Hemodynamic Signal Research and Usage of Mutual Information Method

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***Abstract*–A comparative analysis of the methods used for the treatment of hemodynamic signals was carried out. Their advantages and disadvantages are noted. To eliminate one of the shortcomings, namely, the magnitude of the time lag it is suggested to use mutual information. It is known that in the theory of information, the mutual information function is used to measure the mutual dependence between two random variables.**

I. INTRODUCTION

Nowadays, as a result of fast development of infocommunication technologies area of technical supplement of medicine develops swiftly, new opportunities of research and diagnosis of disease appears.

Few decades ago a new statistical characteristic of a signal has been discovered and named as self-similarity. Since that days, a task of searching for self-similarity attributes meets in signals analysis more often.

There are a lot of investigations of signal's self-similarity not only in telecommunication networks, but in biomedical signals as well. Because of that physicians face questions: how to use self-similarity feature of such signals, and if it's possible to optimize both physicians' work and medical equipment?

However, regarding biomedical signal, it's not quite simple to solve that. First of all, such signal isn't stationary, and, secondly, it's slightly difficult to answer a question about "allowable" or so-called "averaged" signal values, which are currently impossible to determine with a high precision [1], [2].

Processes, which occur during the biomedical signals researches (particularly hemodynamic signals) are not stationary by their nature. There are quite many of analysis methods for non-stationary signals. During the work on analyses of a signal a software have been being developed, which allows to analyze hemodynamic signal using various existing methods and approaches. Such methods as statistical analysis, spectral analysis based on the Discrete Fourier Transform and some methods which take into account signals' self-similarity and based on wavelet-analysis and fractal features were used.

It's also necessary to note that a comparison analysis of all the listed above methods and a conclusion regarding pros and cons of their applying to hemodynamic signals have been performed.

As a result it's possible to make a conclusion, that biomedical signals analysis is very important and necessary for efficient management of medical equipment network. Finding signs of self-similarity in a human's body can radically change an approach to diagnosis. Nowadays it's possible to assume that a possibility to reduce a patient's rehabilitation time will appear shortly [5].

II. SPECTRAL ANALYSIS BASED ON THE DISCRETE FOURIER TRANSFORM

As noted before, a hemodynamic signal is not stationary. Its spectrum couldn't be calculated for entire research interval. It's necessary to choose a part of a signal with a definite constant duration and examine the entire interval by a "sliding window" method. It's supposed to calculate spectrum for every part. The main drawback of the Fourier Transform is that frequency components cannot be localized by time. Because of that it's more often used for stationary signals.

III. WAVELET-ANALYSIS

A biomedical signal consists of "short-lived" high-frequency components, which are close by time, and "long-lived" low-frequency components, which are close by frequency. It means that it's required a method which can provide a good resolution both by frequency and time. For such purposes the wavelet-transform is applicable. A signal is analyzed by decomposition on basis-functions, which are taken from a base-wavelet by applying contraction, expanding and shifting. It's important to highlight, that a mistake in choose of base-wavelet can make such analysis significantly inaccurate [3], [5], [6].

Both these methods have a common drawback - they don't have a possibility of prediction.

In this case fractal methods can be used. Exactly the fractal methods have the invariance property: when time scale changes, they may give an evaluation of changing human body's state in the future. It's very important for biomedical signals analysis area.

If fractal nature of a biomedical signal can be proved, than it will be definitely reasonable to use the fractal analysis to build a fractal mathematical model of such medical signal [4].

The one of the most researchable biomedical signals is a hemodynamic one. In previous works RS- and wavelet-analysis have shown that experimental hemodynamic signals have fractal statistic (basing on Hurst exponent). It has been also demonstrated during the search of a time-lag by using auto-correlation function (ACF).

The ACF method showed that time series of hemodynamic signal decreases according to the power law when the time-lag increases. However, the value of time-lag is desired to be increased. Because of that it's suggested to use the mutual information method, exactly for finding a time-lag of a pulse-wave during a measurement of heart activity.

The mutual information method assumes that self-organization laws are equal for different complex systems. Exactly this method allows determining of regularity and correlation, basing on very limited data amount. In this current case the usage of the mutual information method turned out approximately four times more precisely for the search of time-lag, than traditional statistical methods.

A discrete hemodynamic signal is a set of time values U(n) where n=1,...,N (N - count of all time values).

$$x(n) = U(n) - \frac{1}{N} * \sum_{i=1}^{n} U(i)$$

Let's introduce a designation of mutual information via entropy and conditional entropy of two random values.

$$\mathrm{I}(x; y) = \mathrm{H}(x) + \mathrm{H}(y) - \mathrm{H}(x, y)$$

The higher mutual information is, the less entropy is. Finally, in order to optimize calculation process the expression below might be used:

$$\mathrm{I}(\tau) = -\sum \sum_{1}^{Д} [\mathrm{P}(\mathrm{A_i}\, \mathrm{B_j})\,(\tau) - \mathrm{P}(\mathrm{A_i})(\tau)\, \mathrm{P}(\mathrm{B_j})(\tau)]^2$$

This formula keeps disposition of maximums and minimums of the function.

As a drawback, it's necessary to note that work with correlation matrixes is quite complicated.

IV. Conclusions

Mutual information in comparison to other fractal methods is able to detect non-linear correlation between two variables, that allows to perform a processes visualization in medicine.

Mutual information allows finding of regularity and correlation, basing on a very limited data amount.

Mutual information is more accurate several times in searching of ordered states, than traditional statistical methods.

It's supposed to extend this work by evidence of signal persistence, based on chaos theory with its correlation dimension, and show, how this property can be used by physicians to predict a patient's state.

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