Arrhythmia Classification in Long-Term Electrocardiography Data using the Return Map of RR Intervals

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Long-term continuous electrocardiogram monitoring (ECG), also known as Holter monitoring, is used for the detection of many cardiac diseases.
A 24h ECG usually consists of one hundred thousand heart beats which needs to be analysed. The visual inspection of the entire time series is not feasible. Many signal processing techniques are used for the detection and classification of heart beats. For rhythm, variability and segment analysis as well.

Past

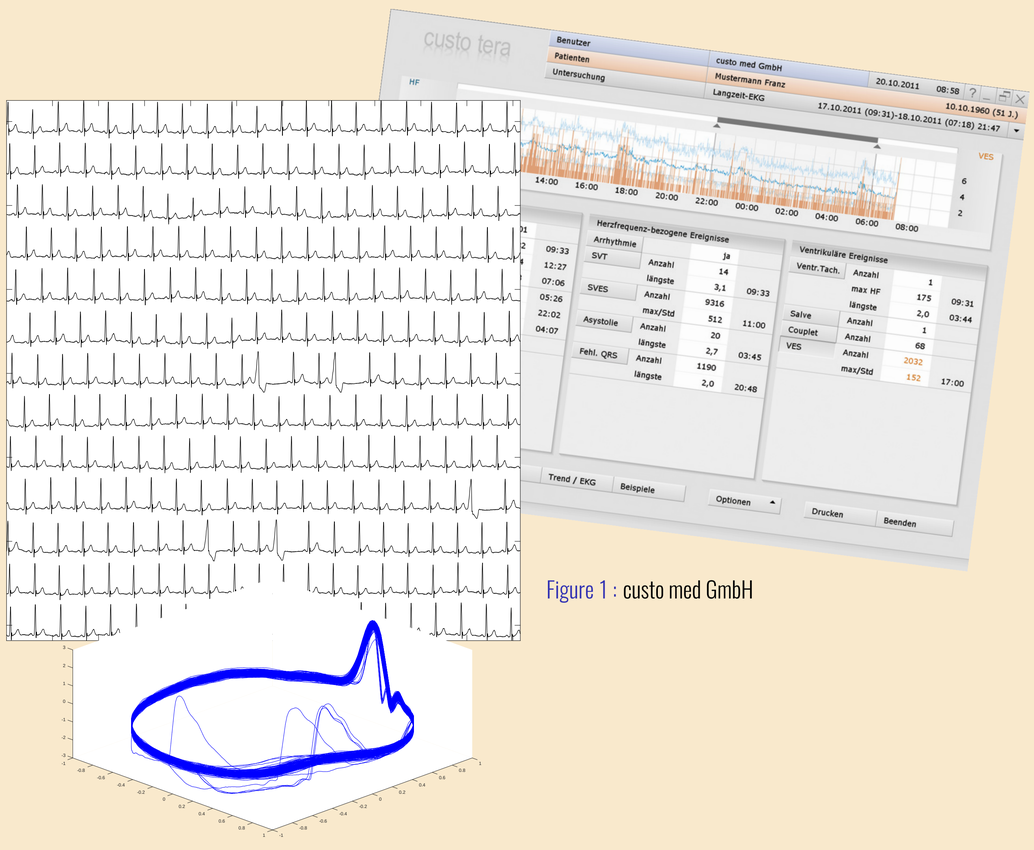


Figure 1 : custo med GmbH

Figure 2 : Current methods of analysing long-term ECG recordings

Purpose

For the analysis of long-term ECG data one can compute RR intervals, which are the time intervals between consecutive heart beats. I used relative RR intervals, which are the changes of two successive RR intervals weighted by their mean[1]. The dynamic structure of relative RR intervals are shown in the first recurrence map.
The coordinates of successive RR intervals are located on specific functions according to the arrhythmia type and offers many diagnostic options, especially in cardiology.
The visualization technique compresses the information of large sequences of RR intervals to a limited domain.

Relative RR Intervals

$$\mathrm{rr}_i := \frac{2(\mathrm{RR}_i - \mathrm{RR}_{i-1})}{\mathrm{RR}_i + \mathrm{RR}_{i-1}}$$

Properties

$-2 \le rr_i \le +2$
$rr_i = \pm 0$ if and only if $RR_i = RR_{i-1}$
$rr_i = -2$ if and only if $RR_i = 0$
$rr_i = +2$ if and only if $RR_{i-1} = 0$

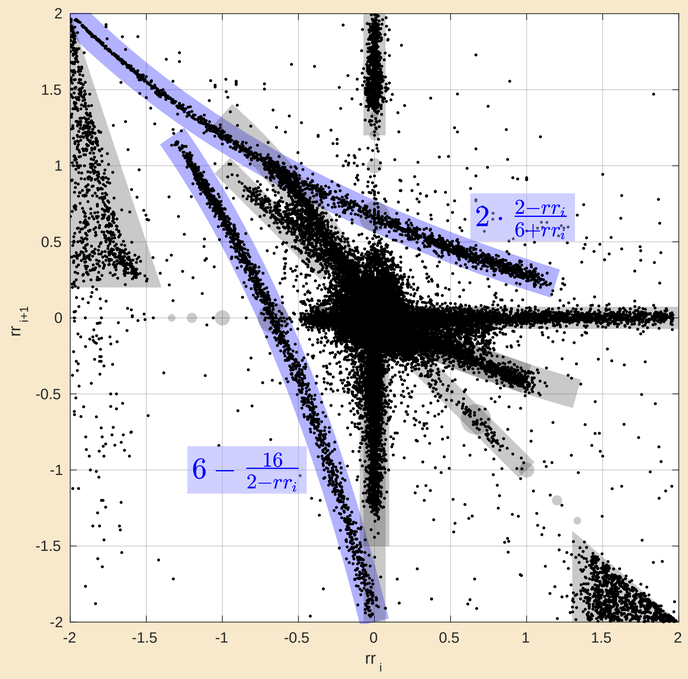


Figure 3 : Scatter plot of successive relative RR intervals of the Normal Sinus Rhythm RR Interval Database[2].

Present

Pattern Recognition

An interpolated extrasystole is sandwiched between two normal beats. The time RR_i between normal beats is almost constant ($RR_i \approx n$). So the extrasystole splits RR_i into the intervals $RR_{i_1}{=}a{\cdot}RR_i$ and $RR_{i_2}{=}(1{-}a){\cdot}RR_i$ with $0{<}a{<}1$.

$$rr_{i_1} = 2 \cdot \frac{RR_{i_1} - RR_{i-1}}{RR_{i_1} + RR_{i-1}} \approx 2 \cdot \frac{a-1}{a+1} = 2 - \frac{4}{a+1} \qquad rr_{i_2} = 2 \cdot \frac{(1-a)RR_i - aRR_i}{RR_i} = 2 - 4a$$

$$rr_{i+1} = 2 \cdot \frac{RR_{i+1} - (1-a)RR_i}{RR_{i+1} + (1-a)RR_i} \approx 2 \cdot \frac{a}{2-a} = \frac{2}{\frac{2}{a} - 1}$$

All relative changes depends on a.
This defines specific structures.

Type	Annotation code	RR intervals	relative RR intervals
Isolated, interpolated	N-N-NVN-N-N	$n^*(1\ 1\ a\ 1{-}a\ 1\ 1)$	$(0\ A\ B\ C\ 0)$
Bigeminy, interpolated	N-N-NVNVN-N-N	$n^*(1\ 1\ a\ 1{-}a\ a\ 1{-}a\ 1\ 1)$	$(0\ A\ B\ -B\ B\ C\ 0)$
Trigeminy, interpolated	N-N-NVN-NVN-N-N	$n^*(1\ 1\ a\ 1{-}a\ 1\ a\ 1{-}a\ 1\ 1)$	$(0\ A\ B\ C\ A\ B\ C\ 0)$
Isolated, pause	N-N-NV--N-N-N	$n^*(1\ 1\ a\ 2{-}a\ 1\ 1)$	$(0\ A\ D\ E\ 0)$
Bigeminy, pause	N-N-NV--NV--N-N-N	$n^*(1\ 1\ a\ 2{-}a\ a\ 2{-}a\ 1\ 1)$	$(0\ A\ D\ -D\ D\ E\ 0)$
Trigeminy, pause	N-N-NV--N-NV--N-N-N	$n^*(1\ 1\ a\ 2{-}a\ 1\ a\ 2{-}a\ 1\ 1)$	$(0\ A\ D\ E\ A\ D\ E\ 0)$
Skipped beats	N-N-N---N-N-N	$n^*(1\ 1\ 1{+}k\ 1\ 1)$	$(0\ F\ -F\ 0\ 0)$

Table 1 : Pattern of common arrhythmia types.

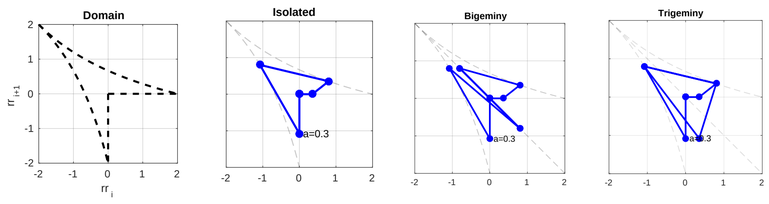


Figure 4 : Pattern of interpolated arrhythmia types (PVC I). From left to right: domain of the coordinates, pattern of an isolated PVC, pattern of a bigeminy, pattern of trigeminy.

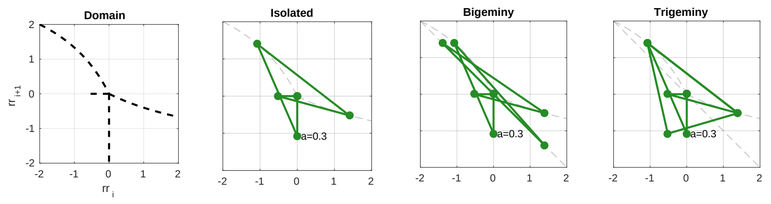


Figure 5 : Pattern of arrhythmia types with compensatory pauses (PVC II). From left to right: domain of the coordinates, pattern of an isolated PVC, pattern of a bigeminy, pattern of trigeminy.

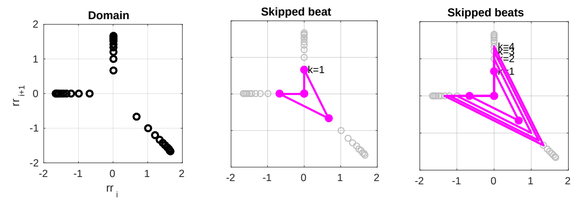
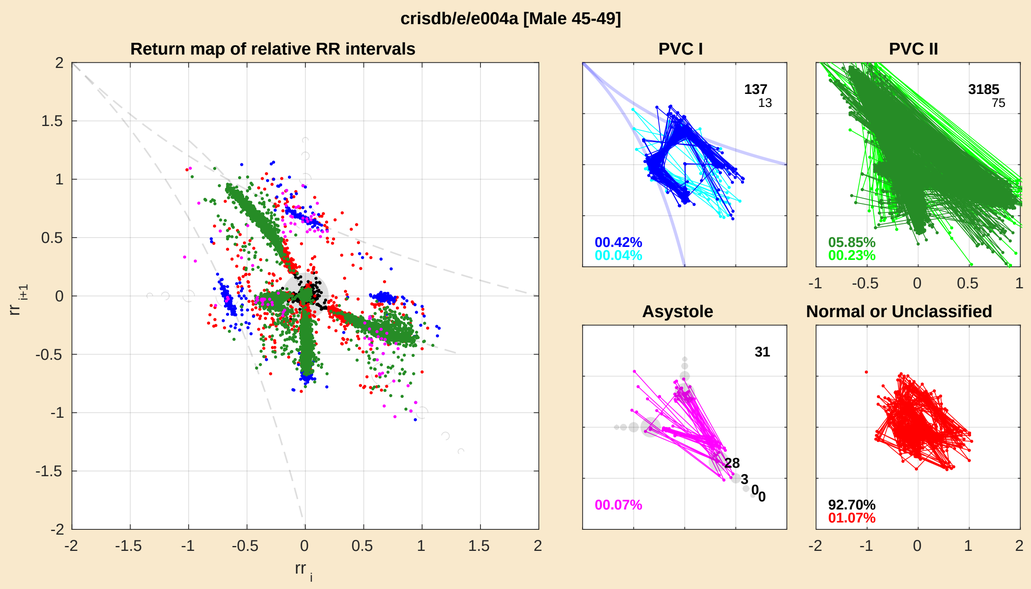


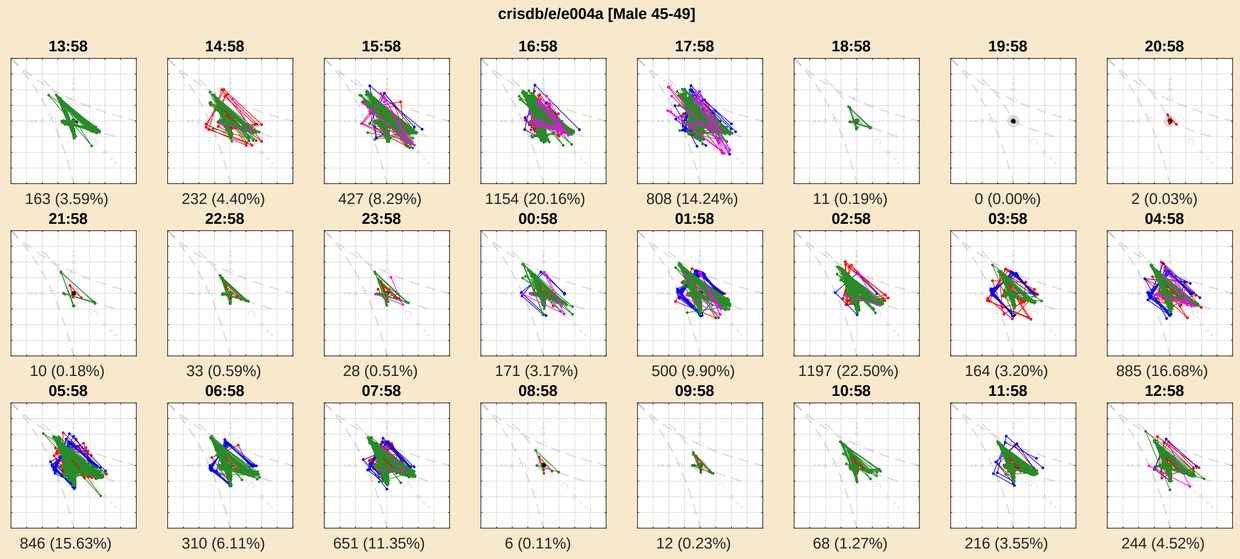
Figure 6 : Pattern of in cases of skipped beats (Asystole). Left: domain of the coordinates. Middle and right: pattern of one and more skipped beats.

Simplified Holter ECG Analysis

Arrhythmia Classification — Survivor of Myocardial Infarction (CAST Database[3;2])



Time-related Arrhythmia Detection in Long Term ECG Records



[1] M. Vollmer, ``A Robust, Simple and Reliable Measure of Heart Rate Variability using Relative RR Intervals,'' in *Computing in Cardiology 2015*, pp. 609--612, Sept 2015.
[2] A. L. Goldberger, L. A. N. 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.
[3] P. K. Stein, R. E. Kleiger, P. P. Domitrovich, K. B. Schechtman, and J. N. Rottman, ``Clinical and demographic determinants of heart rate variability in patients post myocardial infarction: insights from the cardiac arrhythmia suppression trial (CAST),'' *Clinical cardiology*, vol. 23, no. 3, pp. 187--194, 2000.

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