

DOI: <https://doi.org/10.15407/kvt191.01.060>

UDC 004.9

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INFORMATIONAL ASPECTS OF THE HAPTIC STIMULATION BY THE LIGHT FOR CORRECTION OF THE HUMAN' STATE

Introduction. *The study of the laws and principles of information processes in the biological systems of the human body in extreme forms of its activities and the development of the theory of medical information systems of such appointment, taking into account the status and trends of convergence of society, ecosystems and technology become very relevant. This state of affairs makes it possible to affirm that it is an actual scientific and applied problem of radical change of the existing paradigm of designing information systems.*

The purpose of the article is to specify the informational aspects of low intensity, haptic stimulation by the light, which is essential for correction of the functional state of an organism of the human being, who works in extreme conditions, to develop and study such methods and systems.

Methods. *Analyses of requirements, functions and systems for designing synthesis of information technologies and the control biotechnical system of correction of the functional state of an organism of the human, who works in extreme conditions. The theoretical and experimental dependences between the stimulation energy of light emission diode (LED) and the energy are transferred through the layered bio media design. Mathematical modelling and computational simulation. Comparison of these real and model data.*

Results. *The base aspects requirements, functions and systems for designing synthesis of information technologies and the control biotechnical system of correction of the functional state of an organism of the human, who works in extreme conditions, low intensity, haptic stimulation by the light are defined. The methods for determining of intensity I_0 of light emission diode, recursive expression $I_m = C_m I_{m-1}$, $m = \overline{1, M}$ and formula for coefficient C_m , where M — quantity of bio media layers were developed. The bridges, which connects Maxwell's phenomenological theory with the atomistic theory of matter and optics, were used.*

Computer simulation studies have confirmed the specification of requirements, functional and structural schemas of biotechnical system.

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Conclusions. *Thanking to specification of requirements possibility-using recursive determining of the light flux intensity after every bio media layer was got. Under the effect of recursion low computation complexity was caused. Information technology means (for automation optimal control) of the human state under external influences on the organism was developed. Further study to confirm statistical significance in representative samples of observations was opened.*

Keywords: *haptic stimulate, light, information biotechnical system.*

INTRODUCTION

The study of the laws and principles of information processes in the medical and biological systems of the human body in extreme forms of its activities and the development of the theory of medical information systems of such appointment, taking into account the state and trends of convergence of society, ecosystems and technology, becomes very relevant [1]. Solving the problems of prevention, diagnosis, correction and rehabilitation of a person's condition appears to be necessary because of the conditions of its activity [2]. At the same time, information technologies are increasingly gaining importance in solving the problems of collecting, storing, processing and transmitting information and research, modeling, diagnosis, forecasting and correction of the functional state of biological and medical systems of human under extreme conditions. In existing medical information systems, electromagnetic radiation [3] is used for obtaining information from a bioobject and for correction of its state including optical range [4]. Effective in terms of the complexity of managing radiation characteristics are its semiconductor sources [5], but for use in information technology, they are not intended and are investigated only in the direction of increasing the efficiency of converting electricity into radiation energy. The processes of radiation by the source, its propagation to the bioobject, the interaction with the bio-environment are presented in the framework of mathematical models [6], which are used in phototherapy systems, visualization of the results of biomedical research in diagnostics. They do not properly take into account: a) the physical and biological properties of the bioobject as a medium for the transmission of information by radiation; b) own bioelectric activity of organs and tissues; c) basic informational aspects; d) criterion of optimality in the sense of the theory of biosystems.

The optimal solution of each application based on mathematical models, including informational, functional, structural, logical and heuristic, algorithmic modeling of processes in a living organism in norm in extreme conditions. These requires a common theoretical basis, new formulation and solution of a number of tasks of a systemic nature. These are: a) inclusion in the medical information system and information technologies of obtaining, storing, transmitting and analyzing medical and biological information of different levels of organization of information processes in physiological effects, that arise when radiation characteristics are different; b) identification and construction of appropriate metrological norms of radiation, and reactions to its biological objects; c) definition of conceptual foundations for formulating tasks of synthesis of structures and functions of information systems and technologies based on wave and quantum concepts; d) construction of methods for the study of information

processes and management processes in biological and medical systems with the help of intelligent information technologies; e) verification of information and mathematical modeling of medical, biological and biotechnical systems for monitoring and correction of the organism, which is in extreme conditions. This state of affairs makes it possible to affirm that it is an actual scientific and applied problem of change of the existing paradigm of designing information systems, which is essential for informative light correction of the functional state of an organism of the human being, who works in extreme conditions.

INTRACEPTION AND HAPTIC INFORMATIVE SENSORY FUNCTION

The contradiction between the data on interoception and the concepts of psychophysics (i.e., the sensory function was associated with a sensation, that arises when stimulating the receptor) recently had been stated [7, 8]. Later is stated, that interoceptive stimuli do not cause sensations [9]. A reliable evaluation of the interoceptive function was only possible after the development of electrophysiological method and the appearance of the method of conditioned reflexes. In our time, the interoceptive system is considered as an afferent link in the autonomic nervous system. Interoceptors mostly represent diffuse structures; they are similar to the skin receptors. The afferent pathways coming from these receptors are much more complex. Most of the impulses come from the visceral receptors to the central nervous system.

Most afferent interoceptive impulses come to the thalamic nucleus of the item ventralis posterior, that is an important switching station. Cortical representation of interoception can be found in the sensorimotor cortex, as well as in the limbic region located on the medial, latent surface of the cerebral hemispheres. The presence of this central representation makes it possible to understand why interoceptive stimuli, without causing sensations, nevertheless often affect the behavior of humans.

Interoceptors of all types perform two main functions: first, they constitute afferent link of special vegetative reflexes, which play an important role in maintaining homeostasis in the body; secondly, by sending information on the state of internal organs, they affect the state of the central nervous system. Impulses from these receptors have a profound effect on a higher nervous activity. The specificity of interoceptors with respect to different types of physical energy is challenged.

It is proved that interoceptive information is transmitted by the frequency code, some regularities of such a transmission were established, a correlation between the intensity of the stimulus and the frequency of impulses diverted from the nerve was found. To study afferentiation simultaneously recorded EEG. Traced changes were caused by desynchronization of the EEG (the alpha resting rhythm). It was also possible to remove the evoked potentials from certain areas of the cortex. At the same time, these painless irritations did not cause any sensations. This shows that interoceptive impulses do indeed reach the brain and alter the electrical activity of some cortical neurons.

Two types of afferent nerve mechanisms began to be distinguished, namely, conscious and unconscious activity. It is possible to postulate that in humans interoceptive impulses remain in the sphere of the unconscious. Now we do not have any data on the decoding mechanism in the brain responsible for the un-

conscious integration of a huge mass of impulses and the transformation of unconscious signals into conscious information.

Sensory receptors are found all over the body including the skin. Senses are sometimes referred with the understanding that includes the sense of touch (e.g., by the stick), proprioception, and haptic perception. The concept of haptic perception is related to the concept of extended physiological proprioception, according to which when a tool such as a stick is used [10]. Haptic perception relies on the forces experienced during touch. Such force also arises under the influence of light. Then the light is used for the transmission and identification of information, manipulation of biological substances, in fundamental research (obtaining by the influence of light and numerical analysis of the response of the cell by a chemical or thermal gradient), etc. [11].

THE RECEPTORS OF STIMULATING LIGHT

Light penetrated into the organism through eyes, and through the skin — with attenuation down to 1% occurs for wavelengths of (250-280) nm at around 40 μm depth, and for (300-1.2·10⁵) nm at (100-800) μm [12].

The skin consists of three main layers: the epidermis, dermis and hypoderm [13]. The derma is a layer of skin under the epidermis and closely linked to it by the basal (B) membrane (SB, Fig. 1). There are many specific nerve endings in the dermis, which provide a sense of temperature, touch, pressure, vibration and tissue damage. The non-specificity of the receptors was found to be able to react, including light [9], in particular, the sensory receptors of the autonomic nervous system neurons [11, 14]. These processes cause nociception. Determining the effect of the epidermis on the transfer of light to the dermis is important for optimizing the means of light stimulation to increase its efficiency.

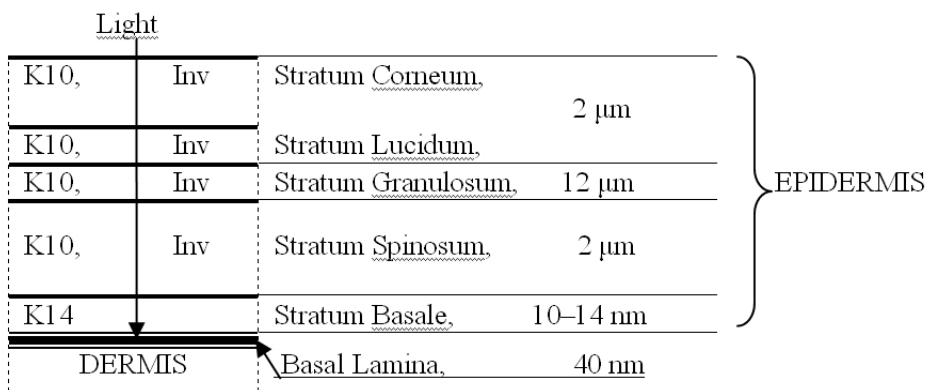


Fig. 1. Scheme of light propagation to dermis. K10, K14 — keratin, Inv — involucrin, a component of the skin, forms the shell of keratin cells

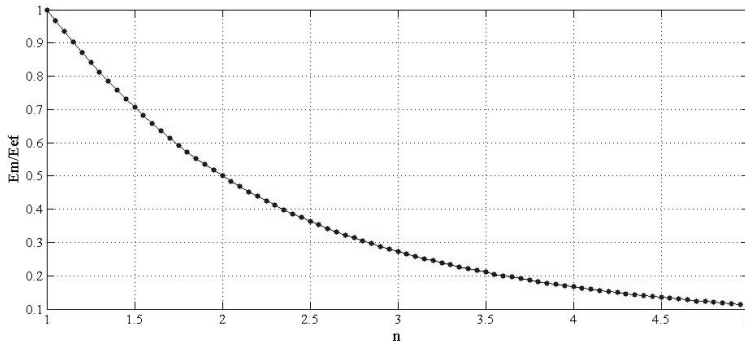


Fig. 2. Graphic of the ratio of the measured and effective strength of the electric field of light on the refractive index n of the medium

In the optical range, the dielectric function of the epidermis and basal is related to the refractive index and the absorption coefficient of light [6]:

$$\varepsilon(\omega) = (n + i\kappa)^2, \tag{1}$$

where $\varepsilon(\omega)$ — dielectric function, $\omega = 2\pi f$, f — frequency, n — refractive index, κ — absorption coefficient, $i = \sqrt{-1}$ [6].

The restrictions on the possible values of the real and imaginary components of the dielectric constant are given by the Kramers-Kronig equations used to reproduce dielectric constant from the values of n and κ . The dielectric properties of the epidermis for the frequency range $(3.75 - 7.5) \times 10^{14} s^{-1}$ are given, for example, in [15], where $n \approx 1,5$.

The valid combination of the phenomenological theory of Maxwell with the atomic theory of matter obtained the bridges: a) between the effective strength and polarization of the medium; b) the effective strength, polarization of the medium, and measured strength [6] (Fig. 2.):

$$\text{a) } N\alpha E_{ef} = P, \quad \text{b) } E_{ef} = E_m + \frac{4\pi}{3}P, \tag{2}$$

where N — the number of molecules per unit volume, $\alpha = \frac{3}{4\pi N} \frac{n^2 - 1}{n^2 + 2}$ — representing the mean polarizability, E_{ef} — effective field of dimensions $[EL^{-2}]$, P — the total electric moment per unit volume (e — charge, l — length of dipole $p=el$, and since p is of dimensions $[EL]$, α is seen to have the dimensions $[L^{-3}]$, i.e. those of a volume), E_m — measured strength [6]. From expressions (2), the dependence on the refractive index n of the relative values of these characteristics, in particular, the ratio (3):

$$\frac{E_m}{E_{ef}} = \frac{3}{n^2 + 2} \tag{3}$$

THE SOURCE OF LIGHT INFORMATIVE STIMULATION

An efficient source to achieve control intensity and quality energy flow is LED [5]. Mathematical models of the transfer of low-intensity light flux from the LED through a multilayer bio-environment to the object of stimulation based on the well-known radiation diagram of the light-emitting diode and the Maxwell equations are developed within the framework of the eikonal theory [6]. The intensity of the radiation of such a source is determined at the appropriate boundary conditions [6] and a recursive algorithm for specifying the intensity of radiation after the transfer of its energy through the layers of the biological environment is constructed [16–18].

In previous studies, the construction of a mathematical model of the source of radiation in a LED is based on a physically abstract object — the dipole [16–18]. In the remote from the source (dipole) in the space P_0 (Fig. 1), waves are represented by strengths:

$$\vec{E}_0 = \vec{e}(r)e^{ik_0\ell(r)}, \quad \vec{H}_0 = \vec{h}(r)e^{ik_0\ell(r)}, \quad (4)$$

where \vec{E}_0, \vec{H}_0 — electric and magnetic field components, r — is the distance from the dipole, $\ell(r)$ — the "optical length", \vec{e} and \vec{h} the vector-function of the position of the dipole, $k_0 = \omega/c = 2\pi/\lambda_0$, λ_0 — the wavelength, c is the speed of light.

In the Cartesian coordinate system (x, y, z) with the origin at the point P_0 (the Gaussian image of the source P_0) and in the direction of applicate z along the axis cP_1 the irradiated points lie.

The approximate expression of the field at these points (in the region of the aperture of radiation, except for points that are in close proximity to its edge, Fig. 3), takes on the form [6, 16–18]:

$$\begin{aligned} \vec{E}_\omega(x, y, z, t) &= Re \left\{ \frac{\omega^2}{c^2} \vec{e}_\omega(x, y, z) e^{i \left\{ \delta(\omega) - \omega \left[t - \frac{1}{c} \ell_\omega(x, y, z) \right] \right\}} \right\}, \\ \vec{H}_\omega(x, y, z, t) &= Re \left\{ \frac{\omega^2}{c^2} \vec{h}_\omega(x, y, z) e^{i \left\{ \delta(\omega) - \omega \left[t - \frac{1}{c} \ell_\omega(x, y, z) \right] \right\}} \right\}, \end{aligned} \quad (5)$$

where $\vec{E}_\omega(x, y, z, t), \vec{H}_\omega(x, y, z, t)$ — is the Fourier transform of the vectors of electrical and magnetic strengths, $\vec{e}_\omega(x, y, z), \vec{h}_\omega(x, y, z)$ — the amplitudes and $\delta(\omega)$ — the phase of their vector functions, $\ell_\omega(x, y, z)$ — the optical length from point P_0 to point $P_1(x, y, z)$.

In the stimulation system (LED — object of action):

(a) the geometric front W of the light wave in the space of its LED source is at a large distance P_0c , (Fig. 3), in comparison with the length of the λ_0 wave, the angles θ , the rays of which form the axis of the system, are small;

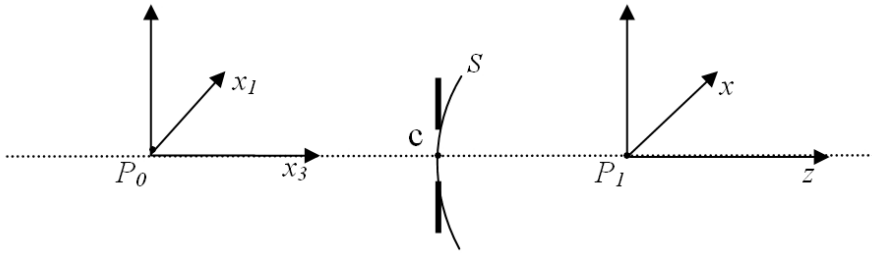


Fig. 3. Scheme of LED's radiation space (dipoles in P_0 and a wave sphere front W conditionally not shown). S — the reference sphere front, c — centre of the LED lens, \cdots — axes of the system

(b) at any given time, the Fourier transform \vec{E}_ω and \vec{H}_ω the field strengths (5) at this distance do not vary significantly in magnitude and direction;

(c) when integrating the expression (5) with respect to part S' (covering the lens) of the reference sphere S (reference for P_1 the sphere S passes through the center of the lens of the light emitting diode, $cP_1 = R$) is neglected by the coefficient of curvature on S' ;

(d) in a homogeneous-layered, non-magnetic irradiation environment $|\vec{h}_\omega| = n|\vec{e}_\omega|$, where n is the refractive index of the corresponding layer;

(e) on to S , as on W , the vectors $|\vec{e}_\omega|$ and $|\vec{h}_\omega|$ amplitudes are practically constant in magnitude and direction, the diameters of the lens pulled to P_1 are small if at a distance R from a certain typical point (x', y', z') in the reference sphere S to P_1 the vectors $\vec{e}_\omega(x', y', z')$ and $\vec{h}_\omega(x', y', z')$ do not change noticeably on the surface of the integration. It is possible to assume, that their values, which they gain in the center c with an LED lens — $\vec{e}_\omega(0,0,-R)$ and $n\vec{e}_\omega(0,0,-R)$ where $R = cP_1$, Fig. 3;

(f) according to (e) conditions, $\vec{e}_\omega(0,0,-R) = a(\omega)\vec{\alpha}(\omega)$, $\vec{h}_\omega(0,0,-R) = na(\omega)\vec{\beta}(\omega)$, where $\vec{\alpha}(\omega)$ and $\vec{\beta}(\omega)$ is unit orthogonal vectors in a plane perpendicular to z .

The result of the integration in the region of the Gaussian image of the radiation source P_0 in the direction along the axis z to the point $P_1(X, Y, Z)$ (where the intensity will be determined) [6]:

$$\vec{E}_\omega(X, Y, Z, t) = Re \left\{ \frac{\omega^2}{c^2} U_\omega(X, Y, Z) a(\omega) \vec{\alpha}(\omega) e^{i[\delta(\omega) - \omega t]} \right\},$$

$$\vec{H}_\omega(X, Y, Z, t) = Re \left\{ \frac{\omega^2}{c^2} U_\omega(X, Y, Z) n a(\omega) \vec{\beta}(\omega) e^{i[\delta(\omega) - \omega t]} \right\},$$
(6)

where

$$U_{\omega}(X, Y, Z) = \frac{\omega}{2\pi ic} \iint_{S'} \frac{e^{i\omega[\ell(x', y', z') + s]/c}}{S}, \quad (7)$$

the scalar wave function, is determined from the eikonal radiation function at the point P_0 [6].

From (6), the Poynting vector $S_{\omega} = c[E_{\omega} \times H_{\omega}]/4\pi$; by the average over time it is established that the intensity of the radiation in $P_l(X, Y, Z)$ of the total dipole in P_0 is proportional to the square of the module of the scalar wave function (7). In calculating the intensity in the irradiation area averaging over time is performed for each of the frequency components of each Cartesian component E and H of the complete field [6]. Only the contribution of the components of the dipoles along the axes x_1 and x_2 is significant. For the angles $\theta_1(\omega)$ and $\theta_2(\omega)$ between the unit vectors $\alpha_1(\omega)$ and $\alpha_2(\omega)$ along the x axes and $\alpha_1(\omega)$, $\beta_1(\omega)$ and $\alpha_2(\omega)$, $\beta_2(\omega)$ — the mutually orthogonal vectors in the plane perpendicular to the direction z (Fig.3), the components E and H are approximated this way [6]:

$$\begin{aligned} E_z(X, Y, Z, t) &= H_z(X, Y, Z, t) = 0, \\ E_x(X, Y, Z, t) &= \frac{1}{2\pi} \int_{-\infty}^{\infty} U_{\omega}(X, Y, Z) f(\omega) e^{-i\omega t} d\omega, \\ H_y(X, Y, Z, t) &= \frac{1}{2\pi} \int_{-\infty}^{\infty} U_{\omega}(X, Y, Z) f(\omega) e^{-i\omega t} d\omega, \\ E_y(X, Y, Z, t) &= \frac{1}{2\pi} \int_{-\infty}^{\infty} U_{\omega}(X, Y, Z) g(\omega) e^{-i\omega t} d\omega, \\ -H_x(X, Y, Z, t) &= \frac{1}{2\pi} \int_{-\infty}^{\infty} U_{\omega}(X, Y, Z) g(\omega) e^{-i\omega t} d\omega, \end{aligned} \quad (8)$$

where

$$\begin{aligned} f(\omega) &= \frac{\omega^2}{c^2} \left[a_1(\omega) \cos \theta_1(\omega) e^{i\delta_1(\omega)} + a_2(\omega) \cos \theta_2(\omega) e^{i\delta_2(\omega)} \right], \\ g(\omega) &= \frac{\omega^2}{c^2} \left[a_1(\omega) \sin \theta_1(\omega) e^{i\delta_1(\omega)} + a_2(\omega) \sin \theta_2(\omega) e^{i\delta_2(\omega)} \right]. \end{aligned} \quad (9)$$

For reasons of convergence it is assumed that the radiation field exists only between the moments $t < |T|$, where $T \gg 2\pi/\omega$ to go to the limit $T \rightarrow \infty$.

Thus, at the point $P_l(X, Y, Z)$ the intensity $I(X, Y, Z)$ is defined as the time average over the energy U^2 , which is transferred across the unit area [6]:

$$I(X, Y, Z) = \frac{c}{4\pi T} \int_0^{\infty} |U_{\omega}(X, Y, Z)|^2 \left[|f(\omega)|^2 + |g(\omega)|^2 \right] d\omega =$$

$$= C \int_0^{\infty} |U_{\omega}(X, Y, Z)|^2 d\omega,$$

$$C = \frac{c}{4\pi T} \int_0^{\infty} \left[|f(\omega)|^2 + |g(\omega)|^2 \right] d\omega.$$

If the interval $|\Delta\omega|$ small enough then $|U_{\omega}|$ practically does not depend on ω in the effective frequency range, so that:

$$I(X, Y, Z) = C |U_{\omega}(X, Y, Z)|^2.$$

The coefficients a_1 and a_2 are determined from the set of dependencies between $\vec{e}(r)$, $\vec{h}(r)$ and ℓ , that follows from the Maxwell equations [16], and the averaging over time of the Poynting vector $\langle S \rangle = (c/8\pi) \text{Re}(\vec{e} \times \vec{h}^*)$ [6, 16]:

$$\langle S \rangle = (c/8\pi\mu) \left\{ (\vec{e} \cdot \vec{e}^*) \nabla \ell - (\vec{e} \cdot \nabla \ell) \vec{e}^* \right\} = (2c/n^2) \langle w_e \rangle \nabla \ell,$$

where $\langle w_e \rangle$ — the energy density of the electric field is averaged over time; since in air $\langle w_e \rangle = \langle w_h \rangle$, then, the density of the total energy of the field $\langle w \rangle = \langle w_h \rangle + \langle w_e \rangle = 2\langle w_e \rangle$, $c/n = v$ — is the velocity of its transfer. Than we obtain strength vectors \vec{e}, \vec{h} , since

$$(\vec{e} \cdot \vec{e}^*) \vec{s} = (8\pi/\varepsilon v) \langle S \rangle,$$

where $\langle S \rangle = I_0$ — the power of the emitted light.

For a light emitting diode it is determined from its diagram. Thus, it is established that the average time energy transferred through the unit of surface area allows the vectors of the LED radiation source to be determined from its radiation diagram [6, 18]. Using the relation (3), and formula (11) one can determine: a) the intensity of I_1 after the first layer of the medium; b) vectors \vec{e}_1 and \vec{h}_1 ; c) the intensity I_{m+1} , after the subsequent layers of the medium and the vectors \vec{e}_{m+1} and \vec{h}_{m+1} . A generalized formula for determining the intensity of irradiation of a surface after the m-layer of the medium acquires the form:

$$I_m = C_m I_{m-1}, \quad m = \overline{1, M},$$

where M — the number of layers of the medium, C_m — is determined by formula (11) taking into account the values of the refractive indices n_m of the layers of the bio-environment, the intensity I_0 is determined by measurement.

The algorithm of this method of non-invasive determination of intensity through skin irradiation at the level of dermis when stimulating the human body is given in [18].

RESULTS OF SPECIFICATION OF INFORMATIONAL ASPECTS GAPTIC STIMULATION BY THE LIGHT

Ensuring the optimality of processes in biological systems of the human body in the extreme forms of its activity requires the study of the role of informational aspects and taking into account them in the development of technical systems for such appointment. Systems of the automated control of an organism's condition, using transcutaneous stimulation with light and an analysis of the response to stimulation, are perspective. Contradictory requirements for non-invasiveness, informativeness, computational and hardware complexity necessitate the use of haptic stimulation with the light, control of its intensity at the receptor level, and a statistically reliable evaluation of feedback received from the body in the normal and under the influence of external extreme conditions.

For the effective obtaining of reliable results of stimulation it is necessary to provide metrological testing of the source's LED. It is established that passport data are not all metrological sources of LED sources, for example, LED diagrams HL-508H238WC-MD [19], Fig. 4 (a).

Measuring the intensity of the HL-508H238WC-MD radiation, Fig. 4 (b), it was established that the diagram was obtained by testing in the conditions B of the CIE standard light intensity measurements [20, 21], Table 1.

For the angle $\theta = 0^\circ$, when $\varepsilon = 1$, $n = 1$, under the formula (11) it is obtained that $|e|=|h|=4 \cdot 10^{-4}$ v/m. The value used to calculate the intensity of light on the dermis (Fig. 1).

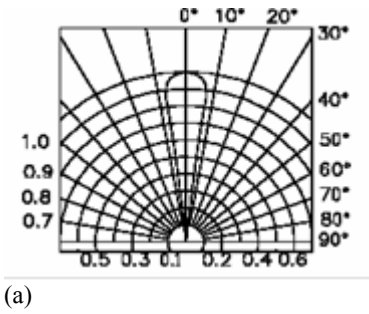
$$a_1 = |e|/n_1, \quad a_2 = |e|. \tag{16}$$

When the dipole field strengths E and H located along axes x_1 and x_2 (Fig. 3), and $\delta(\omega) \rightarrow 0$, to see (5), the coefficient C at different refractive index takes of the view is given on Fig. 5.

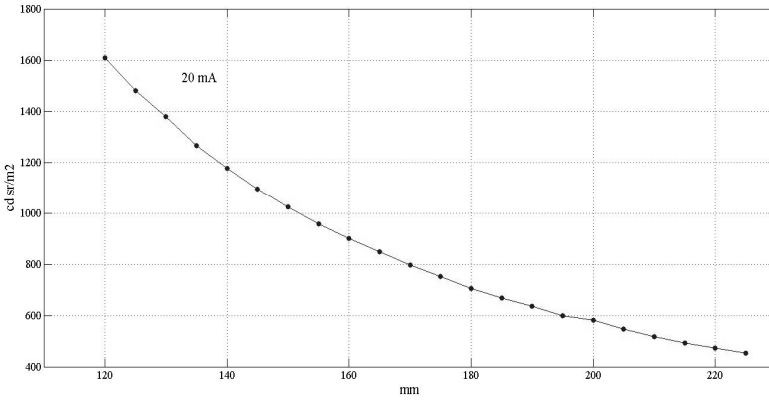
The intensity of irradiation (10, 12) decreases according to formula (11) of the coefficient C with an increase in the index of refraction of the medium layer, Fig. 5. The change in the relative values of the tensions in (2), in particular, the ratio (3), Fig. 2, made it possible to construct a formula (15) for determining the intensity of irradiation of the layer at a predetermined intensity level, and the scheme of the structure of the biotechnical system, Fig. 6.

Table 1. Results of the measurements of LED radiation

Input		Output	
Direct current, mA	20	E, lx	130
Distance, m	$1.2 \cdot 10^{-1}$	I0, cd	18.7
Surface square, m2	$4.9 \cdot 10^{-4}$	Power, W	$9.34 \cdot 10^{-4}$
Solid angle, sr	3.410^{-2}	I9, W/m2	1.9



(a)



(b)

Fig. 4. a) LED radiation diagram. $k_r = l_0 / r$, l_0 — standard distance, θ — angle; (b) Intensity $I(\theta,r)$ of LED radiation, $\theta = 0$

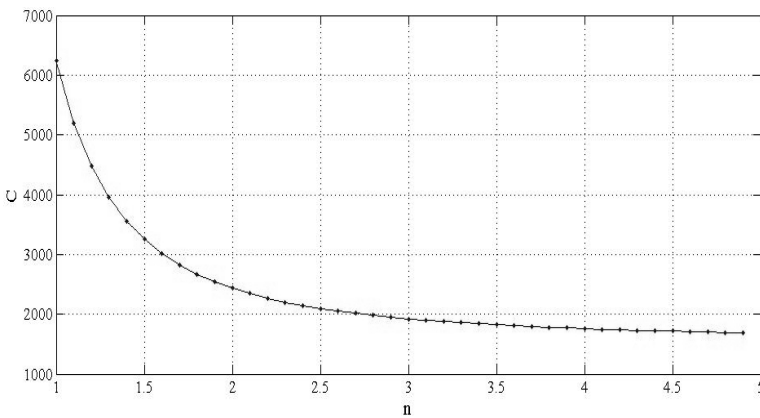


Fig. 5. Graphic of the view of the coefficient C at different refractive index

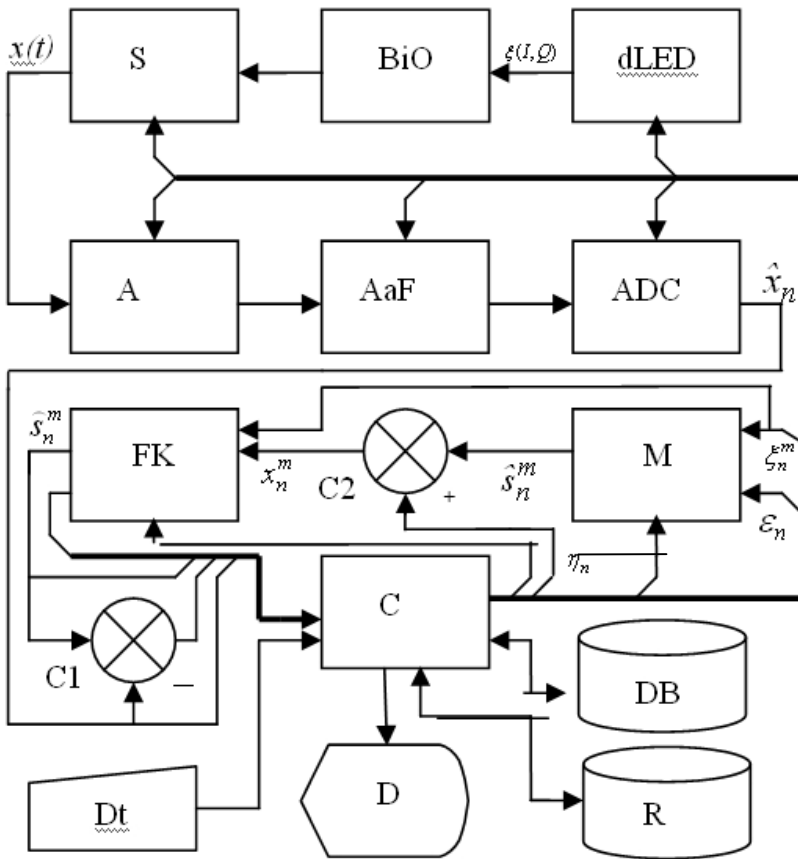


Fig. 6. Schema of the biotechnical system

In the system, the intensity of the stimuli is controlled by the change in the amplitude-spectral characteristics of the I radiation and the frequency-time parameters of the Q (duty cycle) of the shape of the pulses of stimulation by the controller C through the LED-driver dLED — programmatically or remotely, through the keyboard Dt, the display D, the network (router R). The stimulus is fed to the bioactive point of the BiO of the organism, with the S sensor being selected from the corresponding point and fed to the bioamplifier A, an antialiasing filter AaF and an analog-to-digital ADC converter. The sequence of the response sample code is fed to the Kalman filter (FK, C1, M) for optimal filtration (the result of the filtering is the sequence of the m-type response sampling code, and the error estimate), and the DB database. In the memory of M there are stored models of noise, responses of biological objects in the normal state. The comparator C2 serves when selecting from the database the types of noise and feedback normally in the Kalman filter.

The system is multifunctional, in particular, with the metrological testing of the LED's source of stimulation, automated control and correction of the body's condition with the search and use of the haptic level of transcutaneous stimulation by the light, statistical estimation of the response to stimulation, etc.

CONCLUSIONS

Due to the specification of the problem of controlling and correcting the state of the human organism in the extreme conditions of its life on the basis of the combination of Maxwell's phenomenological theory and the atomic theory of matter and optics, it was obtained:

- a) requirements to the functions and structure of the body's stimulation system with the light;
- b) calculation formulas for representing the functional blocks of the system;
- c) the method of recursive determination of the intensity of the light flux after each layer of the biological environment;
- d) low computational complexity of testing and automated haptic control and correction of the body's condition;
- e) conditions are provided to confirm the statistical significance of representative samples of the body's responses to haptic stimulation of it through biologically active points.

REFERENCES

1. NRC. 2024. *Convergence: Facilitating Transdisciplinary Integration of Life Sciences, Physical Sciences, Engineering and Beyond*. Washington, DC: The National Academies Press 153 p. URL: http://ribonode.ucsc.edu/SciEd/pdfs/NAP_Convergence.pdf (Last accessed: 20.03.17).
2. Eyre H. A. et al. Strengthening the role of convergence science in medicine. *Convergent science physical oncology*. 2015. vol. 1. №2. 11 p. URL: <http://iopscience.iop.org/article/10.1088/2057-1739/1/2/026001/pdf> (Last accessed: 20.03.17).
3. Baker-Jarvis J., Kim S. The Interaction of Radio — Frequency Fields With Dielectric Materials at Macroscopic to Mesoscopic Scales. *Journ. of Research of the National Institute of Standards and Technology*. 2012. vol. 117. February 2. 60 p.
4. Yanenko O., Adamenko V., Shevchenko K., Kuz V. Automated system for irradiation of biologically active points of the human body. *Scientific Journal of TNTU (Tern.)*. 2017. vol. 86. №2. P. 83–89.
5. Nair G.B., Dhoble S.J. A perspective perception on the applications of light-emitting diodes. *Wiley Online Library, Luminescence*. 2015. vol. 30 P. 1167–1175 URL: <http://onlinelibrary.wiley.com/doi/10.1002/bio.2919/full> (Last accessed: 13.03.2015).
6. Born M., Wolf E. *Principles of optics*, Great Britain, Exeter, 1986. 831 p.
7. Adam D. *Perception, consciousness, memory. Fusion of a biologist*, Moscow, 1983. 152 p. (in Russian).
8. King A. S. A Historical Note on the Discovery of the Depressor Nerve. *British Veterinary Journal*, 1956, vol. 112, Issue 9 pp. 353–356.
9. Sherrington C. S. *The Integrative Action of the Nervous System*, USA, 1920. 412 p.
10. Gibson J.J. *The perception of the visual world*, Cambridge, Massachusetts: The Riverside Press, 1950. 240 p.
11. Glückstad J., Palima D. *Light Robotics — Structure-mediated Nanobiophotonics*, Elsevier, 2017. 452 p.
12. *Health Effects of Artificial Light*. European Commission - Europa EU : SCENIHR. 118 p. URL: https://ec.europa.eu/health/scientific_committees/emerging/docs/scenih_r_o_035.pdf (Last accessed: 20.03.17).
13. McGrath J. A., Eady R. A. J., Pope F. M. *Anatomy and organization of human skin. Rook's Textbook of dermatology*, Oxford : Blackwell Science Ltd Oxford, 2004. pp. 3.1–3.84.
14. Okamoto K., Tashiro A., Chang Z., and Bereiter D. A. Bright light activates a trigeminal nociceptive pathway. *Pain*, 2010, vol. 149, № 2 pp. 235–242.

15. Tuchin V.V. *Optics of biological tissues. Methods of light scattering in medical diagnostics*. M : Fizmatlit, 2013. 812 p. *In Russian*
16. Bachynskyy M.V., Stoyanov Yu. M., Yavorskyy B.I. Identification of parameters of dipole model of the LED radiation source. *Scientific Journal of TNTU (Tern.)*, 2017, vol. 85, №1 pp. 118–125.
17. Bachynskyy M.V., Stoyanov Yu. M., Yavorskyy B.I. Mathematical modeling of LED radiation in the system of medical diagnostics. *Scientific Journal of TNTU (Tern.)*, 2016, vol. 84, №4 pp. 124–130.
18. Bachynskyy M.V., Stoyanov Yu. M., Yavorskyy B.I. Determination of non-intensive light flux intensity after propagation through layered biological environment. *Scientific Journal of TNTU (Tern.)*, 2017, vol. 86, №2 pp. 101–107.
19. HONGLITRONIC, Part: HL-508H238WC-MD. — Honglitronic. — 5.23.2012. — 5 p. [Electronic resource]. Access mode: <http://leds.com.ua/assets/products/datasheets/121.pdf> (last access: 20.03.17).
20. *Handbook of LED Metrology*. INSTRUMENT SYSTEMS GmbH, version 1.1, 2016. 42 p.
21. Bachynskyy M.V., Tymkiv P.O., Demchuk L.B. *Determination of lighting characteristics of low intensity medical light-emitting diodes. Methodic of measurement MB-001LED-2017*. Ternopil : National Technical University named after Ivan Puluji, Testing laboratory of X-ray medical technique, 2012. 19 p. (In Ukrainian).

Received 15.11.2017

ЛИТЕРАТУРА

1. NRC. 2024. Convergence: Facilitating Transdisciplinary Integration of Life Sciences, Physical Sciences, Engineering and Beyond. Washington, DC: The National Academies Press 153 p. URL: http://ribbonode.ucsc.edu/SciEd/pdfs/NAP_Convergence.pdf (Last accessed: 20.03.17).
2. Eyre H. A. et al. Strengthening the role of convergence science in medicine. *Convergent science physical oncology*, 2015, vol.1, №2 11 p. URL: [Http://lopscience.lop.Org/Article/10.1088/2057-1739/1/2/026001/Pdf](http://lopscience.lop.Org/Article/10.1088/2057-1739/1/2/026001/Pdf) (last accessed: 20.03.17).
3. Baker-Jarvis J., Kim S. The Interaction of Radio - Frequency Fields With Dielectric Materials at Macroscopic to Mesoscopic Scales. *Journal of Research of the National Institute of Standards and Technology*, 2012, vol. 117, February 2, 60 p.
4. Yanenko O., Adamenko V., Shevchenko K., Kuz V. Automated system for irradiation of biologically active points of the human body. *Scientific Journal of TNTU (Tern.)*, 2017, vol. 86, №2 pp. 83–89.
5. Nair G.B., Dhoble S.J. A perspective perception on the applications of light-emitting diodes. *Wiley Online Library, Luminescence*, 2015, vol. 30 pp. 1167–1175 URL: <http://onlinelibrary.wiley.com/doi/10.1002/bio.2919/full> (Last accessed: 13.03.2015).
6. Born M., Wolf E. *Principles of optics*, Great Britain, Exeter : A. Eaton & Co. Ltd., 1986. 831 p.
7. Адам Д. *Восприятие, сознание, память. Размышление биолога*, М.: Мир, 1983. 152 с.
8. King A. S. A Historical Note on the Discovery of the Depressor Nerve. *British Veterinary Journal*, 1956, vol. 112, Issue 9 pp. 353–356.
9. Sherrington C. S. *The Integrative Action of the Nervous System*, USA, 1920. 412 p.
10. Gibson J.J. *The perception of the visual world*, Cambridge, Massachusetts: The Riverside Press, 1950. 240 p.
11. Glückstad J., Palima D. *Light Robotics — Structure-mediated Nanobiophotonics*, Elsevier, 2017. 452 p.
12. *Health Effects of Artificial Light*. European Commission — Europa EU : SCENIHR. 18 p. URL: https://ec.europa.eu/health/scientific_committees/emerging/docs/scenihr_o_035.pdf (Last accessed: 20.03.17).
13. McGrath J. A., Eady R. A. J., Pope F. M. *Anatomy and organization of human skin. Rook's Textbook of dermatology*, Oxford : Blackwell Science Ltd Oxford, 2004. pp. 3.1–3.84.
14. Okamoto K., Tashiro A., Chang Z., and Bereiter D. A. Bright light activates a trigeminal nociceptive pathway. *Pain*, 2010, vol. 149, №2 pp. 235–242.

15. Тучин В.В. *Оптика биологических тканей. Методы рассеяния света в медицинской диагностике*. М : Физматлит, 2013. 812 с.
16. Bachynskyy M.V., Stoyanov Yu. M., Yavorskyu B.I. Identification of parameters of dipole model of the LED radiation source. *Scientific Journal of TNTU (Tern.)*, 2017, vol. 85, №1 pp. 118–125.
17. Bachynskyy M.V., Stoyanov Yu. M., Yavorskyu B.I. Mathematical modeling of LED radiation in the system of medical diagnostics. *Scientific Journal of TNTU (Tern.)*, 2016, vol. 84, №4 pp. 124–130.
18. Bachynskyy M.V., Stoyanov Yu. M., Yavorskyu B.I. Determination of non-intensive light flux intensity after propagation through layered biological environment. *Scientific Journal of TNTU (Tern.)*, 2017, vol. 86, №2 pp. 101–107.
19. HONGLITRONIC, Part: HL-508H238WC-MD. — Honglitronic. — 5.23.2012. — 5 p. URL: <http://leds.com.ua/assets/products/datasheets/121.pdf> (Last accessed: 20.03.17).
20. *Handbook of LED Metrology*. INSTRUMENT SYSTEMS GmbH. version 1.1, 2016. 42 p.
21. Бачынський М.В., Тымків П.О., Дэмчук Л.Б. *Определение светотехнических параметров низкой интенсивности светодиодов медицинского назначения. Методика измерения MB-001LED-2017*. Тернопіль: Национальный технический университет имени Ивана Пулюя. Испытательная лаборатория X-лучевой медицины, 2012. 19 с.

Получено 15.11.2017

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ІНФОРМАЦІЙНІ АСПЕКТИ ГАПТИЧНОГО СТИМУЛЮВАННЯ СВІТЛОМ ДЛЯ КОРЕГУВАННЯ СТАНУ ЛЮДИНИ

Розглянуто аспекти інформаційних процесів в медико-біологічних системах організму людини в екстремальних умовах її діяльності та розвинуто теорію медичних інформаційних систем з урахуванням стану і тенденцій конвергенції суспільства, екосистеми і технологій. Запропоновано специфікацію інформаційних аспектів гаптичної стимуляції світлом для корекції функціонального стану організму та розвитку й дослідження вимог до функцій, методів та структур відповідних біотехнічних систем. Наведено функціональну схему біотехнічної системи та результати аналізу зміни інтенсивності світла при поширенні його у шаруватому біо середовищі від світлодіодного джерела стимуляції.

Ключові слова: гаптична стимуляція, світло, інформаційна біотехнічна система.

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ИНФОРМАЦИОННЫЕ АСПЕКТЫ ГАПТИЧЕСКОГО СТИМУЛИРОВАНИЯ СВЕТОМ ДЛЯ КОРРЕКЦИИ СОСТОЯНИЯ ЧЕЛОВЕКА

Введение. Изучение законов и принципов информационных процессов в медико-биологических системах человеческого тела в экстремальных условиях его деятельности и развитие теории медицинских информационных систем такого назначения с учетом состояния и тенденций сближения общества, экосистемы и технологии становятся очень актуальными. Такое положение дел позволяет утверждать, что это актуальная научная и прикладная проблема радикального изменения существующей парадигмы проектирования информационных систем.

Цель статьи — уточнить информационные аспекты низкой интенсивности тактильной стимуляции светом, которая необходима для коррекции функционального состояния организма человека, работающего в экстремальных условиях, и дальнейшего развития и исследования таких методов и систем.

Методы. Анализ требований, функций и систем для проектирования синтеза информационных технологий и контрольной биотехнической системы коррекции функционального состояния организма человека, работающего в экстремальных условиях. Теоретические и экспериментальные зависимости между энергией стимуляции светового излучающего диода и энергией передаются через слоистую структуру биоресурсов. Математическое моделирование и компьютерное моделирование. Сравнение этих реальных и модельных данных.

Результаты. Базовые аспекты требований, функций и систем для разработки, синтеза информационных технологий и управляющих биотехнических систем коррекции функционального состояния организма человека, работающего в экстремальных условиях, с низкой интенсивностью тактильной стимуляции светом. Получены методы определения интенсивности I_0 излучения светодиода, рекурсивные выражения $I_m = C_m I_{m-1}$, $m = \overline{1, M}$ и формулы для коэффициента C_m , где M — количество слоев биосреды. Использована связь феноменологической теории Максвелла с атомистической теорией материи и оптикой.

Исследования компьютерного моделирования подтвердили результат спецификации требований, функциональных и структурных схем биотехнической системы.

Выводы. Благодаря спецификации требований была получена возможность построения рекурсивного определения интенсивности светового потока после каждого слоя биосреды и низкая вычислительная сложность. Разработаны информационные технологии для автоматизации оптимального управления состоянием человека при внешних воздействиях на организм. Открыты пути дальнейшего исследования для подтверждения статистической значимости и репрезентативности выборок наблюдений.

Ключевые слова: тактильная стимуляция, свет, информационная биотехническая система.