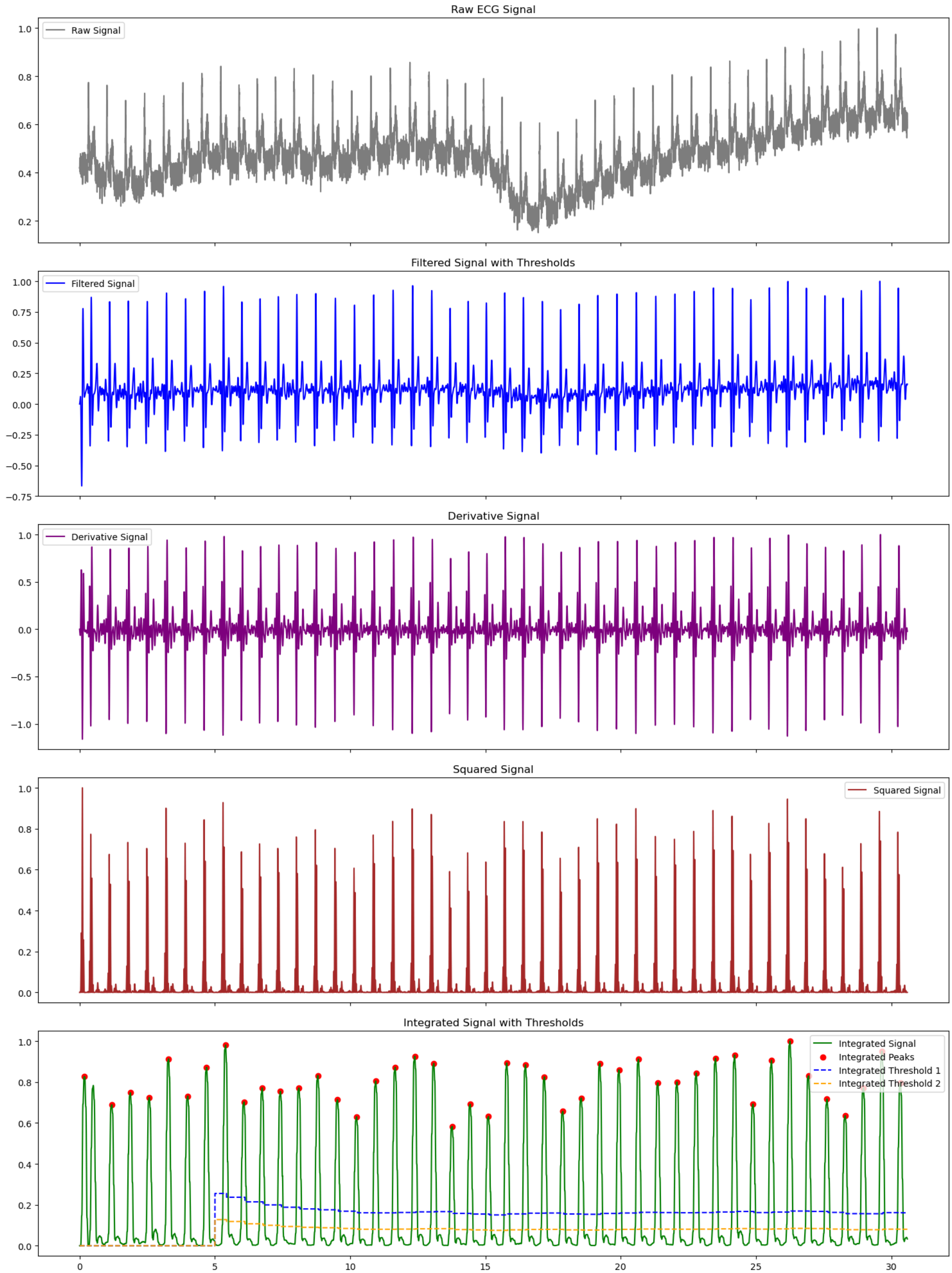


Fig. 1. Screenshot from [1]

Example Recording



Parameters

Key signal processing parameters include:

1. MOVING_AVG_LEN_S = 0.15 seconds. Description: Window size for smoothing the squared derivative signal. Increasing would create a smoother, more averaged signal, reducing high-frequency noise
2. FIR Bandpass Filter Parameters:
    a. Low Cutoff = 7 Hz
    b. High Cutoff = 15 Hz
    c. N_taps (filter order) = 200

Increasing low cutoff would attenuate more low-frequency components, filtering out more baseline wander. Decreasing low cutoff would remove less low-frequency noise, which increases risk of adaptive thresholds also drifting. Increasing high frequency would capture more high-frequency signal details, potentially including unwanted noise. Decreasing high frequency would create a smoother signal, but risk losing important QRS complex details. A filter order of 200 was determined via a magnitude plot of the frequency response to have the sufficient rolloff of the stop bands while minimizing group delay.

3. find_peaks(distance=60*FS/max_hr). Criteria for identifying potential QRS complexes. Increasing distance would potentially risk missing peaks. Decreasing distance would potentially risk finding too many peaks.

Minimum Latency

The minimum latency as a result of all signal processing steps can be calculated by the summing the following:

1. Delay of FIR bandpass filter (filter order = 200, delay = 100)
2. Delay of differentiator (window size = delay = 5)
3. Delay of moving average filter (window size = delay = 5)
4. Delay of real time peak finder (window size = delay = 101)

Total sample delay = 211 samples (with a sampling rate of 1000 Hz, the sample delay time is 211 ms)

Minimum Sampling Rate

As the signal of interest has a frequency range of [5, 15], which yields a theoretical limit of 30 Hz as the minimum sampling rate, there are practical considerations to keep in mind. Most importantly, the tradeoff between peak detection accuracy. The lower the sampling rate, the less accurate the system would be at detecting the correct peak location. This would be due to the fact that maintaining latency requirements at a lower sampling rate would prevent larger window sizes and higher filter orders. A practical recommendation for a minimum would be 250 Hz.

References

[1] J. Pan and W. J. Tompkins, “A real-time QRS detection algorithm,” IEEE Transactions on Biomedical Engineering, vol. BME-32, no. 3, pp. 230–236, Mar. 2007. doi:10.1109/tbme.1985.325532