THE AMERICAN UNIVERSITY IN CAIRO

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CSCE 363/3611 - Digital Signal Processing

Project: ECG Processing

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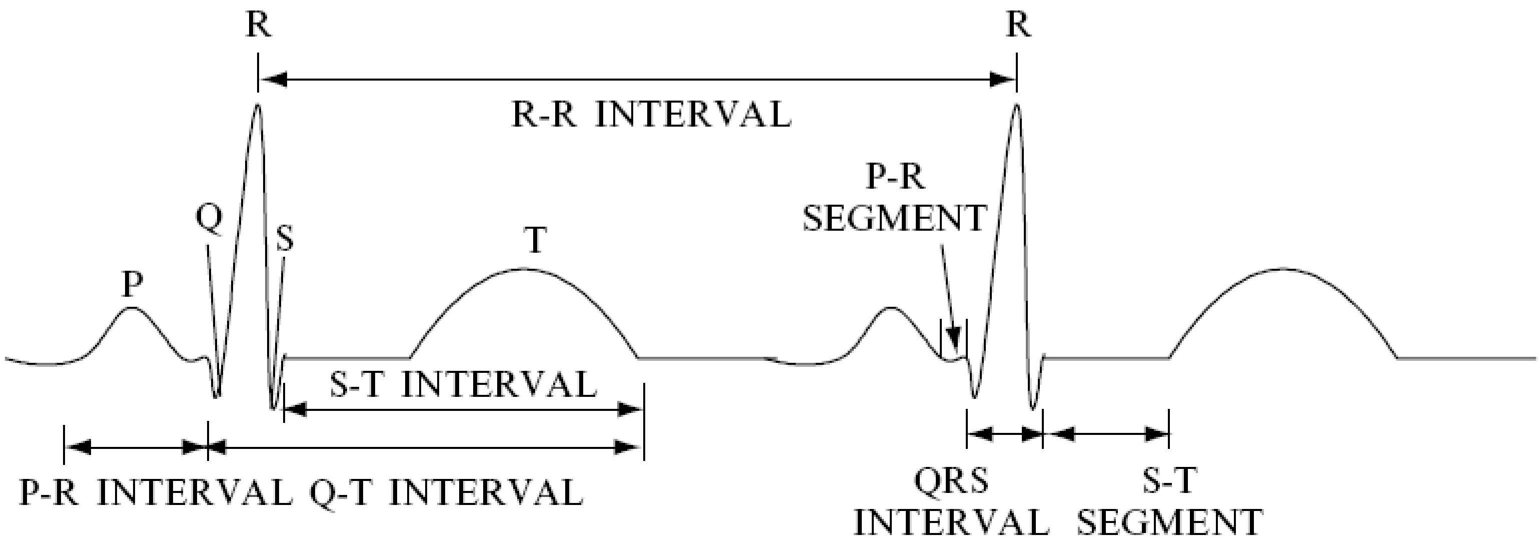
ECG and Heart Signals

- References:
  - U.R. Acharya, J.S. Suri, J.A.E. Spaan, S.M. Krishnan, "Advances in Cardiac Signal Processing", Springer (Chapter 1) (available through Springer)
  - K. Blinowska and J. Zygierewicz, “Practical Biomedical Signal Analysis Using Matlab,” CRC Press, Boca Raton, FL, USA, 2011 (Chapter 4: Section 4.2) (available through AUC Library website)

ECG Waveform

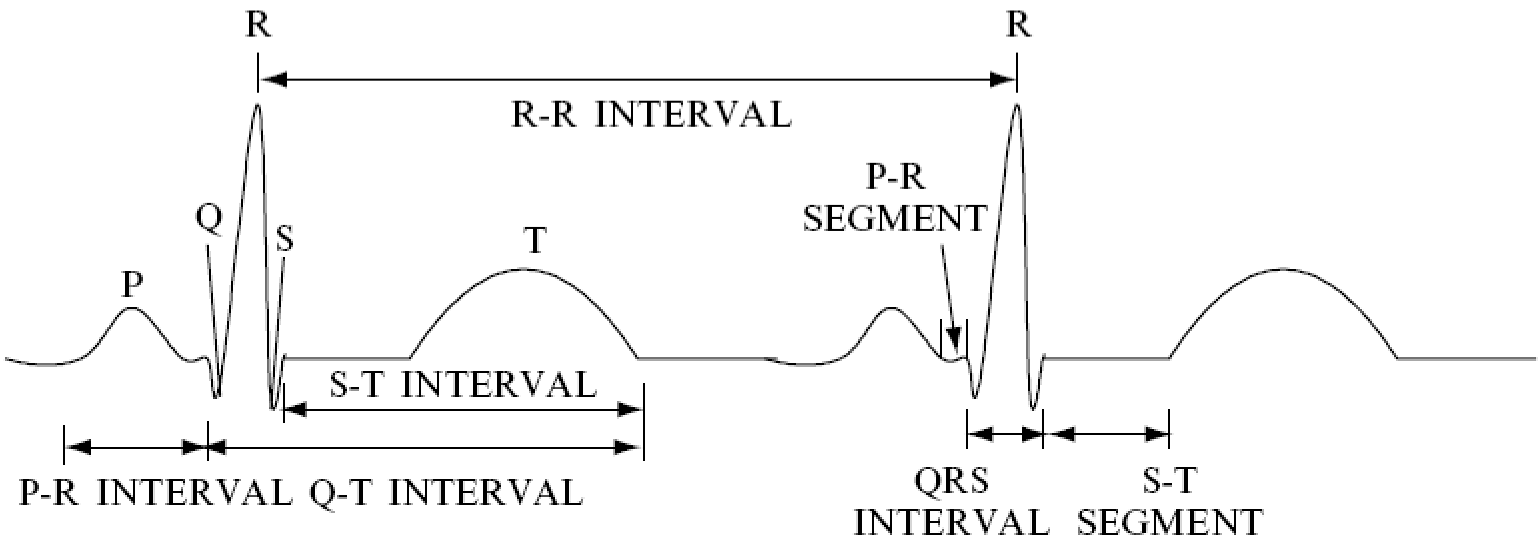
- A typical Electrocardiogram (ECG) signal of a normal person is as follows:



- P-wave corresponds to the depolarization of the atria and indicates the start of atrial contraction that pumps blood to the ventricles
- The Q, R, and S waves are usually treated as a single composite wave known as the QRS-complex. The QRS-complex reflects the depolarization of ventricles, and indicates the start of ventricular contraction that pumps blood to the lungs and the rest of the body

ECG Waveform

- A typical Electrocardiogram (ECG) signal of a normal person is as follows:



- The T-wave corresponds to the repolarization of the ventricles, which is a necessary recovery process for the heart to depolarize and contract again. The end of the T-wave coincides with the end of ventricular contraction. Atrial repolarization (Ta-wave) is usually not visible as it normally coincides with the QRS-complex (and is buried in the larger waveform)

ECG Signal Processing

- The first step in ECG signal processing is artifact removal

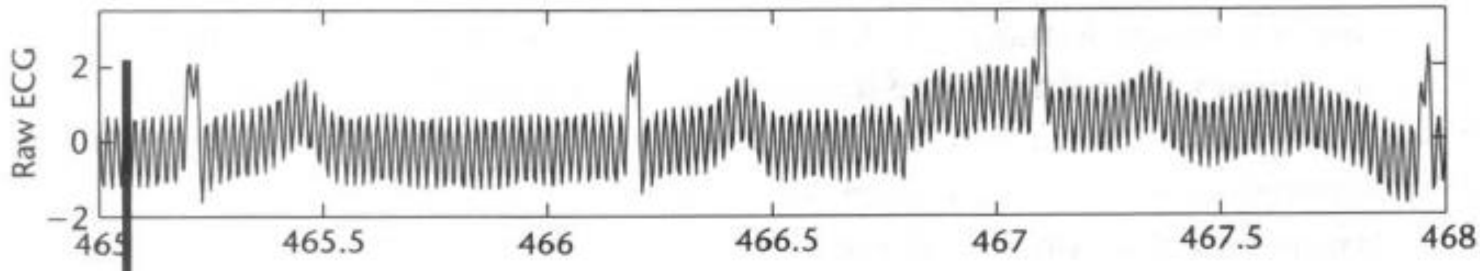
- ECG maybe corrupted with two types of artifacts:
  - Technical artifacts: such as power line interferences, artifacts due to bad electrode contacts, quantization or aliasing errors, noise generated by other medical equipment present in the patient care environment

  - Biological artifacts: such as patient-electrode motion artifacts, muscular activity, baseline drift—usually due to respiration

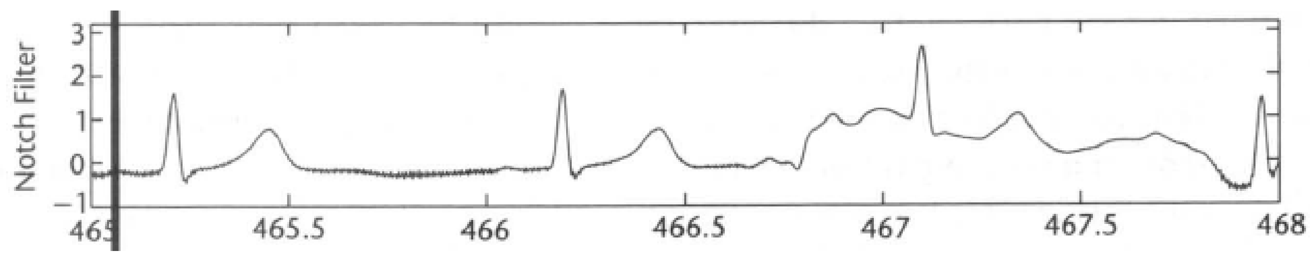
- Technical artifacts may be avoided by designing proper measurement procedures. Elimination of biological artifacts is much more difficult and requires special signal analysis techniques

ECG Signal Processing: Noise Filtering

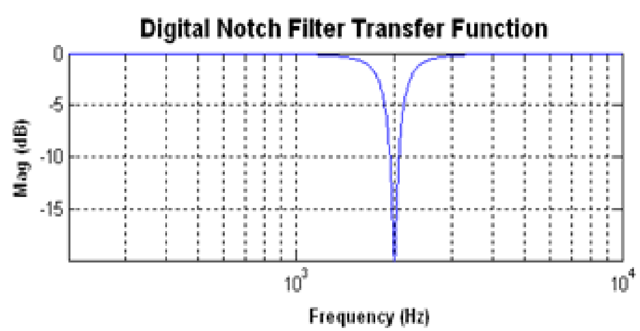
- A typical noisy ECG signal will appear along with a 50Hz (or 60 Hz) mains noise



- A notch filter with a filtered frequency of 50Hz can be used to remove the baseline 50Hz

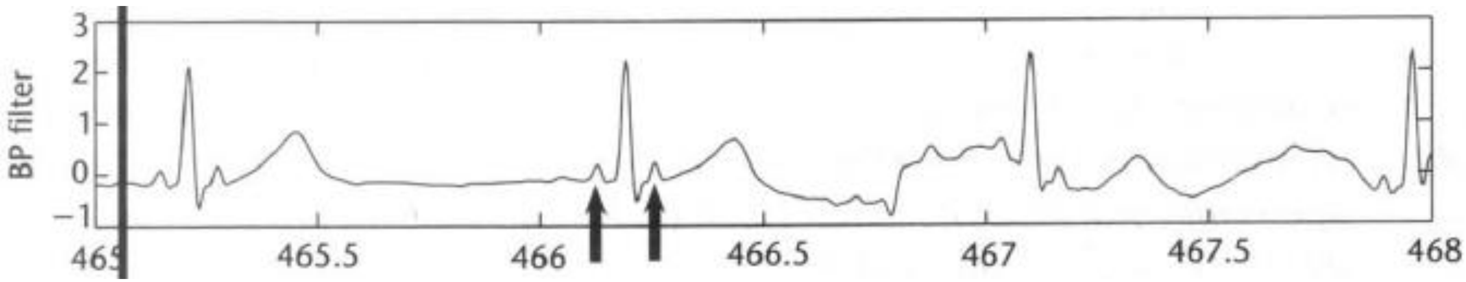


- Example of a notch Filter with a stop frequency of 2000 Hz



ECG Signal Processing: Noise Filtering

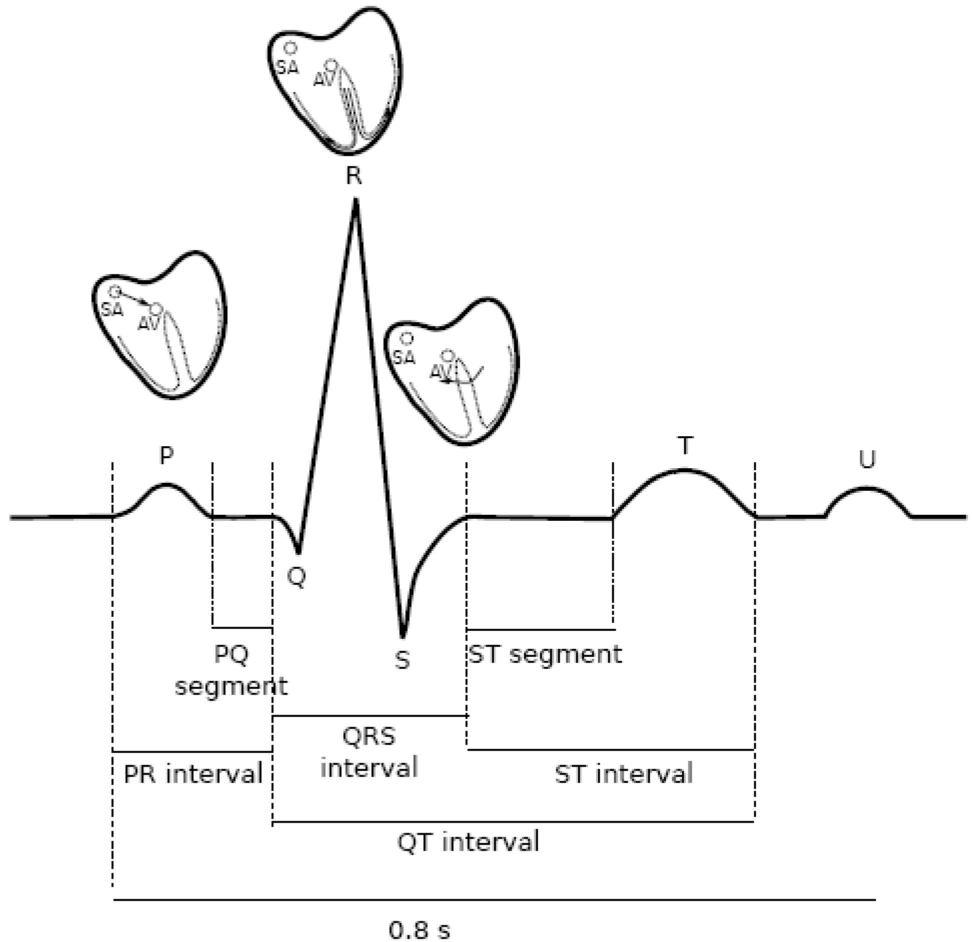
- The ECG signal is further filtered using a Band-pass filter with a bandwidth of 0.1-45 Hz



- Cut-off frequency above 0.8Hz would distort the ECG waveform

ECG Signal Processing: Morphological Features

- Clinical assessment of ECG mostly relies on evaluation of its time domain morphological features such as positions, durations, amplitudes, and slopes of its complexes and segments

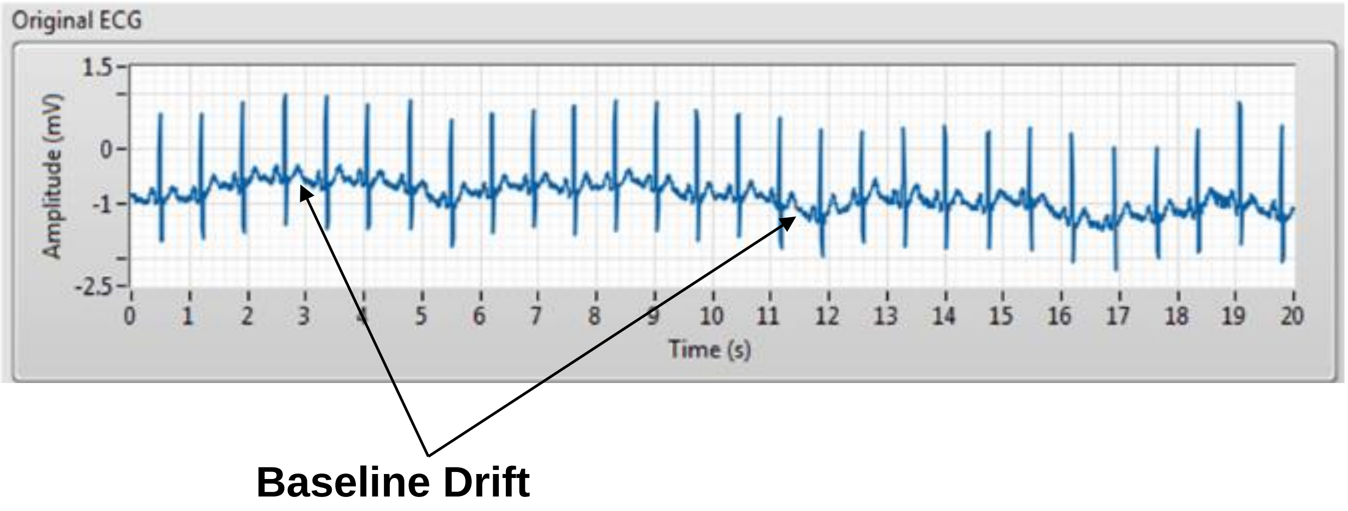


ECG Signal Processing: Morphological Features

- The first step in the analysis is usually detection of the QRS complex; it serves as a marker for averaging of heart cycles, for evaluation of heart rate, for finding the heart axis

- One way to detect ECG is to use a single threshold above which any signal would be considered as part of the QRS complex

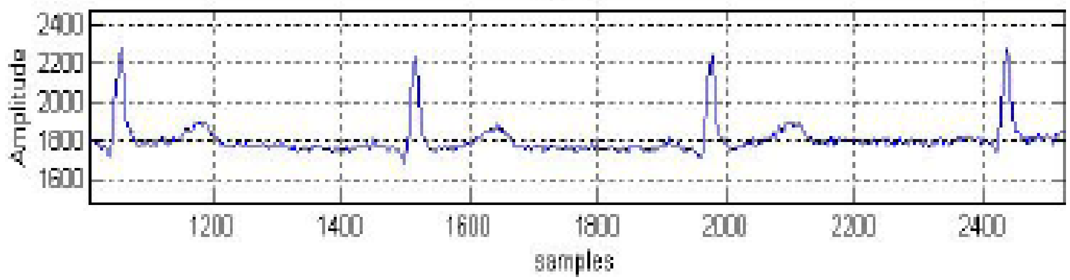
- One problem with this method is baseline drift with which a single threshold might detect false signals



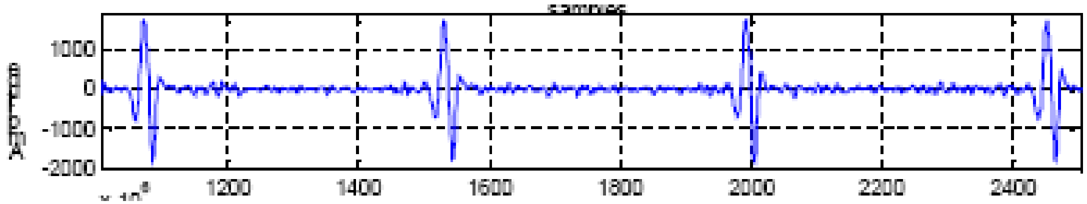
ECG Signal Processing: Morphological Features

- One way to overcome baseline drifts is to differentiate the ECG signal since we are looking for large slopes in the signal

ECG Signal



After Differentiation



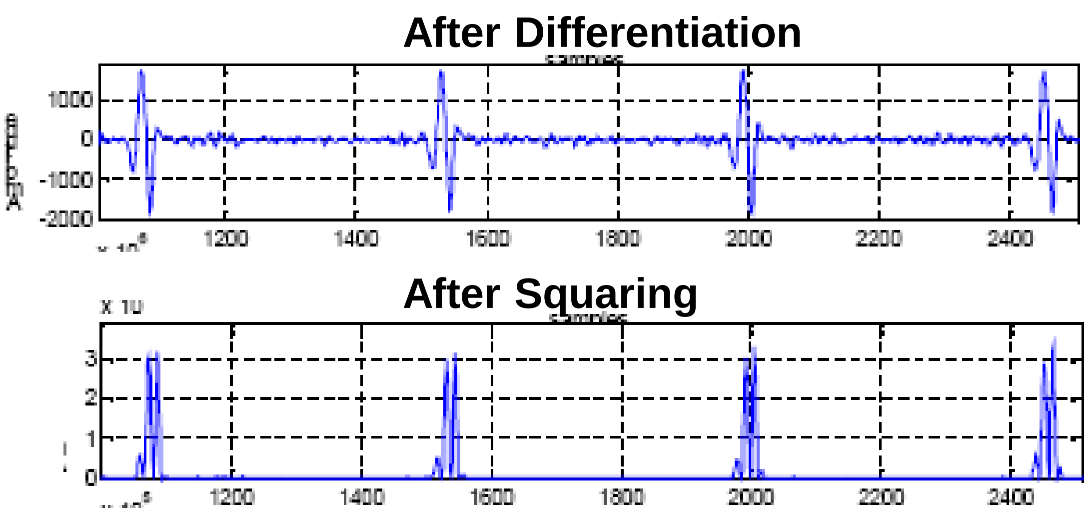
- To do the derivative, the following 5-point difference equation can be used

$$y(nT) = (1/8T)\,[-x(nT - 2T) - 2x(nT - T) + 2x(nT + T) + x(nT + 2T)]\,.$$

ECG Signal Processing: Morphological Features

- The next step is to square the derivative. This makes all data points positive and does nonlinear amplification of the output of the derivative emphasizing the higher frequencies (i.e., predominantly the ECG frequencies)

$$y(nT) = [x(nT)]^2$$



ECG Signal Processing: Morphological Features

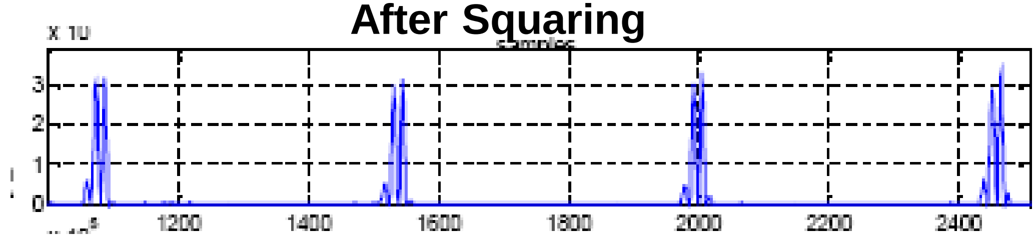
- The next step is to smooth the squared signal using a moving average window

$$y(nT) = (1/N)\,[x(nT - (N-1)T) + x(nT - (N-2)T) + \cdots + x(nT)]$$

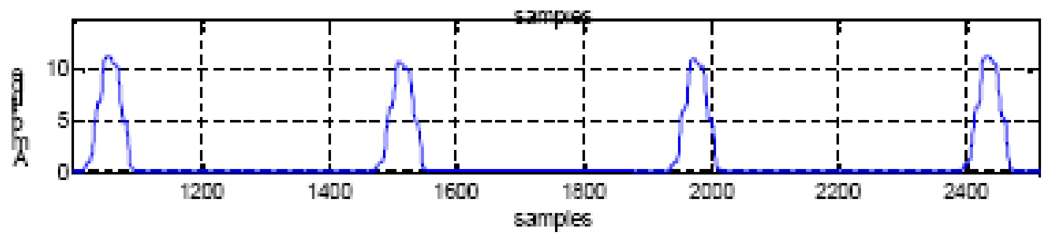
where N is the number of samples in the width of the moving average window

- N should be set approximately the same as the widest possible QRS complex

After Squaring

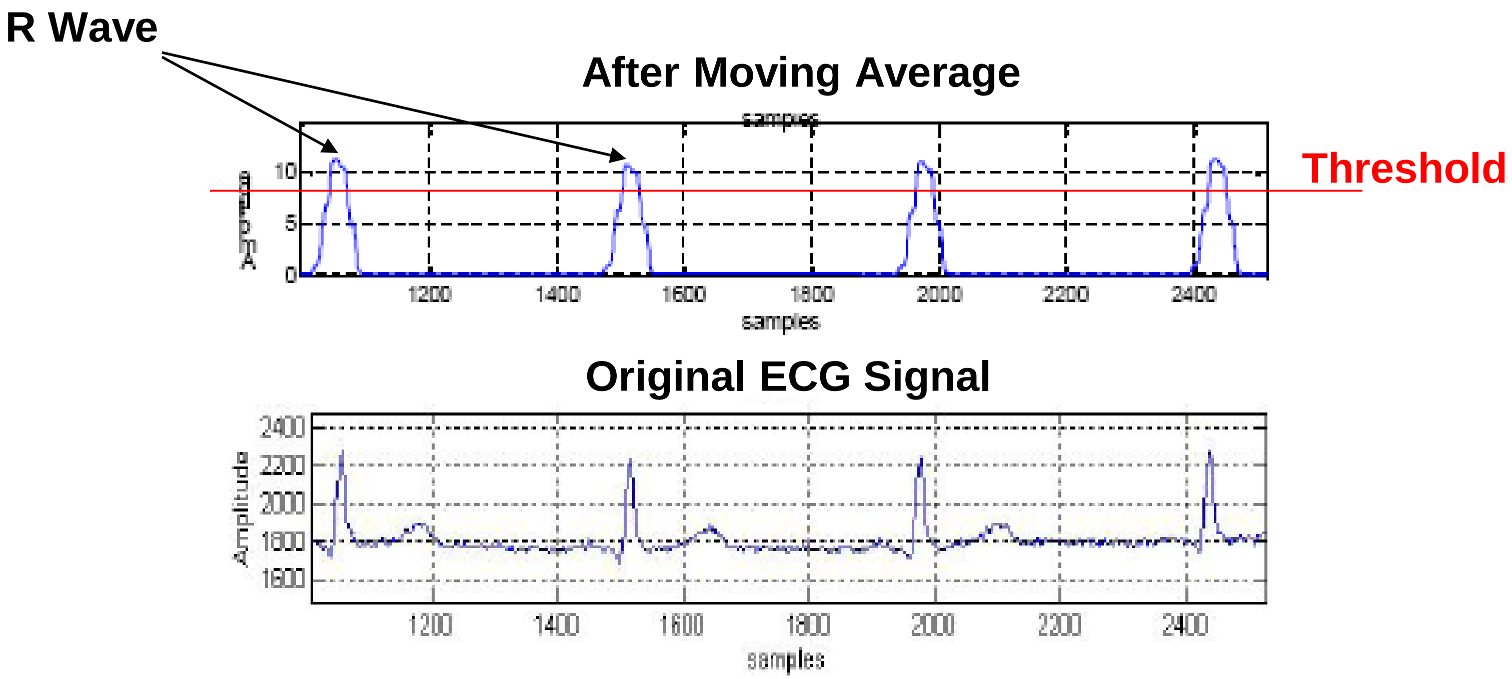


After Moving Average



ECG Signal Processing: Morphological Features

- The final step is to set a threshold on the moving average output. The peak value above the threshold within the moving average window is approximately the R wave



Heart Rate Variability Analysis

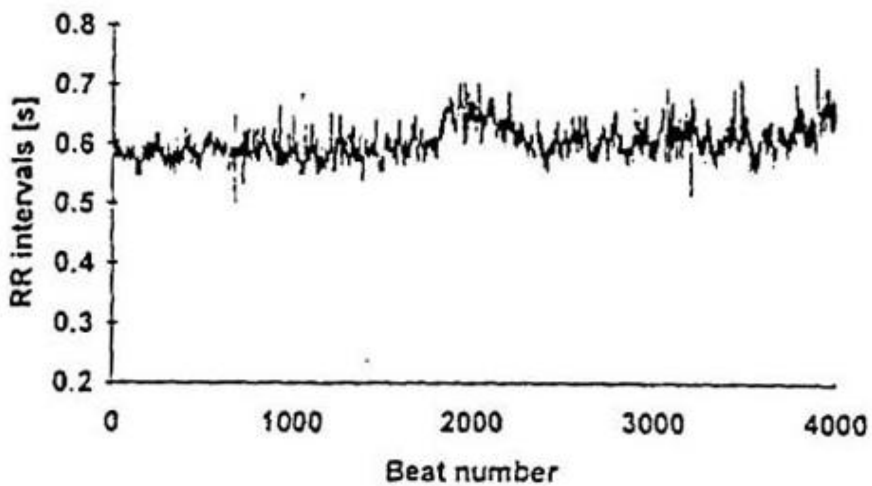
- The sequence of RR intervals—that is, all intervals between adjacent QRS complexes resulting from sinus node depolarizations—forms the RR interval time series or RR tachogram

$$\mathrm{RR}_i = t_i - t_{i-1}$$

- A corresponding sequence of instantaneous heart rate is defined as

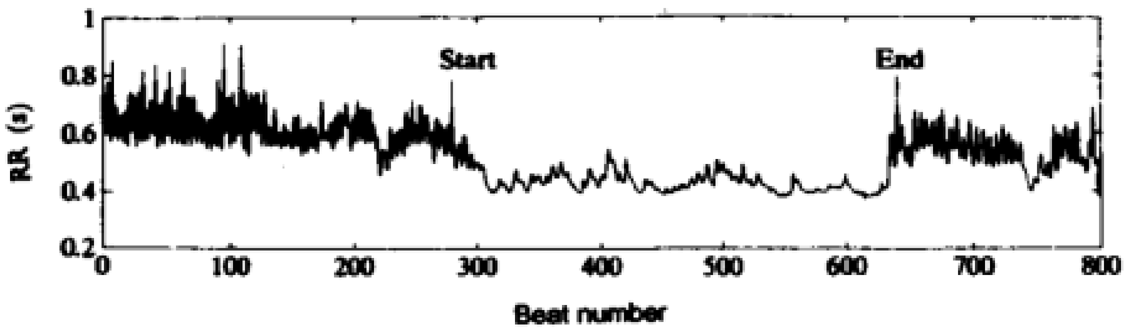
$$\mathrm{ff}_i = \frac{1}{\mathrm{RR}_i}$$

- Heart rate variability (HRV) is a physiological phenomenon of the variation of the time interval between heartbeats



Heart Rate Variability Analysis

- Symptoms and diseases affect the HRV signal. For example, the HRV of a heart with a period of artery occlusion will be as shown below



Heart Disorders and ECG

- Looking at an ECG, one can determine the type of heart disorder of a patient

- The manner in which the heart contracts over time determines the rhythm of the heart

- **Normal sinus rhythm** (NSR) is the normal rhythm of the heart when there is no disease or disorder affecting it. NSR is characterized by a heart rate of 60 to 100 beats per minute

- The regularity of the R-R interval varies slightly with the breathing cycle, typically shortening slightly during respiration

Sinus Node Arrhythmias

- The arrhythmia arises from the S-A node for this group of disorders. Since the electrical impulse is generated from the normal pacemaker, the consistent characteristic feature of these arrhythmias is that P-wave wave shape of the ECG is normal

- Sinus Arrest:

  The S-A node intermittently fails to fire. There is no P-wave and therefore no accompanying QRS-complex and no T-wave