Review of ECG Analysis

In 1887, Augustus D. Waller published the first human electrocardiogram (ECG) recorded with a capillary electrometer. Subsequently, Willem Einthoven invented a more sensitive galvanometer for producing ECG using a fine quartz string coated in silver. He invented the lead system for ECG recording and identified the five deflection points in the cardiac cycle by naming them P, Q, R, S and T which are still being used in the present standards (see Fig. 1.2). Einthoven also started transmission of ECG from hospital to his laboratory on telephone lines [33]. Since then a huge knowledge base has been generated covering clinical and engineering aspects of electrocardiography. Since last few decades electronic recorders have been developed for digital recording of the ECG signal. In recent years the ECG recorders are available in a much compact form so that the user can wear it for ECG recording without much of obstruction in the routine activities. Recently, the wearable ECG recorders (W-ECG) are becoming very popular because of their low cost, long term recording capability and ease of use.

Since a huge volume of ECG data is generated by the W-ECG, automated methods are preferred for analysis of the ECG signal. The ECG data may be composed of single-lead or multiple-lead ECG signals depending upon the type and configuration of the ECG recorder. Accordingly, the method of analysis is also different. Single-lead ECG waveform analysis includes wave shapes (morphologies), spectra and repeatability of the cardiac cycle. On the other hand, multi-lead ECG processing algorithms can utilize additional information like simultaneous features from other leads. This may lead to a greater immunity against interference signals. The disadvantage of multiple leads lie in increased patient discomfort and stress, especially for ambulatory testing. For the purpose of basic cardiac monitoring during ambulatory testing, it is desirable to have fewer leads and hence single-lead algorithms are more suitable for W-ECG applications. In this chapter we will review some of the existing techniques developed for analysis of single-lead ECG signals.
2.1 QRS Detection Methods

As we have seen in Chapter 1, ECG is a pseudo-periodic signal in the sense that the cardiac cycle repeats according to heart rate. However, the heart rate may not remain constant. The components of cardiac cycles appear in a regular sequence P-QRS-T. The variations in the heart rate may affect the durations of PQ and ST segments while the durations of P wave, QRS complex and T wave may still remain the same for a normal heart. The R peak in the QRS complex is the dominant feature of the cardiac cycle, which can be distinctly recognized from the sharp edges and a high amplitude as we have seen in Fig 1.2. Therefore, it is relatively easy to locate the QRS complex in the ECG even in the presence of low frequency noise (like baseline wandering due to respiration) and hence this is used for determining the current heart beat. The QRS detection forms the basis of most ECG analysis algorithms, particularly those used for arrhythmia monitoring [19, 77, 127]. The current heart rate may be determined by calculating the time period between the two consecutive R peaks. Moreover, specific ECG parameters can be derived using the R peak locations. For example, ST segment is measured at a certain predefined time interval from the end of the QRS complex [121] and the corrected QT interval is derived by well known Bazzet’s formula using the current QT and RR intervals [14]. This explains the importance of QRS detection in cardiac monitoring using ECG.

QRS detection algorithms, in general, use the relatively high energy contents of the QRS complex that lie in 5-25Hz band [63, 96, 128]. The more complex QRS detection algorithms involve application of neural network, hidden Markov model (HMM), syntactic methods, etc. [22, 48, 124, 133], but they are rarely used in low cost W-ECG applications. Further details of the QRS detection methods and the comparisons of their performances in presence of noise and their computational complexities can be found in [35, 63, 95]. Most of the simple QRS detection algorithms are based on one of the following methods: derivatives, filter-banks, wavelets, mathematical morphology and correlation [35, 63]. Here a few of the approaches in literature for QRS complex detection are discussed in brief.

The characteristic of higher slopes of the QRS complex inspires one to use temporal derivatives for its detection. In the derivative based methods, the ECG signal is first smoothed with an appropriate moving average filter for suppressing any high frequency noise outside the 5-25Hz band. The smoothed signal is differentiated to emphasize the high slopes and to suppress smooth ECG waves and baseline wanders. The overall response of these two simple arithmetic operations results in a bandpass filter to match the spectral band of the QRS while suppressing the relatively low frequencies in P and T waves. The squared magnitude of the derivative signal is used to enhance further the high derivatives of the QRS complex. A moving average integration filter with the window length matching the duration of QRS complex is applied after the squaring operation. The integrated signal is then searched for the