Rheography and Spirography Signal Analysis by Method of Nonlinear Dynamics

Anna Kiseleva[1], Peter Luzhnov[1], Alexander Dyachenko[2] and Yuriy Semenov[2]
[1]Department of Biomedical Techniques, Bauman Moscow State Technical University, Moscow, Russian Federation
[2]Russian Academy of Sciences, Moscow, Russian Federation

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Abstract: The method for identifying rheocardiographic signal reference points was considered by means of nonlinear dynamics. Its application was shown for the analysis with the spirographic signals together. Seven male volunteers participated in the study as test subjects. Comparative analysis and efficiency of the developed algorithm were demonstrated.

1 INTRODUCTION

Biological signals have supplied vital information for diagnosis of disease for many years. Traditional algorithms of analysis are based on a priori information about the structure of the biosignals. Therefore, the main disadvantages of such methods are their complexity and poor adaptation for signals having an atypical structure. Also, such methods cannot remove the noise without signal damage.

In recent years, researchers have discovered that biosignals show nonlinear dynamical behaviour and chaos phenomenon. This discovery made it possible to apply methods of nonlinear dynamics to living systems (Cohen M.E., Hudson D.L., 2004). At present, methods of nonlinear dynamics are used in various fields of medicine. First of all, it is the processing of the most commonly diagnostic biosignals such as the electrocardiogram (ECG) (Ming-rong Ren, Pu Wang, Hui-qing Zhang, 2008), the electromyogram (EMG) (Diab A., Falou O., Hassan M. 2015; Padmanabhan P., Puthusserypady S., 2004), the electroencephalogram (EEG) (Akar S.A., Kara S., Agambayev S., Bilgic V., 2015). Also, these methods are used in processing biomedical images (Mendonca A. M., Campilho A., 2006). One of the main advantages of methods of nonlinear dynamics is the ability to process signals in real time (Dhivya R., Premkumar R., Nithyaa, A.N., 2015).

In this paper, we consider methods of nonlinear dynamics with respect to signals of the rheography and the spirography. An algorithm for signal processing was considered based on the analysis of attractors of phase trajectories. The proposed algorithm allows without destroying and losing useful information about the signal to filter these signals.

2 MATERIALS AND METHODS

Nonlinear dynamics offers the following methods of analysis: calculation of Lyapunov's exponents and determination of the time for forgetting the initial conditions, evolution of phase volume, analysis of attractors of phase trajectories (Morgavi G., et al., 2002).

The analysis of attractors is one of the simplest and most obvious ways of analyzing a nonlinear system. This method is one of the most common in the analysis of biosignals (Charlton P.H., Bonnici T., Tarassenko L., 2015; Aston P.J., Manasi N., Christie M.I., Huang Y.I., 2014; Velez A.H., Gonzalez-Hernandez H.G., Reyes Guerra, B., 2014). It determines the dependence of each subsequent value on the previous one with a temporary delay. Blurring of the pseudo-phase portrait occurs after forgetting the initial conditions by a nonlinear system. The non-linear system parameters represents the dynamics of the cardiovascular system.

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2.1 Data Set

The rheography allows to investigate a tissues hemodynamic in physiological conditions. Description of an impedance cardiac system are presented in the paper (Kubicek W.G., Karnegis J.N., Patterson R.P., 1966). Now are used a tetrapolar system of electrodes usually. It means that four electrodes are positioned on a body surface on one straight line. The pair measuring electrodes is between pair current electrodes (Shamaev D.M., Luzhnov P.V., Iomdina E.N., 2017). Tetrapolar rheocardiography is a noninvasive method for the measurement of cardiac output, cardiac index, systolic time intervals, and other hemodynamic parameters (Vasilyeva R.M., 2017). Rheographic signals are depend on many physiological factors: pulse blood flow, blood pressure (Luzhnov P.V., Shamaev D.M., Iomdina E.N. et al., 2017), breath.

Our research was aimed to study the reaction of the human cardiovascular system to breath (Semenov Yu.S., Dyachenko A.I., Popova Yu.A., et al. 2017). In order to analyze the nonlinear system for isolating its main mathematical dependencies, a study was conducted based on the rheocardiographic and spirographic signals. Seven male volunteers aged 22 to 35 years participated in the study as test subjects. None of the subjects took medication and did not suffer from chronic or acute diseases. The study was performed in 2014 in the Institute of BioMedical Problems of the Russian Academy of Sciences. Informed consent from test subjects was received prior to study. The experiment was adopted by the Bioethics Committee of the Institute of BioMedical Problems.

2.2 Pre – processing of Signals

2.2.1 Selection of the Stationary Signal Sections

The choice of stationary sites during the study is important, as the stationary condition, as a rule, limits the sample size for subsequent analysis. We used without artefact 30 seconds records as the considering sections of the signal.

2.2.2 Pre - filtration

The selected sites were pre-filtered. A second-order Butterworth high-pass filter with a cut off frequency of 0.05 Hz was used to process the rheocardiographic signals, and then a second order Butterworth filter with a cut off frequency of 30 Hz was used. A moving average filter was used (the window width was 20 samples) to smooth the noise on the spirographic signal.

2.3 The Nonlinear Filter Implementing

The correct offset must be selected to calculate the parameters (Palit K., Mukherjee S., Bhattacharya D.K. 2013). It is known that if the reconstruction window is too small, then the image of the attractor turns out to be "compressed", if it is large, then the image is "stretched and folded". In both cases, it is necessary to distinguish very small scales to study the details (Palit K., Mukherjee S., 2011). Usually, the bias is chosen so that each next reconstructed vector adds the most information about the attractor or correlates as little as possible with the previous one. Researched signals and the filter points are presented on the figures below:

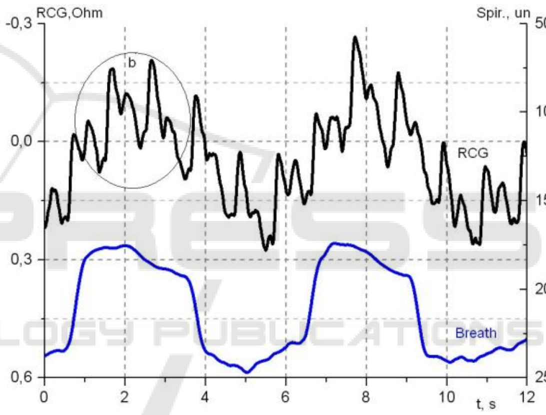

Figure 1: The filter points – the rheocardiographic and spirographic signals.

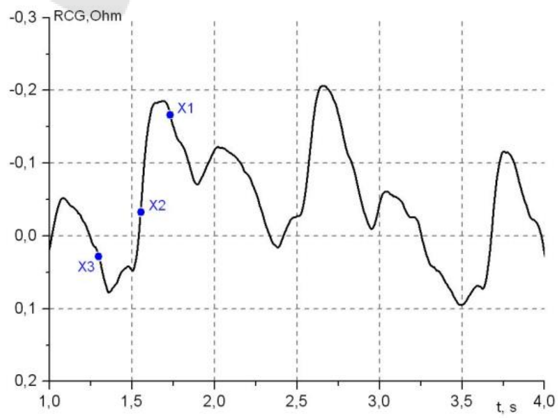

Figure 2: The filter points – the rheocardiographic filter points.

We set the displacement as suggested in the paper (Gracia J., Seppa V-P., Pelkonen A., 2017).

2.3.1 Definition of Points Attraction

We defined the moments of the beginnings of an inspiration and an exhalation for the spirographic signal. For the analysis allocated six whole cycles of breath. On the basis of the obtained value, we constructed pseudo-phase portraits of signals and determined the main points of attraction on them. It is the systolic peak, the pulse wave beginning, and the diastolic wave for a rheocardiographic signal. The coordinates of the obtaining centres are presented in Table 1.

Table 1: Coordinates of the reference points centres.

Reference point	X1	X2	X3
Systolic peak, Ohm	0,147	0,086	0,042
Pulse wave beginning, Ohm	0,120	0,071	0,066
Diastolic wave, Ohm	0,086	0,058	0,070

2.3.2 Identification of Reference Points by Analyzing Its Pseudo-phase Portraits

Geometric shapes (cube, sphere, ellipsoid) were used to identify the local points of the signal, namely, the data was located in the centres of the points of attraction of the registered signals (see figure 3).

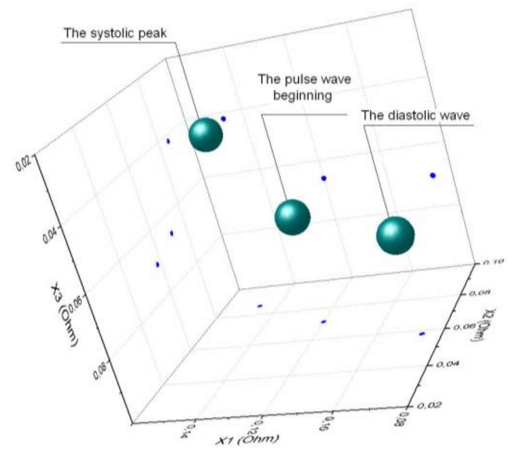

Figure 3: Identification of the rheocardiographic signal reference points.

The size of these shapes was selected from the consideration of the difference between the maximum and minimum value of the received signals. Table 2 shows the main parameters of geometric shapes (the units correspond to the value).

Table 2: The main parameters of geometric shapes.

Shapes	Systolic peak	Pulse wave beginning	Diastolic wave
Cube, the edges length, Ohm	0,162	0,154	0,148
Sphere, the radius, Ohm	0,140	0,133	0,128
Ellipsoid, the X1-axis, Ohm	0,018	0,010	0,101
Ellipsoid, the X2-axis, Ohm	0,105	0,068	0,084

2.3.3 The Error Analysis

We estimated the error in identifying the reference points of the signal using the coordinates and sizes of the obtained geometric shapes and performed a correlation analysis to determine the optimal geometric shape.

The maximum value of the correlation coefficient is 0.81 for spherical area. So the most optimal shape is the sphere for nonlinear filtering with the purpose of selecting reference points of rheocardiographic signals.

3 RESULTS

On the basis of the chosen geometric shape, a contour analysis of the signal section was carried out. In particular, its main structure elements were marked. It is the systolic peak, the pulse wave beginning point, and the diastolic wave for a rheocardiographic signal.

Figures 4, 5, 6 show a contour analysis of signal carried out with the help of the obtained method of nonlinear filtering.

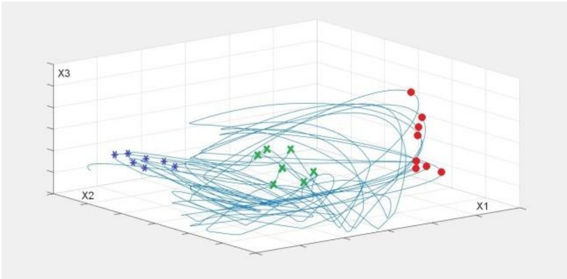

Figure 4: The example of main point selection for the rheocardiographic signal – the rheocardiographic signal in phase space.

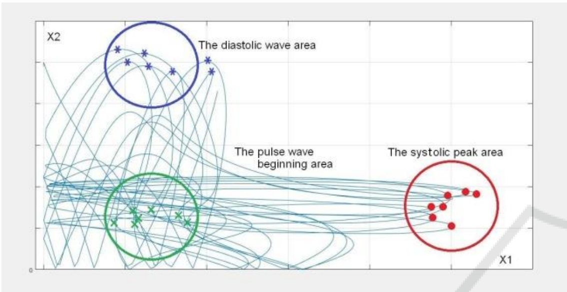

Figure 5: The example of main point selection for the rheocardiographic signal – the projection of the rheocardiographic signal portrait on the X1 and X2 axis.

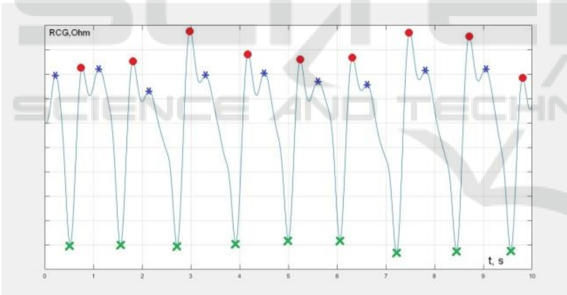

Figure 6: The example of main point selection for the rheocardiographic signal – the rheocardiographic signal with selection of the main points.

4 CONCLUSIONS

In this paper, we considered a new complex method for analysing biosignals. The received technique is presented on rheocardiographic signals. The study showed that analysis of the attractors is the way to reference points of rheocardiographic signals with breath identify. For the purpose of the analysis, stationary signal sections were selected, as well as the optimal displacement time. A nonlinear filtering method based on filtering by geometric shapes (sphere and ellipsoid) in phase space - was proposed on the basis of the data obtained. A correlation analysis was performed to evaluate the error of the filtration.

This work is a continuation of the work of analyzing the signals of the cardiovascular system (Aston PJ, Nandi M, 2004; Ming-Rong Ren, Pu Wang, Hui-Qing Zhang, 2008) and the respiratory system (Gracia J., Seppa V-P., Pelkonen A., Kotaniemi-Syrjanen A. et al., 2017).

In the future, the non-linear filtering method will serve as a basis for processing signals in real time. Analysis of pseudo-phase portraits can be used as a diagnostic method for assessing the state of the cardiovascular and respiratory systems.

5 CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

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