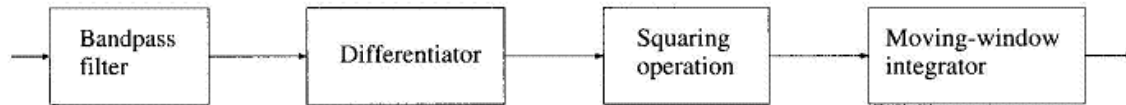# Pan-Tompkins algorithm to detect QRS complex in ECG signal

(from R.M. Rangayyan, Biomedical Signal Analysis, IEEE Press)

Problem: *Propose an algorithm to detect QRS complexes in an ongoing ECG signal.*

Solution: Pan and Tompkins [103, 27] proposed a real-time QRS detection algorithm based on analysis of the slope, amplitude, and width of QRS complexes. The algorithm includes a series of filters and methods that perform lowpass, highpass, derivative, squaring, integration, adaptive thresholding, and search procedures. Figure   illustrates the steps of the algorithm in schematic form.

Block diagram of the Pan-Tompkins algorithm for QRS detection.

Lowpass filter: The recursive lowpass filter used in the Pan-Tompkins algorithm has integer coefficients to reduce computational complexity, with the transfer function defined as

$$H(z) = \frac{1}{32} \frac{(1 - z^{-6})^2}{(1 - z^{-1})^2} .$$

The output $y(n)$ is related to the input $x(n)$ as

$$y(n) = 2y(n - 1) - y(n - 2) + \frac{1}{32} [x(n) - 2x(n - 6) + x(n - 12)].$$

With the sampling rate being 200 Hz, the filter has a rather low cutoff frequency of $f_c = 11\ Hz$, and introduces a delay of 5 samples or 25 ms. The filter provides an attenuation greater than 35 dB at 60 Hz, and effectively suppresses power-line interference, if present.

Highpass filter: The highpass filter used in the algorithm is implemented as an allpass filter minus a lowpass filter. The lowpass component has the transfer function

$$H_{lp}(z) = \frac{(1 - z^{-32})}{(1 - z^{-1})};$$

the input – output relationship is

$$y(n) = y(n - 1) + x(n) - x(n - 32).$$

The transfer function $H_{hp}(z)$ of the highpass filter is specified as

$$H_{hp}(z) = z^{-16} - \frac{1}{32} H_{lp}(z).$$

Equivalently, the output $p(n)$ of the highpass filter is given by the difference equation

$$p(n) = x(n - 16) - \frac{1}{32} [y(n - 1) + x(n) - x(n - 32)],$$

with $x(n)$ and $y(n)$ being related as in Equation 4.10. The highpass filter has a cutoff frequency of 5 Hz and introduces a delay of 80 ms.

Derivative operator: The derivative operation used by Pan and Tompkins is specified as

$$y(n) = \frac{1}{8} [2x(n) + x(n - 1) - x(n - 3) - 2x(n - 4)],$$

and approximates the ideal $\frac{d}{dt}$ operator up to 30 Hz. The derivative procedure suppresses the low-frequency components of the P and T waves, and provides a large gain to the high-frequency components arising from the high slopes of the QRS complex.

Squaring: The squaring operation makes the result positive and emphasizes large differences resulting from QRS complexes; the small differences arising from P and T waves are suppressed. The high-frequency components in the signal related to the QRS complex are further enhanced.

Integration: As observed in the previous subsection, the output of a derivative-based operation will exhibit multiple peaks within the duration of a single QRS complex. The Pan-Tompkins algorithm performs smoothing of the output of the preceding operations through a moving-window integration filter as

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

The choice of the window width N is to be made with the following considerations: too large a value will result in the outputs due to the QRS and T waves being merged, whereas too small a value could yield several peaks for a single QRS. A window width of $N = 30$ was found to be suitable for $f_s = 200\ Hz$.

Illustration of application:

The Pan-Tompkins algorithm as above was implemented in MATLAB. The outputs of the various stages of the algorithm are illustrated in sequence in the same figure. The observations to be made are similar to those in the preceding section on the derivative-based method. The derivative operator suppresses the P and T waves and provides a large output at the QRS locations. The squaring operation preferentially enhances large values, and boosts high-frequency components. The result still possesses multiple peaks for each QRS, and hence needs to be smoothed. The final output of the integrator is a single smooth pulse for each QRS. Observe the shift between the actual QRS location and the pulse output due to the cumulative delays of the various filters.