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Hierarchical Cluster-analysis of Transient Heart Rate using a Digital Spectral Analysis in the Complex Frequency Plane

A. Ragozin, V. Telezhkin, and P. Podkorytov

***Abstract*—The object of the study in the article is the spectral analysis of heart rate variability in stationary and transient states. For this purpose, the technology of digital modeling based on spectral analysis in the plane of complex frequencies is applied, which gives great opportunities for mobile medicine due to the identification of the correct diagnosis and the ability to suggest methods of treatment in emergency cases. To classify the obtained spectra (obtaining homogeneous groups of spectra), the method of hierarchical cluster analysis (clustering of diseases) is used, which allows the treatment of diseases or symptoms due to widely used taxonomies. Clustering allows the use of some measure of similarity between objects to build a hierarchical tree. The spectrum calculation on the plane of complex frequencies assumes the representation of the studied signal as the sum of a certain number of sinusoids (harmonics), characterized by phase, frequency and amplitude, changing in time (increasing or decreasing) exponentially. When the data has a clear "structure" in terms of clusters of objects similar to each other, then this structure is likely to be reflected in the hierarchical tree by different branches. As a result of successful analysis by the method of association, it becomes possible to detect clusters (branches), interpret them and use them in the future for the correct diagnosis.**

***Index Terms*—Analysis, digital, heart, modeling, rate, spectral stationary technology transient, variability.**

I. Introduction

For spectral analysis of heart rate variability (HRV) in stationary and transient states, the technology of spectral analysis in the plane of complex frequencies is applied [1-3]. To classify the spectra obtained (to obtain spectra groups homogeneous in structure), the hierarchical cluster analysis method [4] is used.

II. MODELING

The spectrum calculation on the plane of complex frequencies (SCF) assumes the representation of the investigated signal (transient HRV) as the sum of a certain (estimated by the algorithm) number of sinusoids (harmonics), characterized by phase, frequency and amplitude, changing in time (increasing or decreasing) exponentially. In this case, the dependence of HRV is represented in the form of a set of rhythms with different frequencies, initial phases, but with exponential changes in time by exponential law. The SCF reflects the process of disappearance and generation of harmonics (change in the frequency composition) of the studied transient HRV process. Parameters for constructing the SCF of the analyzed transient HRV process are: f [Hz] – harmonic frequency, α [sec-1] – coefficient of amplitude harmonic amplitude exponential, P [msec2] – harmonic power. The SCF is a generalization of the concept of the ordinary spectrum. The image of the SCF is peaks with heights P [msec2] located on the plane of the complex frequency (f, α).

A. *Problem statement*

The purpose of the cluster analysis of HRV dependencies is to find groups of similar HRV dependencies by the degree of proximity of their SCF. The process of clustering is to start with the search for the two most similar (close in structure) SCF. At the next step, the two closest SCFPs are combined with closest dependence as for SCF structure, etc. As a result, interval diagrams (a series of R-R intervals) are created.

B. *Problem solution*

The problem solution consists of clustering the dependences of SCF interval diagrams. As they are sequentially combined, the most similar SCF dependencies become apparent. The process of sequential clustering takes the form of ascending hierarchical classification (AHC). Each step, where a pair of SCF dependencies was combined, is represented by an AHC node. At the topmost level, the AHC node combines SCF dependencies of all processed interval diagrams.

Developed at South Ural State University, the KLAST program for classification of HRV transients enables work on databases in a convenient way to store, view and edit recordings of HRV, apply processing of the series of HRV spectral analysis in the complex frequency plane, and classify (to combine into a homogeneous structure of the group) received SCF by the method of hierarchical cluster

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A. N. Ragozin is with the Department of information and communication technology, Federal State Autonomous Educational Institution of Higher Education "South Ural State University (National Research University)", Chelyabinsk, Russia (e-mail: anr_n@mail.ru).
V. F. Telezhkin is with the Department of information and communication technology, Federal State Autonomous Educational Institution of Higher Education "South Ural State University (National Research University)", Chelyabinsk, Russia (e-mail: telezhkinvf@susu.ru).
P. S. Podkorytov is with the Department of information and communication technology, Federal State Autonomous Educational Institution of Higher Education "South Ural State University (National Research University)", Chelyabinsk, Russia (e-mail: pavel@napoleonit.ru).

analysis.

As an example, in the process of development the database of time series of HRV was processed (it consists of thirteen interval chart records with 300 samples each). Based on the results of data analysis, it is calculated and displayed in fig. 1 AIC SCF. When calculating the SCF, the analyzed interval chart was transformed (by means of interpolation technology) into a time series of R-R intervals with a constant sampling rate of 0.4 sec and subsequent smoothing over ten samples.

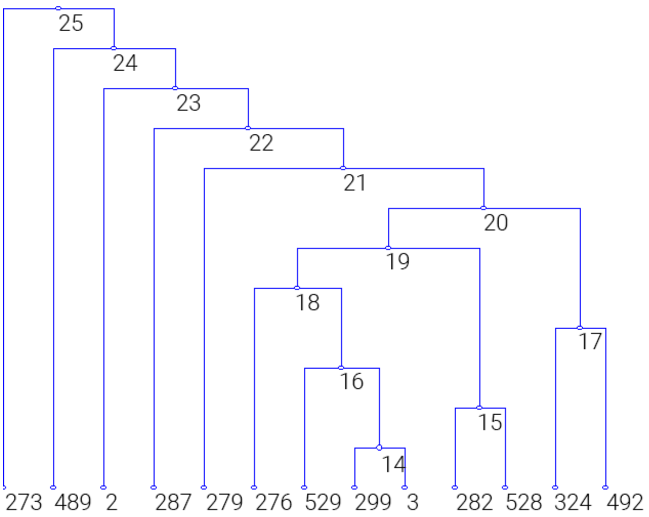

Fig. 1 Hierarchical classification of thirteen interval charts

Summation of all harmonics depicted on the SCF will lead to the restoration of the time dependence of the trend of the analyzed interval chart. From Fig. 1 it can be seen that in the structure of SCF the interval chart number 3, 299 (the union at the lowest level) were the closest in the obtained partition. An interval chart with the number 529 was found to unite the interval chart (node 14) with numbers 3 and 299 with the closest in structure of the SCF. We can also single out the class of interval chart (node 16) with structurally similar SCF (interval chart with numbers 529, 299, 3). A graphical representation of the spectra in the plane of the complex frequencies of the corresponding interval chart (529, 299, 3) is shown in Fig. 2-4. The figures show the original interval chart, also combined on the same graph with trends (smoothed interval chart for 10 samples). Interval chart trends reflect the temporal dynamics of the HRV transient processes without taking into account high-frequency components. Also, the spectra of the SCF (two projections) and the first four (for power) harmonics of the SCF are shown.

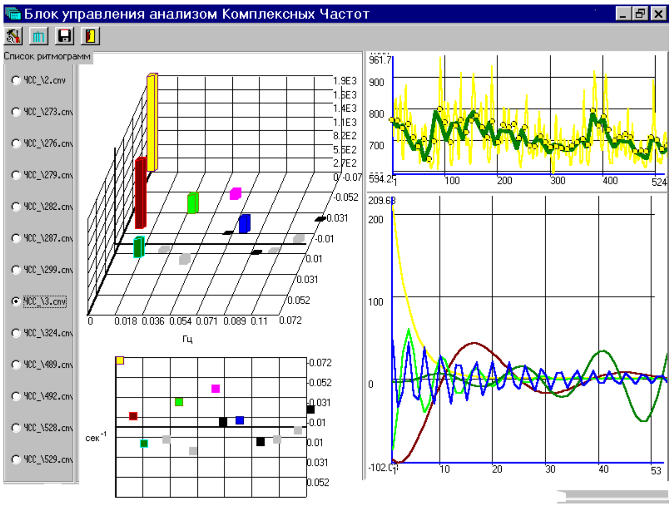

Fig. 2. Graphical representation of the SCF interval chart number 3

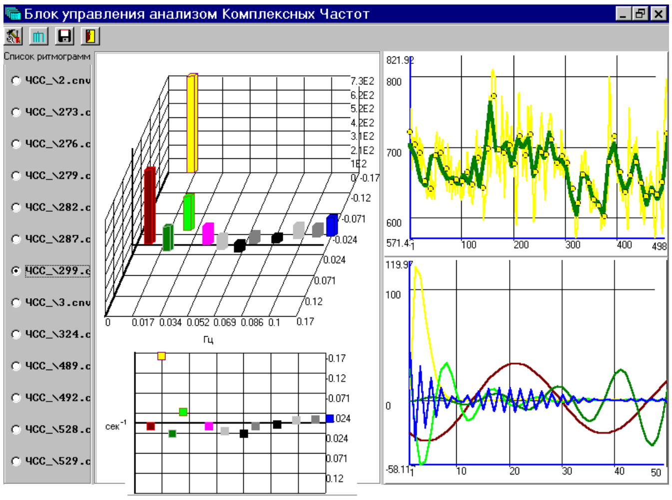

Fig. 3. Graphical representation of the SCF interval chart number 299

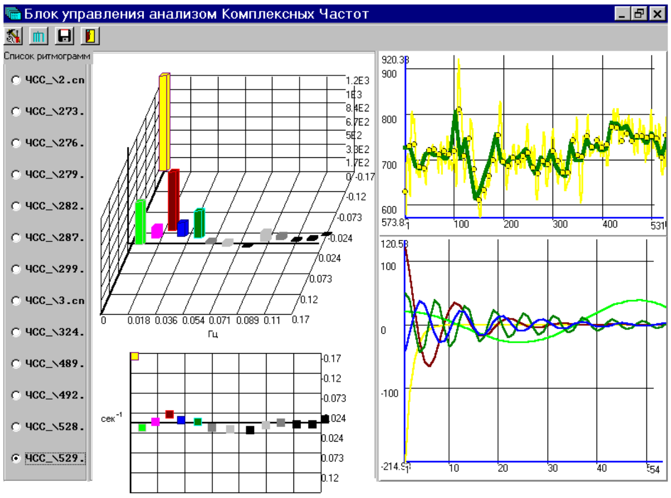

Fig. 4. Graphical representation of the SCF interval chart number 529

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From the figures shown, it can be seen that the structures of the SCF of the interval chart with numbers 3, 299 and 529 are similar to each other. SCF interval chart number 2 (fig. 5) is not included in the node 16 of the unification (fig. 1), but is combined with others (node 23, fig. 1) at a high level, which highlights its strong difference in the structure of the SC from the interval chart 3, 299 and 529 (node- class 16).

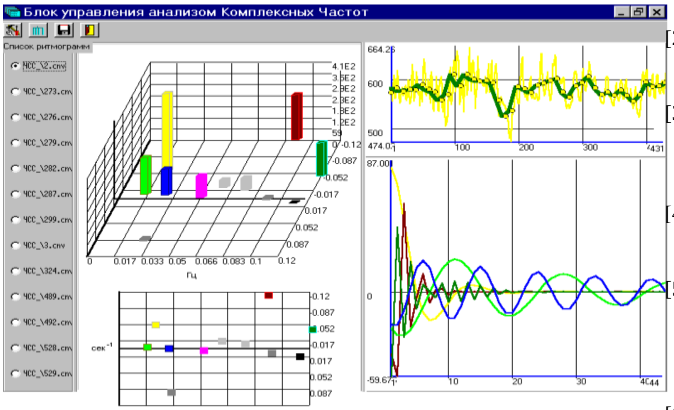

Fig. 5. Graphical representation of the SCF interval chart number 2

Fig. 5 shows the difference between the SCF of the interval chart 2 from the SCR of the interval chart 3, 299, 529 included in the class (node) 16. The topmost node 25 combines all the interval charts.

III. Conclusion

The study presents a new field of data analysis, coming from the search for interrelations of the aforementioned subjects, construction of their classification and examination of the subjects' development through time. In other words, the SCR data analysis is used to highlight groups of alike subjects and studying their key characteristics by carrying out cluster analysis to partition all subjects of the selection into non-overlapping clusters in order to form their classification. The structure of ascending hierarchical classification (Fig. 1) reflects the integration of the analyzed interval chart (transient HRV processes) according to the degree of similarity of their SCF frequency patterns. The higher the level of the VIC node, the lower the level of uniformity in the structure of the SCF of the interval chart combined into this node-class. For the selection of classes of interval charts for the required degree of homogeneity of their SCF, further analysis of the statistical parameters of the SCF array entering the AIC node under consideration is necessary (fig. 2, 3, 4, 5). In this way clustering allows the use of some measure of similarity between objects to build a hierarchical tree. The spectrum calculation in the plane of complex frequencies assumes the representation of the studied signal as the sum of a certain number of sinusoids (harmonics), characterized by phase, frequency and amplitude, changing in time (increasing or decreasing) exponentially. When the data has a clear "structure" in terms of clusters of objects similar to each other, then this structure is likely to be reflected in the hierarchical tree by different branches. As a result of the successful analysis by the method of association, it becomes possible to detect clusters (branches), interpret them and use them in the future for the correct diagnosis.

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