International R&T Center for Information Technologies and Systems NAS and MES of Ukraine

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MATHEMATICAL METHODS FOR ANALYSIS AND INTERPRETATION OF CLIMATE CYCLICAL PROCESSES

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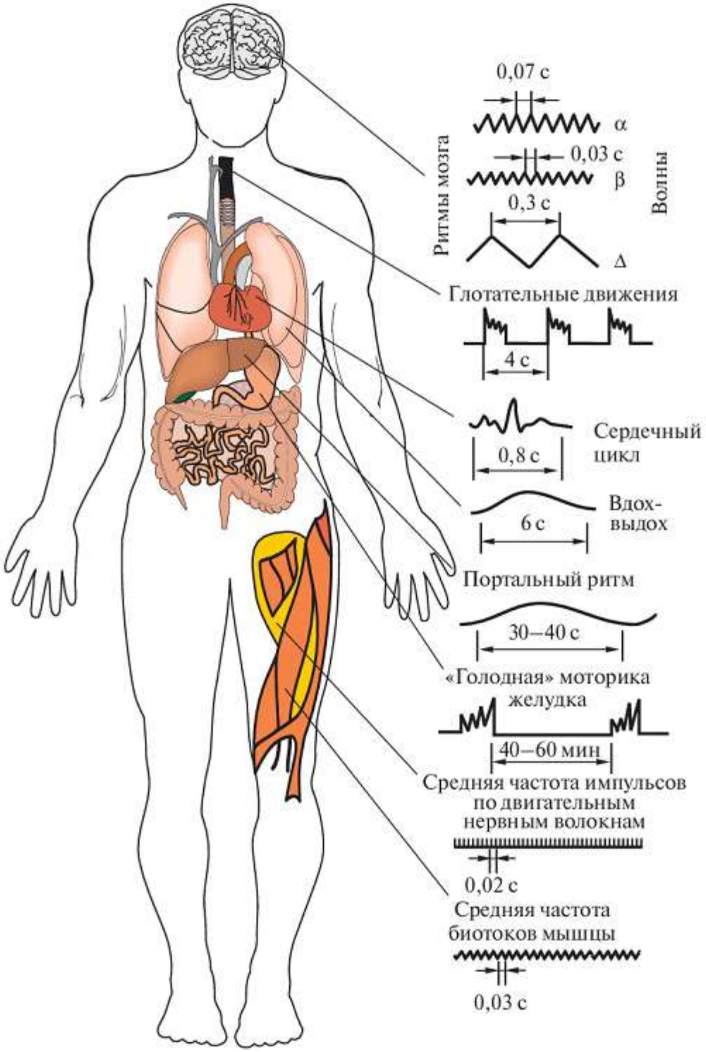
Cyclic process in the human body



Rhythmic processes in the brain

Cyclic swallowing movements

Cyclic processes in the heart

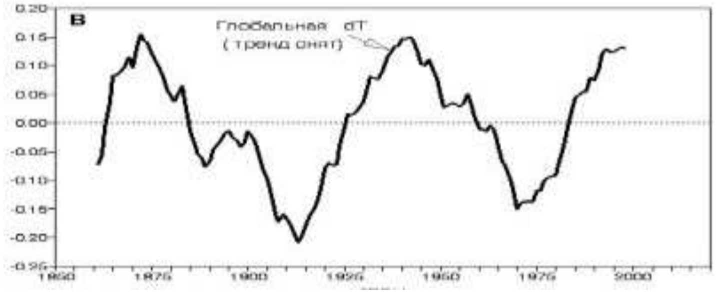
Respiratory rhythms

Hungry gastric motility

Muscle biorhythms

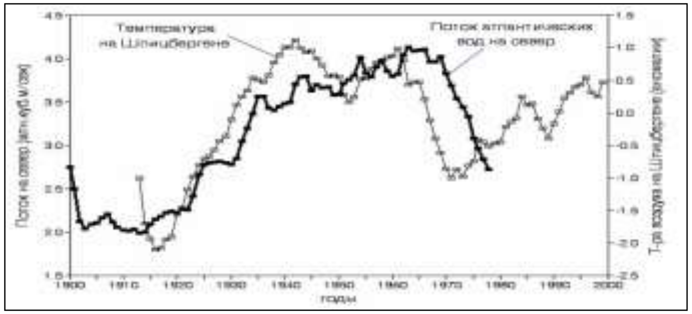
https://www.grandars.ru/college/medicina/bioritmy-cheloveka.html

Cyclic climate changes

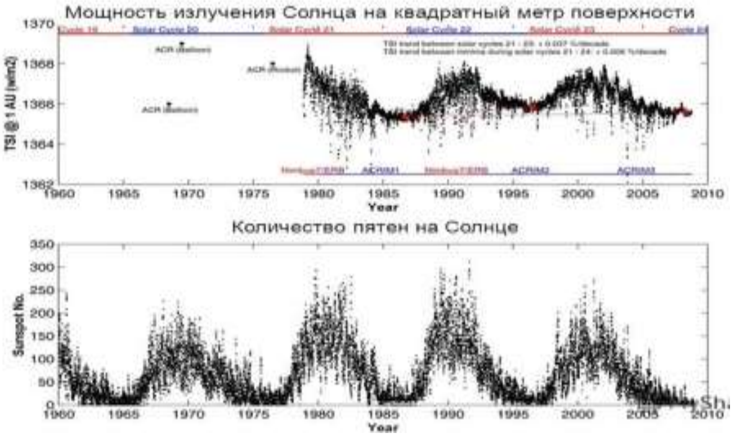


Global temperature anomaly

http://alexeylyubushin.narod.ru/Climate_Changes



Dynamics of Atlantic water discharge



Dynamics of solar activity

http://www.solar-climate.com/sc/sactivnost.htm

Basic mathematical model

$$z(t) = \Phi[z_0(t), \zeta(t)] + h(t)$$

Observed signal

Unobservable useful signal

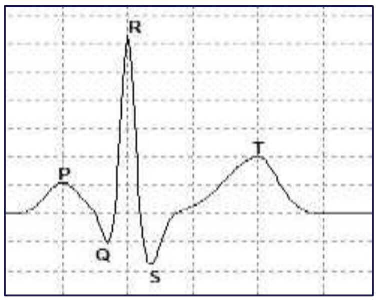
Unknown function

Internal disturbances

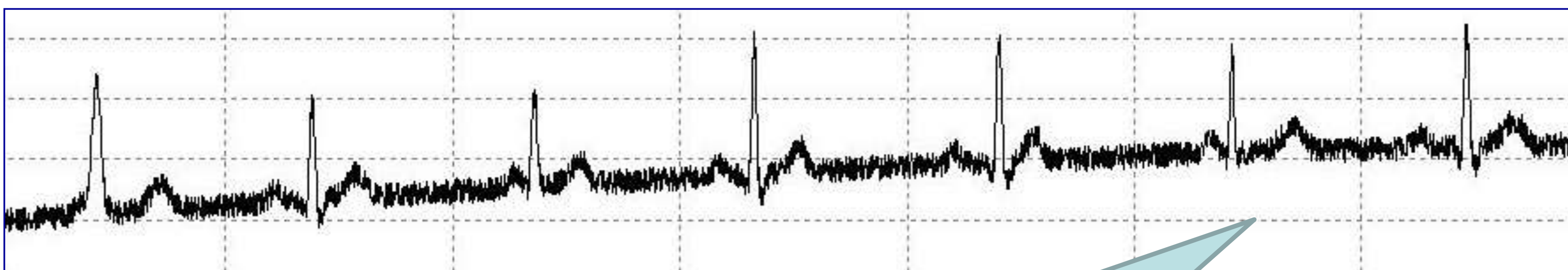
External disturbances

Example of a cyclic signal (ECG)

Unobservable useful signal (ECG cycle) $z_0(t)$

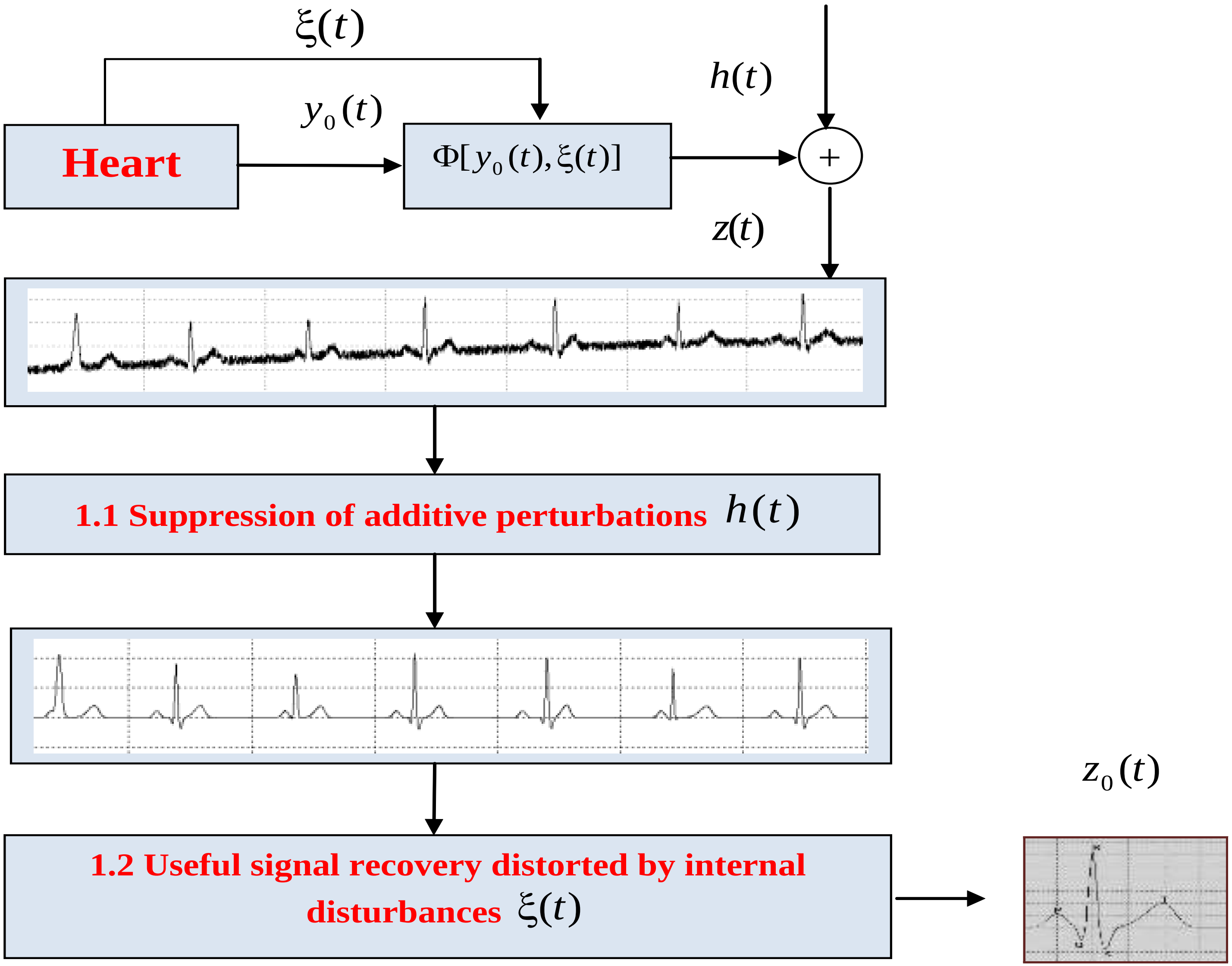


$$z(t) = \Phi[z_0(t), \zeta(t)] + h(t)$$



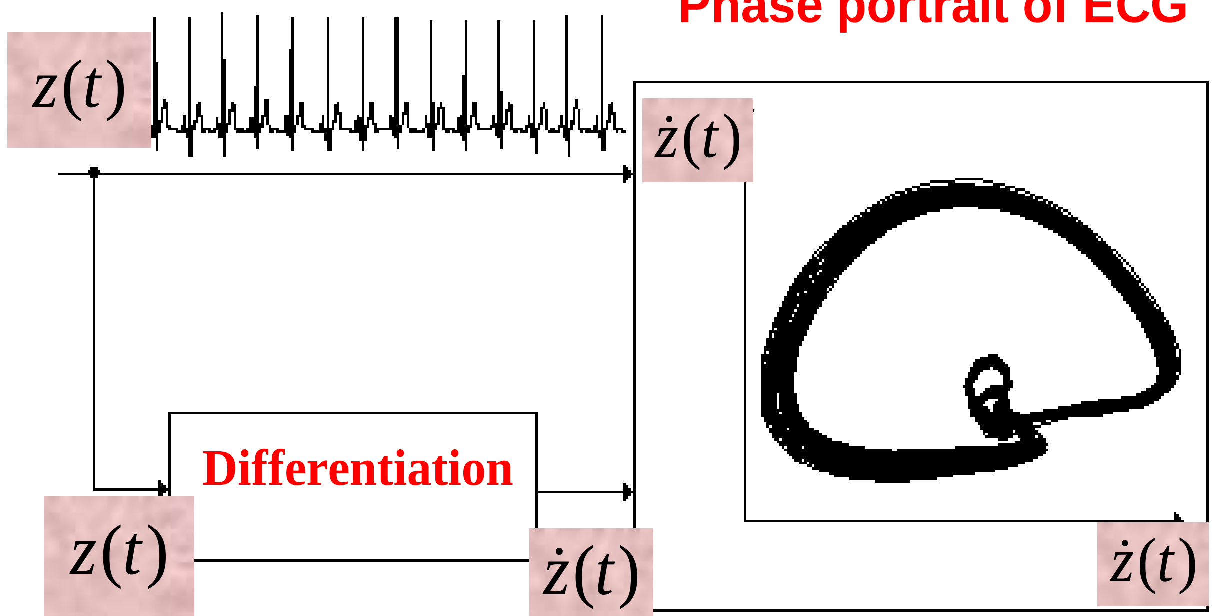
Observed signal (ECG)

TASK 1: Reconstruct a useful signal from a distorted observation

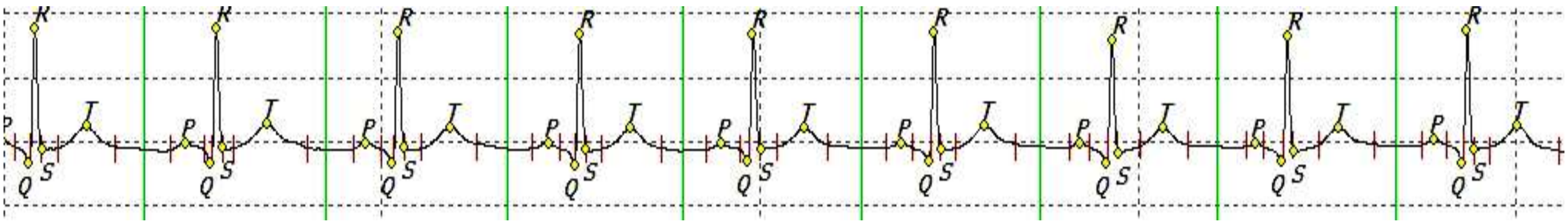


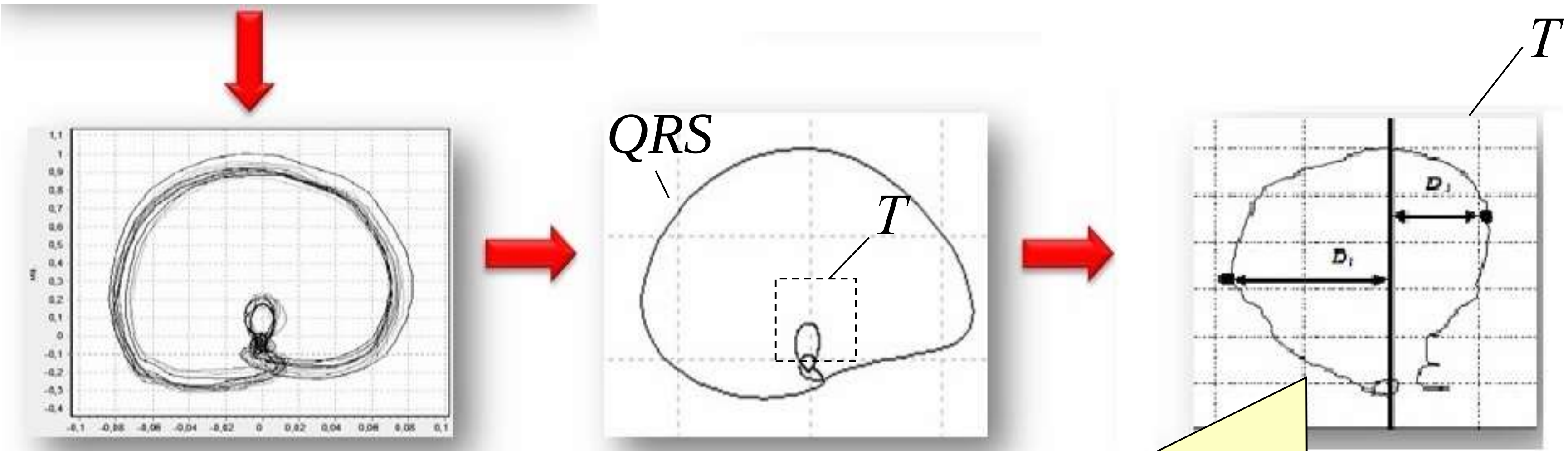
Information technology PHASEGRAPHY

Phase portrait of ECG



Basic idea of IT PHASEGRAPHY





New diagnostic feature β_T

PHASEGRAPHY implements intelligent signal processing algorithms based on the calculation of the Hausdorff distance

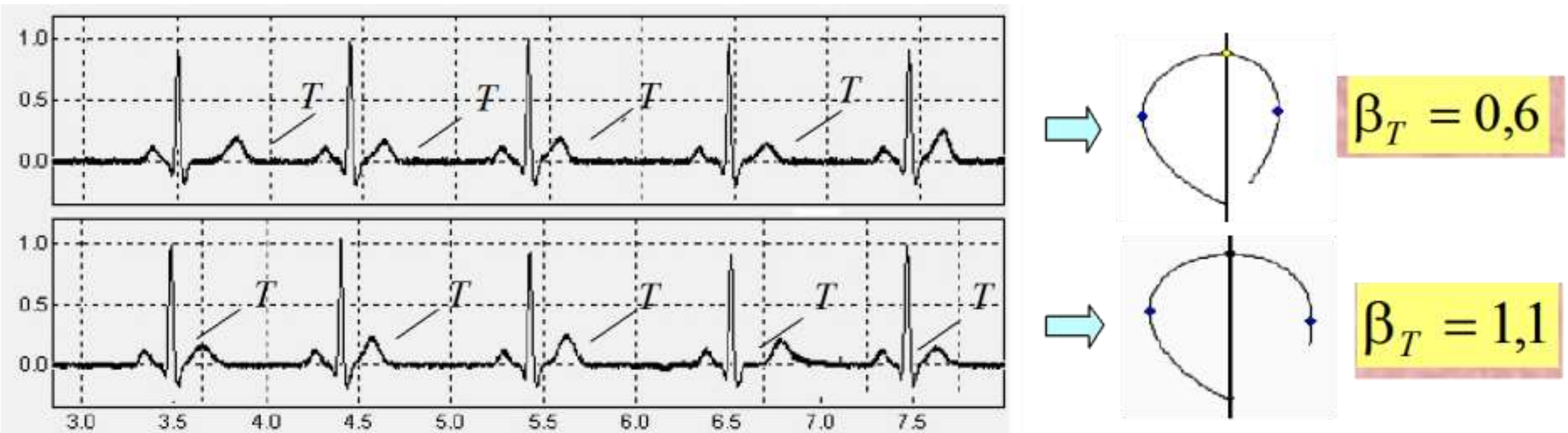
$$R_H(Q_n, Q_m) = \max\left\{ \max_{q_n \in Q_n} \min_{q_m \in Q_m} \rho(q_n, q_m), \max_{q_m \in Q_m} \min_{q_n \in Q_n} \rho(q_n, q_m) \right\}$$

where $\rho(q_n, q_m)$ is the Euclidean distance between the points of the phase trajectories Q_n, Q_m

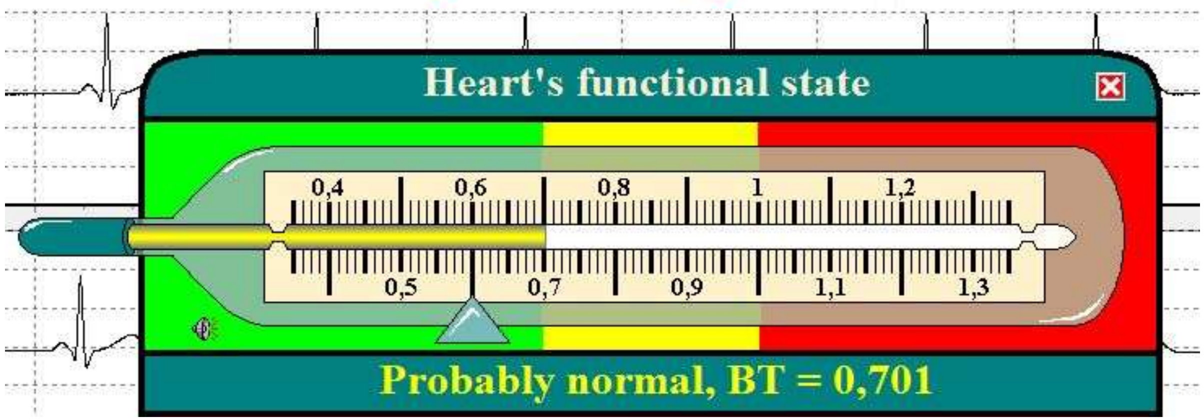
The row of the Gausdorfian distance matrix whose sum of elements is minimal determines the dominant phase trajectory

$$Q_0 = \arg\max_{1 \le n \le M} \sum_{m=1}^{M} R_H(Q_n, Q_m)$$

PHASEGRAPHY reveals **subtle** ECG changes that are **invisible** with traditional processing



Traditional ECG processing | **New feature analysis**



PHASEGRAPHY made it possible to obtain novel scientific results in the Climatology**.** In particular, **the relationship** between the β_T (T wave symmetry index of ECG phase portrait , **SCT index**) and the global geomagnetic disturbance index (**Kp-index**) was found:

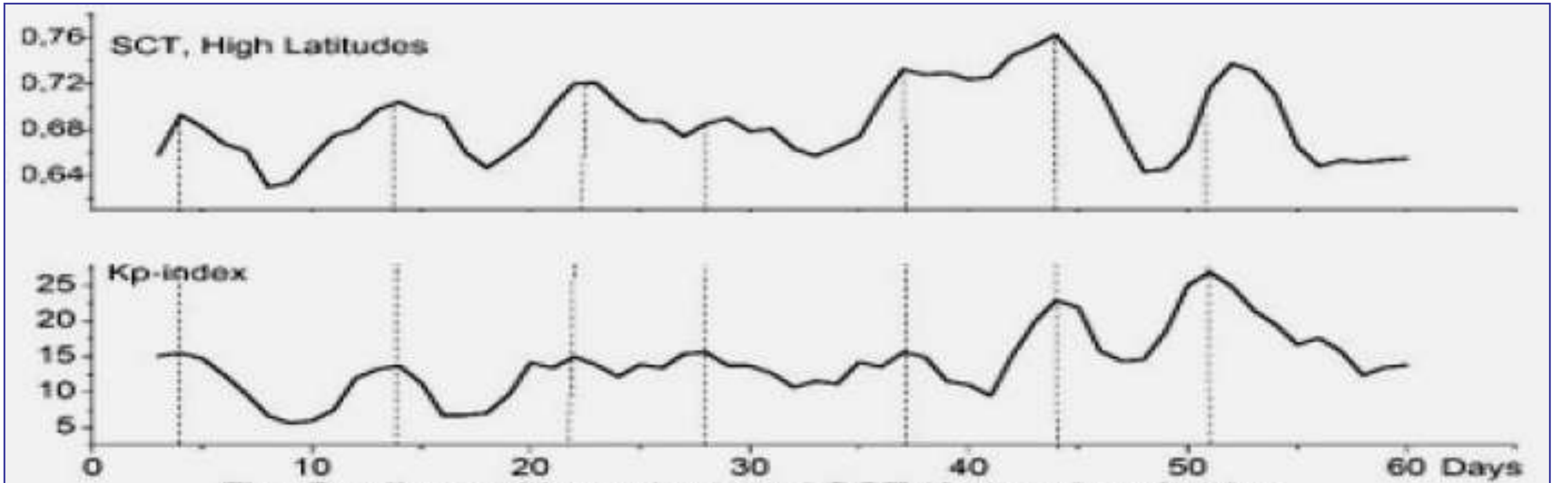
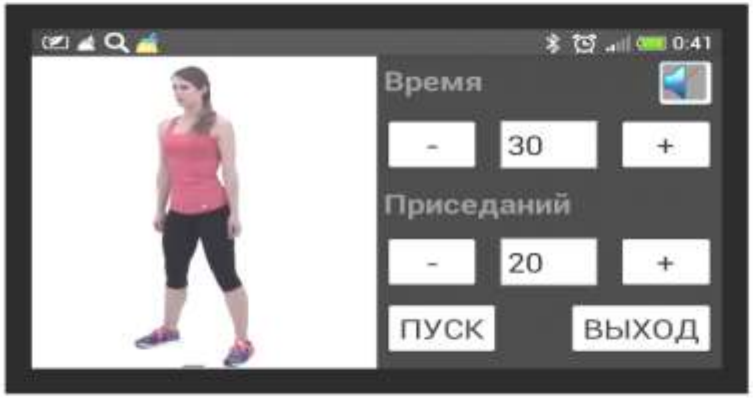


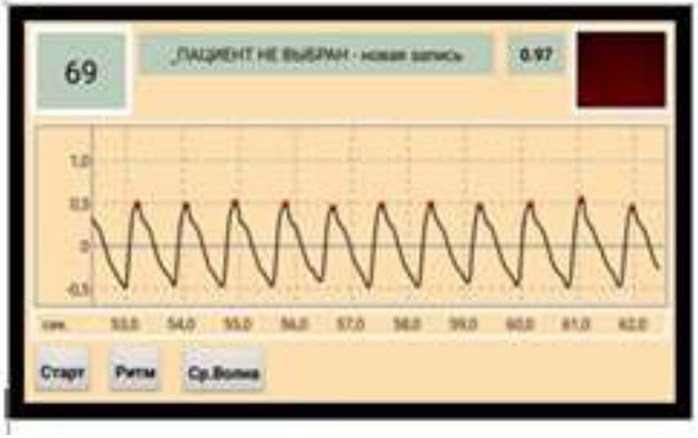
Fig. Cardiosensitive volunteers' SCT-Kp synchronization

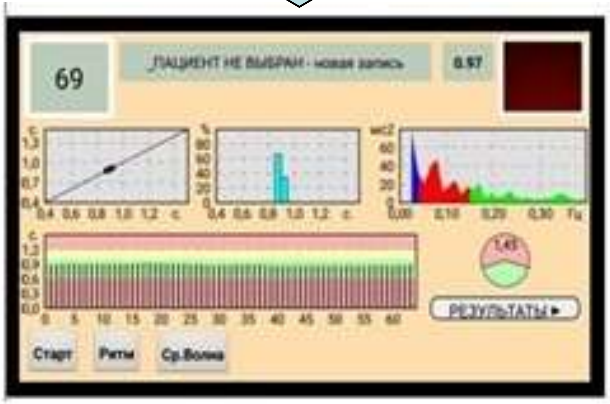
New opportunities of biophysical monitoring in high and middle latitudes for the evaluation of the impact of geomagnetic disturbance on human health . *Revista Turismo: Estudos e Práticas (RTEP/UERN)*
https://geplat.com/rtep/index.php/tourism/article/view/450/428

MOBILE PHASEGRAPH ON SMARTPHONE



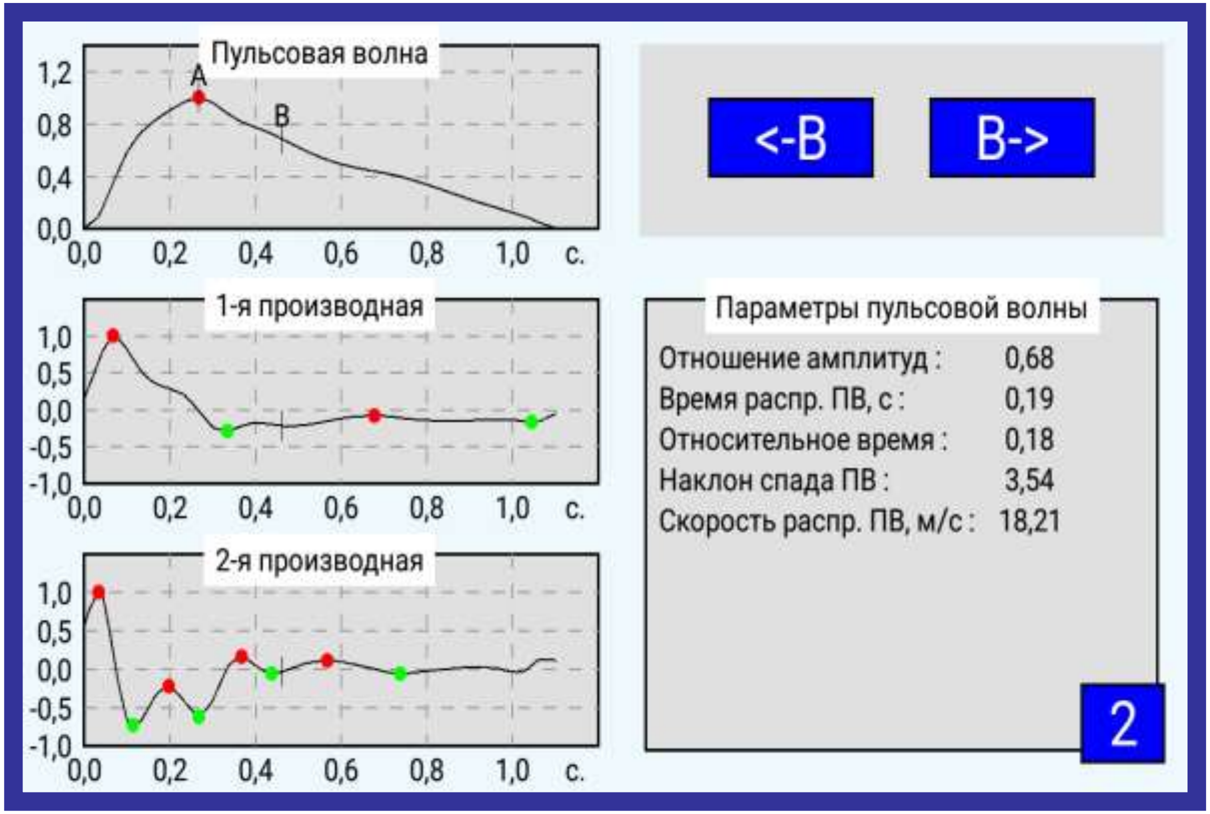
AI-RITHMOGRAPH





ASSESSMENT OF ADAPTATION RESERVES FOR HEART RATE VARIABILITY

AI-ARTERIOGRAPH



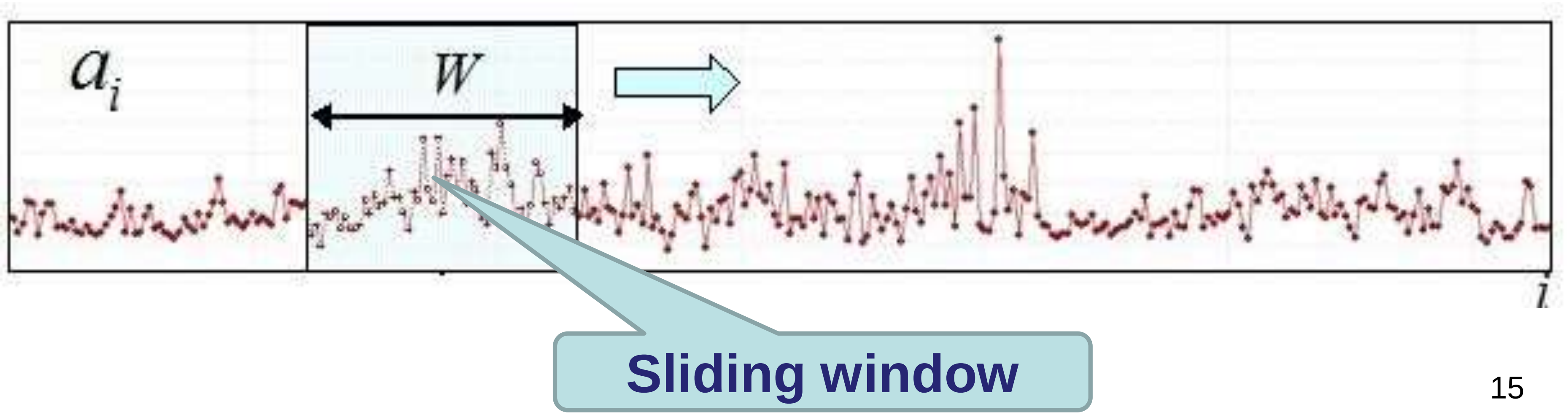
INTEGRALLY CHARACTERIZE OF THE BLOOD VESSELS ELASTICITY

<u>TASK 2.</u> Cyclic signals classification by the dynamics of shape changing

2.1. Phase portrait of **a permutational entropy**

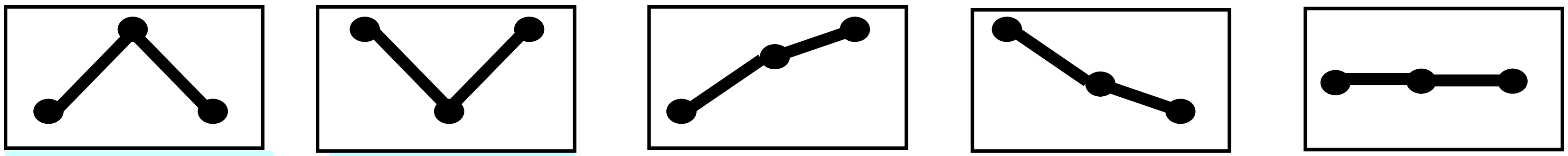
To assess the **dynamics of the cyclic signal**, we will analyze the sequence of parameters that characterize the shape of cycles

$$A = a_1,\ a_2,\ \ldots,\ a_M$$



In each window, we will analyze a three-element pattern

$$a_{i-1}, a_i, a_{i+1}, \quad i = 2,\ldots,N-1$$



Maximum | Minimum | Ascending | Descending | Constant

π_1 π_2 π_3 π_4 π_5

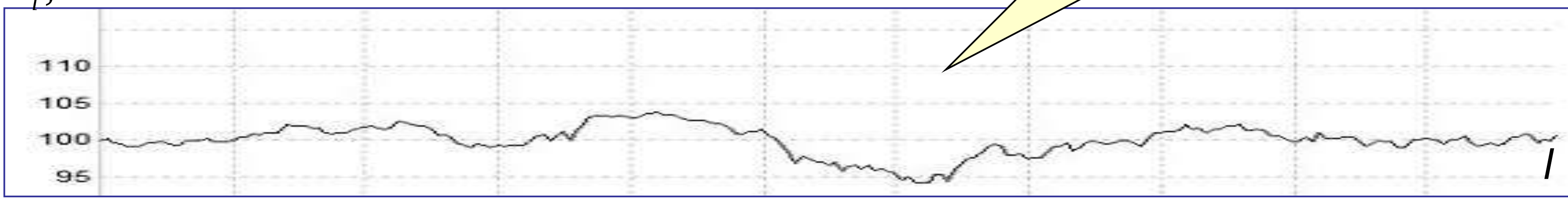
Permutational entropy

$$PE = -\sum_{j=1}^{5} p(\pi_j)\log_2 p(\pi_j),$$

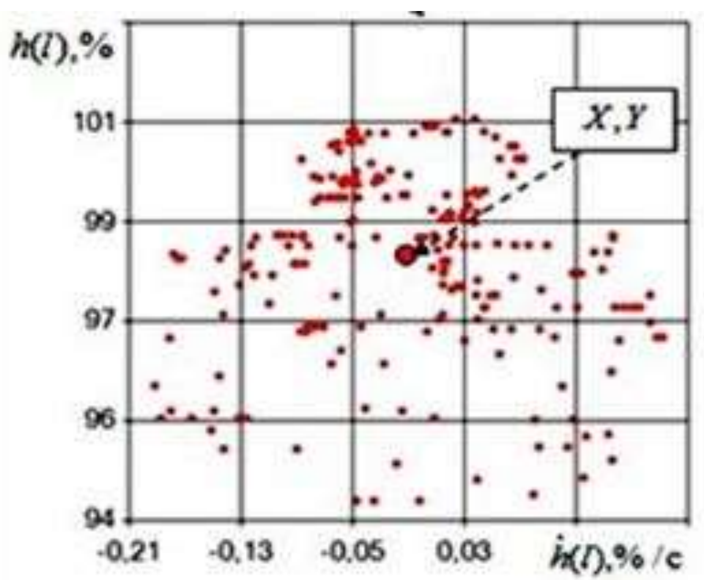
$p(\pi_j)$ - pattern occurrence frequency

$$h_l = \frac{H_l}{H_1} \cdot 100\%, \qquad H_1 \neq 0$$

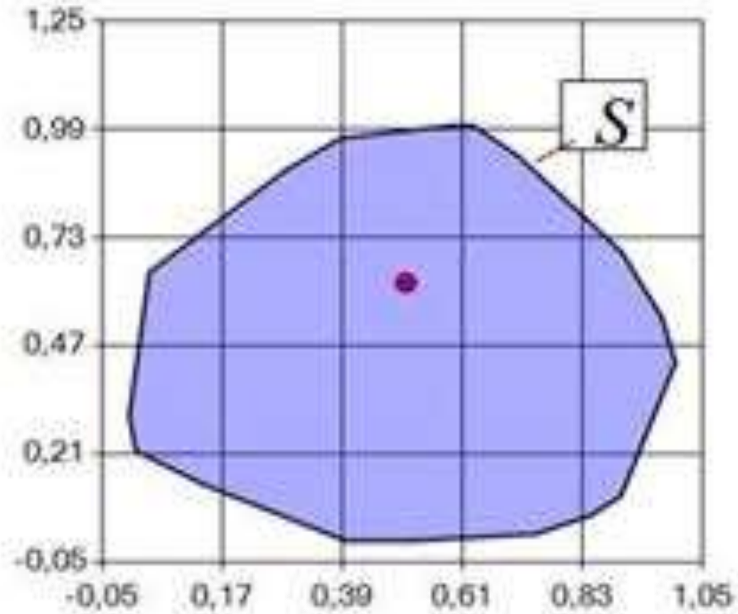
Sliding entropy



Phase portrait of entropy



Convex hull



The area of the convex hull is a new diagnostic feature !

2.1. **Linguistic approach** to classification problem

Syclical signal $z_k(t)$

Chain of characters $\alpha_j \in A$

$$S_k = \alpha_1 \alpha_2 \cdots \alpha_K$$

$$V_n^{(m)} = \begin{cases} +1, & \text{if} \quad x_n^{(m)} - x_{n-1}^{(m)} > \varepsilon, \\ 0, & \text{if} \quad \left| x_n^{(m)} - x_{n-1}^{(m)} \right| \le \varepsilon, \\ -1, & \text{if} \quad x_n^{(m)} - x_{n-1}^{(m)} < -\varepsilon, \end{cases}$$

$m = 1, \ldots, M,$ $\quad n = 2, \ldots, N_0$

No	$V_n^{(1)}$	$V_n^{(2)}$	$V_n^{(3)}$	Symbol $\alpha_n \in A$
	RR-intervals	*T*-wave symmetries	*R*-wave amplitudes	
0	0	0	0	=
1	0	0	-1	*A*
2	0	0	+1	*B*
3	-1	0	0	*C*
…				
26	+1	+1	+1	*Z*

The method provides an estimate the proximity between any pair of codegrams S_μ, S_ν based on the **Levenshtein distance** $L(S_\mu, S_\nu)$ which determines the minimum number of editing operations (insertion, deletion and replacement of a character) that provides a transition from S_μ to S_ν

To define the **standards** $S_0^{(1)},\ldots,S_0^{(G)}$ of classes $\Psi_1,\ldots,\Psi_G$ we use the formula:

$$S_0^{(g)} = \arg\min_{1\le\nu\le Q_g} \sum_{\mu=1}^{Qg} L(S_\mu^{(g)}, S_\nu^{(g)})$$

We make decisions about the current signal codegram S_t according to **the rule**

$$\text{CLASS } \Psi_\varphi, \text{ if } L(S_t, S_0^{(\varphi)}) = \min_{1\le g\le G} L(S_t, S_0^{(g)})$$

CONCLUSION

The successful application of the proposed methods in solving practical problems of biomedical signals processing allows us to hope that, with some refinement, these methods will find application in solving actual problems of climatology.

Thank you for attention!

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