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MATHEMATICAL SUPPORT VERIFICATION OF METHODS, ALGORITHMS AND SOFTWARE PROCESSING OF PULSE SIGNALS UNDER PHYSICAL LOAD IN COMPUTER DIAGNOSTIC SYSTEMS

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In sports medicine, screening tests are used to prevent sudden death during exercise, in which functional tests in the form of dosed exercise are used to diagnose the functional state of the cardiovascular system.

The study of changes in the structure of the pulse signal (Fig. 1) during dosed physical exertion is a universal method of controlling and regulating the intensity of physical exertion and serves to identify hidden pathologies of the cardiovascular system, which are the causes of sudden death [7].

ERG-signals [12, 16], EEG-signals, phonocardiosignals [15], rhythmocardiosignals [14] and others can also be studied to detect hidden pathologies of the visual, nervous, and cardiovascular systems during physical exertion.

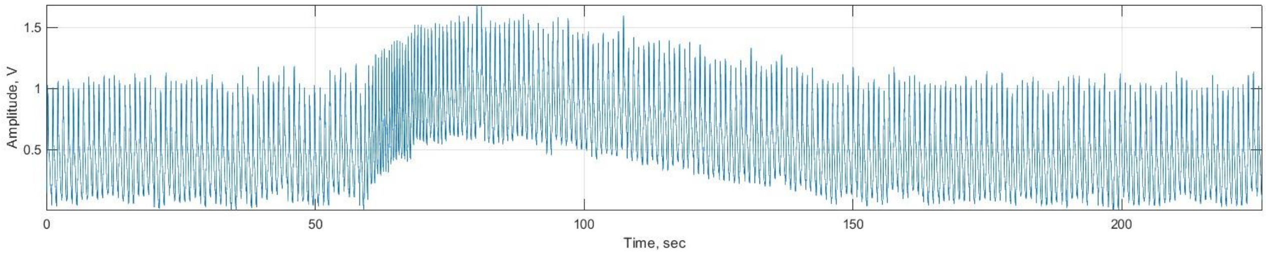

Figure 1. The structure of the pulse signal during physical exertion

The effectiveness and correctness of determining the functional state of human blood vessels based on the pulse signal in computer diagnostic systems depends on the structure of the mathematical model of the studied signal and the simulation model developed on its basis as the core of mathematical verification of methods, algorithms and software for processing pulse signals during physical exertion.

Currently, there are a number of simulation models of the pulse signal, in particular, the linearized Navier-Stokes equations in cylindrical coordinates [1], the harmonic three-phase model [2], the harmonic oscillator with exponential damping, an additive mixture of random and deterministic components, periodically extended sums of two functions with given Gaussian laws [3, 4, 5], a model based on the theory of solitons using the Korteweg De Vries equation and the Hirot method, an adaptive non-harmonic model in the form of a waveform function and the time-frequency analysis method [6].

The analysis of the well-known cores of mathematical support for verification, in particular the simulation models of the pulse signal, showed that they do not simultaneously take into account randomness, repetition and period change (cardiac cycle) in their structure. Such a feature is inherent in signals during physical exertion and is an urgent task in the verification of methods, algorithms and software for processing pulse signals during physical exertion as part of computer diagnostic systems.

Therefore, the development of mathematical support for the verification of pulse signal processing methods on the basis of their simulation model, which takes into account randomness, repetition and change of the oscillation period in its structure, is an urgent scientific task.

The pulse signal in its structure consists of direct and reflected waves with time and amplitude parameters $(A_1, A_2, m_1, m_{2,} T_1, T_1, t_{01}, t_{02})$ (Fig. 2) as indicated in the works of Liliia Khvostivska and Mykola Khvostivskyi [3, 4, 5].

The application of the procedure for finding the minimum functional variation of the average values of the centered signal provides effective and accurate determination of the value of the pulse signal duration period [13].

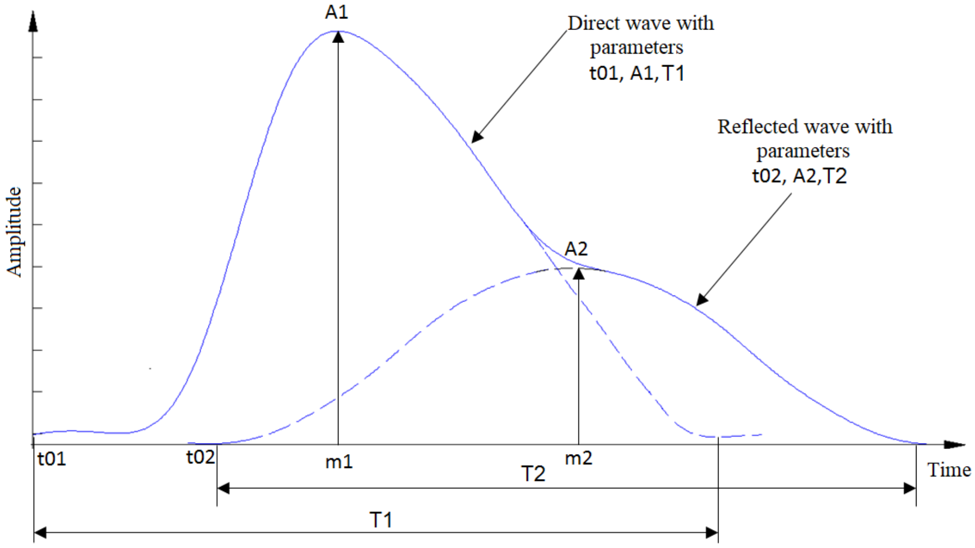

Fig. 2. The structure of the pulse signal within one repetition (pulse wave) [3, 4, 5]: m_1 and m_2 - the central moments of the max blood filling time of A_1 and A_2; t_{01} and t_{02} - the time of the beginning of blood filling; T_1 and T_2 - durations of direct and reflected waves

Taking into account the exponential increases/decreases of direct/reflected waves, their temporal repetitions and the presence of temporal randomness, the work [3, 4, 5] proposed a pulse signal model in the form of an expression:

$$\xi(t)=\sum_{k=1}^{N_k}\left(\begin{cases}\sum\limits_{n=1,N}(A_{nk}+\psi_{Ak})\cdot e^{-\frac{(t-(m_{nk}+\psi_{mk}))^2}{2(T_{nk}+\psi_{Tk})^2}\cdot e^{-tK_{nk}}} & ,t\in[T_{k-1},T_k)\\ 0 & ,t\notin[T_{k-1},T_k)\end{cases}\right)+n(t), \tag{1}$$

where T_k - pulse wave that is localized on the *k*-th repetition;

A_{nk}, m_{nk}, T_{nk} - amplitude, central moment of time, time duration of the nth wave of the pulse wave in the *k*-th period;

ψ_{Ak}, ψ_{mk}, ψ_{Tk} - the randomness of the amplitude A_{nk}, the central moment of time m_{nk} and the time duration T_{nk} of the pulse wave on the *k*-th repetition;

K_{nk} - coefficient of the phase component for the *n*-th wave of the pulse wave at the *k*-th repetition

N – the number of pulse wave waves;

N_k – number of repetitions;

$n(t)$ - additive pulse wave interference.

The proposed model in works [3, 4, 5] perfectly describes the behavior of the pulse signal in time, taking into account the factors of randomness and repetition, but the change in period, which is important for pulse signals during physical exertion, is not taken into account.

The graphic change in the period of the pulse signal during physical exertion is shown in fig. 3, where D1, D2 and D3 indicate the areas where the period changes its value, and A is the maximum value of the amplitude period (peak load).

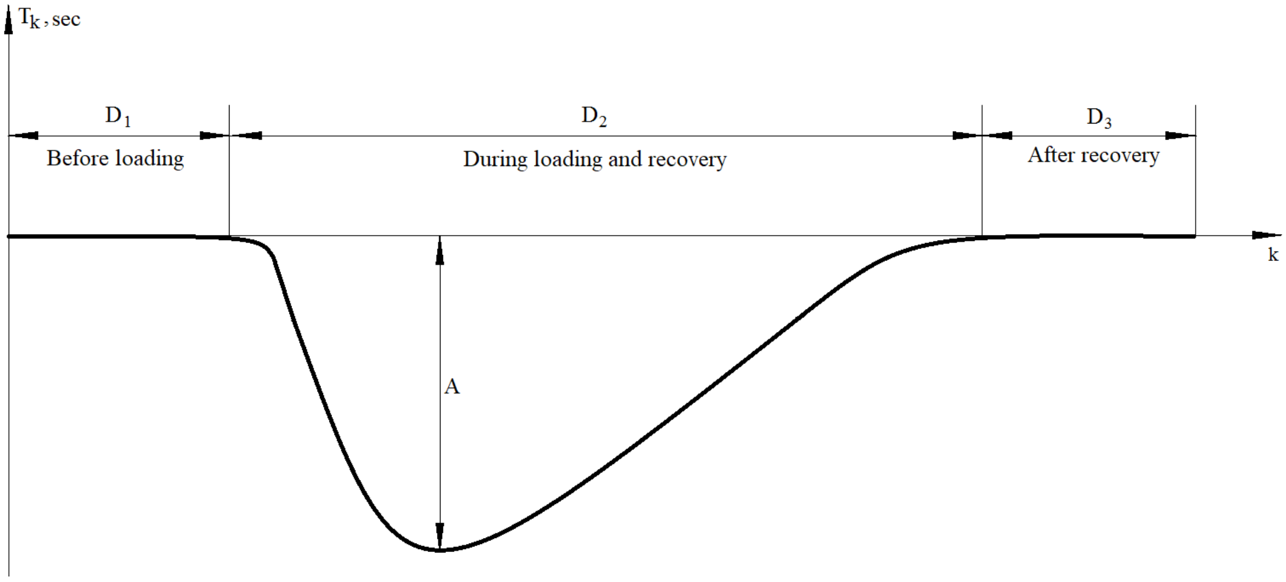

Fig. 3. Change in the period of the pulse signal during physical exertion

To change the period of the pulse signal during physical exertion, it is proposed to introduce the coefficient of change of the period K_{T_k} (amplification or reduction coefficient), which will ensure the imitation of the pulse signal according to the form (Fig. 3), by multiplying it by the value of the kth period $T_k \cdot K_{T_k}$ in the expression (1).

In fig. 3, it can be seen that the value of the period of the pulse signal changes according to the exponential law, namely, it increases sharply during loading, and falls smoothly during recovery, therefore the value of the coefficient of variation K_{T_k} should change according to the same law.

The expression for modeling the coefficient of change of the period is described by the expression:

$$K_{T_k} = \sum_{n=\overline{1,3}} \left(\begin{cases} A_{T\,nk} \sin\left(2 \cdot \pi \cdot k \cdot f_{T\,nk}\right) \cdot e^{-k \cdot M_{Tnk}} \cdot L_{T_{nk}}, & k \in D_n \\ 0, & k \notin D_n \end{cases} \right), \; k = \overline{1, K_{\max}} \quad (2)$$

де D_n – n-on the area in which the period changes its value;

$K_{\max}$ – maximum period change value.

Expression (2) describes the coefficient of period change, which takes into account in its structure all the properties of the real period change of the pulse signal during physical exertion.

The implemented core of mathematical support for verification in the form of a simulation model provides the process of computer generation of test signals for the verification of methods, algorithms and software for processing pulse signals during physical exertion in computer diagnostic systems.

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