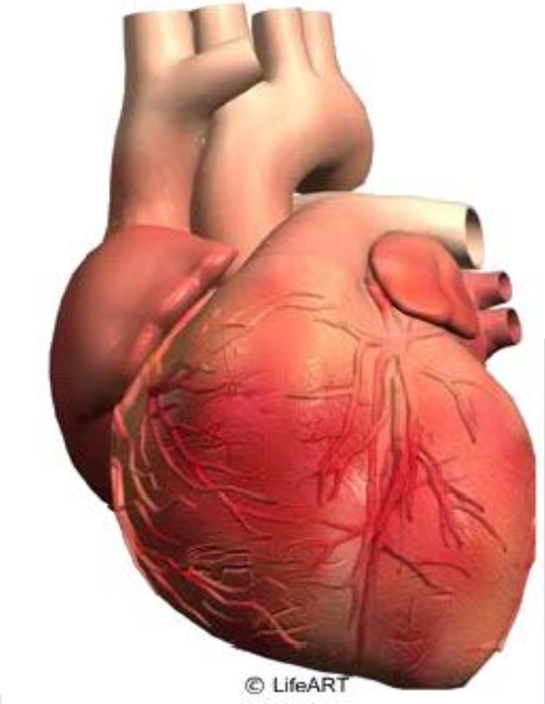
THE HEART ANATOMY

The HEART Organ

- The heart is a powerful muscle that lies in the chest cavity between the lungs and is slightly larger than the one's clenched fist.

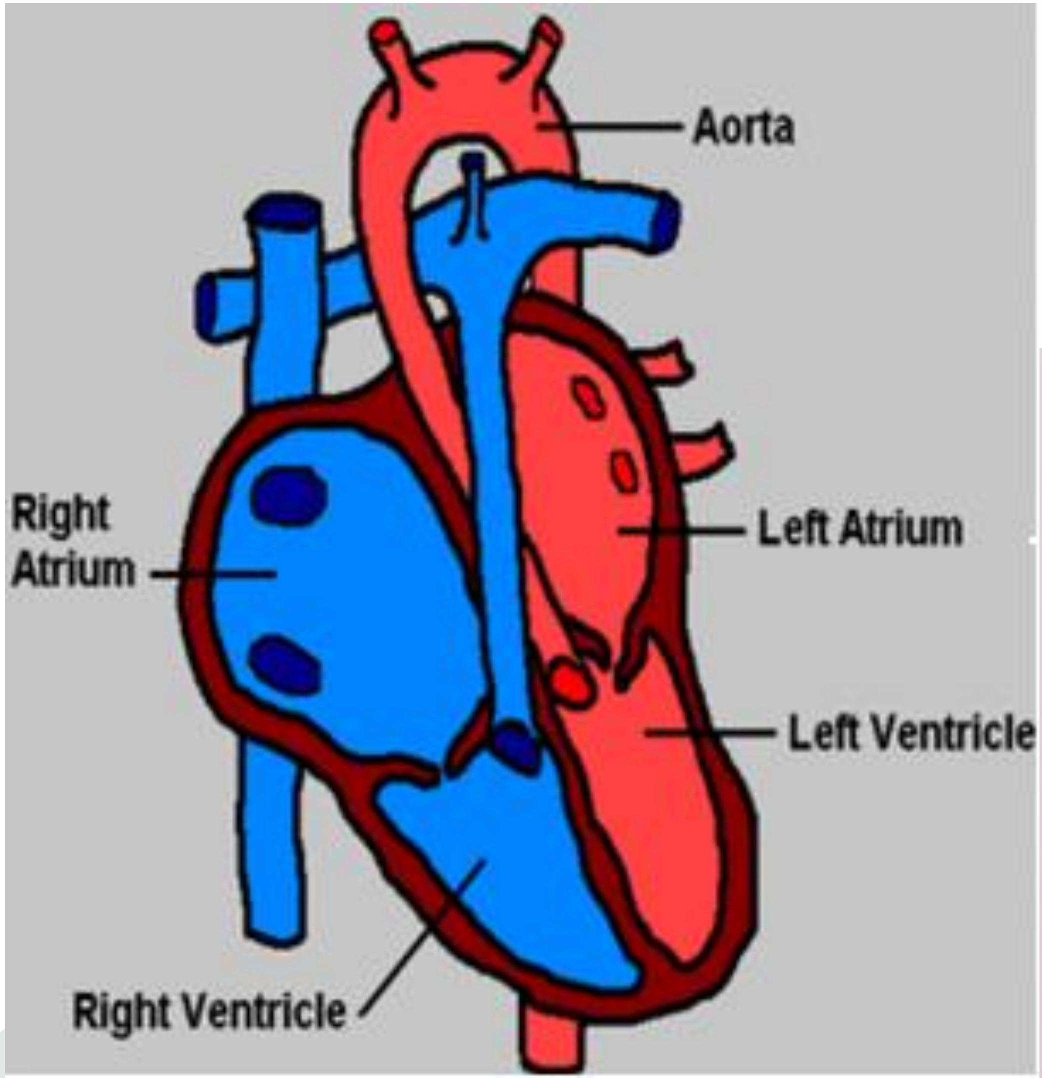
- A heartbeat is the physical contraction of the heart muscles for pumping blood.



The HEART Anatomy

- It is composed of four chambers, many large arteries, many veins and valves.

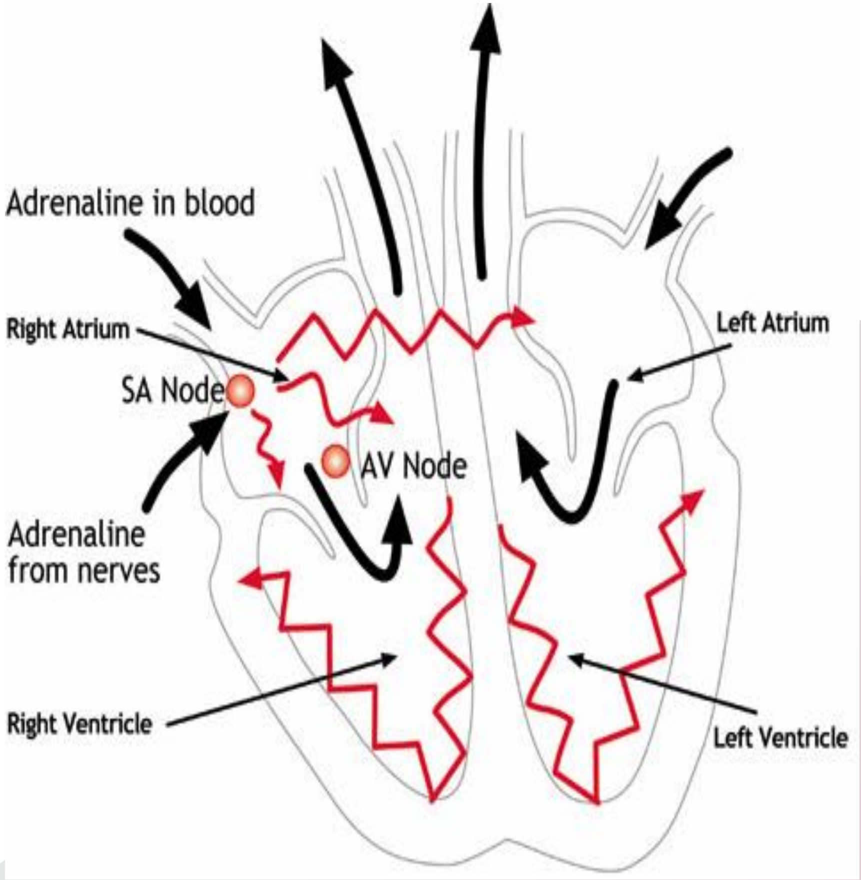
- A wall of muscle divides the heart into two cavities: Two chambers of the heart lie in the left cavity and two chambers lie in the right cavity. The four chambers are called *atria* and *ventricles*. The two upper chambers of the heart are called atria (one of them is called atrium); the bottom chambers are called ventricles.



How the heart functions electrically

- The heart normally beats between 60 and 100 times per minute. This rate is set by a small collection of specialized heart cells called the Sinoatrial (SA) or sinus node, which is located in the right atrium.

- The SA node is the heart's "natural pacemaker." It discharges by itself without control from the brain. Two events occur with each discharge: (1) both atria contract; (2) an electrical impulse travels through the atria to reach another area of the heart called the Atrioventricular (AV) node, which lies in the wall between the two ventricles.



How the heart functions electrically

- The *AV node* serves as a relay point to further propagate the electrical impulse. From the *AV node*, an electrical wave travels to ventricles, causing them to contract and pump blood. The blood from the right ventricle goes to the lungs, and the blood from the left ventricle goes to the body.
- The normal delay between the contraction of the atria and of the ventricles is 0.12 to 0.20 seconds. This delay is perfectly timed to account for the physical passage of the blood from the atrium to the ventricle. Intervals shorter or longer than this range indicate possible problems.

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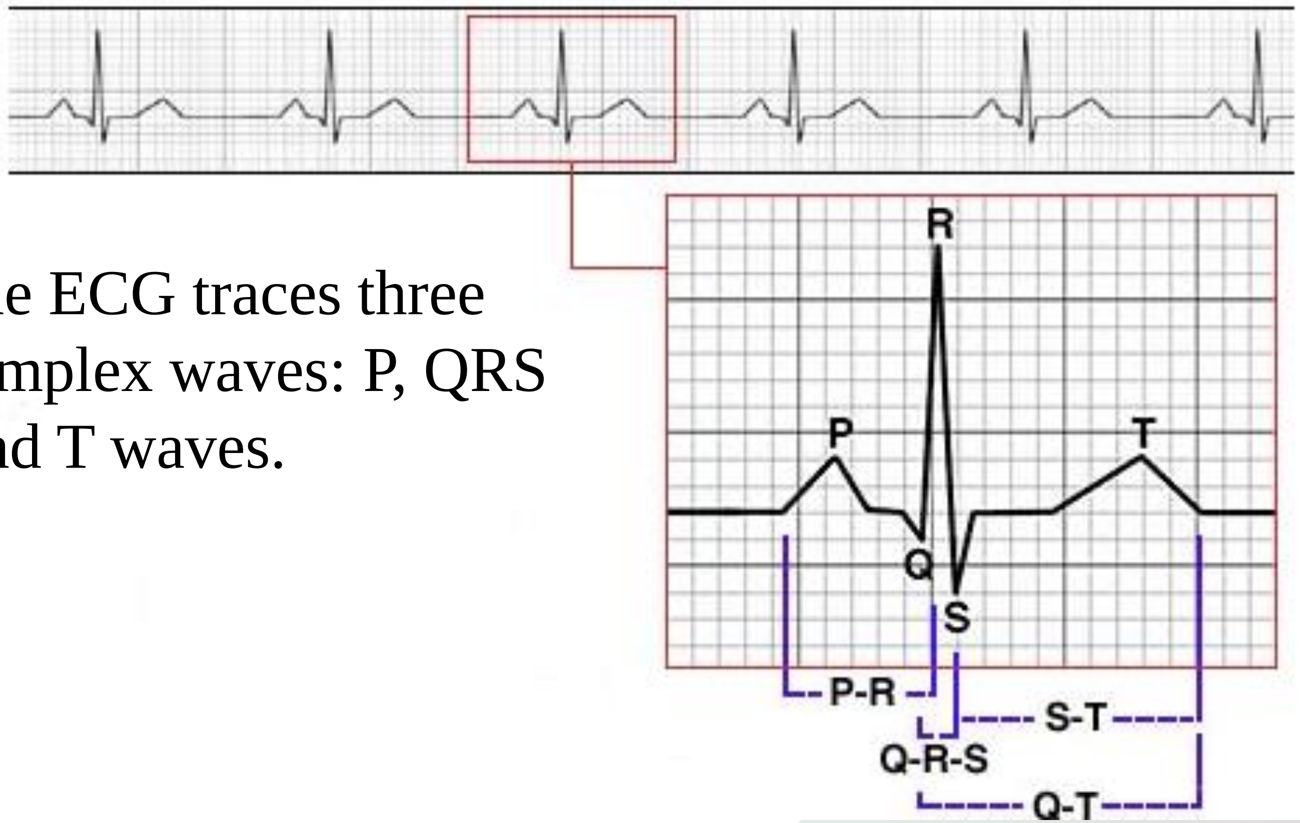
The Electrocardiogram (ECG or EKG) signals

- The term electrocardiogram (ECG) was introduced by Willem Einthoven in 1893 .
- ECG is recorded by placing electrodes (up to 12 electrodes) at various strategic body points such as chest, neck, arms, and legs.
- The ECG machine records the electrical activity (electrical impulses) of the heart in exquisite detail that results when the heart muscle cells in the atria and ventricles contract. The results of the impulses are displayed on a computer monitor and then printed onto graph paper.

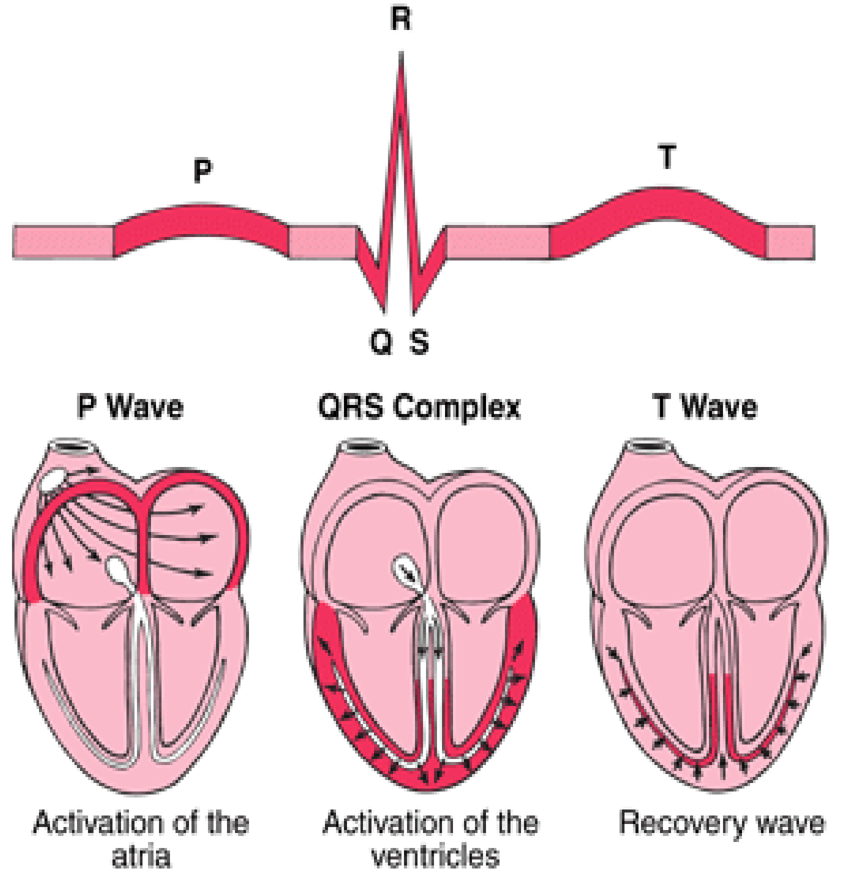
ECG Signal



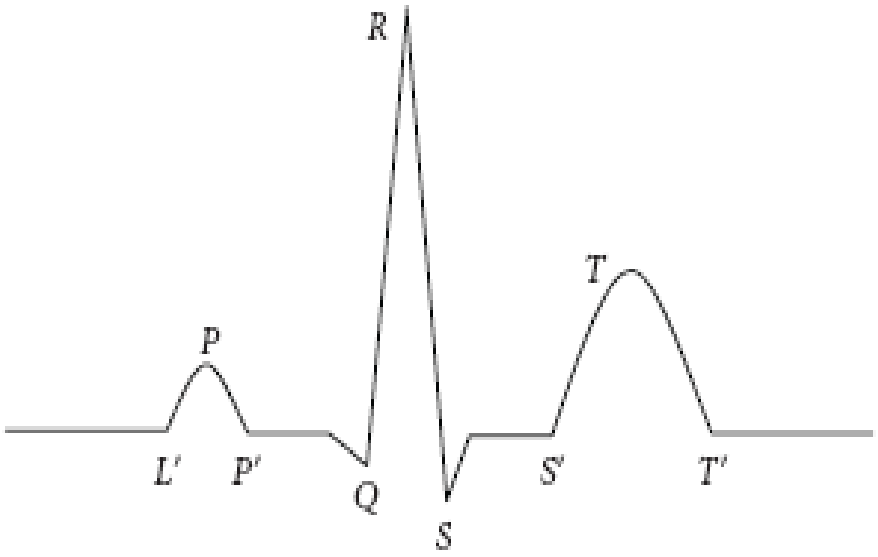
The ECG traces three complex waves: P, QRS and T waves.

ECG Signal

The *Atria* contractions (both right and left) shows up as the *P wave*; while the ventricular contractions (both right and left) show as a series of 3 waves, Q-R-S, known as the QRS complex; finally, the third and last common wave in an ECG is the *T wave*. This reflects the electrical activity produced when the ventricles are recharging for the next contraction (repolarizing).



ECG Signal



- The three complex waves differ in their durations and spectral characteristics. The duration of the P wave is less than 120 milliseconds. The spectral characteristic of a normal *P* wave is usually considered to be low frequency, below 10–15 Hz.

ECG Signal

- The *QRS* complex lasts for about 70–110 milliseconds in a normal heartbeat, and it has the largest amplitude of the ECG waveforms. Due to its steep slopes, the frequency content of the *QRS* complex is considerably higher than that of the other ECG waves, and it is mostly concentrated in the interval of 10–40 Hz.
- Finally, the *T* wave extends about 300 milliseconds after the *QRS* complex. The position of the *T* wave is strongly dependent on heart rate, becoming narrower and closer to the *QRS* complex at rapid rates.

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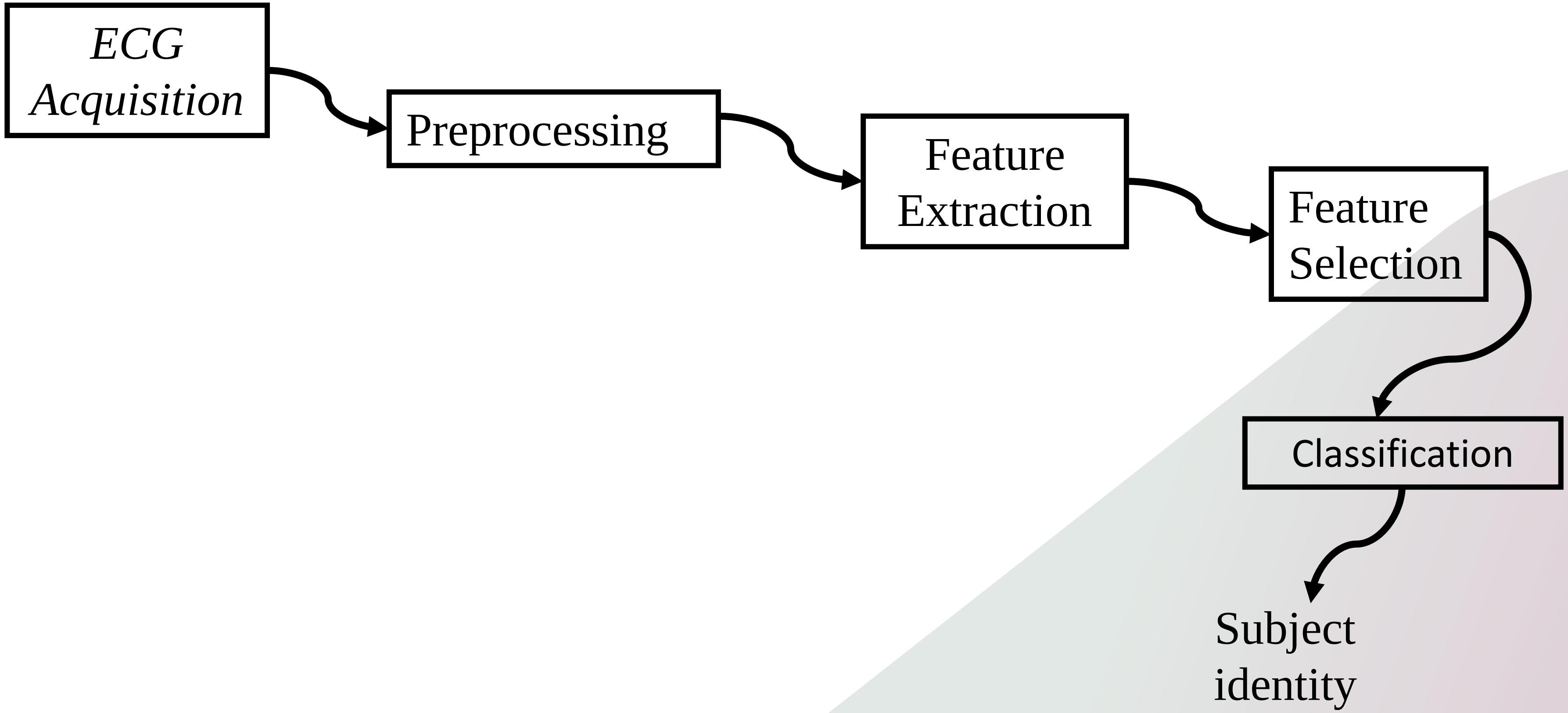
Benefits of ECG

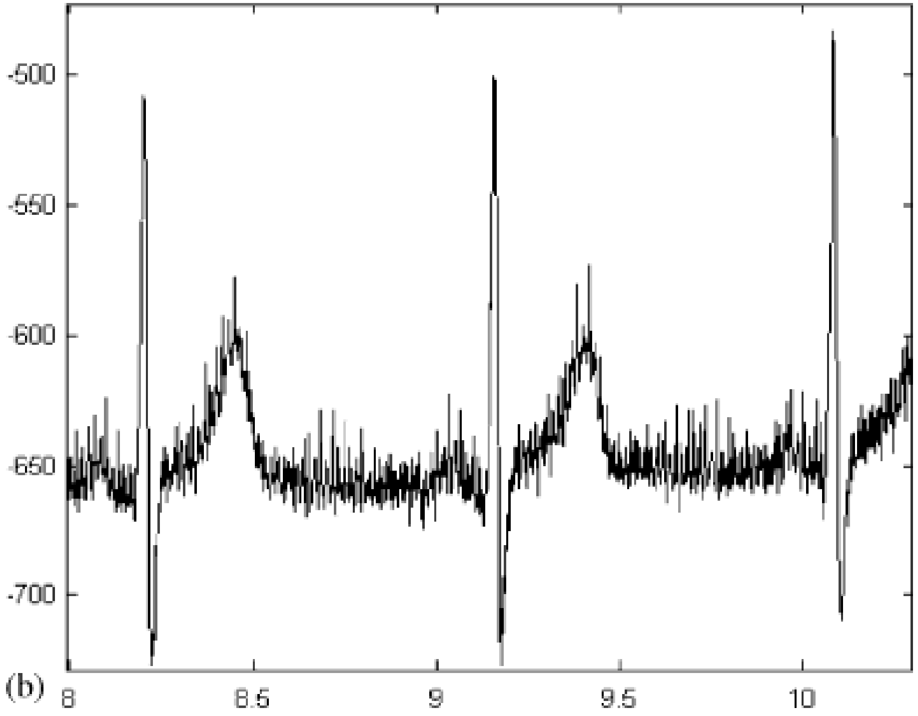
- ECG is a wealth source of information, and it has been used as a reliable diagnostic tool since the early 20th century.
- It carries information about heart rate, heart rhythm and morphology.
- it can indicate the weaknesses in different parts of the heart muscle.
- The ECG can also identify if the heart muscle has been damaged in specific areas.
- In the last two decades, it has been discovered that crucial information about human identity can be deduced from an ECG recording .this by its role open up the possibility of using ECG as a new biometrics modality for human identification.

Stages of an ECG Based Classification System



Preprocessing

Raw ECG data contain noise and artifact components that alter the expression of the ECG trace from the ideal structure and render any interpretation inaccurate and misleading.



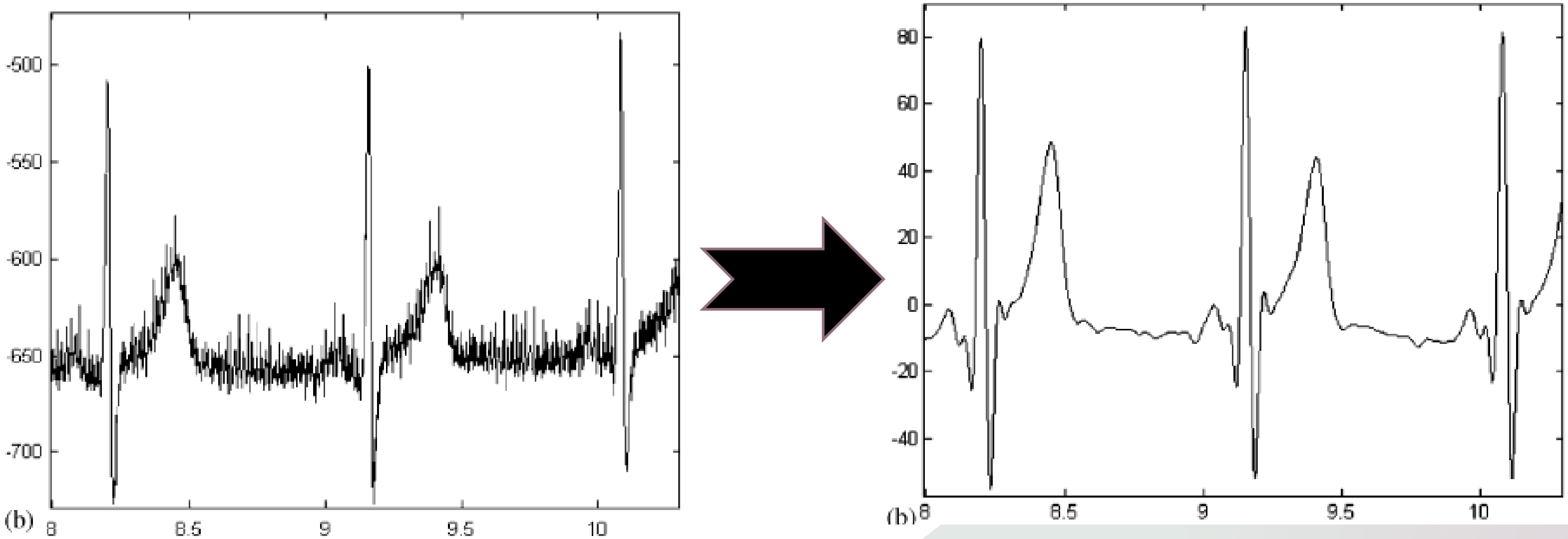
(b)

Preprocessing
ECG Noise Sources

Noise name	Noise source(s)	Amplitude	Spectral content	Comment
Baseline wander	perspiration, respiration, body movements, and poor electrode contact	exceed the amplitude of the *QRS* complex	interval below *1Hz*	Removed by band path filter
Electrode motion artifacts	skin stretching which alters the impedance of the skin around the electrode	large amplitude waveforms	Interval between 1 and 10 Hz	overlaps ECG spectra
Power line interference	interferences from nearby equipments as a result of improper grounding of the ECG equipment		*50/60 Hz*	Removed by band path filter
Electromyographic noise (EMG)	electric al activity of skeletal muscles during periods of contraction or due to a sudden body movement		Overlap with spectra of the *QRS* complex and extends to higher frequencies	overlaps ECG spectra with a part of its spectra

Preprocessing

Most of the existing systems utilize a simple Butterworth filter with cut-off frequencies of 1 - 40Hz (ECG spectra) in order to remove noise. However, not all frequencies of noise are below 1 or more than 40 Hz, some of them overlap with the spectra of the ECG signal .

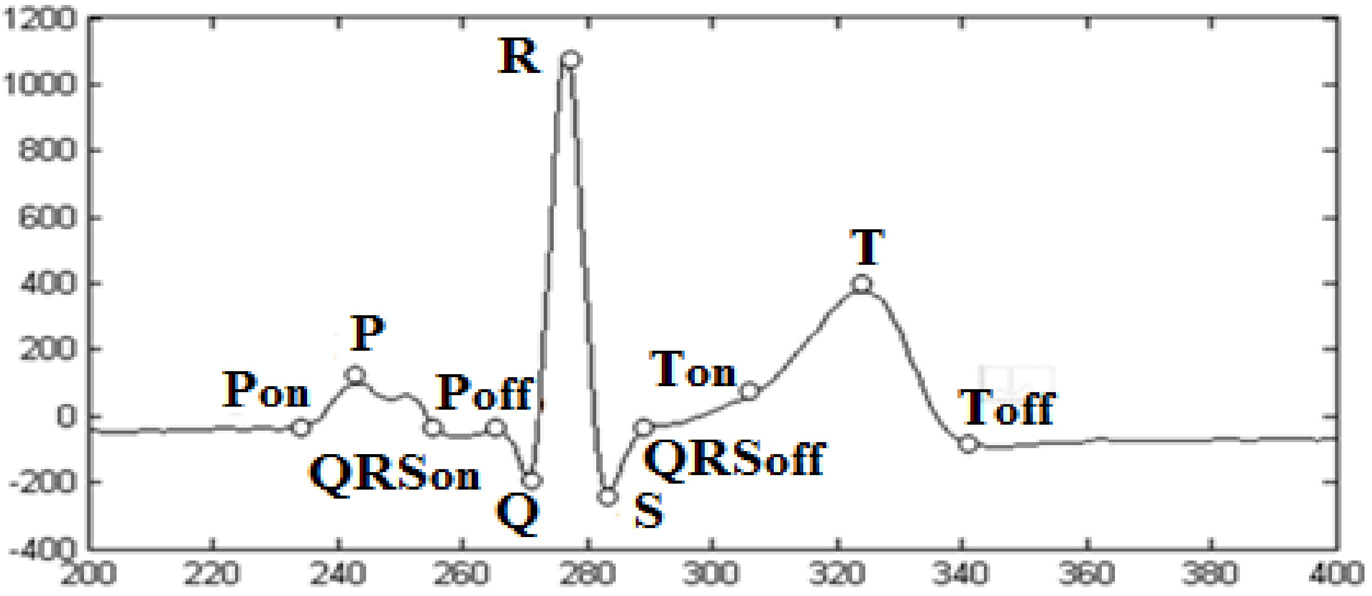


Feature Extraction

- There are two kind of features: fiducial and non-fiducial features.
- The fiducial features represents the amplitude of the signal fiducial points: P, Q, R, S and T and also the durations between them.

Fiducial Points Detection

- Detection of fiducial points: includes detecting 11 points that represent the peak and the end points of each of the three complexes QRS, P and T.



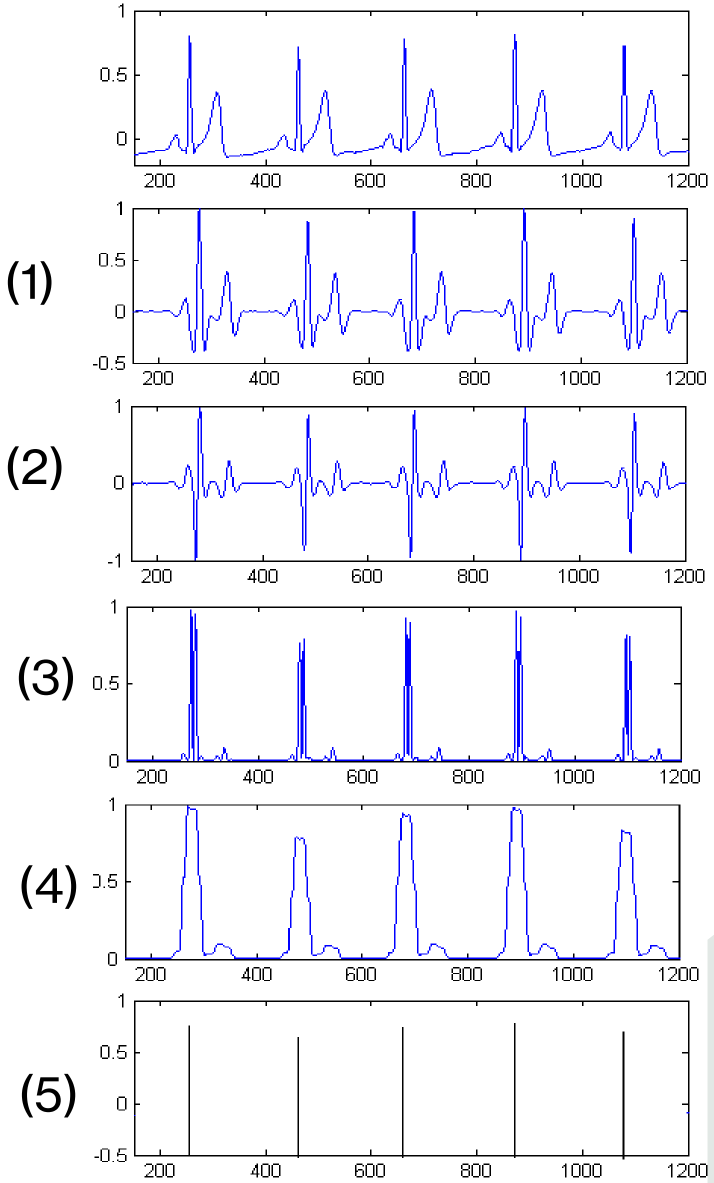
Fiducial Points Detection (QRS complex)

- The most popular algorithm for QRS complex detection is Pan and Tompkins.
- The algorithm is implemented in a series of steps:1) low & high pass filtering;2) differentiation; 3) squaring; 4) moving-window integration; 5) thresholding; 6) search back for missing R waves and remove misclassified T waves as R waves due to their height.

Fiducial Points Detection (QRS complex)

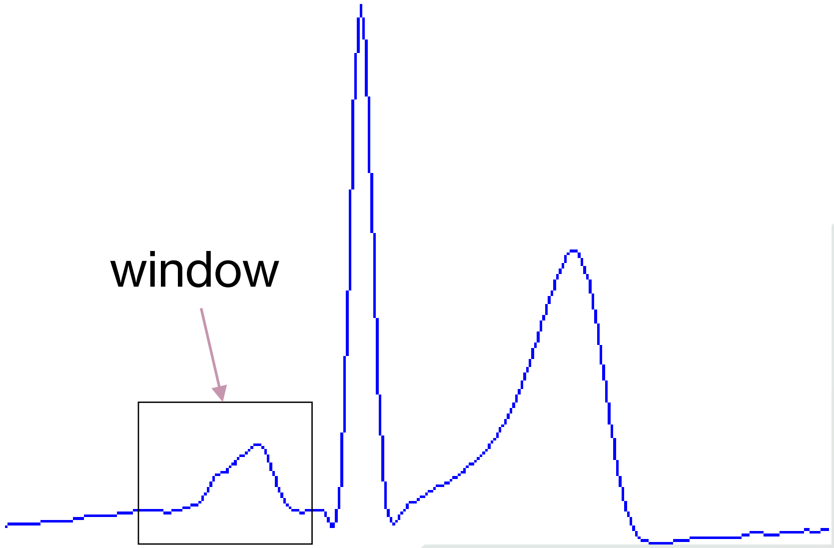
R peak

- After detecting R peak Q and S can be detected as finding local minimum before and after R peak.
- In addition, the beginning and end of QRS can be found by detecting the onset and offset of the peak in (4), since peak in (4) includes all the QRS complex.



Fiducial Points Detection (P peak) Example

- A search window is defined for the p wave before the QRS complex. It begins from the QRS onset with width 200ms (medical base). The peak of the p wave is the local maximum in the search window. If two peaks are found with ratio between them is less than Θr and duration between them less than Θd then this p wave has a M shape. In this case the P peak is considered the one with higher amplitude. Θr and Θd are found empirically.



Fiducial Points Detection (T peak) Example

A search window is defined after the QRS complex to detect T peak. It begins from the QRS offset and remains for 400ms (figure 5.4 (b)). This width of the window was computed empirically through experiments on medical base. The T peak can be detected using the wing functions. This method has been chosen due to its efficiency, simplicity and its ability to detect both positive and negative (inverted) T waves. The 'wings' function obtained at each successive sample in the search window, wings are modeled with 2 neighboring segments W1 and W2 as follows:

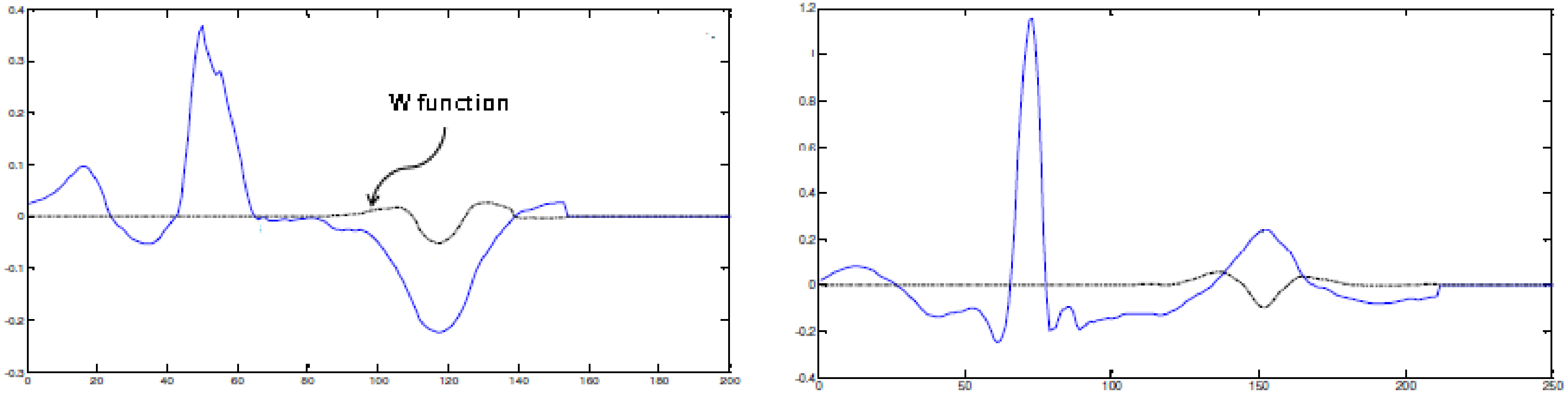
$$W_1 = X_{i-16} - X_i$$

$$W_2 = X_i - X_{i+16}$$

where, X is the input sample to the wing function.

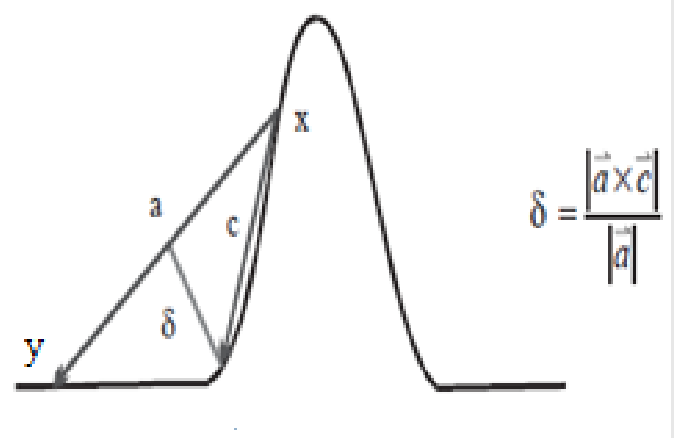
Fiducial Points Detection (T peak) Example

- A Wing function W is computed by multiplying W1 and W2. The minimum point of the W signal inside the search window is considered the T peak.



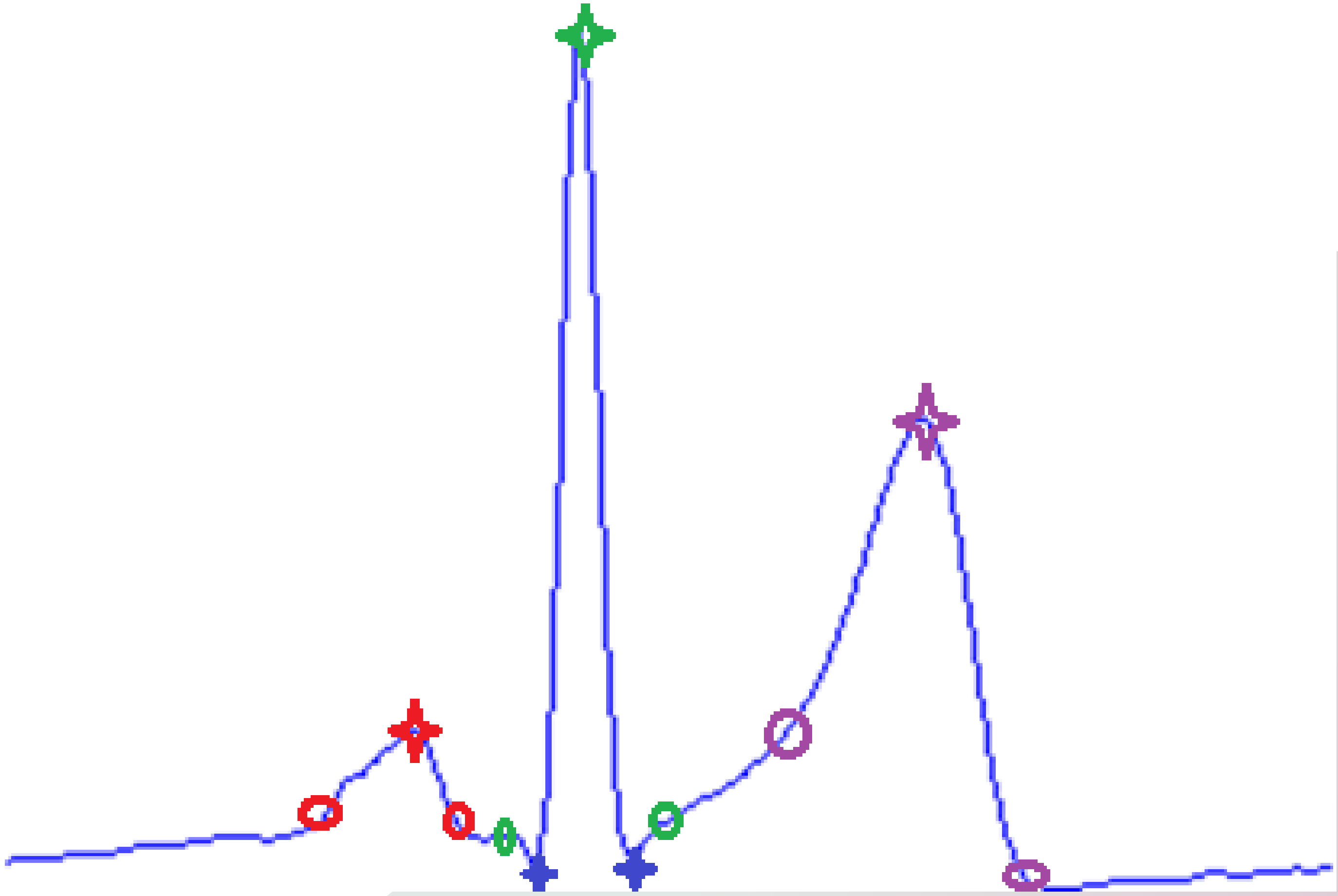
Fiducial Points Detection (onset & offset of each wave) Example

- The onset & offset of each wave can be computed by defined using the method of minimum radius of curvature. The onset is defined by tracking downhill from the right side, the X and Y fixed then the minimum radius of curvature is found by maximizing the value of δ using the vector cross product between the two directed line segments a and c.
- The offset is defined in the same way but this time by tracking downhill from the left side of the P wave. For M shape P wave, to define the onset we track downhill before left peak, while for the offset we track downhill after the right peak. In case of the negative T wave (inverted), the same algorithm is applied but this time we are climbing up the valley not tracking downhill as in the positive case.

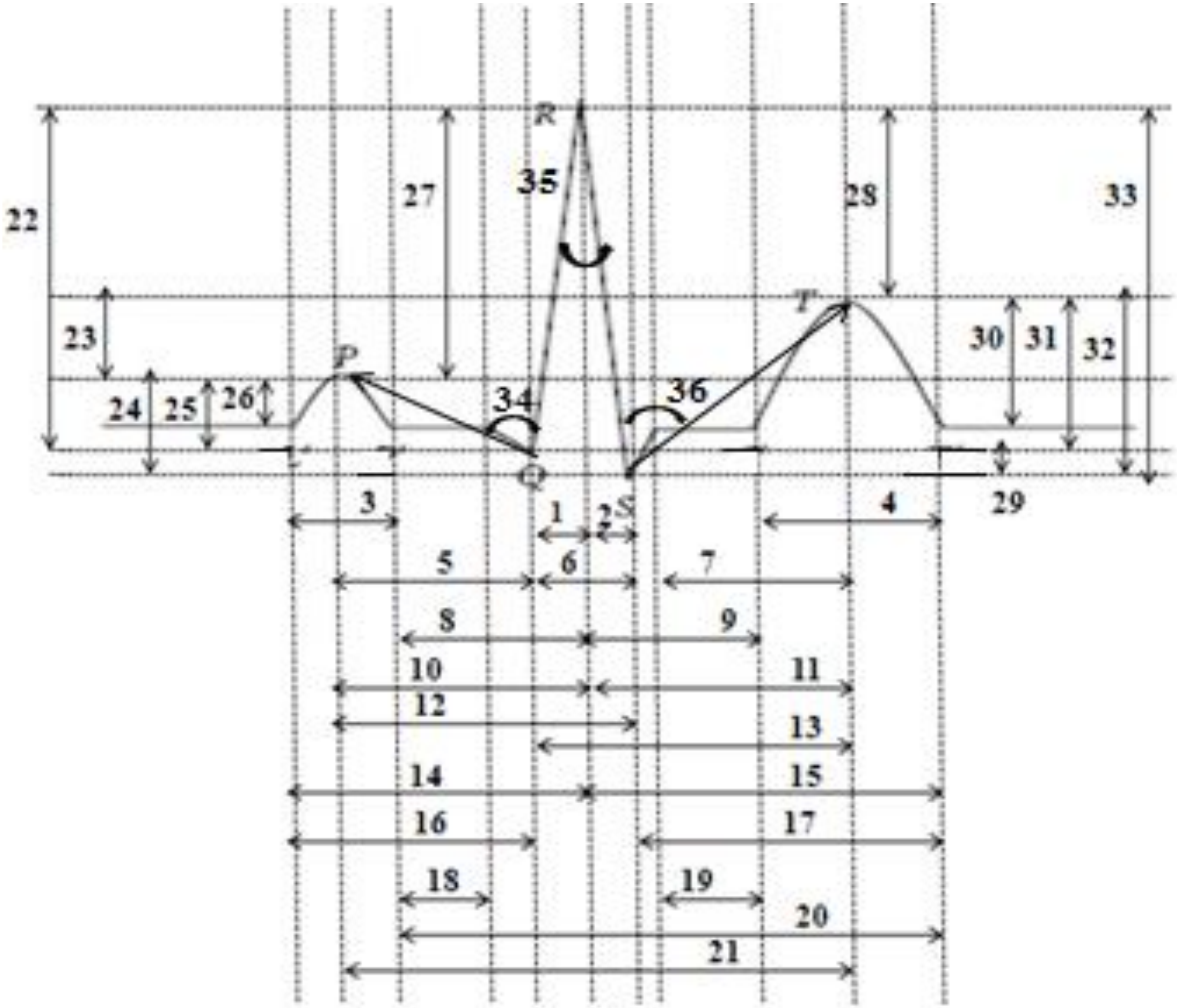


Fiducial Points Detection

- The detected 11 fiducial points



Feature Extraction (fiducial features)



To avoid heart rate variability, duration features are usually divided by QT duration.

Feature Extraction

- These features utterly depend on accurate detection of fiducial points. However, this is a very challenging task since these points are susceptible to noise, Moreover, there is no standards to tell us where these points exactly exit, even cardiologists will give different marker position for same point.

- These reasons encourage the researchers recently to utilize non-fiducial feature extraction methods (ex: Wavelet, AC\DCT ..etc) where only R peak detection is needed and sometimes without fiducial points detection at all.

- Non-Fiducial features represent holistic patterns in ECG signals, instead of amplitude and duration between fiducial points.

ECG Segmentation for non-Fiducial Features
Heartbeat Segmentation

- Each ECG trace (record) is segmented into ECG heartbeats. Each heartbeat must encompass the three complex waves P, QRS and T. In the literature, due to the difficulty in detecting the beginning and the end of each heartbeat, a fixed segmentation has been considered by taking a definite number of samples before and after each R peak. However, this strategy ignores the effect of heart rate changes.
- As the heart rate increases (decreases), the one segment may include more (less) than one heartbeat which by its role, may violate the later extracted features. Thus, dynamic segmentation is suggested where the number of samples considered before and after each R peak is counted according to the duration between the current R peak and the previous R (RR previous) and the duration between the current R peak and the next R (RR next). The RR interval is usually considered as heartbeat duration since it includes all three complex waves. Thus, when the heart rate increases (decreases), correspondingly the RR duration decreases (increases).

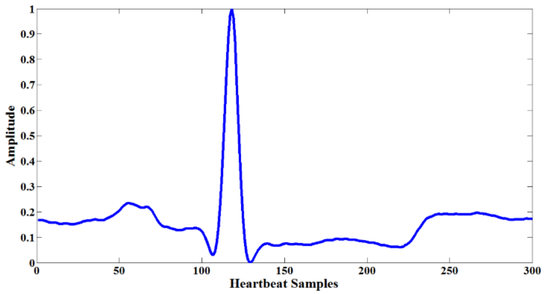
$$Before\ Rpeak = \frac{1}{3} * \frac{RR\ previous\ +\ RRnext}{2}$$

$$After\ Rpeak = \frac{2}{3} * \frac{RR\ previuos +\ RRnext}{2}$$

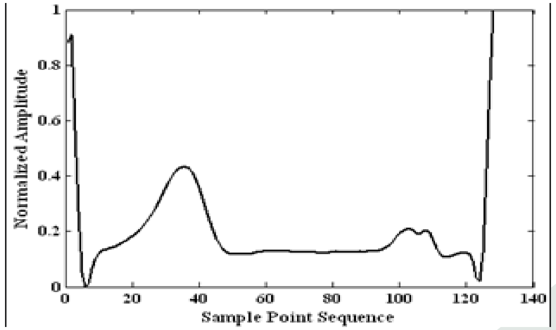
ECG Segmentation for non-Fiducial Features
ECG Segments

- ECG can be segmented into RR intervals; each RR interval can be considered as one beat since it includes the three waves. RR intervals are used in biometrics applications.

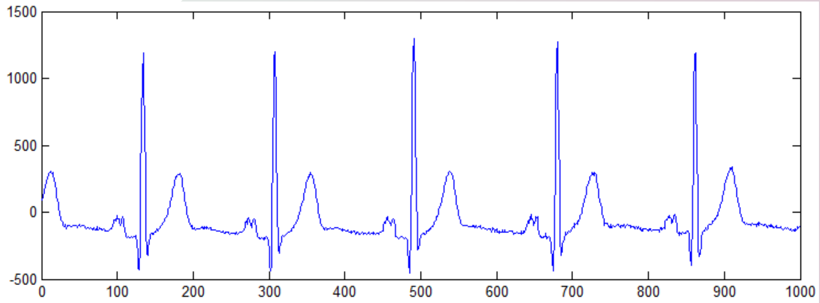
- ECG records are partitioned into ECG segments, where each segment can include more than one beat but not less than one beat.



Single heartbeat



RR interval



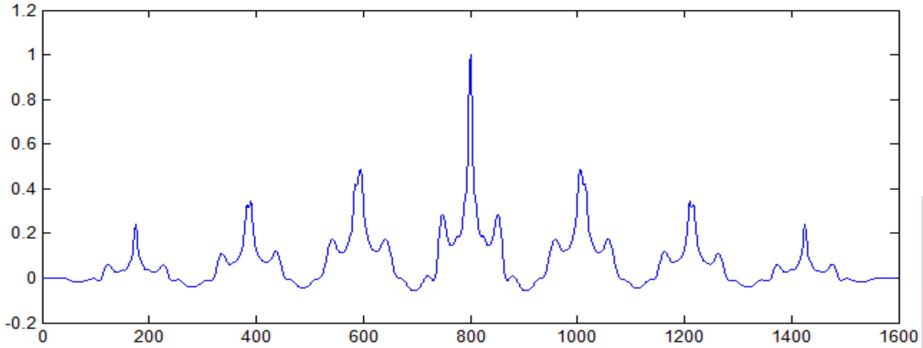
ECG segment

Non-Fiducial Features
Wavelets

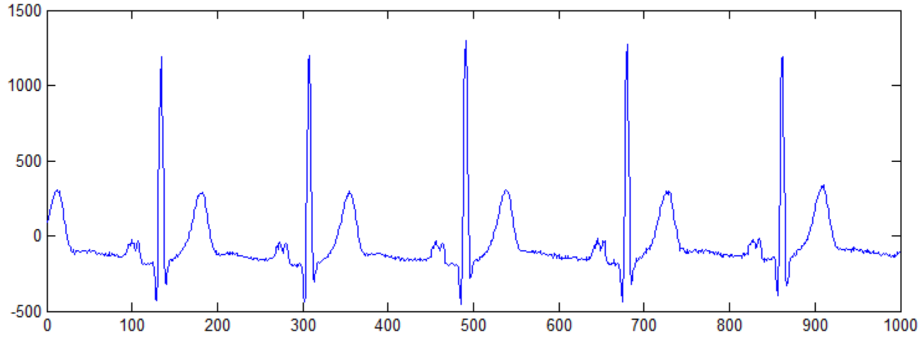
- Decompose the ECG segments\heartbeats in suitable number of levels using mother wavelets that suits in shape the ECG waves (ex: Daubechies family). Thereafter, preserve only the coefficients of ECG band (1-40) and utilize them as features.

Non-Fiducial Features
AC\DCT

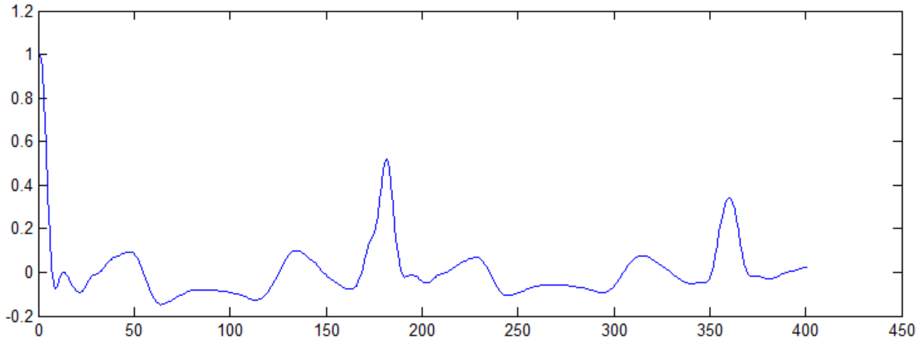
Apply Autocorrelation (AC) to ECG segments and then apply DCT to reduce the dimension.



After AC

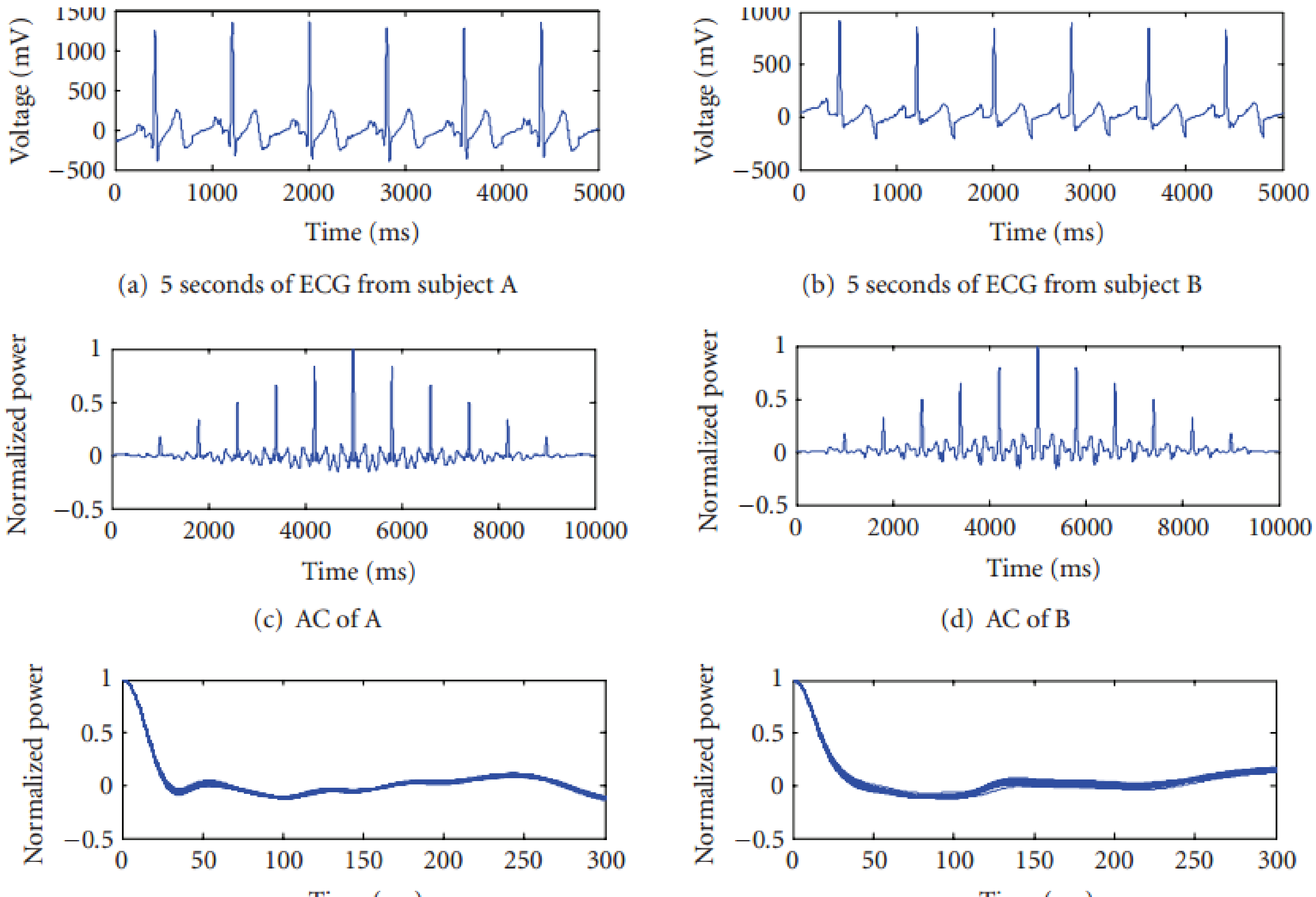


ECG segment



400 autocorrelation Coefficients

Non-Fiducial Features
AC\DCT



(a) 5 seconds of ECG from subject A

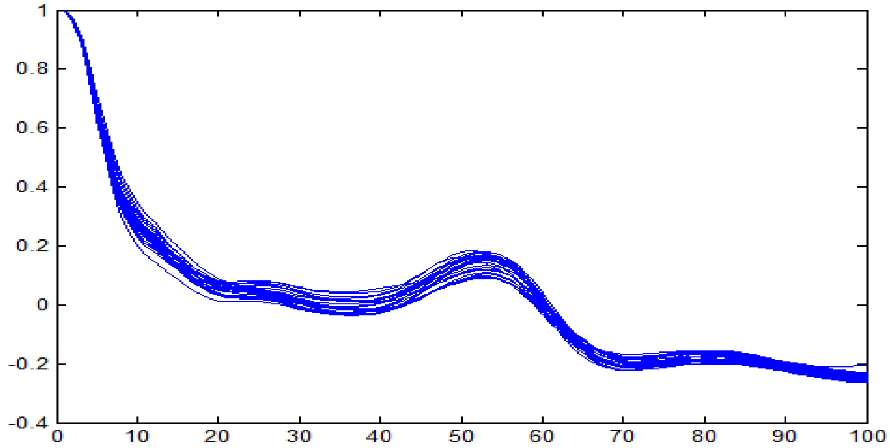
(b) 5 seconds of ECG from subject B

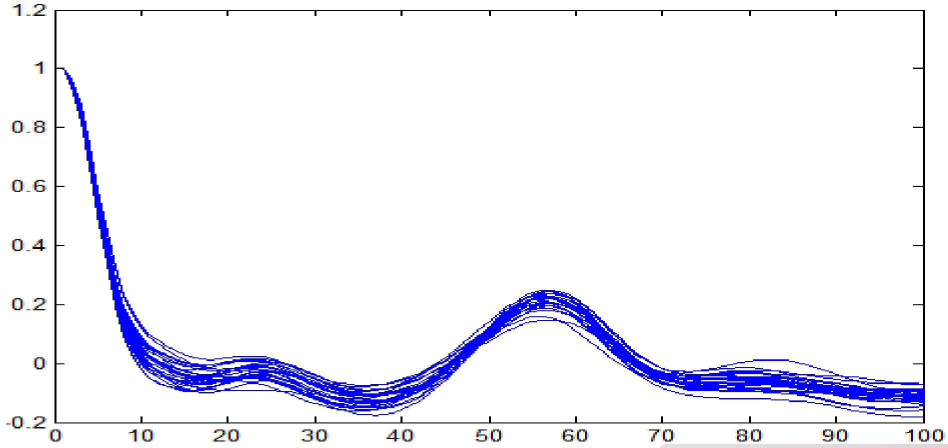
(c) AC of A

(d) AC of B

Non-Fiducial Features
AC\DCT

AC Coefficients





After DCT