Analysis of ECG Signals
Part B: Heart Rate Variability
Project in SSY130

Tomas McKelvey

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1 Introduction

In part one of the project the analysis of the heart rate was made based on a very simplified model, i.e., the assumption that the heart beats are periodic. However, a closer analysis of the heart beats reveals that the beats are appearing at irregular time instances. This variability has many physiological sources and can be of clinical use for monitoring and diagnostic purposes. The overall phenomenon of the irregularity of the heart beats is called *heart rate variability (HRV)* and can be analyses in several ways. In this project you will develop some signal processing tools and use them to assess the HRV found in some ECG recordings provided. You find all data and scripts on the git page `https://git.chalmers.se/tomas.mckelvey/ssy130-ecg-analysis.git`

1.1 ECG Data

The data for this project task are long term ECG readings obtained with a sampling frequency of 128 Hz. The origin of the data is "MIT-BIH Normal Sinus Rhythm Database" from the PhysioNet database [1].

1.2 RR Interval

All heart rate variability analysis depart from the *RR interval* which is the time between two consecutive heart beats. The electrical pattern in an ECG signal has several parts which origins from the different phases a heart experience during a heart beat. The different phases are named P-Q-R-S-T waves, see illustration in Figure 1. The R-wave is the segment which is mostly pronounced and is, in a normal ECG, a fast large peak. Hence, to pin down an ECG complex to a specific time instance the peak of the R-wave is often used and the time elapsed between to consecutive R-peaks is hence called the RR interval.

In order to successfully apply HRV analysis the RR intervals need to be accurately estimated. This essentially boils down to the have a robust method to detect the location of the peak of the R-wave.

1.3 Tasks

1. The script `hrvRRdetect.m` illustrates how the ECG data is loaded and how results can be plotted. Complete the file with code which detects the R peaks and plot the R-peak detections in the ECG graph. The R-wave is characterised by rapid changes, i.e. the derivative is high. This property could be utilized in the detection bny using a FIR filter which calculates the derivative of the signal. The following issues should be considered.

   - For some individuals the ECG has a high gain and for some lower gain. The peak detection method should automatically compensate for this.
   - In some cases there is a slowly varying bias, i.e. the baseline is drifting. Remove this effect by some appropriate filter.

   Using a FIR local model approach with monomial basis functions and using the derivative as the output could be one possibility.

2. The respiratory activity has an impact on the RR intervals and the IHR. Analyze this in some of the ECG traces and try to determine the respiratory rate.

3. It is clear that it is almost impossible to find a filtering and peak detection method which is fail-safe. In order to further analyze the RR intervals the data need to be curated by removing so called outliers in the data. In the sequence of RR intervals should an outlier be removed or replaced by neighbour data?

4. We can define the instantaneous heart rate (IHR) as the rate (in beats/min) that a given RR interval indicates. Derive the expression of the IHR if the RR interval is q samples and the sampling frequency is $f_s = 128$ Hz. Use this calculation when scale the IHR when plotting it.

5. For each new R-peak detected a new RR interval can be determined. This implies that the RR interval data are obtained at a non-equidistant time instances. Discuss how such data should be plotted and further analyzed with respect to this issue.

1.4 Analysis of long term HRV data

The variability of the RR intervals around an average gives some indications of the status of the individual. A high variability of the RR interval is a recognized index of the ability of the cardiovascular system to cope with environmental challenges.

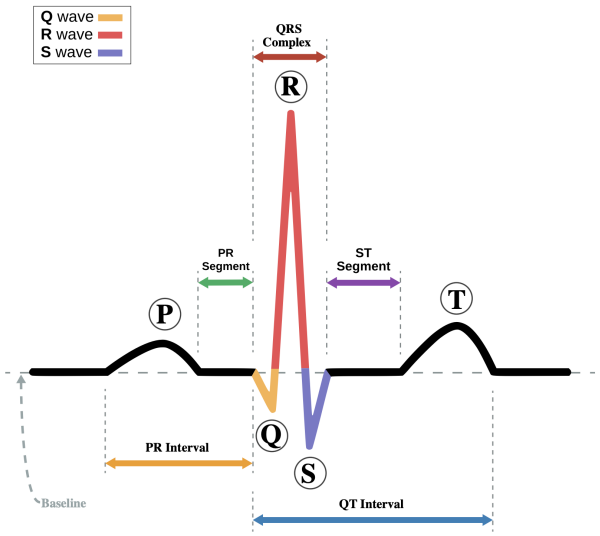

Figure 1: ECG wave and the sub-waves. Created by Agateller (Anthony Atkielski), converted to svg by atom. - SinusRhythmLabels.png, Public Domain, https://commons.wikimedia.org/w/index.php?curid=1560893

1.5 Tasks

1. Create a script that segment the ECG data into 1 minute parts. For each segment derive the RR intervals and calculate the mean value and the standard deviation. This analysis will generate two new time series with a sampling interval of 1 minute. Plot the result and discuss the long term variation seen in the data.

1.6 (Optional) Long term frequency analysis of the RR intervals

The RR intervals time-series can also be analysed using Fourier Analysis to reveal various periodic behavior. RR intervals manifest short-term oscillations in a frequency range between 0 and 0.5 Hz, which appear to be the result of intrinsic autonomic rhythms and of respiratory inputs. Spectral analysis of RR intervals provides an estimate on how power (i.e., variance) of the signal is distributed as a function of frequency. RR intervals appear to be organized in three major components, the high-frequency (HF) (> 0.15 Hz) respiratory band, the low-frequency (LF) band (around 0.1 Hz) and the very–low-frequency (VLF) band (0.003-0.039 Hz). The HF components of RR variability primarily reflect the respiration-driven modulation of sinus rhythm. Feel free to experiment with your code and see if the data reveals the HF, LF and VLF components mentioned above.

References

[1] A. L. Goldberger, L. A. Amaral, L. Glass, J. M. Hausdorff, P. C. Ivanov, R. G. Mark, J. E. Mietus, G. B. Moody, C.-K. Peng, and H. E. Stanley, "PhysioBank, PhysioToolkit, and PhysioNet: Components of a new research resource for complex physiologic signals," *circulation*, vol. 101, no. 23, pp. e215–e220, 2000.