RECURRENCE PLOT FEATURES OF ECG SIGNALS

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Abstract
Single beats from ECG recording were used to demonstrate how the nonlinear dynamical analysis method of recurrence plots can be used to qualitatively describe data.
Keywords: nonlinear dynamics, recurrence plot, ECG

Introduction

The aim of this study was to demonstrate how features that can be clearly observed in a signal, namely the electrocardiogram (ECG), give rise to particular features in recurrence plots of the data. Broadly, recurrence plots are a nonlinear dynamical analysis method describing time correlation information between two sliding windows of a signal. The data in each window data is treated as a vector, and the Euclidean distance between the two vectors is compared to a threshold to determine if they are close [1]. The recurrence plot is formed by placing points where the vectors are close on a set of axes corresponding to the time shifts of the sliding windows.

Materials and Methods

ECG records of several beats were obtained from the MIT-BIH *Arrhythmia Database* (*Massachusetts Institute of Technology*, 1992). A single beat each from a noisy, normal ECG and an abnormal paced ECG are shown in figure 1(a) and 1(b) respectively. Software was written using Matlab (version 5.2, The MathWorks, Inc., Natick, MA) to determine an appropriate time lag and dimension for creating vectors from the data [2], and for generating recurrence plots [1] using a threshold of 10% of the maximum Euclidean distance.

Recurrence Plots of ECG Records

Recurrence plots for the single beats are shown in figure 1(c) and (d). The plots consist of isolated points, line segments and white spaces [1]. In figure 1(c), there are a series of short horizontal and vertical segments indicating the baseline crossing between the R and S waves. In figure 1(d), a short downwards segment indicates the falling side of the R wave. The solid shapes can be considered to consist of horizontal and vertical segments, indicating regions where the signal both changes little and is also similar to a window of a different part of the signal. Examples in both plots include the regions corresponding to baseline activity, and the prominent region in the centre of each plot corresponding to the S wave. Figure 1(d) also has a distinguishing feature in a small, square region corresponding to the plateau between the R and S waves. Solid shapes could alternatively be considered to consist of upward diagonal segments, indicating a closeness that is maintained as the two windows slide simultaneously along the signal. An example in both plots is the rise from the S wave to the T wave. This part of both signals also causes downwards line segments in the recurrence plots because it is opposite in direction to the downwards part of the S wave. The effect is more prominent in figure (d) because the rise in the signal is more gradual.

Perhaps the most notable difference between these two recurrence plots is the white areas caused by transient parts of the signal. Both plots have white bands due to the R wave, however the prominent S wave in figure 1(a) causes an additional band that merges with the first in figure 1(c). In contrast, the S wave in figure 1(b) only causes white regions when compared with the initial baseline activity and with the T wave. Because the T wave is partly obscured by noise in figure 1(a), its peak does not cause white regions late in the recurrence plot as does the T wave in figure 1(b). For ECG records of several beats (not shown), white regions also indicate differences between individual beats due to abnormalities or recording artefacts such as baseline drift.

Conclusion

For ECG examples, the characteristics of the signals that cause particular features of the recurrence plots are easily identified. However, features in recurrence plots obtained from other signals must have similar underlying causes. Recurrence plots may therefore reveal time-domain features of a signal that make it easier to describe.

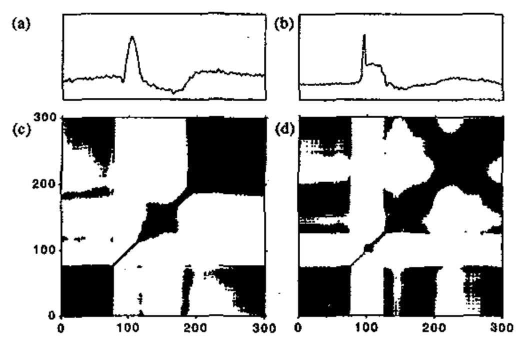

Figure 1. (a) Normal ECG. (b) Abnormal paced ECG.
(c) Recurrence plot of (a). (d) Recurrence plot of (b).
ECG shown using arbitrary scale. Recurrence plots found using lag = 4 and embedding dimension = 5.

References

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