Event detection

Biosignal processing, 521273S

Autumn 2019

ECG event detection

- P wave: depolarization of the atrium
- QRS-complex: depolarization of ventricle
- T wave: repolarization of ventricle

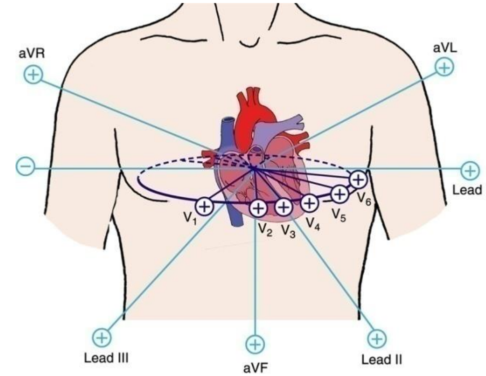
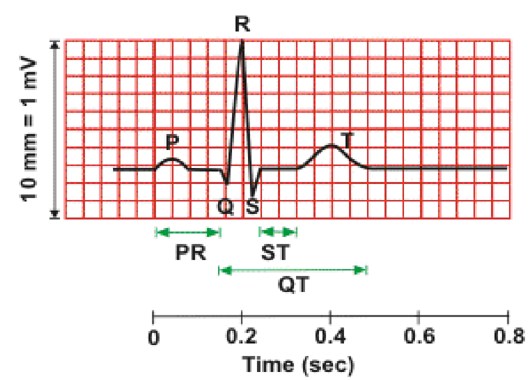


Figure 17-42 Electrocardiographic views of the heart.

- Each event represents one phase of the electrical activity of the heart functioning
  - Any deviations from the normal may imply important pathophysiologic changes in the heart tissue



P wave (0.08 - 0.10 s) QRS (0.06 - 0.10 s)

P-R interval (0.12 - 0.20 s) Q-T_C interval ($\leq$ 0.44 s)*

$$^{*}QT_c = QT/\sqrt{RR}$$

ECG events

Morphological analysis of waveforms: first QRS event is detected, then other waves are detected, finally their shapes and timing are analyzed

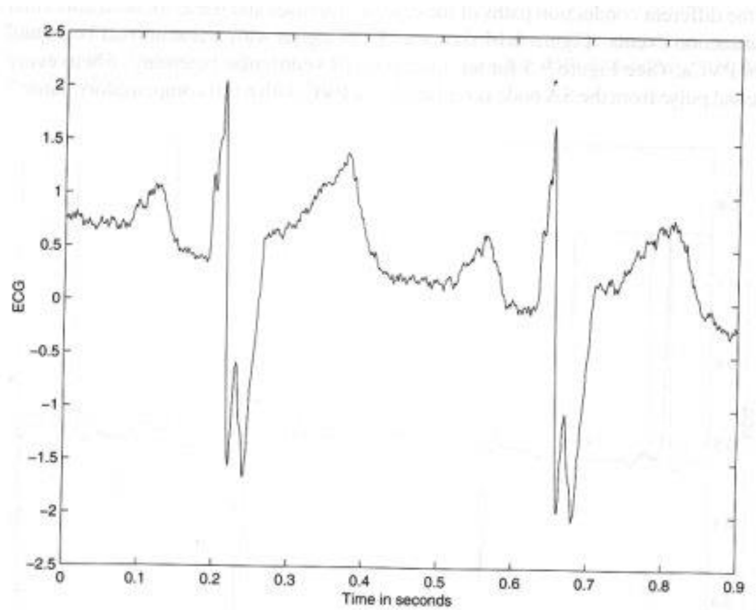


Figure 1.15 ECG signal of a patient with right bundle-branch block and hypertrophy (male patient of age 3 months). The QRS complex is wider than normal, and displays an abnormal, jagged waveform due to desynchronized contraction of the ventricles. (The signal also has a base-line drift, which has not been corrected for.)

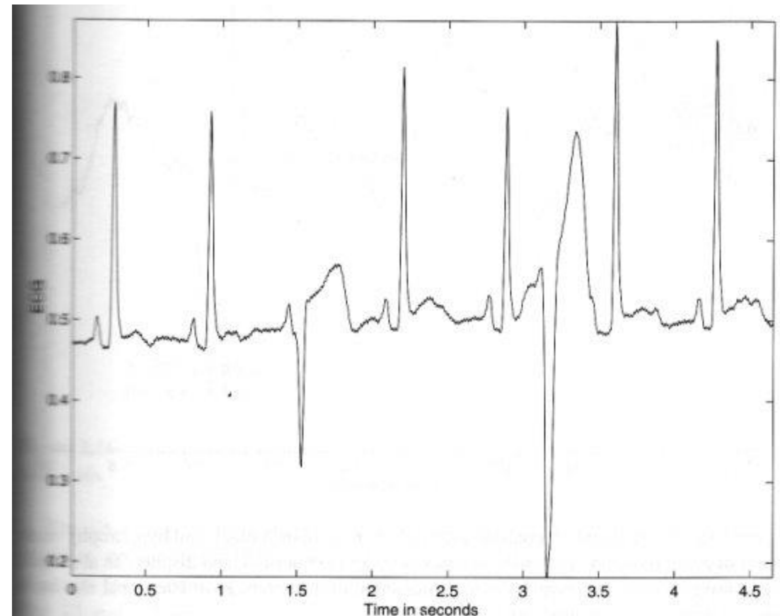


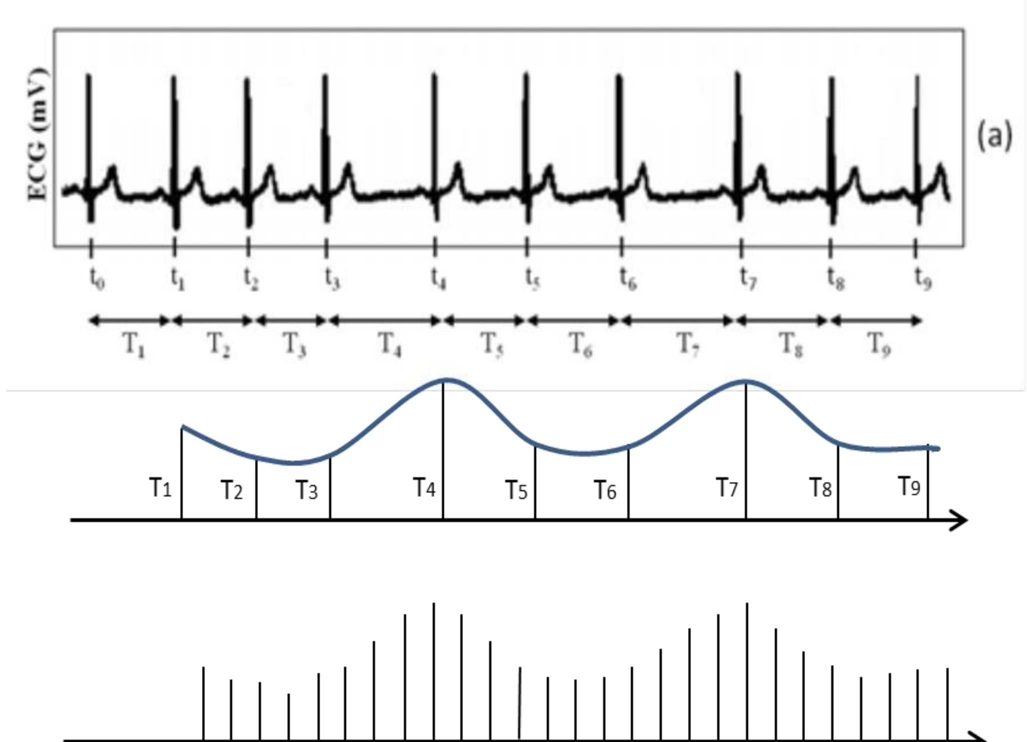
Figure 1.14 ECG signal with PVCs. The third and sixth beats are PVCs. The first PVC has blocked the normal beat that would have appeared at about the same time instant, but the second PVC has not blocked any normal beat triggered by the SA node. Data courtesy of G. Groves and J. Tyberg, Department of Physiology and Biophysics, University of Calgary.

Right bundle-branch block and hypertrophy
- Widened QRS complex + jagged shape

Premature ventricular contraction
- Abnormal timing and wave shape

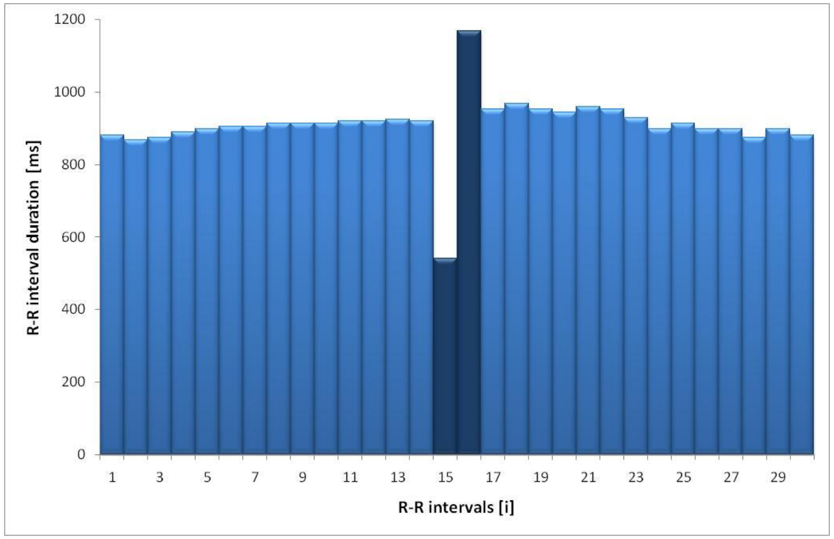
Heart rate variability: arrhythmias

- Tachogram:
  RR-interval series
- Detection of anomalies of heart rhythm



PVC detection from heart rate signal

- For example: An extra beat followed by compensatory pause
- Simple threshold criteria are used for detection:
  - Maximum [%] allowed change between consecutive beat intervals
  - Maximum [ms] allowed change between consecutive beat intervals



Ectopic beat in the R-R interval time series of a MI patient. Ectopic beat appears as a short R-R interval followed by a compensatory pause.

Detection of QRS (Pan & Tompkins)

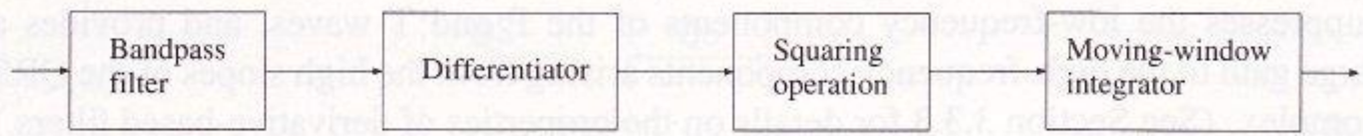


Figure 4.4 Block diagram of the Pan-Tompkins algorithm for QRS detection.

Only the basic idea is presented here. Further details can be found in the original paper:
Pan J, Tompkins WJ. A real-time QRS detection algorithm.
IEEE Transactions on Biomedical Engineering, Vol. BME-32, No. 3, March 1985, pp. 230-236.

The algorithms are given for sampling frequency Fs = 200Hz.

Detection of QRS

- Bandpass filtering is performed in two steps
  - Supresses noise and power-line interference
  - 1. LP filtering (Fc=11Hz):

$$H(z) = \frac{1}{32}\frac{\left(1-z^{-6}\right)^2}{\left(1-z^{-1}\right)^2} = \frac{1}{32}\frac{1-2z^{-6}+z^{-12}}{1-2z^{-1}+z^{-2}}$$

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

  - 2. HP filtering (Fc=5Hz):

$$H(z) = z^{-16} - \frac{1}{32}\frac{\left(1-z^{-32}\right)}{\left(1-z^{-1}\right)}$$

$$y(n) = y(n-1) - \frac{1}{32}x(n) + x(n-16) - x(n-17) + \frac{1}{32}x(n-32)$$

Detection of QRS

- Derivative operator is applied next:

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

  – Supresses slow components: P and T waves
  – Amplifies fast components: QRS wave
  – Measures the rate of change of signal amplitude
- Squaring: $y(n) = x^2(n)$
  – Produces positive values, further supresses T and P, and further amplifies QRS
- Moving window integration:

$$y(n) = \frac{1}{N}\sum_{i=0}^{N-1} x(n-i)$$

  – Smoothes squared signal
  – Window size N: too large value will fuse waves together, too small value will produce split peaks

Detection of QRS

- Adaptive thresholding for peak detection
  - Peak definition: a local maximum when signal amplitude changes direction in a small window
- Definitions:
  - SPKI: QRS peak hight estimate
  - NPKI: noise peak hight estimate
  - PEAKI: current peak under consideration
  - THRESHOLD_I1: primary threshold for peak detection
  - THRESHOLD_I2: secondary threshold for peak detection

Detection of QRS

- Find the next peak from signal: PEAKI
  - However, if no peak is found within the MISSED time window, perform as instructed on the next slide and come back here to continue from threshold update step below
- If PEAKI > THRESHOLD_I1 (QRS is detected here!)

  SPKI = PEAKI x (1/8) + SPKI x (7/8) (update signal amplitude estimate)

  Else (noise peak found instead)

  NPKI = PEAKI x (1/8) + NPKI x (7/8) (update noise amplitude estimate)
- Update the thresholds:

  THRESHOLD_I1 = NPKI + (SPKI-NPKI)/4

  THRESHOLD_I2 = THRESHOLD_I1 / 2
- Look for the next peak

Detection of QRS

- However:

  if no peak PEAKI was found within the MISSED time window of 1.66 x RR_AVERAGE from the previous beat

  then

  find the highest peak within the MISSED time window

  if PEAKI > THRESHOLD_I2   (a lowered QRS peak was found)

  SPKI = PEAKI x (1/4) + SPKI x (3/4)   (update <u>signal</u>...)

  else (noise peak was found instead)

  NPKI = PEAKI x (1/8) + NPKI x (7/8) (update <u>noise</u>...)

  GO back to threshold updating on previous slide

- RR_AVERAGE: the average beat interval of 8 those previous beats which are within the limits of:

  0.92 x RR_AVERAGE – 1.16 x RR_AVERAGE

  – RR_AVERAGE is updated at every QRS detection!

Detection of QRS

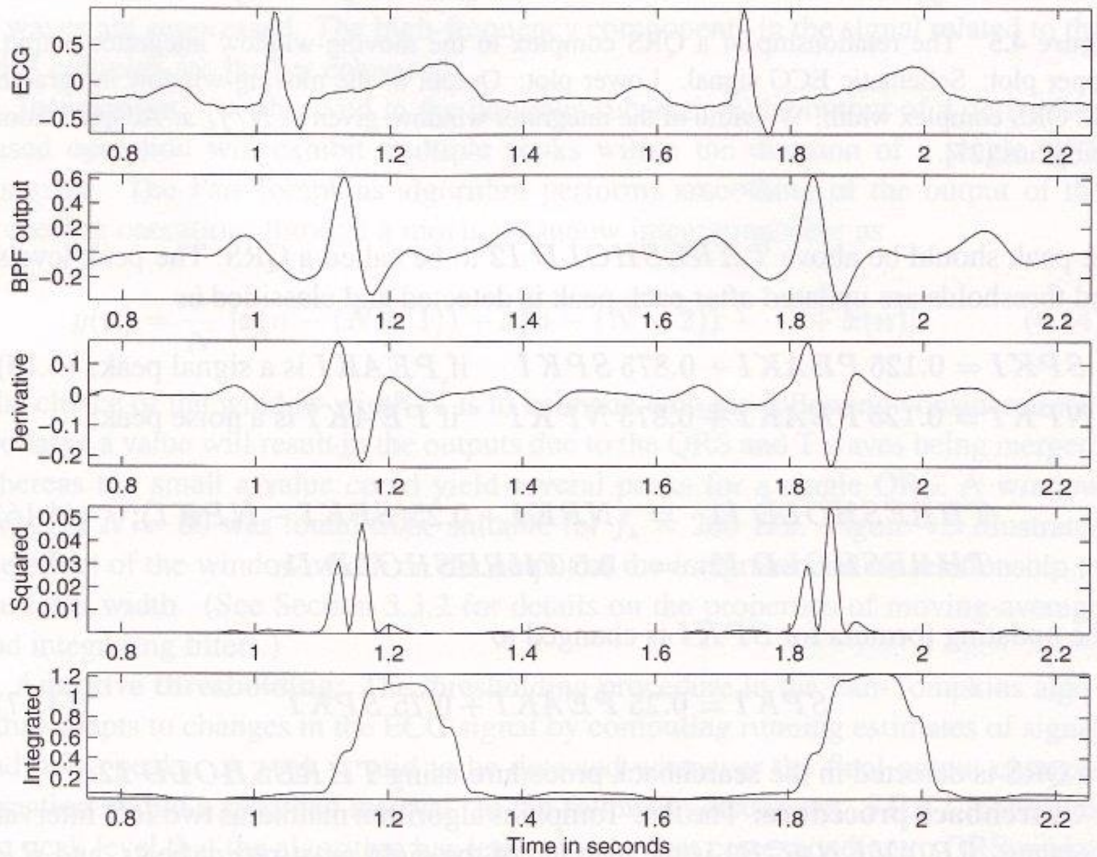


Figure 4.6 Results of the Pan-Tompkins algorithm. From top to bottom: two cycles of a filtered version of the ECG signal shown in Figure 3.5 (the same as that in Figure 4.2); output of the bandpass filter (BPF, a combination of lowpass and highpass filters); output of the derivative-based operator; the result of squaring; and 100× the result of the final integrator.

Detection of QRS

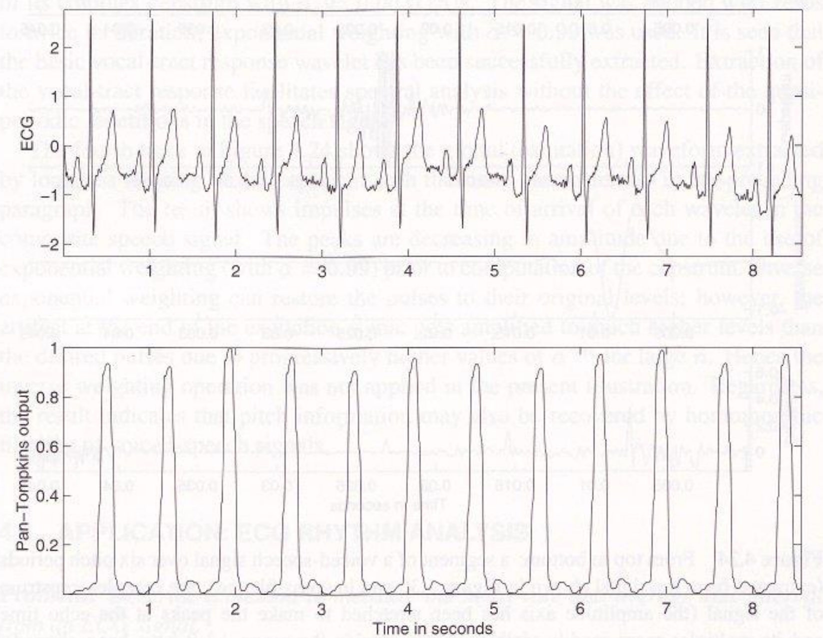


Figure 4.25 Results of the Pan-Tompkins algorithm. Top: lowpass-filtered version of the ECG signal shown in Figure 3.5. Bottom: normalized result of the final integrator.

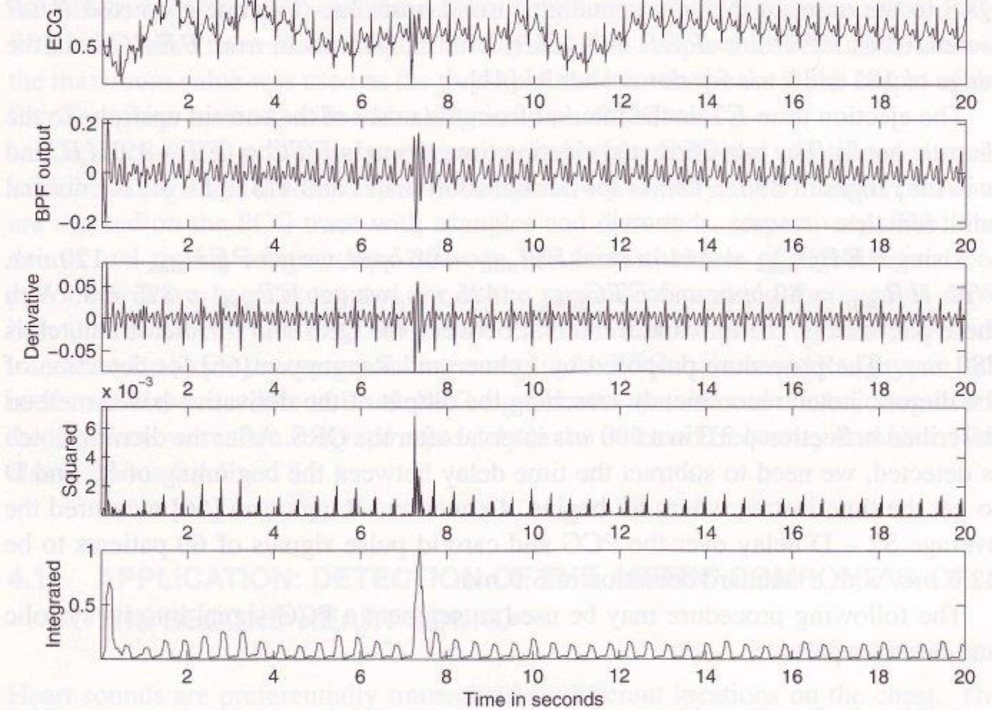


Figure 4.26 Results of the Pan-Tompkins algorithm with a noisy ECG signal. From top to bottom: ECG signal sampled at 200 Hz; output of the bandpass filter (BPF); output of the derivative-based operator; the result of squaring; and normalized result of the final integrator.

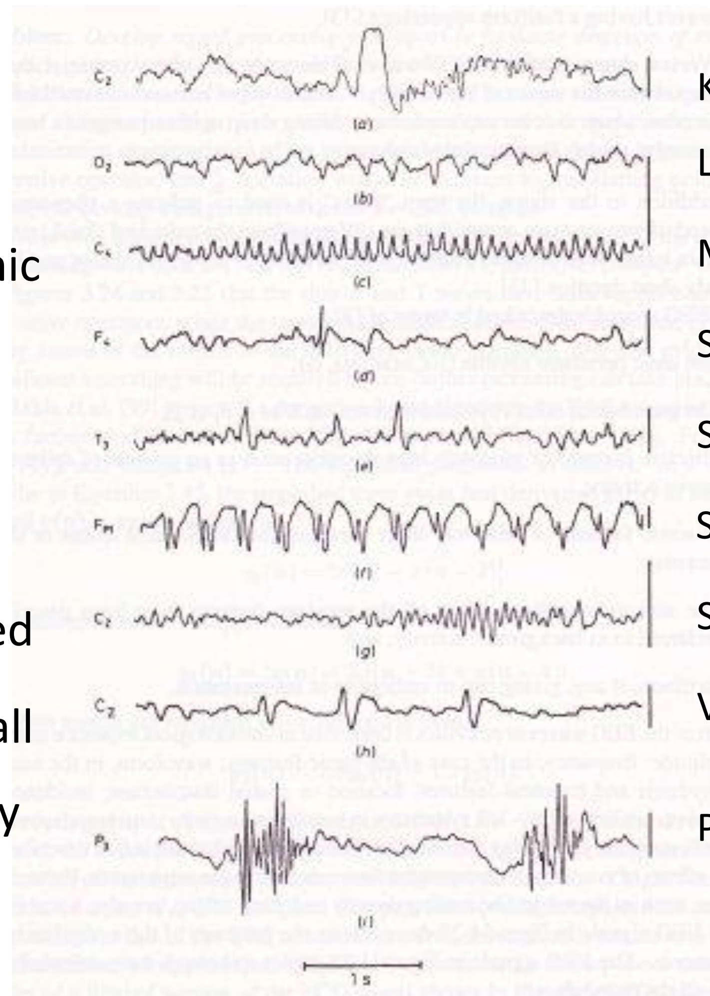
Rhythmicity detection

- Autocorrelation function, spectrum (power spectral density, PSD)
- Cross-correlation function, cross-spectrum
- Coherence analysis

Examples of events: EEG

EEG record can be described in terms of:

- The most persistent rhythm (e.g., α frequency)
- The presence of other rhythmic features, such as δ, θ, β frequencies
- Discrete features of relatively long duration, such as an episode of spike-and-wave activity
- Discrete features of relatively short duration, such as isolated spikes or sharp waves
- The activity remaining when all previous features have been described, background activity
- Artifacts giving rise to ambiguity in interpretation



K-complex
Lambda wave
Mu rhythm
Spike
Sharp waves
Spike-and-wave complexes
Sleep spindle
Vertex sharp wave
Polyspike discharges

Band: δ θ α β

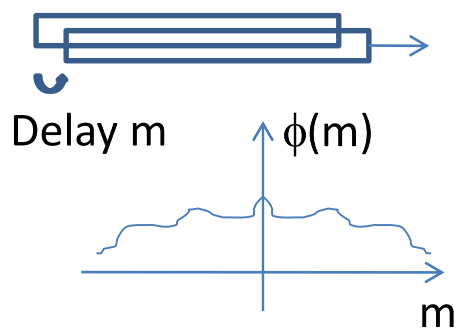
0.5 4 8 13 f [Hz]

Autocorrelation function, periodogram

- Periodogram estimate of PSD can be achieved through Fourier transforming the autocorrelation function of the signal

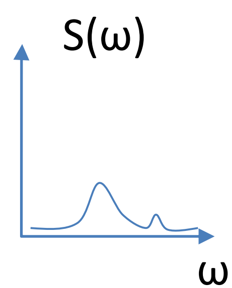
$$S(\omega) = \sum_{m=-(N-1)}^{N-1} \phi(m) e^{-j\omega m}$$

$$\phi(m) = \frac{1}{N} \sum_{n=0}^{N-|m|-1} x(n)x(n+m)$$



- PSD can also be computed from DFT of the windowed signal:

$$S(\omega) = \frac{1}{ME_w} \left| \sum_{n=0}^{M-1} x_i(n) w(n) e^{-j\omega n} \right|^2 \qquad E_w = \frac{1}{M} \sum_{n=0}^{M-1} w^2(n)$$



Autocorrelation, PSD

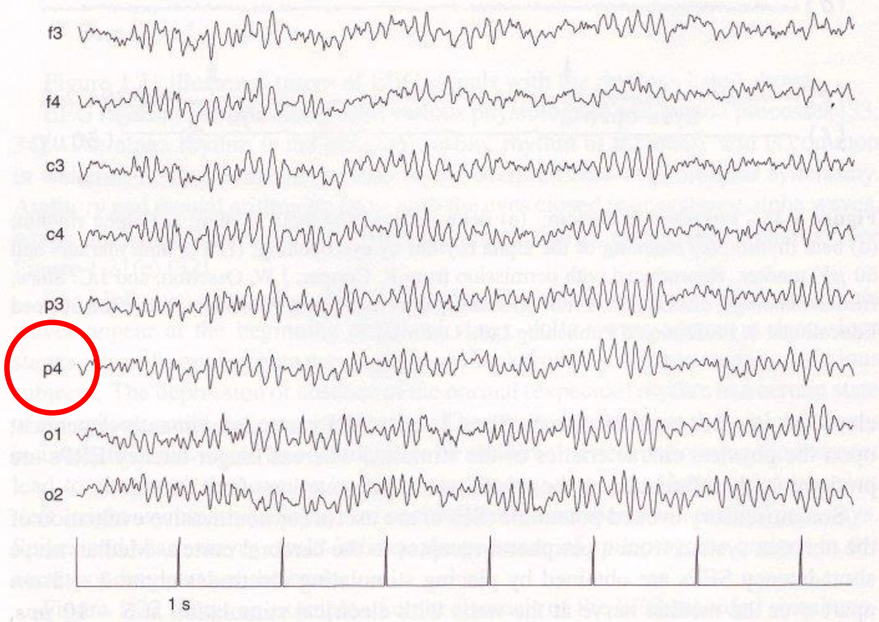


Figure 1.22 Eight channels of the EEG of a subject displaying alpha rhythm. See Figure 1.20 for details regarding channel labels. Data courtesy of Y. Mizuno-Matsumoto, Osaka University Medical School, Osaka, Japan.

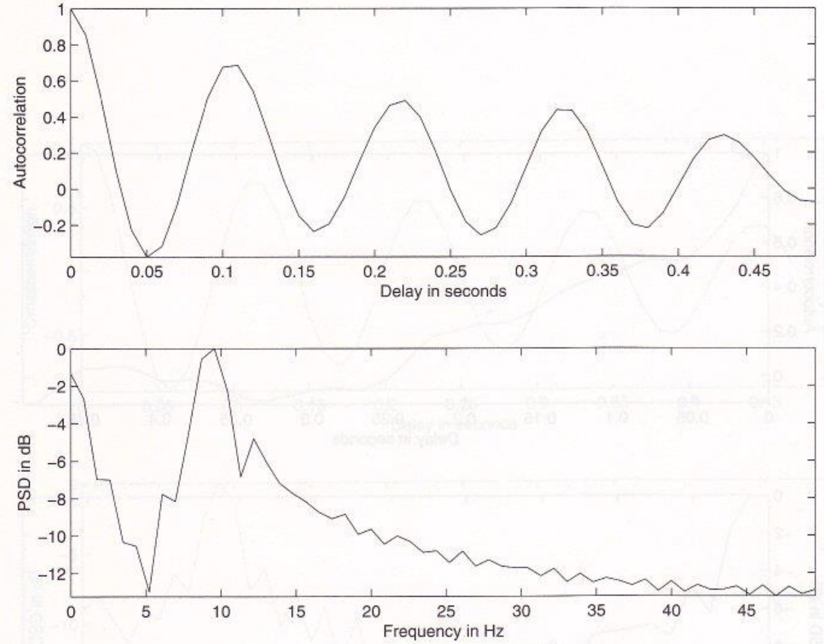


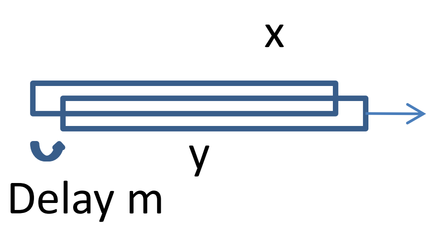
Figure 4.8 Upper trace: ACF of the 4.67 − 5.81 s portion of the p4 channel of the EEG signal shown in Figure 1.22. Lower trace: The PSD of the signal segment in dB, given by the Fourier transform of the ACF.

Cross-correlation function, cross-spectrum

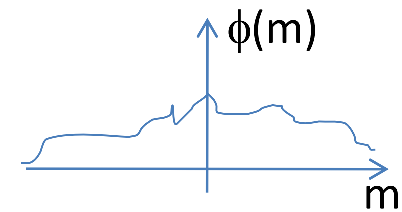
- Cross-correlation function between two signals
  - Are there similar waveforms in the signals? Repetition?
- Cross-spectrum
  - Is there power in the same frequencies in the two signals?

  - Either:

$$\phi_{xy}(m) = \frac{1}{N} \sum_{n=0}^{N-|m|-1} x(n) y(n+m)$$

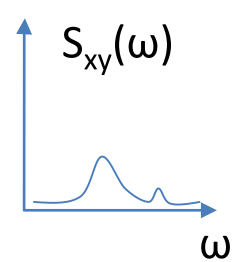


$$S_{xy}(\omega) = \sum_{m=-(N-1)}^{N-1} \phi_{xy}(m) e^{-j\omega m}$$



  - Or:

$$S_{xy}(\omega) = X(\omega) Y^{*}(\omega)$$



Cross-correlation function, cross-spectrum

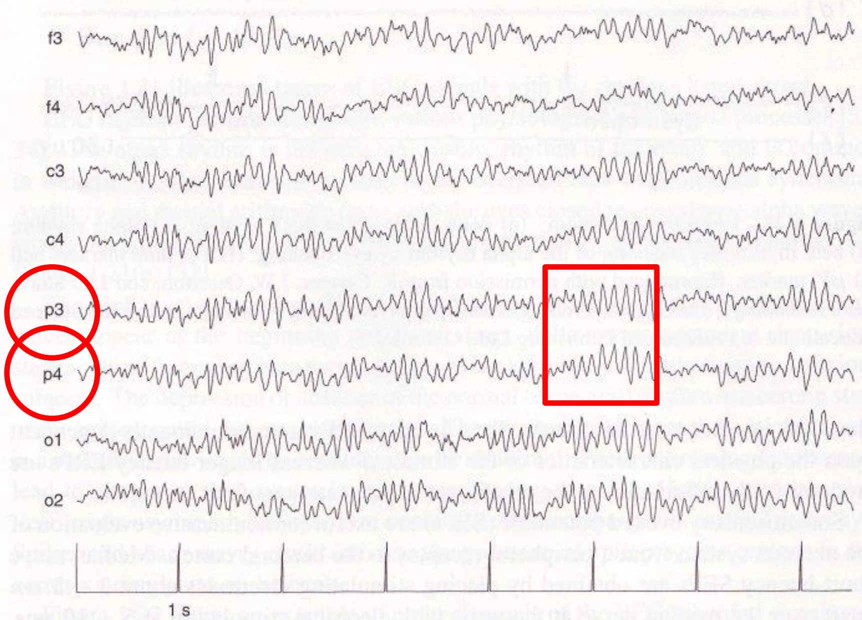


Figure 1.22 Eight channels of the EEG of a subject displaying alpha rhythm. See Figure 1.20 for details regarding channel labels. Data courtesy of Y. Mizuno-Matsumoto, Osaka University Medical School, Osaka, Japan.

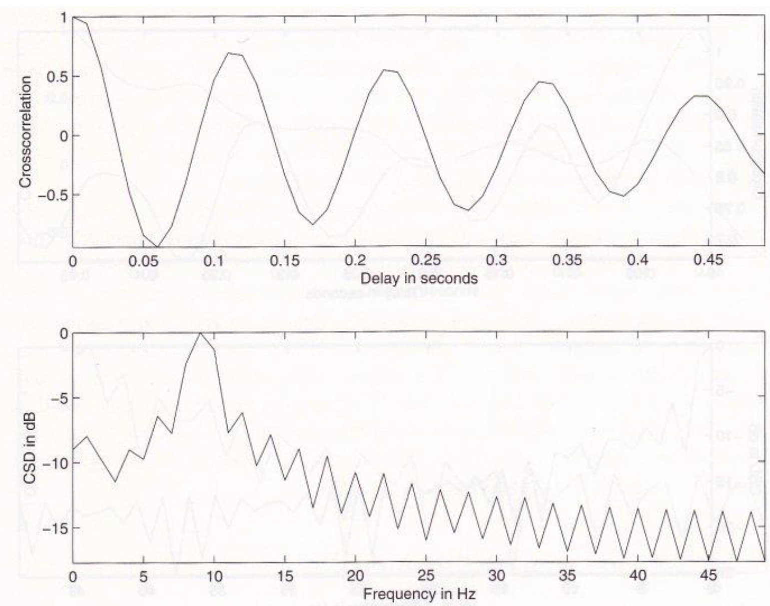
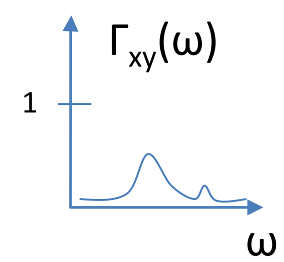


Figure 4.10 Upper trace: CCF between the 4.72 – 5.71 s portions of the p3 and p4 channels of the EEG signal shown in Figure 1.22. Lower trace: The CSD of the signal segments in dB, computed as the Fourier transform of the CCF.

Coherence function

- Normalized cross-spectrum
  - Is there correlation between the spectral powers in particular frequencies in the signals?
  - Values are in the range [0,1]

$$\Gamma_{xy}(\omega) = \left[\frac{\left| X(\omega) Y^*(\omega) \right|^2}{\left| X(\omega) \right|^2 \left| Y(\omega) \right|^2} \right]^{1/2}$$



Detection of pulses: Matched filter

- Convolution of a pulse sample (y) and a signal (x)
  - Time-reversed pulse sample forms the convolution kernel
  - A kind of cross-correlation operation
- Finds waveshape matches: similar pulse instances as the pulse sample

$$g(n) = \sum_{m=0}^{M-1} x(n-m)\,y(m)$$

  - High response when pulse present, otherwise low response
  - Negative-valued responses: the found wave shape is ”upside-down”

Pulse detection (EEG example)

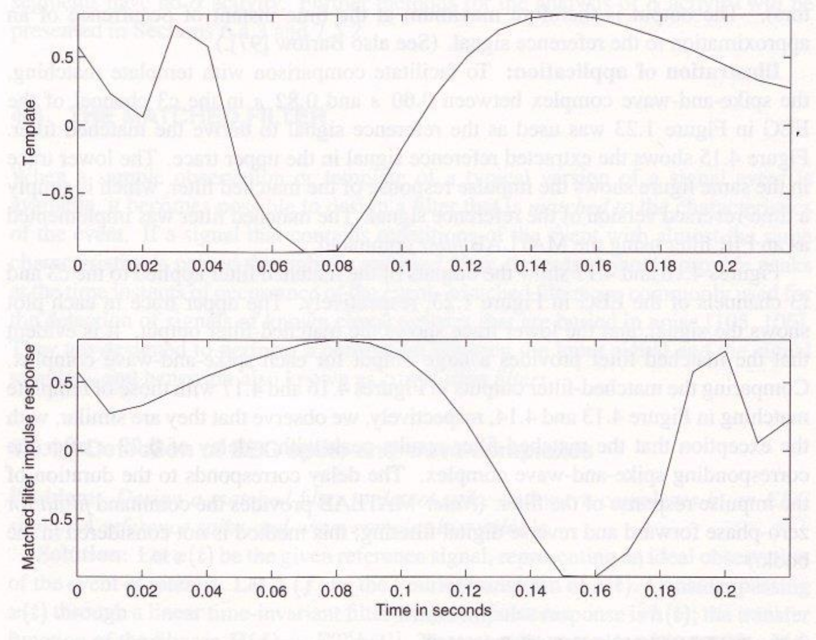


Figure 4.15 Upper trace: The spike-and-wave complex between 0.60 *s* and 0.82 *s* in the c3 channel of the EEG signal shown in Figure 1.23. Lower trace: Impulse response of the matched filter derived from the signal segment in the upper trace. Observe that the latter is a time-reversed version of the former.

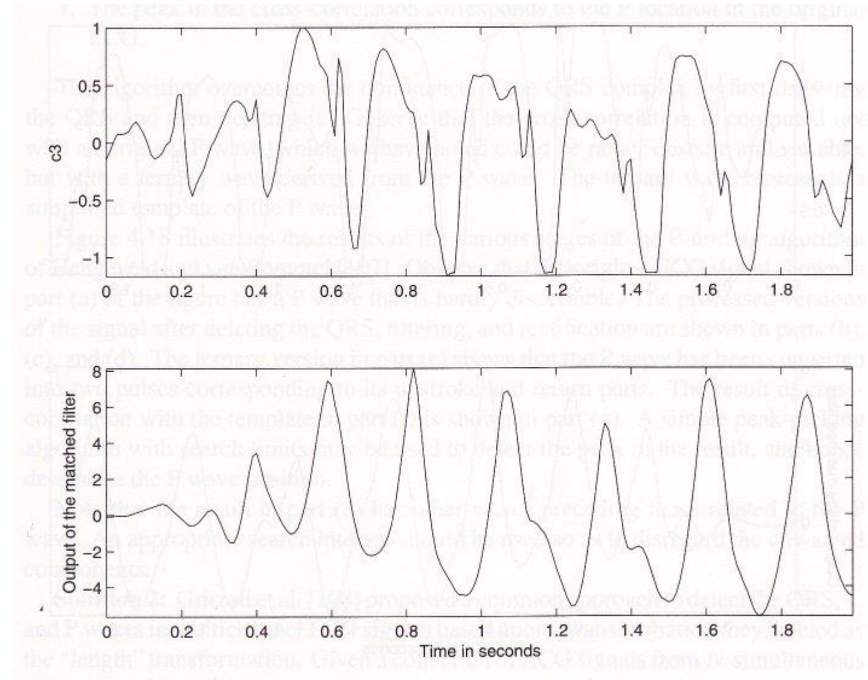


Figure 4.16 Upper trace: The c3 channel of the EEG signal shown in Figure 1.23, used as input to the matched filter in Figure 4.15. Lower trace: Output of the matched filter. See also Figure 4.13.

Spike-and-wave complex

Detection results

Selected references

Course book: Chapter 4

Journal article

- Pan J, Tompkins WJ. A real-time QRS detection algorithm.
  IEEE Transactions on Biomedical Engineering, Vol. BME-32, No. 3, March 1985, pp. 230-236.