Critical Condition in Human.
New Approach To The Entropy Based Technology of Definition.

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Abstract. The Entropy based technology of definition allows determine the state of system and get the short forecast of a state transition in real-time mode on usage of periodic signals of a system of any nature. It's discussed the technology details for human in critical condition.
Key words: heart rate variability; deterministic chaos; informational entropy, correlation dimension

1. Introduction

When considering complex dynamic systems to determine their current state and to get **short** forecast for state transition it's necessary to measure huge amount of various system characteristics. Often there are situations when such measurements are impossible, in cases of needed time and devices absence. At the same time, it is necessary to estimate system state and short-term dynamics of its further transition, using for this purpose one or several signals of periodic nature which can be measured from system in a real time mode.

One of the practically important application is medicine. It is necessary, to estimate human state on the basis of his elementary physiological data (pulse, an intimate rhythm, pressure, a body temperature and etc) measurement. Nowadays devices for automatic measurement of such characteristics are widely accessible, mobile, and able to output a signal in a real time mode. The measurement technique of such values and their interpretation has found wide reflection in the scientific researches and practical use. For the last three decades it has been proved for the high self-descriptiveness in HRV considering to estimate stressful reactions of the cardiovascular system at physical and emotional load. Heart Rate Variability (HRV) consists of fluctuations of an interval between consecutive heart beats, and also fluctuations between consecutive frequencies of heart beats. "Heart Rate Variability" has become the conventionally accepted term to describe variations of both instantaneous heart rate and RR intervals. In order to describe oscillation in instantaneous cardiac cycles, other terms have been used in the literature, for example cycle length variability, heart period variability, RR variability and RR interval tachogram (see Fig. 1), and they more appropriately emphasize the fact that it is the interval between consecutive beats that is being analyzed rather than the heart rate per se. However, these terms have not gained as wide acceptance as HRV, thus we will use the term HRV in this document.

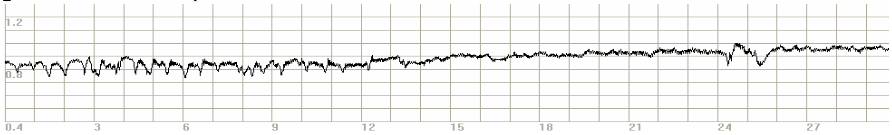

Fig. 1. RR-tachogram

As many commercial devices now provide automated measurement of HRV, the cardiologist has been provided with a seemingly simple tool for both research and clinical studies. However, the significance and meaning of the many different measures of HRV are more complex than generally appreciated and there is a potential for incorrect conclusions and for excessive or unfounded extrapolations. Recognition of these problems led the European Society of Cardiology and the North American Society of Pacing and Electrophysiology to constitute a Task Force charged with the responsibility of developing appropriate standards [Malik, 1996]. The specific goals of this Task Force were to: standardize nomenclature and develop definitions of terms; specify standard methods of measurement; define physiological and pathophysiological correlates; describe currently appropriate clinical applications, and identify areas for future research.
Durations of the recordings used to determine values (and similarly other HRV measures) should be standardized. Short-term 5-min recordings and nominal 24 h long-term recordings seem to be appropriate options. As only short-term analysis is discussed in this paper we consider only 5-min recordings. All integral values are measured for the time period, where each period is shifted forward by one RR-peak (see Fig. 2)

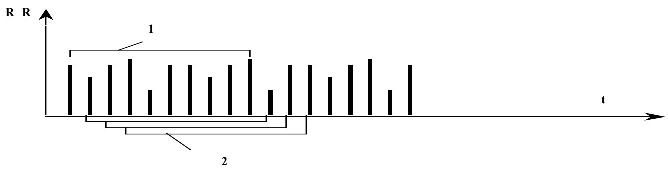

Fig. 2. Data series from RR-peaks

All the methods described in standards are function analysis standard linear methods applied to RR-function: statistical methods in time domain, geometrical methods, autocorrelation analysis, correlation rythmography, frequency domain methods, digital filtration. All these methods have been already implemented and used on practice.
Non-linear phenomena are certainly involved in the genesis of HRV. They are determined by complex interactions of haemodynamic, electrophysiological and humoral variables, as well as by autonomic and central nervous regulations. It has been speculated that analysis of HRV based on the methods of non-linear dynamics might elicit valuable information for the physiological interpretation of HRV and for the assessment of the risk of sudden death. Although in principle these techniques have been shown to be powerful tools for characterization of various complex systems, no major breakthrough has yet been achieved by their application to bio-medical data including HRV analysis. Though this time the practical application of these methods is limited, all they represent the great research interest.
We have developed a technology of non-linear HRV analysis based on entropy definition and described our method and technology of evaluation of entropy correlation dimension [Antonov et all, 2006]. Current paper fully describes methodology, its functional analysis and our last results in practice applications.

2. Method

When developing our method we supposed that human's critical condition is indicated by two polar cases of HRV – absolutely rigid heart rate without any fluctuation and absolutely variable chaotic heart rate – white noise. Approaching to the both cases means the system don't react on external influence. Our main goal is to define the numeric quantity of heart rate chaos (**I**) and use this value for express analysis of human condition. We suppose

stability of this value in the middle of its range means good forecast of human condition, in other cases human system approaches to the critical condition.
We define **I** is equal to zero means absolutely determined state of system – rigid heart rate and the greater is **I** the system changes to the more variable state. In other words, our value **I** is measure of system chaos and it is very close Boltzmann's thermodynamical entropy. But we can't measure human thermodynamical entropy on practice. We use the value of informational entropy instead. The definition of this value and its properties similar to thermodynamical entropy can be found here [Shannon, 1948]. The value of informational entropy is measured by normalized finite array of values $\{p_i\}$,i=1..N

$$E = \frac{1}{\log_2 N} \sum_{i=1}^{N} p_i \log_2 \frac{1}{p_i}$$

We define our quantity **I** as **E** – value of informational entropy of RR-function power spectrum. This way **I** = 0 where spectrum of RR-function is represented by one peak – absolutely rigid heart rate, **I** = 1 when power is uniformly distributed by all frequencies – absolutely chaotic heart rate and **I** is between 0 and 1 in all other cases. **I** increase where systems becomes more indeterministic.

All evaluation process can be presented in scheme shown below (Fig. 3). Every next step value is calculated as function of time and it is integral characteristic of previous step value.

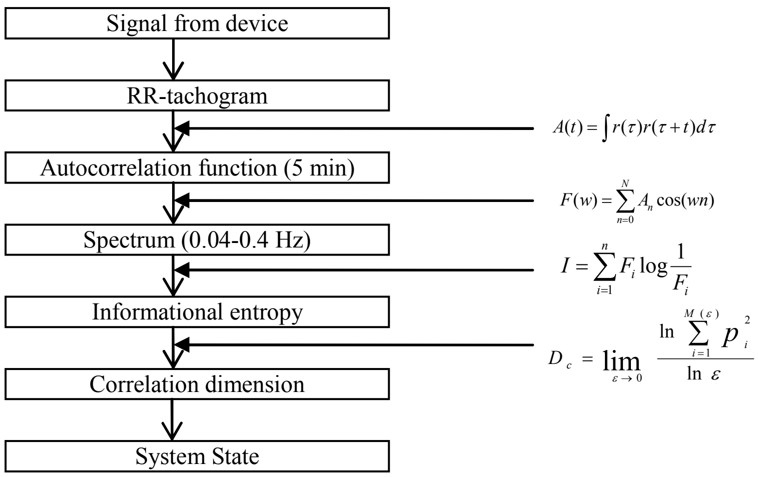

Fig. 3. Technology of definition - evaluation scheme

Some notes:

1) Correlation dimension D_c is good quantity to analyse of entropy dynamics [Grassberger and Procaccia, 1983]. The technology of correlation dimension evaluation can be found here [Antonov et al., 2006];
2) When implementing our method we used spectrum of autocorrelation function of RR-function instead the spectrum of source RR-function. The main goal of such transformations is to avoid the influence of source RR-function noise. The value of any constant additive noise doesn't bring influence on autocorrelation function, and the value of additive high frequency noise got from measurement devices doesn't bring influence on power spectrum;

3. Summary

The technology presented above has been implemented by ourselves as demonstration software. The software uses modern computer-science technology and works in real-time mode. The same time the application evaluates both standard well-known methods and our know-how technology. You can see screen-shot of application on the picture below [Fig. 4].

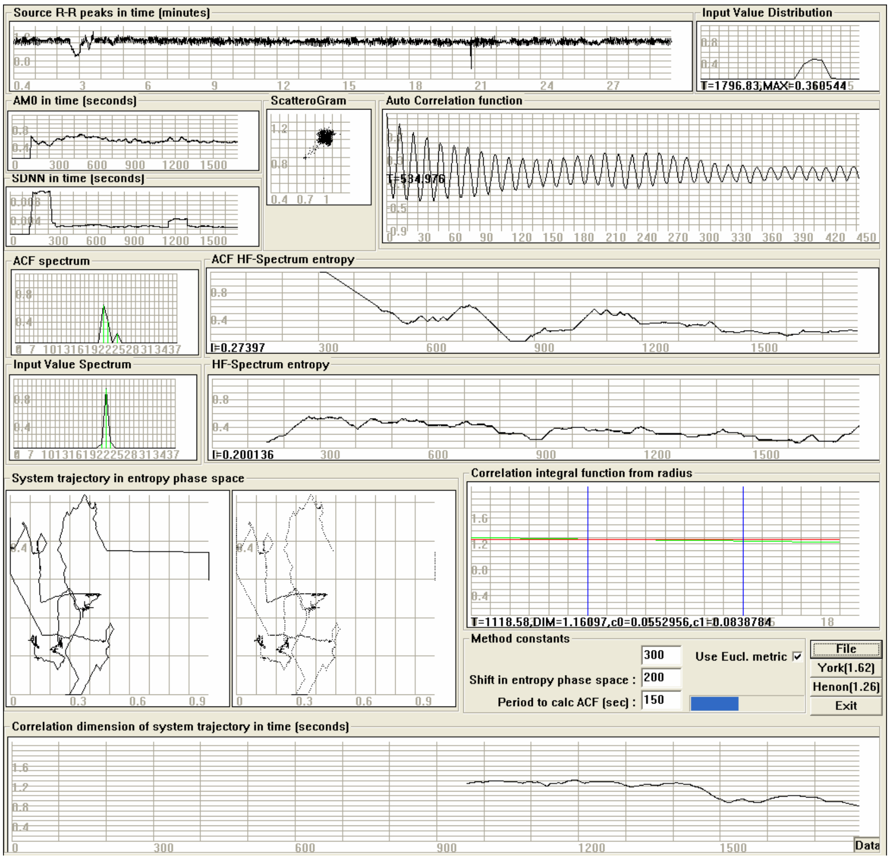

Fig. 4. Demonstration Application Screen

Our nearest goal is using application to predict the human state in critical condition of surgery and compare our technology and the standard technology.

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