Performance improvement of a phase space detection algorithm for ECG wave morphology classification

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Introduction

- An algorithm based on phase space was proposed to detect the characteristic points of the ECG, see reference [1].
- The algorithm was used to extract the ECG waves and to classify them by clusters, see reference [2].
- Now a graph interface user (GUI) has been developed to extract the ECG waves easily and obtain their cluster morphologies and distances.
- This GUI can help professionals to analyze medium/large ECG easily and to detect changes in the morphology waves.
- These morphology changes are in many cases pathology symptoms.

Description of the phase space detection algorithm

- Nonlinear dynamic systems can be described in discrete time as,

$$\mathbf{x(t+1) = F(x(t)), \quad x(t) := x(t \cdot \tau_s) \in \Re^n.}$$

  where τ_s is the sampling time and $\mathbf{x(t)}$ the state vector.
- The phase space embedding method obtains an estimation of the nonlinear system state variables $\mathbf{X(t)}$ from observable measurements $\mathbf{s(t)}$. The vectors $\mathbf{X(t)}$ of the embedding phase space are obtained as,

$$\mathbf{X(t)} = \begin{bmatrix} \mathbf{s(t-(N-1)\delta)} \\ \mathbf{s(t-(N-2)\delta)} \\ \vdots \\ \mathbf{s(t)} \end{bmatrix},$$

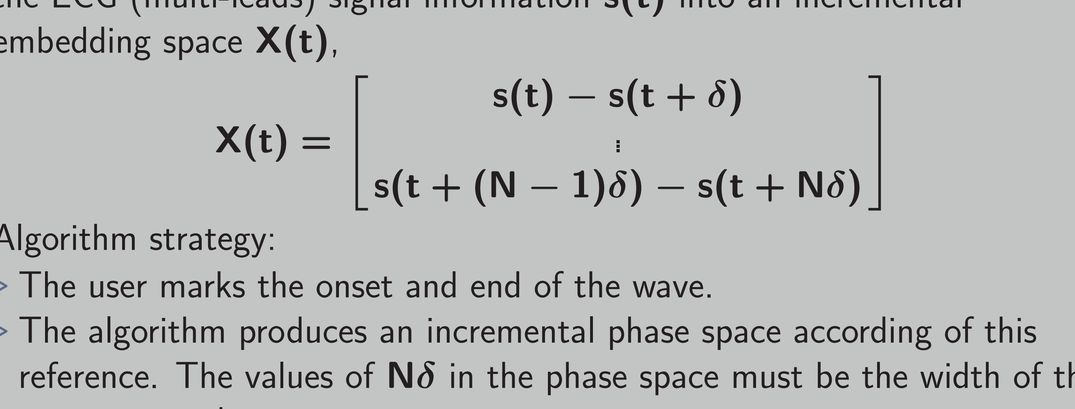
  where $\mathbf{N}$ is the embedding dimension and δ is the delay.
- Incremental phase space embedding: The detection algorithm transforms the ECG (multi-leads) signal information $\mathbf{s(t)}$ into an incremental embedding space $\mathbf{X(t)}$,

$$\mathbf{X(t)} = \begin{bmatrix} \mathbf{s(t) - s(t+\delta)} \\ \vdots \\ \mathbf{s(t+(N-1)\delta) - s(t+N\delta)} \end{bmatrix}$$

- Algorithm strategy:
  - The user marks the onset and end of the wave.
  - The algorithm produces an incremental phase space according of this reference. The values of $\mathbf{N\delta}$ in the phase space must be the width of the wave to search.
  - The delay δ filters the high frequency noises.
  - The incremental space filters the ECG baseline oscillations.
  - Similar waves in $\mathbf{s(t)}$ are near points in $\mathbf{X(t)}$.
  - Inverse distance: Measure to detect the points in $\mathbf{X(t)}$ close to the reference one. These points are the waves in $\mathbf{s(t)}$ similar to the reference one.

General GUI description

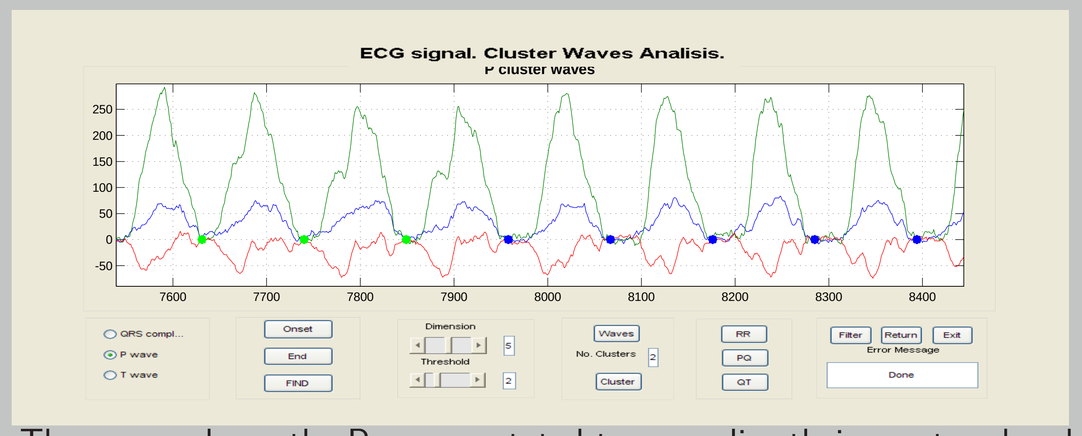
- The main screen of the GUI is the following



  - Graph to show the ECG multi-leads signal and the chosen waves.
  - Buttons to mark the reference points of the QRS complex, P waves and T waves.
  - Buttons for algorithm control, default values are given.
  - Buttons to extract the selected waves and the cluster.
  - Buttons to extract the distances between characteristic points.
  - Other buttons, for example to filter the signal.

ECG wave extraction

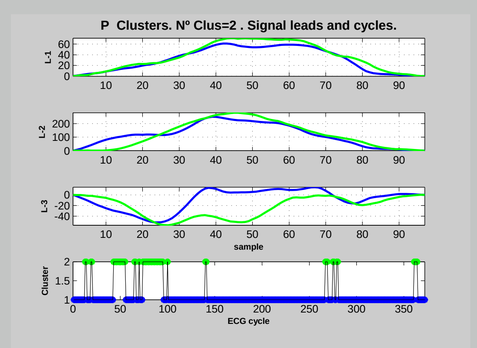
- The protocol for wave extraction is the following,
  - Mark QRS complex button with an onset and end reference points.
  - The algorithm finds the QRS complexes similar to the reference one. This step is a filter to ventricular QRS.
  - Mark P and T wave buttons with an onset and end reference points.
  - The algorithm finds the P and T waves, making use of the QRS complexes found before.
- The button "wave" extracts the chosen waves, in this example the P waves,

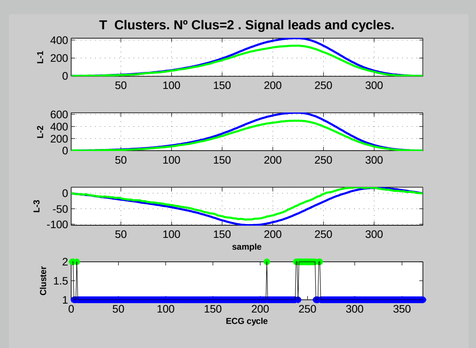


  - The screen shows the P waves rotated to normalize their onset and end to zero.
  - The K-means algorithm detects clusters (default two) in these waves.
  - The onset of each wave is marked with an $*$ of different colours to show the cluster membership.
  - The user can vary the number of clusters and repeat the process.

Wave cluster extraction

- When the user agrees with the cluster numbers, the GUI algorithm can extract the average of the cluster waves.
- The following figures show the cluster of the P and T waves.

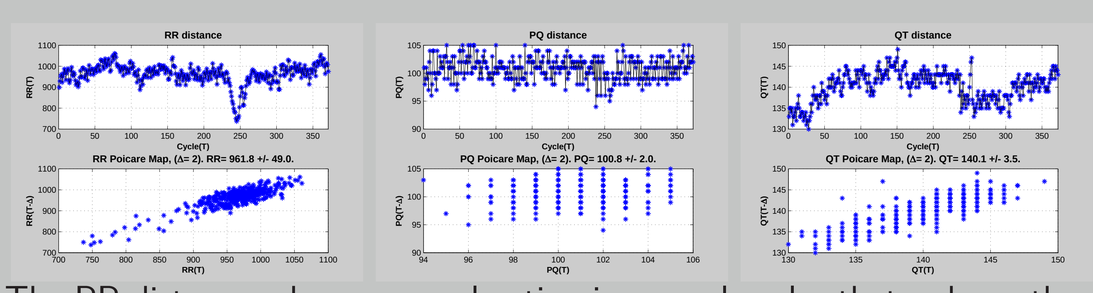




  - Graph shows three leads of the two clusters and the ECG dynamic cycle of these clusters.
  - In the P waves, the changes in morphology are clear. In the T waves, the changes are in magnitude.

Characteristic point distances extraction

- The algorithm can show the distance of characteristic points, RR, PQ and QT and their Poincarè maps,



- The RR distances show an acceleration in several cycles that reduces the PQ distance of these cycles.

Conclusion and references

- A GUI algorithm has been developed to extract the ECG waves and to classify them in clusters.
- The algorithm is based on the phase space algorithm.
- The algorithm is useful to analyze medium/large ECG, and can detect changes in the wave morphologies.

[1] A. Herreros , E. Baeyens, J.R. Perán, R. Johansson, J. Carlson and B. Olsson. "An Algorithm for Phase-Space Detection of the P Characteristic Points" Conference Proceedings of IEEE Engineering in Medicine and Biology Society (pag. 2004-2007). ISBN: 1-4244-0788-5, ISSN: 1557-170X.

[2] A. Herreros, E. Baeyens, R. Johansson, J. Carlson, J. R. Perán and B. Olsson "Analysis of Changes in the Beat-To-Beat P-Wave Morphology Using Clustering Techniques". Biomedical Signal Processing and Control (ISSN:1746-8094). October 4 (Issue 4), 2009 doi:10.1016/j.bspc.2009.02.006