Biosignal Processing

Assignment 4. Pan-Tompkins Algorithm for QRS Detection

LEARNING OUTCOMES

After this assignment, student can detect QRS complexes in ECG signal using the Pan–Tompkins algorithm.

BACKGROUND

The Pan-Tompkins algorithm identifies QRS complexes (see Fig. 1) based on analysis of the slope, amplitude and width of the QRS. The various stages of the algorithm are shown in Fig. 2.

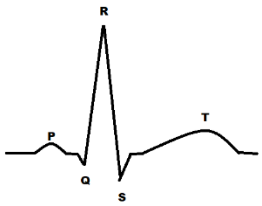

Figure 1. Schematic representation of normal ECG

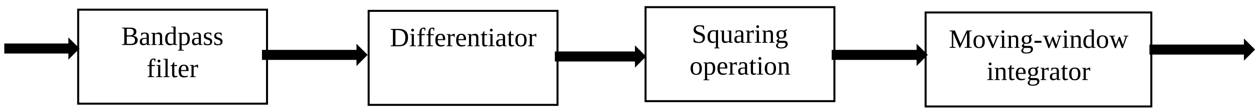

Figure 2. Block diagram of the Pan-Tompkins algorithm

The bandpass filter, formed using low-pass and high-pass filters, reduces noise (such as muscle noise, 60 Hz interference and baseline drift) in the ECG signal. After that, the signal is passed through a differentiator to provide a large response at the high slopes that distinguish QRS complexes from low-frequency ECG components such as the P and T waves.

The next operation is the squaring operation, which emphasizes the higher values expected within QRS complexes and suppresses smaller values related to the P and T waves among noise in the output of the preceding stage. The squared signal is then passed through a moving-window integrator of window length N = 30 samples (for the sampling frequency of F_S = 200 Hz). The expected result is a single smooth peak related to the QRS complex for each ECG cycle. The output of the moving-window integrator may be used to detect QRS complexes, measure RR intervals, and determine the duration of the QRS complex (see Fig. 3).

DATA

For this task, you need a sample ECG signal ***`ECG.txt`*** and a black box peak detection function ***`findQRS`*** provided for you by the teacher. The sampling frequency of the ECG signal is 200 Hz.

TASKS

Implement the following in the selected programming language:

Create a script to perform various filtering procedures that compose the Pan-Tompkins algorithm.

Plot the input (original ECG) and output signals at each stage of the program in a single figure as subplots. As a result, you should have a figure with 6 subplots. Ensure that the axes of the plots are labeled in suitable units such as seconds. The amplitude of the signals may be shown in arbitrary units (AU). Remember also to put the titles on all plots!

All the transfer functions of the filters are given in the course book. Before applying the filters, use the transfer function representation to get the coefficients *a* and *b*:

$$Y(z) = \frac{b(1) + b(2)z^{-1} + \cdots + b(m+1)z^{-m}}{1 + a(2)z^{-1} + \cdots + a(n+1)z^{-n}} X(z)$$

Please note that the amplitude of an ECG signal may start with a value other than zero. Consequently, the differentiator in the Pan-Tompkins algorithm will amplify the initial step, possibly resulting in an erroneous beat detection. To prevent this problem, subtract the value of its first sample from the entire ECG signal prior to processing by the Pan-Tompkins algorithm.

Steps of **Pan-Tompkins (P-T) algorithm** that you need to apply:

1. Subtract the value of the first sample of the ECG signal from the entire ECG
2. Low pass filter with $H(z) = \frac{1}{32}\frac{(1-z^{-6})^2}{(1-z^{-1})^2}$. Show the results in the subplot 2.
3. High pass filter with $H(z) = z^{-16} - \frac{1}{32}\frac{(1-z^{-32})}{(1-z^{-1})}$. Show the results in the subplot 3.
4. Derivative filter with $y(n) = \frac{1}{8}\left[x(n) + 2x(n-1) - 2x(n-3) - x(n-4)\right]$. Show the results in the subplot 4.
5. Both *(A)* squaring and then *(B)* integration with

   $y(n) = \frac{1}{N}\left[x\big(n-(N-1)\big) + x\big(n-(N-2)\big) + \cdots + x(n)\right]$, N = 30

   Show the results in the subplot 5. This is the end results of the algorithm.

6. Plot the original ECG signal from the first subplot again into the subplot 6.

Next step is to detect QRS complexes. Use the `findQRS` black-box function that the teacher provides. The function will have threshold values for the detection of the waves and also a blanking interval parameter to disallow QRS detection too shortly after the previous one. The teacher will provide the calling syntax details for the function.

You should use a blanking interval of *250 ms,* but select the other `findQRS` detection threshold parameters by yourself.

Mark the detected peak locations on the output of the integrator (subplot 5) using red stars for the starting points and red circles for the ending points. Also mark the corresponding original ECG signal with the same symbols in the last subplot. After taking filtering delay into account, the markings should be found at the beginning and at the end of each QRS complex. Thus, you need to take into account delays introduced by the filters!

You will need to re-adjust your threshold values observing the subplot 5 for so long that all QRS complexes are found!