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ON INVERSE STOCHASTIC RECONSTRUCTION PROBLEM

Abstract. In this paper, general reconstruction problem in the class of second-order stochastic differential equations of the Ito type is considered for given properties of motion, when the control is included in the drift coefficient. And the form of control parameters is determined by the quasi-inversion method, which provides necessary and sufficient conditions for existence of a given integral manifold. Further, the solution of the Meshchersky's stochastic problem is given, which is one of the inverse problems of dynamics and, according to the well-known Galiullin's classification, refers to the restoration problem.

It is assumed that random perturbations belong to the class of processes with independent increments. To solve the posed problem an equation of perturbed motion is drawn up by the Ito rule of stochastic differentiation. And, further, the Erugin method in combination with the quasi-inversion method is used to construct: 1) a set of control vector functions and 2) a set of diffusion matrices that provide necessary and sufficient conditions for a given second-order differential equation of Ito type to have a given integral manifold.

The linear case of a stochastic problem with drift control is considered separately. In the linear setting, in contrast to the nonlinear formulation, the conditions of solvability in the presence of random perturbations from the class of processes with independent increments coincide with the conditions of solvability in a similar linear case in the presence of random perturbations from the class of independent Wiener processes. Also considered is the scalar case of the recovery problem with drift controls.

Key Words: Ito stochastic differential equation, reconstruction problem, Meshchersky's problem, integral manifold, quasi-inversion method.

Introductionю The theory of inverse problems of the dynamics of systems described by ordinary differential equations [1-6, etc.] goes back to the fundamental work of Erugin [7]. In 7, a set of ordinary differential equations is constructed that have a given integral curve. The inverse problems of constructing automatic control systems for program motion are studied in [8-11]. It should be noted that one of the general methods for solving inverse problems of dynamics in the class of ordinary differential equations, namely, the quasi-inversion method was proposed in [3].

Inverse problems of dynamics in the class of partial differential equations are studied in [12-14], and in the class of stochastic differential equations in [15-19].

1 Stochastic reconstruction problem

Let us consider the general reconstruction problem in the class of second-order Ito stochastic differential equations by the given properties of motion, when the control is included in the drift coefficient. And by the quasi-inversion method we define the form of control parameters that provides necessary and sufficient conditions for the existence of a given integral manifold. Further, the solution of Meshchersky's stochastic problem is given, which is one of the inverse problems of dynamics and it belongs to reconstruction problem according to the well-known Galiullin's classification of [1].

1.1 Problem statement. Let us consider the second-order Ito stochastic differential equation

$$\ddot{x} = f(x,\dot{x},t) + D(x,\dot{x},t)u + \sigma(x,\dot{x},t)\dot{\xi}. \tag{1.1}$$

It is required to determine the vector-function $u = u(x,\dot{x},t) \in R^r$ included in the drift coefficient for the given integral manifold

$$\Lambda(t): \lambda(x,\dot{x},t) = 0, \quad \lambda = \lambda(x,\dot{x},t) \in C^{121}_{x\dot{x}t}, \quad \lambda \in R^m, \tag{1.2}$$

here $C^{121}_{x\dot{x}t}$ is set of $\gamma(x,\dot{x},t)$ functions, which are continuously differentiable with respect to x and t and twice continuously differentiable with respect to $\dot{x}$.

In other words, for the given f, D, σ and λ, the control u should be defined so that the set (1.2) is the integral set of equation (1.1).

It is assumed that the functions $f(x,\dot{x},t)$, $D(x,\dot{x},t)$, $\sigma(x,\dot{x},t)$, included in the above equation, have the smoothness necessary for further reasoning and satisfy the existence and uniqueness theorem up to stochastic equivalence of the solution $(x(t)^T, \dot{x}(t)^T)^T$ of (1.1) with the initial condition $(x(t_0)^T, \dot{x}(t_0)^T)^T = (x_0{}^T, \dot{x}_0{}^T)^T$, which is continuous strictly Markov process with probability 1 [20].

Here $\{\xi_1(t,\omega),\ldots,\xi_k(t,\omega)\}$ is a system of random processes with independent increments, which, following [19], can be represented as a sum $\xi = \xi_0 + \int c(y)P^0(t,dy)$ of processes Wiener process ξ_0 and Poisson process P^0. $P^0(t,dy)$ is the number of process P^0 jumps in the interval [0, t] that fall on the set dy; $c(y)$ is a vector function that maps space R^{2n} into the space R^k of values of process $\xi(t)$ for any t.

This problem is one of the inverse problems of dynamics, and in the absence of random perturbations $(\sigma \equiv 0)$ it has been sufficiently fully investigated in [1-6], and the case $\sigma \neq 0$ and $\{\xi_1(t,\omega),\ldots,\xi_k(t,\omega)\}$ is a system of independent Wiener processes, as a particular form of processes with independent increments, is considered in [21].

In this paper, the quasi-inversion method is used to solve the stochastic recovery problem [3, p. 12].

By Ito rule of stochastic differentiation [20, p.204] for solving the posed problem the equation of perturbed motion

$$\dot{\lambda} = \frac{\partial\lambda}{\partial t} + \frac{\partial\lambda}{\partial x}\dot{x} + \frac{\partial\lambda}{\partial\dot{x}}f + \frac{\partial\lambda}{\partial\dot{x}}Du + \frac{\partial\lambda}{\partial\dot{x}}\sigma\dot{\xi}_0 + S_1 + S_2 + S_3, \tag{1.4}$$

is compiled. Here $S_1 = \frac{1}{2}\frac{\partial^2\lambda}{\partial\dot{x}^2} : \sigma\sigma^T$; $S_2 = \int[\lambda(x,\dot{x}+\sigma c(y),t) - \lambda(x,\dot{x},t) - \frac{\partial\lambda}{\partial x}\sigma\dot{x}c(y)]dy$;

$S_3 = \int[\lambda(x,\dot{x}+\sigma c(y),t) - \lambda(x,\dot{x},t)]\dot{P}_0(t,dy)$. Following [20], $\frac{1}{2}\frac{\partial^2\lambda}{\partial\dot{x}^2} : D$ is a vector whose elements are the traces of the products of the matrices of the second derivatives of the corresponding elements $\lambda_\mu(x,\dot{x},t)$ of the vector $\lambda(x,\dot{x},t)$ with respect to components $\dot{x}$ by the matrix D

$$\frac{\partial^2\lambda}{\partial\dot{x}^2} : D = \begin{bmatrix} tr\left(\frac{\partial^2\lambda_1}{\partial\dot{x}^2}D\right) \\ \vdots \\ tr\left(\frac{\partial^2\lambda_m}{\partial\dot{x}^2}D\right) \end{bmatrix}, \; D = \sigma\sigma^T.$$

We introduce arbitrary Erugin functions [1]: an m-dimensional vector function A and a $(m\times k)$-matrix B, with the properties $A(0,x,\dot{x},t)\equiv 0,\ B(0,x,\dot{x},t)\equiv 0,$ such that

$$\dot{\lambda}=A(\lambda,x,\dot{x},t)+B(\lambda,x,\dot{x},t)\dot{\xi}, \tag{1.5}$$

takes place. Here ξ is the same process with independent increments included in (1.1) and represented as a sum of Wiener process and Poisson process [20]:

$\xi=\xi_0+\int c(y)P^0(t,dy)$ or $\dot{\xi}=\dot{\xi}_0+\int c(y)\dot{P}^0(t,dy).$

Based on equations (1.4) and (1.5), we obtain the relations

$$\frac{\partial\lambda}{\partial\dot{x}}Du=A-\frac{\partial\lambda}{\partial t}-\frac{\partial\lambda}{\partial x}\dot{x}-\frac{\partial\lambda}{\partial\dot{x}}f-S_1-S_2-S_3, \tag{1.6}$$

$$\frac{\partial\lambda}{\partial\dot{x}}\sigma=B, \tag{1.7}$$

from which you need to determine the control u and the matrix σ. To solve the problem, you need the following lemma.

Lemma 1[3, p.12-13]. The set of all solutions of a linear system

$$H\vartheta=g,\quad H=\left(h_{\mu\nu}\right),\quad \vartheta=(\vartheta_\nu),\quad g=(g_\mu),\quad \mu=\overline{1,m},\quad \nu=\overline{1,n},\quad m\le n, \tag{1.8}$$

is determined by the expression

$$\vartheta=s\left[H\,C\right]+H^{+}g. \tag{1.9}$$

Here H is matrix has rank m. s is arbitrary scalar, $\left[H\,C\right]=\left[h_1\ldots h_m\ c_{m+1}\ldots c_{n-1}\right]$ is the cross product of vectors $h_\mu=\left(h_{\mu\nu}\right)$ and $c_\rho=(c_{\rho\nu}),\ \rho=\overline{m+1,n-1};\ H^{+}=H^T\left(HH^T\right)^{-1},\ H^T$ is the matrix transposed to H.

Denoting, by formula (1.9) of Lemma 1 from relations (1.6), (1.7), we define the required vector - function and columns, matrices in the form:

Denoting $\widetilde{D}=\dfrac{\partial\lambda}{\partial\dot{x}}D$, by formula (1.9) from (1.6), (1.7) we define the required vector – function u and columns $\sigma_i,\ i=\overline{1,k}$ of σ in the form :

$$u=s_1\left[\widetilde{D}C\right]+\left(\widetilde{D}\right)^{+}\left(A-\frac{\partial\lambda}{\partial t}-\frac{\partial\lambda}{\partial x}\dot{x}-\frac{\partial\lambda}{\partial\dot{x}}f-S_1-S_2-S_3\right), \tag{1.10}$$

$$\sigma_i=s_2\left[\frac{\partial\lambda}{\partial\dot{x}}C\right]+\left(\frac{\partial\lambda}{\partial\dot{x}}\right)^{+}B_i,\quad i=\overline{1,k}. \tag{1.11}$$

Therefore, the following theorem is true.

Theorem 1.1 A necessary and sufficient condition that second-order Ito differential equation (1.1) has a given integral manifold (1.2) is that the control function u has the form (1.10) and the columns σ_i of diffusion matrix σ have the form (1.11).

Remark 1.1 If $c(y)\equiv 0,$ then $S_2\equiv S_3\equiv 0$ and a solution of this problem coincides with the solution of the reconstruction problem previously considered in [21] in the presence of random perturbations from the class of independent Wiener processes.

Remark 1.2 For $m=n$, formula (1.9) takes the form $\vartheta=H^{-1}g,$ since in this case, the first term of the formula as a cross product of n vectors in $n-$dimensional space identically equals to zero $\left[H\,C\right]\equiv 0$, and the second term $H^{+}g$ takes the form $H^{-1}g$, since for $m=n$, the rectangular matrix H becomes square matrix, and under the assumption $\det H\neq 0$ we have $H^{+}=H^T\left(HH^T\right)^{-1}=H^T(H^T)^{-1}H^{-1}=H^{-1}.$

1.2 The linear case of a stochastic problem with drift control. Let a second-order Ito stochastic differential equation, linear in drift

$$\ddot{x} = E_1(t)x + E_2(t)\dot{x} + D(t)u + l_1(t) + T(t)\dot{\xi} \tag{1.12}$$

be given. It is required the control vector-function $u = u(x,\dot{x},t) \in R^r$ by given integral manifold

$$\Lambda(t): \lambda \equiv G_1 x + G_2 \dot{x} + l_2(t) = 0. \tag{1.13}$$

That is, by the given $(m \times n)$-matrices $G_1(t), G_2(t)$ of the m-dimensional function $l(t)$, also by the given $(n \times n)$-matrices $E_1(t), E_2(t)$, $(n \times r)$-matrix $D(t)$ and n-dimensional function $l_1(t)$, it is required to determine the vector function $u = u(x,\dot{x},t) \in R^r$ and $(n \times k)$-matrix $T(t)$ so that for the constructed equation (1.12) the given properties (1.13) are an integral manifold.

In this problem the equation of perturbed motion (1.4) has the form

$$\dot{\lambda} = \dot{G}_1 x + \dot{G}_2 \dot{x} + \dot{l}_2(t) + \dot{G}_1 \dot{x} + G_2\left(E_1(t)x + E_2(t)\dot{x} + D(t)u + l_1(t)\right) + G_2 T \dot{\xi}_0. \tag{1.14}$$

On the other hand, following Erugin's method with the help of an arbitrary vector-function $A = A_1(t)\lambda$ and a matrix-function B_1 with the property $B_1(0,x,\dot{x},t) \equiv 0$, we have

$$\dot{\lambda} = A_1(t)\lambda + B_1(\lambda, x, \dot{x}, t)\dot{\xi}. \tag{1.15}$$

Hence, relations (1.14) and (1.15) imply the equalities

$$\begin{cases} G_2 D u = \left[A_1 G_1 - \dot{G}_1 - G_2 E_1\right]x + \left[A_1 G_2 - G_2 - G_1 - G_2 E_2\right]\dot{x} + A_1 l_2 - G_2 l_1 - \dot{l}_2, \\ G_2 T = B_1. \end{cases} \tag{1.16}$$

Further, from (1.16) using Lemma 1, we have

$$u = s_1\left[D_1 C\right] + \left(D_1\right)^+ g_1, \tag{1.17}$$

$$T_i = s_2\left[G_2 C\right] + \left(G_2\right)^+ B_i, \quad i = \overline{1,k}, \tag{1.18}$$

here $D_1 = G_2 D$, $g_1 = \left[A_1 G_1 - \dot{G}_1 - G_2 E_1\right]x + \left[A_1 G_2 - G_2 - G_1 - G_2 E_2\right]\dot{x} + A_1 l_2 - G_2 l_1 - \dot{l}_2$, T_i, B_i are i-th columns of matrices T and B respectively. s_1, s_2 are arbitrary scalar values. This proves the following theorem.

Theorem 1.2. A necessary and sufficient condition that second-order Ito stochastic differential equation (1.12) linear in drift, has a given linear integral manifold (1.2) is that the control parameter has the form (1.17) and the diffusion matrix has the form (1.18).

Remark 1.2. In the linear case, in contrast to the nonlinear one $S_1 \equiv S_2 \equiv S_3 \equiv 0$, the conditions of solvability in Theorem 1.2 in the presence of random perturbations from the class of processes with independent increments coincide with the conditions of solvability in a similar linear case in the presence of random perturbations from the class of independent Wiener processes [21].

1.3 Scalar case of the reconstruction problem with drift controls. *Let a second-order Ito stochastic differential equation*

$$\ddot{x} = f_2(x,\dot{x},t) + \gamma_1(x,\dot{x},t)u_1 + \gamma(x,\dot{x},t)\dot{\xi}. \tag{1.20}$$

be given. It is required to determine the scalar function $u_1 = u_1(x,\dot{x},t)$ for a given integral manifold

$$\lambda_2(x,\dot{x},t) = 0, \quad \lambda_2 \in R^1. \tag{1.21}$$

In other words, for given f_2, γ, γ_1 and λ_2 define the control parameter u_1 in such a way that the set (1.21) be an integral set of equation (1.20).

According to the rule of stochastic differentiation, we compose the equation

$$\dot{\lambda}_2 = \frac{\partial \lambda_2}{\partial t} + \frac{\partial \lambda_2}{\partial x}\dot{x} + \frac{\partial \lambda_2}{\partial \dot{x}} f_2 + \frac{\partial \lambda_2}{\partial \dot{x}}\gamma_1 u_1 + \widetilde{S}_1 + \widetilde{S}_2 + \widetilde{S}_3 + \frac{\partial \lambda_2}{\partial \dot{x}}\gamma\dot{\xi}_0, \tag{1.22}$$

of perturbed motion; here

$$\widetilde{S}_1 = \frac{1}{2}\frac{\partial^2 \lambda_2}{\partial \dot{x}^2}\gamma^2,\ \ \tilde{S}_3 = \int [\lambda_2(x, \dot{x} + \gamma c(y), t) - \lambda_1(x, \dot{x}, t)] dP^0(t, dy),$$

$$\widetilde{S}_2 = \int [\lambda_2(x, \dot{x} + \gamma c(y), t) - \lambda_2(x, \dot{x}, t) - \frac{\partial \lambda_2}{\partial \dot{x}}\gamma\, c(y)] dy.$$

We introduce arbitrary Erugin's scalar functions $a = a(\lambda_2, x, \dot{x}, t)$ and $b = b(\lambda_2, x, \dot{x}, t),$ with the properties $a(0, x, \dot{x}, t) \equiv b(0, x, \dot{x}, t) \equiv 0$ and such that

$$\dot{\lambda}_2 = a(\lambda_2, x, \dot{x}, t) + b(\lambda_2, x, \dot{x}, t)\dot{\xi},\ (1.23)$$

In view of (5.3) and (5.4), we arrive at the relations

$$\frac{\partial \lambda_2}{\partial x}\gamma_1 u_1 = a - \frac{\partial \lambda_2}{\partial t} - \frac{\partial \lambda_2}{\partial x}\dot{x} - \frac{\partial \lambda_2}{\partial \dot{x}} f_2 - \widetilde{S}_1 - \widetilde{S}_2 - \widetilde{S}_3, \tag{1.24}$$

$$\frac{\partial \lambda_2}{\partial x}\gamma = b. \tag{1.25}$$

Then, by virtue of equalities (1.24) and (1.25), the control parameter u_1 and the diffusion coefficient are defined in the form

$$u_1 = \left(\frac{\partial \lambda_2}{\partial \dot{x}}\gamma_1\right)^{-1}\left[a - \frac{\partial \lambda_2}{\partial t} - \frac{\partial \lambda_2}{\partial x}\dot{x} - \frac{\partial \lambda_2}{\partial \dot{x}} f_2 - \frac{1}{2}\frac{\partial^2 \lambda_2}{\partial \dot{x}^2}\gamma^2 - \widetilde{S}_2 - \widetilde{S}_3\right], \tag{1.26}$$

$$\gamma = \left(\frac{\partial \lambda_2}{\partial \dot{x}}\right)^{-1} b. \tag{1.27}$$

Consequently, the following theorem holds.

Theorem 1.3 A necessary and sufficient condition that second-order scalar differential equation of Ito type (1.20) has a given integral manifold (1.21) is that the control parameter u_1 has the form (1.26) and diffusion coefficient has the form (1.27).

Thus, in Section 1, we obtained necessary and sufficient conditions for the solvability of the reconstruction problem with drift control in the presence of random perturbations from the class of processes with independent increments in general nonlinear case, linear case and scalar nonlinear case. The considered setting generalizes the reconstruction problem in the presence of random perturbations from the class of independent Wiener processes, previously studied in [21].

2 Meshchersky's stochastic problem

Problem statement. Find the law of change in the mass of a point, at which it describes a given trajectory under the action of given external forces [22, p.19].

Let us consider the problem of realizing the motion of a heavy point of variable mass $m(t)$ in a homogeneous gravity field, namely, vertical ascent according to the laws of change in the range y and height z

$$\Lambda(t):\ \begin{cases} \lambda_1(t) \equiv y - \varphi(t) = 0, \\ \lambda_2(t) \equiv z - \psi(t) = 0, \end{cases} \tag{2.1}$$

The equations of point motion [1, c.16-17] taking into account the action of random perturbing forces have the following form:

$$\begin{cases} m\ddot{y} = \dot{m}(\mu - 1)\dot{y} - mf(z, v)\dfrac{\dot{y}}{v} - \sigma_1(y, z, t)\dot{\xi}, \\ m\ddot{z} = \dot{m}(\eta - 1)\dot{z} - mf(z, v)\dfrac{z}{v} - mg - \sigma_2(y, z, t)\dot{\xi}, \end{cases} \tag{2.2}$$

here $f(z,v)$ is medium resistance per unit mass; $v=\sqrt{\dot{y}^2+\dot{z}^2}$ is point speed; $\mu=\mu(t)$, $\nu=\nu(t)$ are the ratio of the projections of the velocities of the changing mass and the mass of the point itself on the coordinate axis *y*, *z*.

It is required to restore the equations of motion (2.2) (that is, to determine the laws of variation of quantities μ, ν and m) so that they admit a given particular motion (2.1).

The perturbed motion equations have the form

$$\begin{cases} \ddot{\lambda}_1 \equiv \ddot{y}-\ddot{\varphi}(t)=\dfrac{\dot{m}}{m}(\mu-1)\dot{y}-f(z,v)\dfrac{\dot{y}}{v}-\dfrac{\sigma_1}{m}\dot{\xi}-\ddot{\varphi}(t), \\ \ddot{\lambda}_2 \equiv \ddot{z}-\ddot{\psi}(t)=\dfrac{\dot{m}}{m}(\eta-1)\dot{z}-f(z,v)\dfrac{\dot{z}}{v}-g-\dfrac{\sigma_2}{m}\dot{\xi}-\ddot{\psi}(t). \end{cases} \tag{2.3}$$

Further, following Erugin's method [7], we introduce functions $A_1=A_1(\lambda_1,\dot{\lambda}_1,\lambda_2,\dot{\lambda}_2,y,z,t)$, $A_2=A_2(\lambda_1,\dot{\lambda}_1,\lambda_2,\dot{\lambda}_2,y,z,t)$, $B_1=B_1(\lambda_1,\dot{\lambda}_1,\lambda_2,\dot{\lambda}_2,y,z,t)$, $B_2=B_2(\lambda_1,\dot{\lambda}_1,\lambda_2,\dot{\lambda}_2,y,z,t)$, With the properties $A_1(0,0,0,0,y,z,t)\equiv A_2(0,0,0,0,y,z,t)\equiv B_1(0,0,0,0,y,z,t)\equiv$ $\equiv B_2(0,0,0,0,y,z,t)\equiv 0$, and such that

$$\begin{cases} \ddot{\lambda}_1 = A_1 + B_1\dot{\xi}, \\ \ddot{\lambda}_2 = A_2 + B_2\dot{\xi}. \end{cases} \tag{2.4}$$

Comparison of the systems of equations (2.3) and (2.4) leads, if we exclude strictly vertical and strictly horizontal motions (i.e., $\dot{\varphi}$ and $\dot{\psi}$ are not identically zero), to relations that solve the posed Meshchersky stochastic problem

$$\begin{cases} \mu = 1+\dfrac{m}{\dot{m}}\left[\dfrac{A_1}{\dot{y}}+\dfrac{f}{v}+\dfrac{\ddot{\varphi}}{\dot{y}}\right], \\ \eta = 1+\dfrac{m}{\dot{m}}\left[\dfrac{A_2}{\dot{z}}+\dfrac{f}{v}+\dfrac{g}{\dot{z}}+\dfrac{\ddot{\psi}}{\dot{y}}\right], \\ \sigma_{1j} = mB_{1j}, \\ \sigma_{2j} = mB_{2j}. \end{cases} \tag{2.5}$$

In particular, for $\sigma_{ij}\equiv 0$ $(i,j=1,2)$ and $A_1\equiv A_2\equiv B_1\equiv B_2\equiv 0$ conditions (2.5) coincide with conditions in the class of second-order ordinary differential equations [1, p. 17].

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КЕРІ СТОХАСТИКАЛЫҚ ҚАЛПЫНА КЕЛТІРУ ЕСЕБІ ТУРАЛЫ

Аннотация. Аталмыш жұмыста жалпы қалпына келтіру есебі қозғалыс қасиеттері бойынша басқару қирату коэффициентіне кіргенде екінші ретті Ито түріндегі берілген стохастикалық дифференциалдық теңдеулер класында қарастырылады және квазиқайтару әдісімен интегралдық көпбейненің қажетті әрі жеткілікті шарттарын қамтамасыз ететін басқарушы параметрлер түрі анықталады. Төменде Мещерскийдің

стохастикалық есебінің шешімі келтірілген, ол динамиканың кері есептерінің бірі болып табылады және Галиуллиннің белгілі классификациясына сәйкес қалпына келтіру міндетіне жатады.

Кездейсоқ бұзылулар тәуелсіз өсуі бар процестер класына жатады деп болжанады. Берілген мәселені шешу үшін ИТО стохастикалық саралау ережесі бойынша бұзылған қозғалыс теңдеуі жасалады. Бұдан әрі еругин әдісі квазиқайтару әдісімен біріктіріліп құрылады: 1) басқарушы вектор-функциялар жиыны; 2) Ито типінің екінші ретті берілген дифференциалдық теңдеудің берілген интегралдық көпбейне ие болуы үшін қажетті және жеткілікті жағдайларды қамтамасыз ететін диффузия матрицаларының жиынтығы.

Бұзу басқармасы бар стохастикалық мәселенің сызықтық жағдайы бөлек қарастырылады. Сызықтық қойылымда сызықтық емес рұқсат ету жағдайынан айырмашылығы, тәуелсіз өсуі бар процестер класынан кездейсоқ бұзылулар болған кезде, ұқсас сызықтық жағдайда, тәуелсіз винер процестері класынан кездейсоқ бұзылулар болған кезде рұқсат ету шарттарына сәйкес келеді. Сондай-ақ, бұзу басқармаларымен қалпына келтіру мәселесінің скалярлық жағдайы қарастырылады.

Түйін сөздер: ИТО-ның стохастикалық дифференциалдық теңдеуі, қалпына келтіру есебі, Мещерский есебі, интегралдық көпбейне, квазиқайтару әдісі.

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ОБ ОБРАТНОЙ СТОХАСТИЧЕСКОЙ ЗАДАЧЕ ВОССТАНОВЛЕНИЯ

Аннотация. В данной работе рассматривается общая задача восстановления в классе стохастических дифференциальных уравнений второго порядка типа Ито по заданным свойствам движения, когда управление входит в коэффициент сноса и методом квазиобращения определяется вид управляющих параметров, обеспечивающий необходимые и достаточные условия существования заданного интегрального многообразия. Далее приводится решение стохастической задачи Мещерского, которая является одной из обратных задач динамики и по известной классификации Галиуллина относится к задаче восстановления.

Предполагается, что случайные возмущения относятся к классу процессов с независимыми приращениями. Для решения поставленной задачи по правилу стохастического дифференцирования Ито составляется уравнение возмущенного движения. И далее методом Еругина в сочетании с методом квазиобращения строятся: 1) множество управляющих вектор-функций и 2) множество матриц диффузий, которые обеспечивают необходимые и достаточные условия того, чтобы заданное дифференциальное уравнение второго порядка типа Ито имело заданное интегральное многообразие.

Отдельно рассматривается линейный случай стохастической задачи с управлением по сносу**.** В линейной постановке в отличие от нелинейной условия разрешимости при наличии случайных возмущений из класса процессов с независимыми приращениями совпадают с условиями разрешимости в аналогичном линейном случае при наличии случайных возмущений из класса независимых винеровских процессов. Также рассмотрен скалярный случай задачи восстановления с управлениями по сносу.

Ключевые слова: стохастическое дифференциальное уравнение Ито, задача восстановления, задача Мещерского, интегральное многообразие, метод квазиобращения.

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MODERN TOOLS FOR INFORMATION SECURITY SYSTEMS

Abstract. Efficiency of business processes in modern organizations depends on the capabilities of applied information technologies. The article describes and analyzes the role and features of audit tools and other methodological tools and models in ensuring the quality and security of information systems. The standard's principles are reviewed, as well as the importance of meeting business needs. In order to protect virtual values in a company's system environment, the importance of using information security models is revealed. Practical proposals in risk management and information security in information technology are analyzed through the COBIT standard.

Measures for protecting the information system of an organization from accidental, deliberate or fake threats are considered. The possibility of using one of the real information security models by the information recipient or provider in accordance with the requirements of external processes is reported.

Furthermore, in connection with increase in the number of attack methods and techniques and development of their new tools and vectors, the need to improve and ways to ensure information security are being considered.

The essential tasks of security audit are considered, and the stages of their implementation are described. With regard to security of information systems, an analytical model is proposed for determining vulnerability's numerical value.

Key words: COBIT methodology, ITIL library, ISO 20000 standard, information technology, information audit, information security, risk, vulnerability, COBIT ® 2019 Framework.

Digital technology advances automate everything from all social areas of society to the activities of large industrial organizations, including active implementation in the businesses, increased introduction of innovations in general. However, justifying the costs spent on them, rational budget planning for the development of information technologies in organizations and self-completion of new introduced IS in terms of functionality, and the process of improving the quality of control of the (digital) trend of digitalization – such events create the need to audit its IT and increase its relevance.

Although generally, the basis of the IT structure depends on the software, it is largely dependent on technology means, moreover, trends in development, introduction, application, maintenance, etc. require implementation through efficient solutions, which, in turn, requires information technology competence and knowledge to support various regulatory requirements.

Therefore, a number of ITIL libraries, COBIT methodology, ISO 20000 service management standards for managing information services and ensuring their security is applied on the IT market.

Concurrently, the COBIT (Control Objectives for Information and related Technology) methodology which was developed and proposed by ISACA in 1992, is a tool that is necessary directly for the IT audit service, which will gain demand on the modern IT market [1,2]. This abbreviation stands for a set of documents that define the principles of information technology management and audit.

The emergence and formation of this methodology can be described using figure 1 [3.4].

Today, the enhanced COBIT Version 5 standard greatly impacts improvements to meet the requirements of the information technology market, especially large institutions and risk management. As A.V. Repin indicated this, based on the works [1,5], this can be justified by the following principles:

1. Focus on meeting the needs of related party;
2. Coverage of all activities of an enterprise;

3. Reliance on the application of a single integration structure;
4. Ability to implement a seamless method;
5. Its focus on the separation of IT management from management in an institution.

Table 1 – Evolutionary stages of CobiT standards

Years	Versions	Name
1996	CobiT 1	Audit
1998	CobiT 2	Control
2000	CobiT 3	Management
2005/2007	CobiT 4	Information Technology Management
2012	CobiT 5	Company information technology management
2018	COBIT ® 2019	ENTERPRISE GOVERNANCE OF INFORMATION AND TECHNOLOGY (EGIT)

The COBIT standard, which has passed the indicated stages of development, is a combination of about 40 international standards of control, audit and management, information security. In other words, the COBIT standard is based on the generally accepted method, the BSC balanced scorecard, the improved SEI CMM/CMMI model, PMBoK (project management methodology) and the methods of PRINCE2, TickIT, ITIL® and other standards [5,6]. After Version 5, the COBIT ® 2019 Framework: Governance and Management Objectives version covering the ITIL, CMMI and TOGAF structures [7] is now applied more rationally. It is processed as a methodology for management and governance of corporate information and technologies that fully support institutions, and is aimed at managing this information, its security and risks.

Its principle lies in formation of compatibility of mutual understanding between management on the way to achieving the key business goals and IT service, as well as elimination of possible discrepancies. In this regard, a company operating in the COBIT electronic environment offers its managers, users of information systems and related auditors a set of measurements, trends and top practices approved to increase the benefits of information technology, and also creates IT guidelines and rules for a specific company and helps to rationally control the activities.

COBIT predicts which information in information technology management is reliable to achieve the most effective business goals of a company. Along with that, COBIT describes the relationship between business strategy and information technology, subsequently defines and supports IT values and implements control measures. The essential task is that information technologies should fully support and actively increase the competitive advantages defined in a company's strategy and, through the advancement of business requirements for information for the timely rationalization of costs, participate in building its prerequisites. According to this standard, having turned into a business tool, IT presents practical proposals for risk management and information security systems in IT.

In accordance with requirements of the Approach to Information Technology Management international standard (Cobit), the information system verification procedure consists of four stages:

- identification and documentation (planning and organization);
- management mechanisms assessment;
- identity test;
- detailed testing.

When describing the information security system in any institution, protection measures against accidental, intentional or fake threats to its information system based on such widespread information security properties as confidentiality, integrity, and availability [8] are also considered. To do this, regarding external processes requirements the information recipient and/or provider can apply one of the following models: CVSS3.1., Investigation Process, Diamond, Cyber Kill Chain, etc.

If the property of information security means a restriction in access to hidden indicators in the military industry, financial indicators in the economic industry, or to patient data in the medical industry, then the integrity property ensures the exclusion of a violation of reliability and authenticity of

information. The last property ensures unhindered use of any information available to the users of the information system at any time.

Therefore, in the course of reliable use of IS in an institution, the problem of correct choice of the necessary methodological tool arises, which can be solved through the management and control system.

On the practical side, this not only solves information technology problems, but also can ensure that the business needs are met. One of the key values of a company's system environment is virtual value, i.e., information sources in the form of intellectual property need to be protected and secured. For example, there is a need to use MITER ATT&CK (arising from the attacker's point of view) [11], CIA (Confidentiality-Integrity-Availability) models, since the security vulnerability of information systems might allow attacks. Thus, in a virtual environment, one of the ways to remotely use a company assets - the Papa Smurf attack, causes vulnerability of the network receiving ping packets and interferes with its conductive ability. Another attacked called SYN Flood is the action of server's TCP connections half-open on the server and its consequences lead to the closure of access to the server for legal users. Besides, attacking methods and techniques are being improved, as well as their new tools and vectors are being developed.

The main tasks of security audit are:

- Analysis of the risks associated with the likelihood of a threat to the security of IS resources;
- Assessment of the current level of IP security;
- Localization of narrow paths in IP security system;
- Assessment of IS compliance with standards applied in information security;
- Introduction of new techniques for IS security and development of proposals to improve current profitability.

In this regard, when performing these tasks, the IS security audit covers a number of the following stages such as:

- Conduct of a survey;
- Collection of information;
- Analysis of received data;
- Development of proposals;
- Preparing a survey report.

Security audit methods can be based on risk analysis, application of information security standards, or a combination thereof.

The risk magnitude is determined depending on the cost of resources, the likelihood of a threat and the scope of vulnerability based on the following formula [12]:

$$R = \frac{(p*d)}{v}, \quad (1)$$

where R – risk; p – fund cost; d – threat probability; v – vulnerability value.

The goal of risk management is to select proper countermeasures in order to reduce risk levels to a favorable level. While the cost of implementing countermeasures should not exceed the amount of the possible loss. The difference between the cost of countermeasures and the amount of possible damage should be directly proportional to the likelihood of damage.

The vulnerability v magnitude is defined as the probability of inability of the protected item to resist actions of the threat sources, and if the force used from the threat source is stronger than the ability of the protected item to withstand it, then vulnerability v appears. In actual practice, it can arise through factors such as the likelihood of the threat and the level of protective measures. In this case, the vulnerability v magnitude can be determined using the following expression:

$$v = \frac{\sum_{i=1}^{n} P(U_i)}{Z} \quad (2)$$

where $P(U_i)$ – expected threat probability; $i = \overline{1,n}$; – number of expected threats; Z – strength of security $(0 < Z \leq 1)$.

While using this expression and calculating the binding of numerical values with qualitative properties can performed using the following table 2 [13].

Table 2 – Asset value, risk and vulnerability levels

The degree of probability of occurrence of threats		Low			Average			High		
Value of assets	0	0	1	2	1	2	3	2	3	4

The growth of riskiness with an increase in the vulnerability magnitude is determined and analyzed through an audit from a legislative point of view. As a result of the analysis, measures to prevent riskiness should be proposed.

Thereby, the methodology for assessing the quality of IT activity management in relation to business processes in a company is based on the abovementioned ITIL library, COBIT methodology and ISO 20000 standards according to service management through information technology. Its results affect the efficient management of information security using the abovementioned security models.

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АҚПАРАТТЫҚ ҚАУІПСІЗДІКТІ ҚАМТАМАСЫЗ ЕТУДІҢ ҚАЗІРГІ ЖАБДЫҚТАРЫ

Аннотация. Қазіргі ұйымдардағы бизнес-үдерістердің тиімді жүргізілуі онда қолданылатын ақпараттық технология мүмкіндіктеріне тікелей тәуелді. Мақалада ақпараттық жүйе сапасын, қауіпсіздігін қамтамасыз етудегі аудит жабдықтарының орны мен ерекшеліктері және басқада да әдістемелік жабдықтар, модельдер сипатталып, талданған.

Қазіргі қолданыстағы COBIT (ақпаратты және оған қатысты технологияларды бақылау нысандары) әдістемесінің ақпараттық технология нарығындағы сұранысқа ие болатын ақпараттық аудит қызметіне тікелей қажетті құрал екендігі сипатталады.

COBIT стандартының принциптеріне шолу жасалып, сонымен қатар оның бизнес қажеттіліктерін қанағаттандырудағы маңыздылығы негізделеді. Компанияның желілік ортасындағы виртуалды құндылықтарды қорғау мақсатында оған ақпараттық қауіпсіздік модельдерін қолдану маңызы баяндалады. COBIT стандарты арқылы ақпараттық технологиялардағы тәуекелдерді басқару мен ақпараттық қауіпсіздік жүйесін басқару-дағы тәжірибелік ұсыныстар талданады.

Мекемедегі ақпараттық жүйені кездейсоқ немесе қасақана, жасанды қателіктен сақтау немесе қорғау шаралары қарастырылады. Ол үшін ақпаратты қабылдаушы немесе жеткізіп беруші сыртқы үдеріс талап-тарына сәйкес нақты ақпараттық қауіпсіздік модельдерінің бірін қолдануға болатыны баяндалады.

Сонымен қатар, шабуылдардың әдістері мен әдістерінің көбеюіне және олардың жаңа құралдары мен векторларының дамуына байланысты ақпараттық қауіпсіздікті жақсарту және қамтамасыз ету жолдары қарастырылады.

Қауіпсіздік аудитінің негізгі міндеттері қарастырылып, оны атқару кезеңдері баяндалады. Ақпараттық жүйелердегі қауіпсіздікке қатысты осалдық (увязимость) шамасының сандық мәнін табудың аналитикалық моделі ұсынылады.

Түйін сөздер: COBIT әдістемесі, ITIL кітапханасы, ISO 20000 стандарты, ақпараттық технология, ақпараттық аудит, ақпараттық қауіпсіздік, тәуекел, осалдық, COBIT ® 2019 Framework.

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СОВРЕМЕННЫЕ СРЕДСТВА ОБЕСПЕЧЕНИЯ ИНФОРМАЦИОННОЙ БЕЗОПАСНОСТИ

Аннотация. Эффективное ведение бизнес-процессов в современных организациях напрямую зависит от возможностей применяемых в них информационных технологий. В статье описываются и анализируются роль и особенности средств аудита, а также прочих методических средств и моделей в обеспечении качества, безопасности информационных систем.

Современная действующая методика COBIT (Формы контроля информации и смежных технологий) описывается как средство, необходимое непосредственно для информационной службы аудита, которая завоюет спрос на рынке информационных технологий.

Проводится обзор принципов стандарта, а также значение удовлетворения его бизнес-потребностей. В целях защиты виртуальных ценностей в системной среде компании ей излагается о значении использования моделей информационной безопасности. Посредством стандарта COBIT осуществляется анализ практических предложений в управлении рисками и системой информационной безопасности в информационных технологиях.

Рассматриваются мероприятия по охране или защите информационной системы в учреждении от случайных или умышленных, мнимых угроз. Сообщается о возможности использования получателем или поставщиком информации одной из моделей реальной информационной безопасности в соответствии с требованиями внешних процессов.

Кроме того, в связи с увеличением количества методов и приемов атак и разработкой их новых средств и векторов рассматривается необходимость совершенствования и путей обеспечения информационной безопасности.

Рассматриваются основные задачи аудита безопасности и излагаются этапы выполнения этих задач. В отношении безопасности в информационных системах предлагается аналитическая модель определения числового значения меры уявзимости.

Ключевые слова: методология COBIT, библиотека ITIL, стандарты ISO 20000, информационные технологии, информационный аудит, информационная безопасность, риск, уязвимость, COBIT ® 2019 Framework.

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DEVELOPMENT OF THE NEURAL NETWORK FOR SOLVING THE PROBLEM OF SPEECH RECOGNITION

Abstract. The article discusses a method for solving the problem of speech recognition on the example of recognizing individual words of a limited dictionary using a forward propagation neural network trained by the error back propagation method. The goal was to create a neural network model for recognizing the solution of individual words, analyze the training characteristics and behavior of the constructed neural network. Based on the input data and output requirements, a feedback neural network selected. To train the selected neural network model, a back propagation algorithm was chosen. The developed neural network demonstrated the expected behavior associated with learning and generalization errors. It found that even if the generalization error decreases as the learning sequence increases, the errors begin to fluctuate regardless of the introduction of a dynamic learning rate. The network sufficiently trained to meet the generalization error requirements, but there is stillroom to improve the generalization error. Practical results of training the constructed neural network at different sizes of the training sample presented.

Keywords: speech recognition, neural networks, error back propagation algorithm, learning, learning rate.

1. Introduction.

The task of speech recognition is one of the most urgent tasks of our time. Despite the fact that now there are many ready-made speech recognition systems based on various technologies, the problem of speech recognition not completely solved, since existing systems have certain disadvantages. In particular, the dependence of the system on access to data transmission facilities and insufficient recognition accuracy.

One of the promising directions in solving speech recognition problems is the use of artificial neural networks. Neural networks are widely used in solving various classes of pattern recognition problems due to their ability to generalize.

2. Source data of the task

Aspects of the construction and application of neural networks for solving the problem of speech recognition on the example of the problem of recognizing numbers from 1 to 9, i.e. the words "one", "two", "three", "four", "five", "six", "seven", "eight" and "nine", respectively. Since the sounds of human speech lie in the frequency range from 100 to 4000 Hz, to solve this problem, it is enough to use a sampling frequency of 11025 Hz to digitize speech signals. Using this frequency allows you to reduce the flow of audio data, while avoiding the loss of useful components of the signal. As part of the task, audio signals are represented by sets of frames, each of which contains 512 samples.

Based on the experimental analysis of audio recordings of various pronunciation variants of the studied words, the maximum duration of the useful signal was determined (figure 1), which was 1 s. Accordingly, the minimum set of frames covering the duration of the useful signal should consist of 20 frames. Missing samples of the original signal filled with zeros.

The results of the Fourier transform performed for each analyzed frame will used as input data for training the neural network. This approach allows you to analyze the signal both in the frequency domain (using the frame spectrum) and in the time domain - by splitting the original signal into frames. Since

significant information is contained in the real frequency spectrum, after performing the Fourier transform, the real spectrum of the signal is used, discarding the phase information (figure 2, b).

At the output of the neural network, a number is expected that is in the range from 1 to 9 and uniquely corresponds to its verbal representation submitted to the input of the neural network.

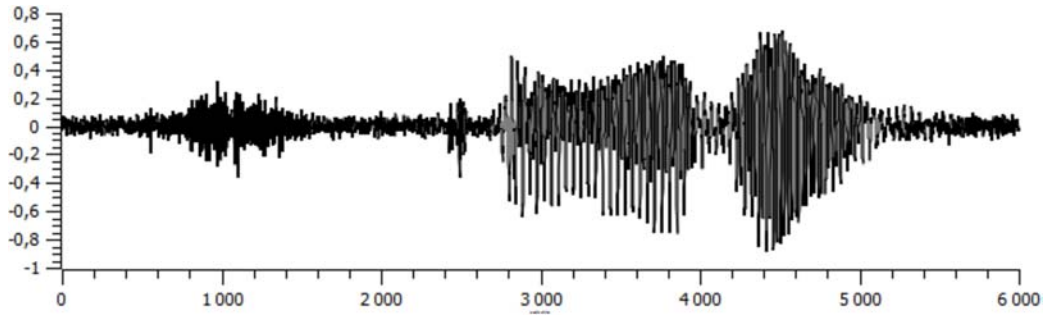

Figure 1 - Time diagram of the word «four»

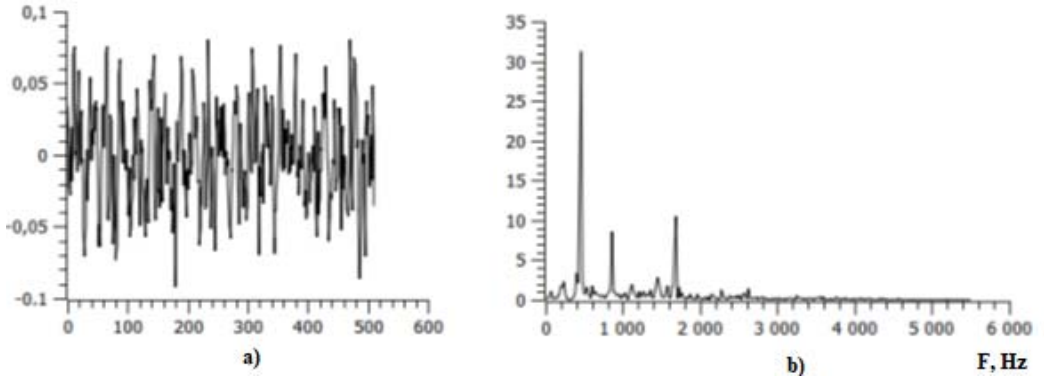

Figure 2 - The first frame of the signal "four":
a-time diagram; b-spectrum of the selected frame

3. Neural network approach to solving the problem

A neural network is a collection of connected and interconnected artificial neurons that accumulate input values and generate an output signal using the activation function. The work of a single neuron can be represented by the formula

$$y_j = F(\sum w_{ij} x_i), \quad (1)$$

where y_j – the output signal of j neuron; w_{ij} – the weight of the connection between i and j neurons; x_i – the output signal of i neuron; F – the activation function of the neuron [1].

Methods of connecting neurons in artificial neural networks determine the topology of the neural network. According to the structure of interneuron connections, two types of neural networks can be distinguished: direct propagation neural networks and recurrent neural networks. In direct propagation neural networks, the communication between layers is unidirectional – each neuron connected only to the neurons of the next layer. Such networks are static due to the lack of feedbacks and dynamic elements. The output of such a network depends only on the input data. Recurrent neural networks are dynamic, due to the presence of feedbacks. The output of a recurrent neural network depends on its previous state [2].

The topology of the neural network is selected directly for the analyzed problem, taking into account the features and complexity of its solution. Optimal configurations already exist for some types of tasks. However, if the problem cannot be reduced to any of the known types, it is necessary to synthesize a new configuration of the neural network directly for the problem solved. Since there is no general method for choosing the optimal configuration of a neural network, the structure of the neural network is selected experimentally.

The most obvious structure is the network of direct signal propagation, so named because the neurons of one layer can only be connected to the neurons of nearby layers without reverse and recurrent connections [3]. Typically, such networks consist of an input layer, one or more hidden layers, and an

output layer. The simplest structure of such a network is shown in figure 3. This network has one hidden layer, an input layer consisting of n neurons and an output layer consisting of m neurons.

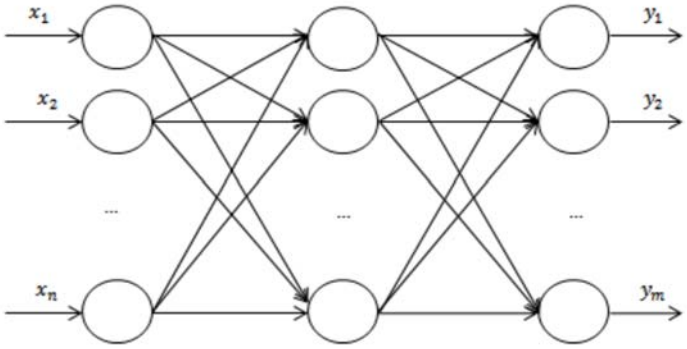

Figure 3 - Typical structure of a neural network

Using such a neural network, data are converted from an n-dimensional input space to an m-dimensional output space. The advantage of this type of neural networks is their relative simplicity and visibility, which allows you to analyze the operation of the neural network used. Based on the format of input and output data, a neural network of direct signal propagation will be used to solve the problem, the input layer of which contains such a number of neurons that corresponds to the number of analyzed features (that is, the number of frames multiplied by the number of analyzed spectral components) [4]. Recurrent neural networks cannot be used in the solution of the problem, as due to the presence of feedback output values of a recurrent neural network depends on the previous state of the network, and since spoken words within the tasks are not linked, the previous state of the network should not affect the recognition result.

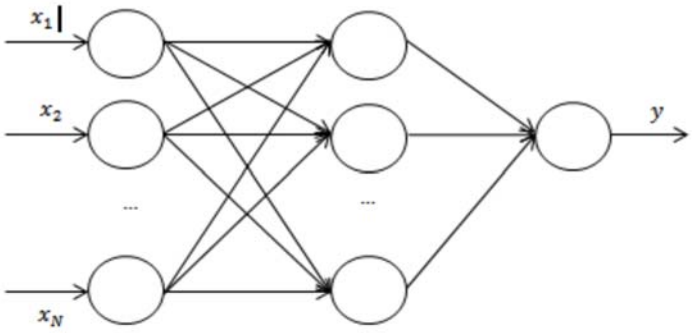

Figure 4 - The neural network structure used

To solve speech recognition problems, the most common solution is to use the number of neurons in the output layer that corresponds to the number of recognized objects. However, when solving this problem, the neural network architecture was chosen, which contains one neuron in the output layer, the output value of which is in the range from 0 to 1, which corresponds to the numbers from 1 to 9. The neural network used also has one hidden layer (figure 4).

After determining the topology of the neural network, you need to choose a learning algorithm. Neural network training can be done in two ways - with a teacher and without a teacher. When using training with a teacher, neural networks are represented by pairs of input and output data vectors, because of which the error is calculated and the weights of the neural network adjusted. The algorithm repeated until the neural network error reaches the required minimum value. In the case of unsupervised learning, the output data are not known in advance, so only the input data are used [5].

When choosing a training algorithm, it is necessary to take into account the topology of the neural network, the model of the analyzed data and the intended method of training the neural network. Since a forward propagation neural network chosen, the most well – known multi-layer perceptron learning algorithm, the error back propagation algorithm, will be used.

4. Training a neural network by back propagation of an error

The error back propagation algorithm involves calculating the error of both the output layer and each neuron of the trained network, as well as correcting the weights of the neurons in accordance with their current values. In the first step of this algorithm, the weights of all interneuron connections initialized to small random values (from 0 to 1). After initializing the weights, the following steps performed in the neural network training process:

- direct signal propagation;
- calculation of the error of neurons of the last layer;
- reverse propagation of the error [6].

Direct spread signal made in layers, starting with the input layer, in this case calculates the sum of the input signals for each neuron using an activation function to generate the response of a neuron that propagates in the next layer, weighted by interneuron connection according to the formula (1). T As a result of this step, a vector of output values of the neural network obtained.

The next stage of training is to calculate the neural network error as the difference between the expected and actual output values. The error is calculated for each neuron of the output layer according to the formula

$$\delta_k = (EXP_k - y_k)F'(y_k), \quad (2)$$

where δ_k – the received error of the k neuron of the output layer; EXP_k – the expected value for k output neuron; y_k – the actual output value of k neuron; $F'(y_k)$ – the derivative of the activation function of k neuron [7].

For subsequent layers of the neural network, the neuron error is calculated using the formula

$$\delta_k = F'(y_k) * \sum_{i=1}^{M} \delta_i w_{ki}, \quad (3)$$

where δ_k – received error for the k neuron; δ_i- error of the i neuron of the previous layer; w_{ki} – the weight connection between neuron k of the current layer and neuron i of previous layer; y_k – the actual output value of neuron k; $F'(y_k)$ – derivative of the activation function of neuron k; M – number of neurons of the previous layer [8].

The resulting error values propagate from the last, output layer of the neural network, to the first. In this case, the values of the correction of the weights of neurons calculated depending on the current value of the link weight, the learning rate and the error made by this neuron.

After completing this step, the steps of the described algorithm are repeated until the error of the output layer reaches the required value.

When correcting the weights of interneuron connections, the concept of learning rate is used. The learning rate of a neural network is one of the most important parameters that control the learning process. This parameter determines the amount of change in the weighting coefficients of interneuron connections. For a perfect approximation to the minimum error of the neural network, the learning rate should tend to an infinitesimal value to ensure the best convergence of the learning algorithm. However, the smaller the selected value of the learning step, the longer the learning takes place online [9].

In order to overcome these problems, the so-called dynamic learning rate is used. When using this method, the learning step is not a constant value, but depends on other parameters of the learning process (time, iteration number, or neuron error in the previous step). The dynamic learning rate can be introduced for each neuron of the network individually, or for the entire network as a whole.

The functions used to calculate the learning rate must have the following properties:

1) $Y(x) = 0$ for $x = 0$;
2) $Y(x) = MAX$ *at* $x \to \pm\infty$;
3) $Y(x) \to 0$ for $x \to 0$.

To work with the neural network, the following function is selected, reflecting the dependence of the learning rate of the neuron on the error value:

$$Y(x) = |MAX * (-CST * |x|)|, \quad (4)$$

where MAX – a constant that determines the maximum possible learning rate; x – the amount of error introduced by the neuron; CST – a constant that determines the degree of steepness of the resulting function. The function is represented by a graph in figure 5.

This function meets the specified requirements and provides the most optimal change in the learning rate. At the beginning of the learning process, the MAX parameter is set to the maximum value of the learning rate (in our case, MAX = 3), because of which, for large values of the learning error, changes in the weight coefficients will be significant. As the neuron error decreases, the learning rate will decrease, and as the learning error tends to zero, the learning rate will also tend to zero [10].

Thus, when solving the problem, dynamic control of the learning rate is implemented, in which the value of the learning step is calculated for each neuron separately, depending on the error made by this neuron. The introduction of this algorithm made it possible to more accurately approach to the minimum learning error of the neural network. When comparing the learning nature of a neural network with an adaptive learning rate and a neural network with a minimum fixed learning step, the former shows a smoother tendency of the error to the minimum value without significant fluctuations.

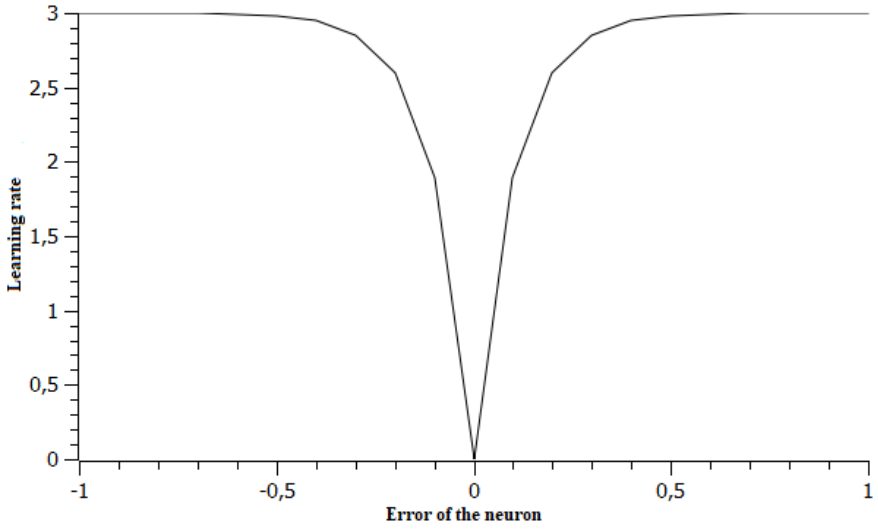

Figure 5 - Graph of the learning rate of an individual neuron

Two types of neural network errors that most fully characterize the learning process are considered. In the process of training a neural network, a training error and a generalization error are distinguished. Generalization error is an error that the neural network demonstrates in examples that were not involved in the learning process. A learning error, on the contrary, is an error that the trained neural network demonstrates on the examples of the training sample [11].

An important aspect of neural network training is the training sample. A training sample is a set of pairs of input and output data (for training with a teacher) used in training a neural network. The control sample-part of the sets that are not involved in training the neural network - used to determine the generalization error.

For correct training of a neural network, the training sample must have the representativeness property. Representativeness in this case should be understood as the presence of a sufficient number of diverse training examples that reflect the patterns that should be detected by the neural network in the learning process. The representativeness of the training sample expressed in the following aspects:

- sufficiency: the number of training examples should be sufficient for training;
- diversity: the training sample should contain a large number of different combinations of input and output data in the training examples;
- uniform representation of classes: examples of different classes should be presented in the training sample in the same proportions.

Increasing the number of examples in the training sample increases the time required for the neural network to reach the specified indicators due to a generalization error [12].

When training the constructed neural network, we obtained results confirming the theoretical dependence of the generalization error on the power of the training sample (Fig. 6, a). The dependence between the power of the training sample and the deviation of the generalization error from the steady-state value also revealed (figure 6, b).

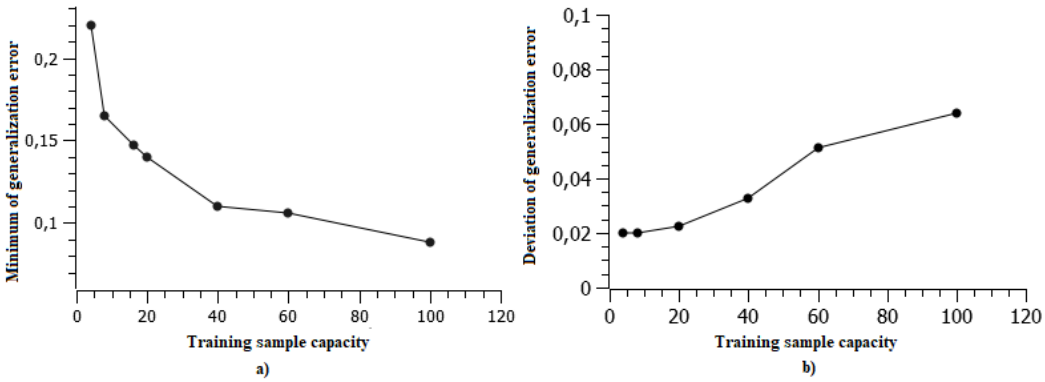

Figure 6 - Behavior of the generalization error depending on the power of the training sample: a-change in the minimum value of the generalization error; b-change in the deviation of the generalization error from the steady-state value

5. Conclusion. Based on the results obtained, it can be concluded that with an increase in the training sample size, the minimum possible value of the generalization error decreases, and the nature of the dependence of the generalization error on the power of the training sample coincides with the theoretical one. However, this increases the time spent on training the neural network, and increases the deviation of the generalization error from the established value.

Thus, a neural network model was implemented to solve the problem of recognizing words corresponding to the pronunciation of numbers from 1 to 9. When analyzing the behavior of the neural network, it was determined that the existing size of the training sample is not enough to achieve a zero error in the generalization of the neural network. However, the constructed network showed the ability to learn, confirmed by experimental data. When the specified generalization error is reached, the program saves the weight coefficients in the form of a header file, which makes it possible to restore the trained neural network for later use.

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СӨЙЛЕУДІ ТАНУ МАҚСАТЫНДА НЕЙРОНДЫҚ ЖЕЛІНІ ҚҰРУ

Аннотация. Мақалада қатені кері тарату әдісімен оқытылған тікелей таратудың нейрондық желісін қол-дана отырып, шектеулі сөздіктің жеке сөзін тану арқылы сөйлеуді тану мәселесін шешу әдісі қарастыры-лады. Мақсатымыз – жеке сөзді тану үшін нейрондық желі моделін құру, құрылған нейрондық желінің оқыту сипат-тамалары мен әрекетін талдау.

Фурье түрлендіру нәтижелері нейрондық желіні оқыту үшін кіріс ретінде пайдаланылады және кіріс деректерін таңдауға негізделген. Мәселені шешу үшін қатенің динамикалық оқу жылдамдығымен кері таралу алго-ритмі таңдалды, өйткені бұл алгоритмді енгізу нейрондық желіні оқытудың минималды қатесіне дәл жақындауға мүмкіндік берді.

Желі жалпылау қатесінің талаптарын қанағаттандыруға жеткілікті дайындалған, бірақ жалпылау қатесін жақсартуға болады. Құрылған нейрондық желіні оқытудың практикалық нәтижелері түрлі оқу үлгісінде ұсы-нылған.

Түйін сөздер: сөйлеуді тану, нейрондық желілер, қателіктерді кері тарату алгоритмі, оқыту, оқу жыл-дамдығы.

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РАЗРАБОТКА НЕЙРОННОЙ СЕТИ ДЛЯ РЕШЕНИЯ ЗАДАЧИ РАСПОЗНАВАНИЯ РЕЧИ

Аннотация. В статье рассматривается метод решения задачи распознавания речи на примере распозна-вания отдельных слов ограниченного словаря с использованием нейронной сети прямого распространения, обученной методом обратного распространения ошибок. Цель состояла в том, чтобы создать нейросетевую модель для

распознавания отдельных слов, проанализировать обучающие характеристики и поведение построенной нейронной сети.

Результаты преобразования Фурье использованы в качестве входных данных для обучения нейронной сети и обоснован выбор входных данных. Для решения поставленной задачи выбран алгоритм обратного распространения ошибки с динамической скоростью обучения, так как введение этого алгоритма позволило более точно приблизиться к минимальной ошибке обучения нейронной сети.

Сеть достаточно обучена, чтобы соответствовать требованиям ошибки обобщения, но есть еще место для улучшения ошибки обобщения. Представлены практические результаты обучения построенной нейрон-ной сети при различных размерах обучающей выборки.

Ключевые слова: распознавание речи, нейронные сети, алгоритм обратного распространения ошибок, обучение, скорость обучения.

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COMPARISON MODELS OF MACHINE LEARNING FOR MOVIE RECOMMENDATION SYSTEMS

Abstract. The trend of the Internet makes the presentation of the right content for the right user inevitable. To this end, recommendation systems are used in areas such as music, books, movies, travel planning, e-commerce, education, and more. One of the most popular recommendation systems in the world is Netflix, which generated record profits during quarantine in the first quartile of 2020. The systematic approach of recommendations is based on the history of user selections, likes and reviews, each of which is interpreted to predict future user selections. This article provides a meaningful analysis of various recommendation systems, such as content-based, collaborative filtering and popularity. We reviewed 7 articles published from 2005 to 2019 to discuss issues related to existing models. The purpose of this article is to compare machine learning algorithms in the Surprise library for a recommendation system. Recommendation system has been implemented and quality has been evaluated using the MAE and RMSE metrics.

Keywords: recommendation system, analysis of machine learning approaches, Surprise library, collaborative filtering.

1. Introduction

Recommender systems are algorithms designed to offer users the appropriate elements. Recommender systems are a class of information filtering systems whose main purpose is to provide personalized recommendations, content and services to users. Recommender systems typically help users find products such as films, books, articles, news, and others that match their personal preferences and needs [1].

Personalized recommendation blocks are the most obvious example of user personalization. The web service ranks the objects in order of relevance for a particular user based on user history. For example, on Netflix service, rough estimates posted continuous content [2]. The user is not able to watch the whole movie, so users search for a movie that they like by using stories at the same time. The task of this system is to build a personal stream that is interesting to the user based on the website.

Recommender systems are not necessarily intended to recommend certain objects to users. To increase the effectiveness of promotions, online stores resort to the help of recommendation systems in order to identify the most interested users in one of the products. Recommendation system predicts the degree of interest of each user to a particular product based on purchases and their responses to promotional letters [3].

Referral systems are really important in some industries, as they can generate huge revenues when they are effective. As evidence of the importance of recommender systems, we can mention that a few years ago Netflix organized a contest with a prize of $ 1 million, where the goal was to create a recommendation system that works better than its own algorithm [4].

Recommender systems work with two types of information:

1. Characteristic information. This is information about elements and users.
2. User interaction. This information is such as ratings, number of purchases, likes, etc.

Based on this, we can distinguish three algorithms used in recommender systems:

1. Content systems that use specific information.
2. Collaborative filtering systems based on user interaction with the element.
3. Hybrid systems that combine both types of information in order to avoid problems that arise when working with only one type.

Collaborative methods of recommendation systems are methods that are based on past interactions recorded between users and subjects to develop new recommendations. These interactions are stored in the so-called "user-element interaction matrix" [3]. Then, the basic idea that governs collaborative methods is that these past user-element interactions are enough to detect similar users or similar elements and predict based on these assumed approximations. However, since only past interactions are taken into account for making recommendations, collaborative filtering suffers from a “cold start problem”: it is not possible to recommend something to new users or recommend a new item to any users, and many users or elements have few interactions too. This drawback can be eliminated in different ways: recommend random items to new users or new items to random users, recommend popular items to new users or new items to most active users, recommend a set of different items for new users or a new item to recruit different users.

Unlike collaborative work methods that rely on the interaction of user elements, content-based approaches use additional information about users or elements. If we look at an example of a movie recommendation system, this additional information could be, for example, age, gender, work or any other personal information for users, as well as the category, main characters, duration or other characteristics for movies [5].

Then the idea of content-based methods is to try to build a model based on the available “functions” that explain the observed user interactions with the element.

Content-based methods suffer much less from the “cold start” problem than collaborative approaches [6]. Only new users or elements with previously unseen features will logically suffer from this shortcoming, but as soon as the system becomes old enough, it will have little chance of not happening at all.

2. Methods

To develop recommendation system algorithms, used the Surprise library, which was built by Nicolas Hug. Surprise is a library in Python scikit for recommender system, which is able to build an algorithm, that is nothing but a class derived from “AlgoBase” that has an “estimate” method. This is the method that is called by the predict() method. It takes in an inner user id, an inner item id, and returns the estimated rating r_{ui} . But the dumbest algorithm returns a set rating value.

In this research used MovieLens datasets by the GroupLens Research Project at the University of Minnesota. Dataset consists of 100,000 ratings (1-5) from 943 users on 1682 movies. Each user has rated at least 20 movies [7].

To fit prediction algorithms, it requires a similarity measure, which builds a similarity matrix and returns value depending on the similarity of films and users.

To make a cleverer algorithm that predicts the average of all the ratings of the train set. As this is a constant value that does not depend on current user or item, we would rather compute it once and for all. This can be done by defining the fit method. This way, we can fit our algorithms for training sets.

To prediction used the prediction algorithms package of Surprise library, which includes the prediction algorithms available for recommendation. We used nine type of prediction algorithm:

1. NormalPredictor is an algorithm which predicts a random rating based on the distribution of the training set, which is assumed to be normal.
2. BaselineOnly is an algorithm which predicts the baseline estimate for a given user and item.
3. KNNBasic is a basic collaborative filtering algorithm.
4. KNNWithMeans is basic collaborative filtering algorithm, taking into account the mean ratings of each user.
5. KNNBaseline is a basic collaborative filtering algorithm taking into account a baseline rating.
6. SVD is equivalent to Probabilistic Matrix Factorization.
7. NMF is a collaborative filtering algorithm based on Non-Negative Matrix Factorization. It is very similar with SVD.

8. SlopeOne is a straightforward implementation of the SlopeOne algorithm. Coclustering is a collaborative filtering algorithm based on co-clustering.

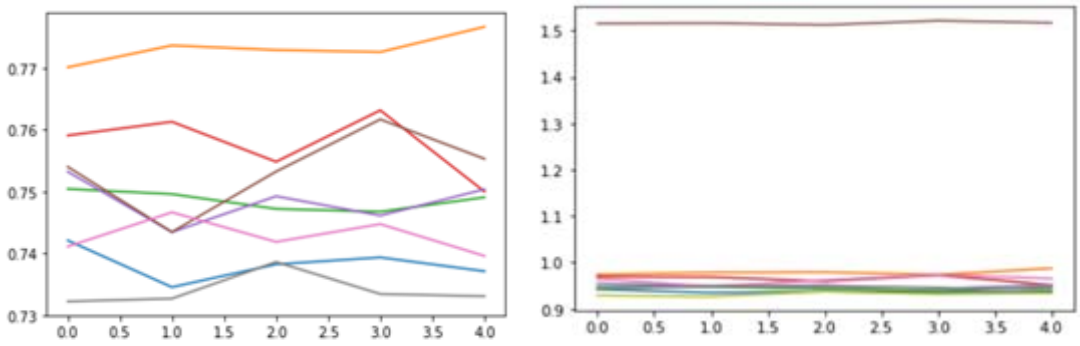
At the end, calculated evaluation metrics root mean square error (RMSE) and mean absolute error (MAE) on a 5-fold cross-validation procedure by formula (1) and (2). The folds are the same for all the algorithms [8].

$$MAE = \frac{1}{N}\sum_{i=1}^{N}|\, y_i - \hat{y}\,| \tag{1}$$

$$RMSE = \sqrt{MAE} = \sqrt{\frac{1}{N}\sum_{i=1}^{N}|\, y_i - \hat{y}\,|}$$

3. Results

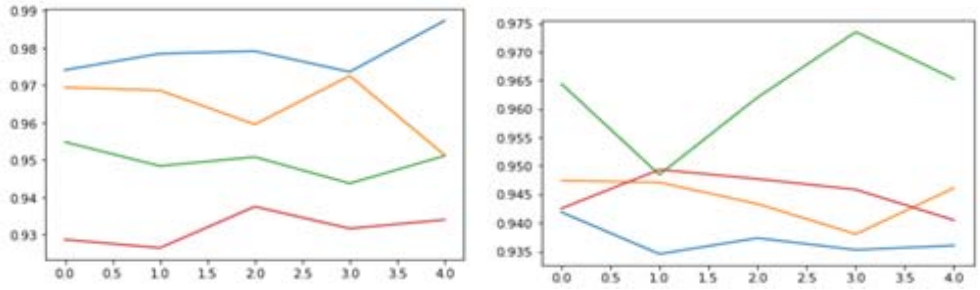
Nine types of machine learning models showed different results for evaluation of quality: MAE and RMSE [9]. Training is conducted for datasets MovieLens 100k to compare the performance of machine learning algorithms: SVD, KNN, KNNwithMeans, KNNBasic, BaselineOnly, Coclustering, SlopeOne, NMF and Normal Predictor. First, the overall results of the MAE and RMSE for all approaches in Figure 1.



(a) (b)

Figure 1 - Results: a - results of MAE for each approach, b - results of RMSE for each approach

Here, brown line – Normal Predictor, orange line is KNN, red line is NMF (Not negative matrix factorization), violet line is KNN with Means and grey blue line for KNN Basic, dark green line is CoClustering, blue line is BaselineOnly, green line is SVD (Support vector machine) and salad green line is for SlopeOne.

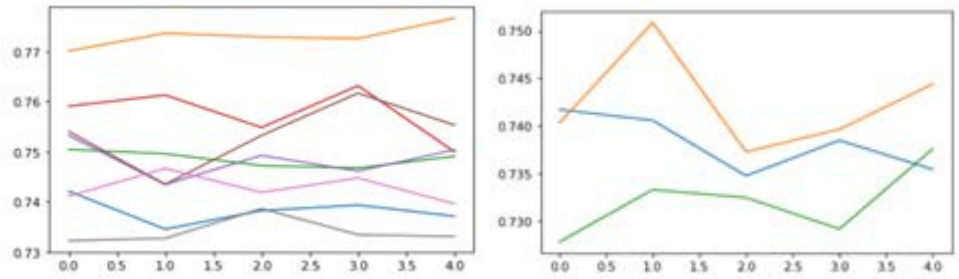


(a) (b)

Figure 2 - RMSE results. a - KNN, KNN with Mean, KNN Basic and NMF and b - SVD, BaselineOnly, Coclustering, SlopeOne

Figure 2.a shows result of RMSE for some algorithms, which are better than Normal Predictor. Here, blue line is KNN, orange line is NMF, green line is KNN with Means and red line is KNN Basic. In Figure 2.b shows top results of RMSE for four algorithms: SVD, BaselineOnly, Coclustering, SlopeOne. Here, green line is Coclustering, red line is BaselineOnly, orange line is SVD and blue line is for SlopeOne.

Figure 3 shows results of MAE for all approaches without Normal Predictor:



(a) (b)

Figure 3 - MAE results: a - all approaches, b - good results

In 3.a, orange line is KNN, red line is NMF, brown line KNN Basic, BaselineOnly by violet line, green line is Coclustering, pink line is SlopeOne, blue line is SVD, grey line KNN with Mean. Mean absolute error returns good results for two approaches: KNN with Means and SlopeOne. Figure 3.b in scaled view for approaches with good result:

Here, the orange line is SlopeOne, the blue line is SVD, the line is for KNN with Means. As we can see that the best results of MAE are KNN with Means and SVD predictions algorithms.

4.Conclusion. Recommendation systems make convenient Internet by predicting the right content for the right user. But also gives the other problem such as: what kind of approach to use, indeed this method is inevitable for a given dataset? This paper discussed the nine traditional approaches and highlighted their advantages and disadvantages by evaluation mean absolute error and root-mean-square error. By measuring the quality closed SVD and KNNwM algorithms predicted with minimal mean absolute error (MAE), but by root-mean-square error (RMSE) the best predictors are SVD and SlopeOne. In table 1 shown prediction algorithms with values of MAE for spited into 5-fold cross validation.

Table 1 - MAE results of the best approaches for given results

Algorithms	Fold 1	Fold 2	Fold 3	Fold 4	Ford 5	Mean	Std
SVD	0.7417	0.7405	0.7347	0.7384	0.7354	0.7381	0.0037
KNN with Means	0.7501	0.7430	0.7528	0.7511	0.7485	0.7491	0.0034

As we can see that the best results of RMSE are BaselineOnly and SlopeOne predictions algorithms. In Table 2 shown prediction algorithms with values of RMSE for spited into 5-fold cross validation:

Table 2 - RMSE results of the best approaches for given results

Algorithms	Fold 1	Fold 2	Fold 3	Fold 4	Ford 5	Mean	Std
SVD	0.9418	0.9345	0.9373	0.9353	0.936	0.937	0.0085
SlopeOne	0.9425	0.9493	0.9477	0.9458	0.9405	0.9452	0.0033

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ФИЛЬМ ҰСЫНУ ЖҮЙЕЛЕРІНЕ АРНАЛҒАН МАШИНАЛЫҚ ОҚЫТУ МОДЕЛЬДЕРІН САЛЫСТЫРУ

Аннотация. Қазіргі интернет тенденциясы қолданушыға нақты әрі қажетті контентті ұсынуды сөзсіз орындайды. Осы мақсатта ұсыныс жүйелері музыка, кітап, фильм, саяхат жоспарлау, электронды сауда, білім беру және тағы басқа салаларда қолданылады. Әлемдегі ең танымал ұсыныс жүйелерінің бірі – Netflix. Бұл карантин кезінде 2020 жылдың бірінші маусымында пайда түсіру жағынан рекордқа жетті.

Ұсыныстарға жүйелі көзқарас пайдаланушылардың таңдауының, ұнатуының және шолуларының тарихына негізделген, олардың әрқайсысы болашақ пайдаланушылардың сайлауын болжау ретінде түсіндіріледі.

Мақала мазмұнға, бірлескен сүзгілеу және танымалдық секілді түрлі ұсыныс жүйелерінің талдамасына негізделген. Қолданыстағы модельдерге қатысты мәселелерді талқылау үшін 2005 жылдан 2019 жылға дейін жарияланған 7 мақаланы қарастырдық. Мақаланың мақсаты – ұсыныстар жүйесі үшін Surprise кітапханасындағы машиналық оқыту алгоритмдерін салыстыру. Ұсыныстар жүйесі бағдарламаланды әрі MAE және RMSE сапа көрсеткіштерін қолдану арқылы бағаланды.

Түйін сөздер: ұсыныстар жүйесі, машиналық оқыту тәсілдерін талдау, Surprise кітапханасы, бірлескен сүзгілеу әдісі.

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СРАВНЕНИЕ МОДЕЛИ МАШИННОГО ОБУЧЕНИЯ ДЛЯ СИСТЕМ РЕКОМЕНДАЦИЙ ФИЛЬМОВ

Аннотация. Интернет-тенденция делает неизбежной презентацию нужного контента для нужного пользователя. С этой целью рекомендательные системы используются в таких областях, как музыка, книги, фильмы, планирование путешествий, электронная коммерция, образование и т.д. Одна из самых популярных систем рекомендаций в мире – Netflix, которая принесла рекордную прибыль во время карантина в первом квартале 2020 года.

Систематический подход к рекомендациям основан на истории пользовательских выборов, лайков и обзоров, каждая из которых интерпретируется как предсказатель будущих выборов пользователей.

В этой статье представлен содержательный анализ различных систем рекомендаций, таких как контентная, совместная фильтрация и популярность. Мы просмотрели 7 статей, опубликованных с 2005 по 2019 год, чтобы обсудить вопросы, связанные с существующими моделями. Цель этой статьи - сравнить алгоритмы машинного обучения в библиотеке Surprise для рекомендательной системы. Внедрена система рекомендаций, и качество оценено с использованием показателей функций MAE и RMSE.

Ключевые слова: рекомендательные системы, анализ подходов к машинному обучению, библиотека сюрпризов, коллаборативная фильтрация.

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AN OVERVIEW OF THE RECOGNITION ALGORITHM OF A HUMAN VOICE

Abstract. Speech recognition has various applications, including human-machine interaction, sorting phone calls by gender classification, categorizing videos with tags, and so on. Currently, machine learning is a popular field that is widely used in various fields and applications, taking advantage of the latest developments in digital technologies and the advantages of data storage capabilities from electronic media. In this article, we will focus on voice gender recognition for a class of text-dependent systems using the Dynamic time distortion (DTW) algorithm and for a class of text-independent systems, the Gaussian mixture model. With this method, it is possible to distinguish a person's voice with the highest accuracy, since the components of Gaussian mixtures can simulate the personality of the voice. The article presents the results of testing the algorithm, and concludes that the Gaussian mixture model is applicable to solving the problem of identifying a person by voice.

Keywords: algorithm; Gaussian mixture; identification; recognition; classification.

1. Introduction.

Speech is one of the most popular and significant means of communicating people, expressing their emotions, cognitive states and intentions with each other. Speech is produced by humans through a natural biological mechanism in which the lungs release air and convert it into speech, passing through the vocal cords and organs, including the tongue, teeth, lips, etc. As a rule, you can use a speech and voice recognition system to identify your gender. The natural voice recognition system is the human ear. The human ear has an excellent mechanism that can effectively distinguish gender by voice and speech based on attributes such as frequency and volume. Similarly, a machine can be taught to do the same by selecting and including the correct features from the voice data in the machine learning algorithm.

Due to the ease of use, there is currently a growing interest in biometric technologies and the method of biometric identification. Identification is a comparison of features of an object. The advantage of voice identification is convenience and affordable price, and the disadvantage is low reliability[[1]] .

The fundamental disadvantage of all biometrics methods, except speech, is the constancy of the biometric code used, since fingerprints or palms, the pattern of the iris and facial features are unchanged for the individual. This disadvantage prevents the use of these methods in cases requiring particularly high reliability of identity identification, since the immutable biometric code can be read by malicious intrusion into the recognition program[[2]].

Unlike fixed-parameter biometrics, voice verification has virtually unlimited potential to reduce error by using increasingly long speech messages. Voice verification can be used in the dark, at a distance, in particular, over a standard telephone channel, in conditions where it is impossible to get a face image.

In modern voice identification systems, text-dependent identification is used to increase reliability, for example, the utterance of a passphrase, which is randomly generated each time. The use of individual characteristics and matching of the generated and the detected passphrases increases the reliability. Text-independent identification implies the use of only individual features[[3]].

An important characteristic of the voice identification system is the speed (speed) of identification. Performance is especially important for applications that process large databases of voice data and work in

real time. Performance improvement can be achieved through the use of new fast algorithms of data processing. Thus, voice identification of a person, despite the shortcomings indicated in this work, under certain conditions has significant advantages that need to be developed. In the problem of voice identification, various mathematical, algorithmic, and technical methods are used, starting with the stage of voice recording and ending with the stage of classification. Virtually every identification system has four main stages: signal acquisition, signal preprocessing, feature extraction, and feature classification.

2. The stage of receiving the signal.

The method of receiving or recording a voice signal, in most cases, is to record the signal using a microphone and present the signal digitally using an analog-to-digital Converter. As an analog-to-digital Converter, a personal computer sound card or a digital voice recorder is usually used. However, it is still necessary to ensure minimal computing costs while maintaining accuracy, noise immunity to various types of interference, and sufficient reliability with common hardware[[4]-[5]].

3. Pre-processing stage.

The received digital signals, as well as analog ones, contain a certain amount of distortion and interference. Distortions are understood as distortions of the speech-forming tract (for example, throat disease) and the speech-transmitting channel (for example, distortions of the telephone channel).

Pre-processing stage. The received digital signals, as well as analog ones, contain a certain amount of distortion and interference. Distortions are understood as distortions of the speech-forming tract (for example, throat disease) and the speech-transmitting channel (for example, distortions of the telephone channel).

4. The stage of feature extraction.

Feature extraction usually takes place using Fourier transform, wavelet transform, linear prediction, and others. The transformation coefficients are used as features. Currently, the voice characteristics that can uniquely identify a person's identity are not precisely defined. The choice of features also affects the reliability of identification. There are methods that describe the integral characteristics of the human voice and are used to extract tones, speech dynamics, and prosodic characteristics. Such methods are the Fourier transform (amplitude-frequency distribution), the cepstral transform (amplitude-time distribution), and the linear prediction transform (amplitude-frequency distribution). There are also formant methods and phoneme extraction methods.

5. Stage of classification of features.

This stage includes the application of mathematical classification methods, which are used to make decisions, as well as the calculation of classification errors.

Speech recognition systems are based on the principles of recognition of recognition forms. The methods and algorithms that have been used so far can be divided into the following large classes [[6]-[7]]:

Classification of speech recognition methods based on comparison with the standard.

- Dynamic programming — time dynamic algorithms (Dynamic Time Warping).
- Context-sensitive classification. When it is implemented, separate lexical elements are distinguished from the speech stream-phonemes and allophones, which are then combined into syllables and morphemes.
- Methods of discriminant analysis based on Bayesian discrimination (Bayesian discrimination);
- Hidden Markov models (Hidden Markov Model);

Neural networks (Neural networks).

Dynamic Time Warping (DTW) is a dynamic time scale transformation algorithm, a dynamic programming method that allows you to find the distance between two time series. As a rule, such sequences have different lengths, so you have to make measurements at different speeds. The main advantage of this algorithm is the ease of implementation [[8]-[9]].

Gaussian mixture models can be applied not only to model the characteristics of the speaker's voice, but also to record the voice signal and the environment. Each of the components of the model reflects some common features of the voice, but individual when they are reproduced by each speaker. Gaussian mixture models have proven to be effective because they have high recognition accuracy. That is why this approach can be successfully used to solve the problem of identifying a text-independent speaker [[10]].

The weighted sum of M components representing the Gaussian mixture model is calculated using the formula [[11]]

$$P(\bar{x}|\lambda) = \sum_{i=1}^{M} p_i \, b_i(\bar{x}) \quad (1)$$

where $\bar{x}$ is a d-dimensional vector of random variables, pi, 1≤ i ≤ M – weights of the model components, $b_i(\bar{x})$, 1≤ i≤ M – density functions of the distribution of the model components:

$$b_i(\bar{x}) = \frac{1}{(2\pi)^{\frac{D}{2}}|\sum i|1/2} exp\left\{-\frac{1}{2}(\bar{x} - \bar{\mu_i})^T \sum_i^{-1} \bar{x} - \bar{\mu_i}\right\} \quad (2)$$

where $\bar{\mu_i}$ is the expectation vector and $|\sum i|$ is the covariance matrix. The weights of the mixture must satisfy the condition:

$$\sum_{i=1}^{M} \bar{p_i} = 1 \quad (3)$$

The entire Gaussian mixture model is defined using expectation vectors, covariance matrices, and mixture weights for each of the model components:

$$\lambda = \{p_i, \bar{\mu_i}, \sum i\}, i = 1, \dots M \quad (4)$$

When using the method, each speaking person can be represented by their own Gaussian mixture model.

To build a system of automatic identification of a person by voice using Gaussian mixtures, it is necessary to solve the following subtasks:

Extract and process the features of the input speech signal;

Develop an algorithm for initializing and evaluating model parameters;

Determine the number of components of the Gaussian mixture model.

First, an analog-to-digital conversion of the audio signal is performed. During sampling, the signal is divided into separate values of the quantized amplitude at certain time intervals.

The entire signal recording is viewed by Windows of pre-set duration that overlap. It is recommended to choose the duration of the time window within 20-30 MS. In this paper, to simplify the calculations, the duration of each window was chosen to be 25 MS.

Then the digitized signal is viewed in small fragments (frames) that are characteristic of individual vocal components of the speech signal and for which it is assumed that the signal retains its properties constant for a given period of time. Next, the window function is selected. The time window function must take a non-zero value inside a certain time interval, and it must be zero outside of it. Then the window function is sequentially superimposed on the signal frames, and information is extracted from the speech frame. This information is extracted by multiplying the value of the signal x[t] taken at time t with the value of the window function w[t] taken at time t:

$$y[t] = w[t]x[t] \quad (5)$$

The characteristics of the window function are the following parameters: width (in milliseconds), offset (the number of milliseconds between the borders of consecutive Windows), and shape. In this paper, a Hamming window with a width of L = 30ms and an offset of 10 MS is used.:

$$w(t) = \begin{cases} 0{,}54 - 0{,}46\cos\left(\frac{2\pi t}{L}\right), 0 \le t \le L - 1 \\ 0, \text{иначе} \end{cases} \quad (6)$$

After filtering each segment, we get a complete signal, which is free of noise, interference and other distortions that can interfere with the correct recognition of the speaker.

Next, it is necessary to extract information about the spectral components from the signal obtained at the previous stages of the algorithm, for which a discrete Fourier transform is used. A signal divided into frames is fed to the input of the computer, and at the output of the computer for each of The t frequency ranges, we get a complex number X[k], which is the amplitude and phase of the original signal. X[k] is calculated by the formula:

$$x_k = \sum_{n=0}^{N-1} x_n \, exp\left(-\frac{2\pi i}{N} kn\right) \quad (7)$$

where k = 0,..., N-1.

Then you need to go from the value of the sound frequency f to the value of the height (Mel). First, you need to place the resulting spectrum on the chalk scale. This operation is carried out according to the formula

$$B(f_{Hz}) = 1127{,}01048 * \ln\left(1 + \left(\frac{f_{Hz}}{700}\right)\right) \quad (8)$$

This operation is necessary to simulate the fact that human hearing has different sensitivity in different frequency ranges.

Then it is necessary to form triangular filters that serve to accumulate the energy value in each of the frequency ranges (10 filters are distributed linearly below 1000Hz, and the rest are logarithmically above 1000Hz) and take the logarithm of each obtained chalk value. The use of the logarithm is necessary so that differences in the input signal delivery methods have less impact on the assessment of individual speech characteristics.

Next, we translate the obtained values into a scale with frequencies. At the next step of the algorithm, the signal kepstr is calculated. This transformation allows you to separate the source of the sound wave from the filter, whose properties allow you to generate the corresponding sound when a wave with the frequency of the main tone of speech passes through the voice channel. At the same time, the filter contains most of the useful information.

Each signal segment can be described using 12 Mel-frequency cepstral coefficients. To find them, use the formula

$$c(n) = \sum_{m=0}^{M-1} S(n) \cos\left(\frac{\pi n\left(m+\frac{1}{2}\right)}{M}\right) \quad (9)$$

where 0≤ n <M

Figure 1 shows a graph of the dependence of the Mel-frequency cepstral coefficients on time for two frames of the speech signal of two different speakers who uttered the same speech phrase. On the graph, you can see that the recording coefficients differ for different speakers. The dependence of the Mel-frequency cepstral coefficients on time for two different recordings of the same speaker's speech is shown in figure 2. From the graph of figure 2, you can see a small difference between the Mel-frequency cepstral coefficients.

After all the coefficients are calculated, the recording signal must be compared with the reference signal stored in the database. The criterion for matching these signals will be the Euclidean distance measure.

Figure 3 shows a complete block diagram of the algorithm, on the basis of which a program for identifying a person by his vocal data is developed.

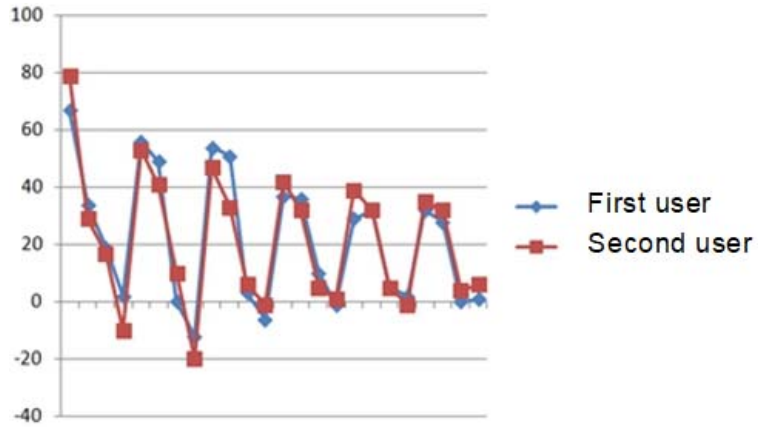

Figure 1 - Dependence of Mel-frequency cepstral coefficients of speech recordings of two different speakers on time in the first two frames of the speech signal

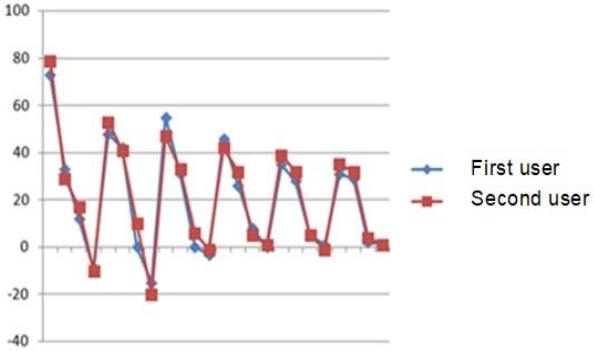

Figure 2 - Dependence of Mel-frequency cepstral coefficients of speech recordings of the same person on time in the first two frames of the speech signal

To initialize the initial parameters of the model, in this paper we used the algorithm of cluster analysis for vectors of speech signal features. The K-means++ algorithm was chosen as the clustering algorithm, which uses Euclidean distance as a distortion measure [[12]].

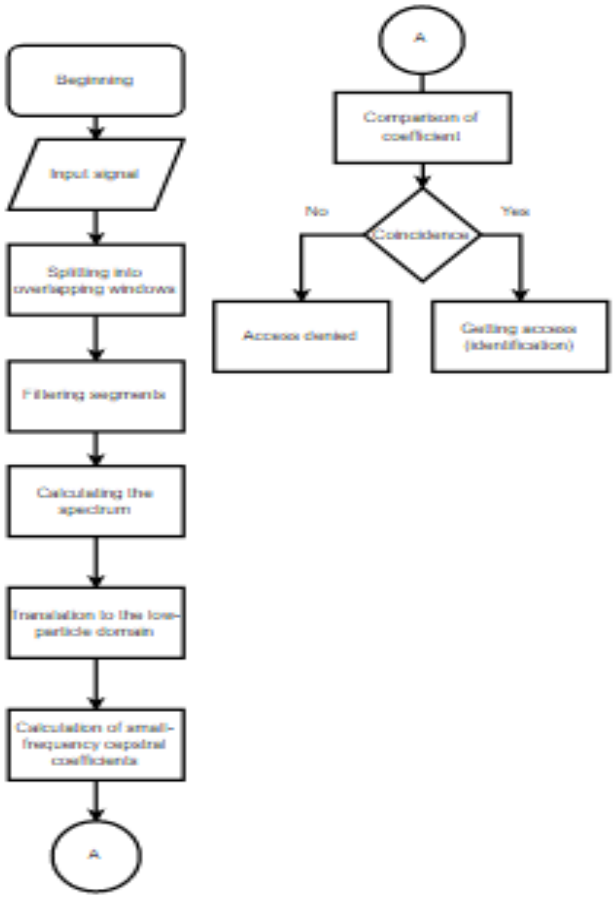

Figure 3 - Block diagram of the algorithm for automating the speaker identification process by voice

the K-means++ Algorithm is a modification of the K-means algorithm. In this algorithm, the center of the first cluster is randomly selected, and then each subsequent center can be selected from the remaining data points with a probability proportional to the square of the distance to the nearest existing cluster center. After that, the standard K-means algorithm is executed. The advantage of this approach is a large reduction in the error of the final result.

To test the developed algorithm, a software tool in the C++language was developed. The voice signals of twenty people were selected. Speech recordings were made in mono mode using a microphone

built into the computer, which has a sampling rate of 16 kHz and an ADC bit rate of 16 bits. The duration of the speech signal was 50 seconds, and the duration of the test signal was 15 seconds. The algorithm was tested for a different number of components of the Gaussian mixture model. Figure 4 shows the dependence of the number of correctly identified speakers (in %) on the number of components of the Gaussian mixture model.

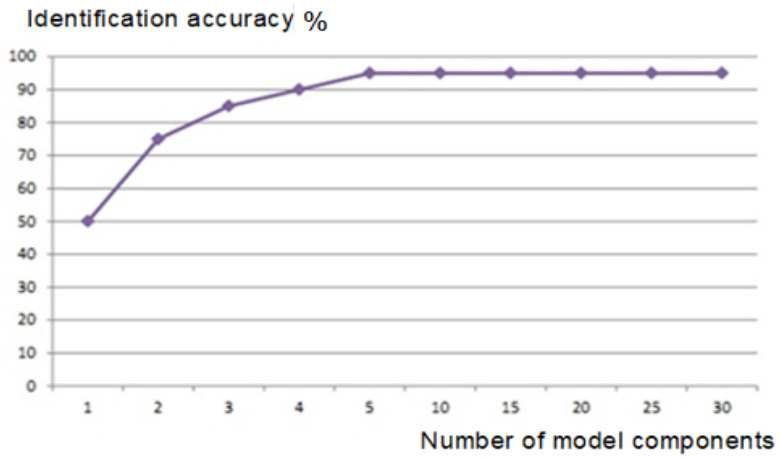

Figure 4 - Dependence of the number of correctly identified speakers (in %) on the number of components of the Gaussian mixture model

6. Conclusion

The results of the development of an algorithm for automatic identification of a person by voice for authorizing access to information obtained in this paper allow us to draw the following conclusions:

For modeling individual voice characteristics, the components of Gaussian mixtures are best suited, since they allow you to recognize speakers with high accuracy.

Determining the initial parameters of the model using the K-means++ algorithm can significantly increase the learning rate and improve the accuracy of identification.

The number of components that is optimal for the effective operation of the system is five. With this number of components, the speaker identification accuracy is 96%, which indicates that the implemented algorithm can be successfully used to authorize access to information by the user's voice.

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ОБЗОР АЛГОРИТМА РАСПОЗНАВАНИЯ ЧЕЛОВЕКА ПО ГОЛОСУ

Аннотация. Распознавание речи имеет различные приложения, включая взаимодействие человека и машины, сортировку телефонных звонков по гендерной категоризации, категоризацию видео с тегированием и т.д. В настоящее время машинное обучение является популярным направлением, которое широко используется в различных областях и приложениях, используя последние разработки в области цифровых технологий и преимущества возможностей хранения данных с электронных носителей.

В статье раскрывается четверной этап классификации признаков. Сосредоточимся на распознавания по голосу, используя Dynamic Time Warping (DTW) – алгоритм. Для характеристики голоса говорящего и для записи сигнала голоса применяется модель гауссовской смеси. С помощью этого метода можно отличить голос человека с высочайшей точностью, поскольку компоненты гауссовых смесей могут моделировать индивидуальности голоса. В статье показаны результаты тестирования алгоритма, делается итог о применимости модели гауссовых смесей для решения задачи идентификации личности по голосу.

Ключевые слова: алгоритм; гауссовская смесь; идентификация; распознавание; классификация.

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АДАМДЫ ДАУЫС АРҚЫЛЫ ТАНУ АЛГОРИТМІНЕ ШОЛУ

Аннотация. Сөйлеуді танудың түрлі қосымшасы бар, соның ішінде адам мен машинаның өзара әрекеті, телефон қоңырауын гендерлік категория бойынша сұрыптау, тегтеу бейнелерін санаттау және т.б. Қазіргі уақытта машиналық оқыту – сандық технологияның соңғы әзірлемелерін және электронды медиадан деректерді сақтаудың артықшылықтарын қолдану арқылы түрлі сала және қосымшада кеңінен қолданылатын бағыт.

Мақалада белгілерді жіктеудің төртінші кезеңі көрсетілген. Dynamic Time Warping (DTW) алгоритмін қолдану негізінде дауыс тануға назар аударды қ. Мәселені шешудің қолданыстағы әдістеріне шолу жасаймыз. Әдіс үшін Гаусс қоспасының моделін қолданамыз. Сөйлеушінің дауысын сипаттау және дауыс сигналын жазу үшін Гаусс қоспасының моделі қолданылады. Бұл әдіс арқылы адам дауысын жоғары дәлдікпен ажыратуға болады, өйткені Гаусс қоспаларының компоненттері дауыстың даралығын модельдей алады. Мақалада алгоритмді тестілеу нәтижелері көрсетілген, дауыстың жеке басын анықтау мәселесін шешу үшін Гаусс қоспаларының моделін қолдану туралы қорытынды жасалады.

Түйін сөздер: алгоритм, Гаусс қоспасы, сәйкестендіру, тану, жіктеу.

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ALGORITHMS FOR FINGERPRINT CLASSIFICATION

Abstract. Currently, biometric methods of personality are becoming more and more relevant recognition technology. The advantage of biometric identification systems, in comparison with traditional approaches, lies in the fact that not an external object belonging to a person is identified, but the person himself. The most widespread technology of personal identification by fingerprints, which is based on the uniqueness for each person of the pattern of papillary patterns. In recent years, many algorithms and models have appeared to improve the accuracy of the recognition system. The modern algorithms (methods) for the classification of fingerprints are analyzed. Algorithms for the classification of fingerprint images by the types of fingerprints based on the Gabor filter, wavelet - Haar, Daubechies transforms and multilayer neural network are proposed. Numerical and results of the proposed experiments of algorithms are carried out. It is shown that the use of an algorithm based on the combined application of the Gabor filter, a five-level wavelet-Daubechies transform and a multilayer neural network makes it possible to effectively classify fingerprints.

Key words: Fingerprint classification, Gabor filter, wavelet transform, neural networks.

1. Introduction

Today biometric personality identification systems have been widely used in many areas of human life. For example, personal identification according to some characteristics is used in information security, forensic science, in the field of social services, and so on. One of the most common biometric technologies is fingerprint identification. It is this technology that has been widely used in various fields of activity. Since fingerprints do not change over the years and are unique for each person, this sign gives a high probability of correct identification of a person. Currently, computer technology is also involved in the process of personal identification by fingerprint. Each print has its own individual pattern, its own characteristics.

Fingerprints are one of the reliable biometric features successfully used for personal identification [1]. The advantages of a fingerprint for personal identification are:

• The uniqueness of fingerprints, different from each other and from other fingerprints of any other person. Even twins have different fingerprints.

• Unlike passwords, PIN codes cannot be lost or forgotten.

• Fingerprints do not change over time.

• Fingerprints have been used for many years for personal identification, therefore it is possible to test the developed algorithms using existing databases.

In each fingerprint, you can define two types of attributes - global and local. Global features are characteristics of a fingerprint that can be seen with the naked eye. Global features include image area, core, delta point, line counter, papillary pattern. Local signs, called minutiae, are small, unique dots for each fingerprint that are successfully used to identify individuals. A fingerprint may have the same global attributes, but local attributes are always unique.

However, the fingerprint image may be fuzzy, with indistinct lines and a lot of noise. Therefore, the image must go through a stage of preprocessing, during which noise and distortion are removed from the image, the readability of the fingerprint is increased.

The aim of this work is to create an algorithm for the classification of fingerprints by types of papillary patterns based on the combined application of the Gabor filter, wavelet transform and neural network. Solving this problem will speed up the search for fingerprints in large databases.

2. Global fingerprint signs

The image area is a fragment of a fingerprint in which all global features are located [1]. Fingerprints can be read and classified based on the image area information. Minutes that are used to identify a person may be outside the area of the image, so it is better to use information from a whole fingerprint when identifying a person.

The nucleus is the point that is located at the approximate center of the fingerprint and is used as a reference for reading and classification.

The «delta» point is the starting point where the separation or connection of the grooves of the papillary lines occurs, it can look like a very short groove, in the extreme case - a point. Line counter - the number of papillary lines on the image area, or between the core and the «delta» point.

Papillary patterns are divided into three types: arches (arcs), loops and curls [2]. Arches are rare and occupy 5 ... 10% of all fingerprints. Loops are found in most people (60 ... 65%). Curls appear much less often - 30% of all fingerprints.

3. Local signs of a fingerprint

The use of local features allows for detailed image analysis. To do this, the image is usually divided into rectangular areas, for each of which a vector of feature values is formed.

Examples of local features are statistical characteristics of the intensity distribution of image points.

Fingerprint lines are not straight. They are often broken, branched, reversed, and ripped. Points where lines end, branch, or change direction are called minutia points. These minus points provide unique information about the fingerprint for identification purposes.

Practice shows that fingerprints of different people can have the same global features, but it is impossible to have the same local features, i. e. points of mination. Therefore, the process of personal identification usually consists of two stages. The first step is globally categorizing fingerprints, using databases to classify them. The second step is to recognize the fingerprint based on the comparison of the structure and the coincidence rate of the minutia points.

4. Gabor filter

Gabor filter is a linear filter, the impulse transient response of which is represented as the product of a Gaussian function by a harmonic function [3]:

$$g(x,y) = \text{Gauss}\,(x',y')\cos(\tfrac{2\pi x'}{\lambda}), \tag{1}$$

$$\text{Gauss}(x',y') = e^{-(\frac{x'^2}{2\pi\sigma_x^2}+\frac{y^2 y'^2}{2\pi\sigma_y^2})}, \tag{2}$$

$$x' = x\cos\theta + y\sin\theta, \tag{3}$$

$$y' = -x\cos\theta + y\cos\theta, \tag{4}$$

where λ is the wavelength; ϕ – phase; the angle θ indicates the orientation of the normal to the parallel stripes of the Gabor function; γ is the compression ratio. Changing the orientation of θ makes it possible to change the direction of edge detection.

Fingerprint lines can be multidirectional, so it is necessary to find the orientation of the lines within each processed area of the image. This result can be achieved by applying different orientations of the Gabor filter to the image. In this case, by changing the angle of rotation θ, it is possible to change the direction in which the edges are to be detected. Therefore, the Gabor filter function will be a function of three variables – h (x, y, θ).

To find the orientation angle of the segment line, that is, the angle θ, it is necessary to construct a field of image directions, which is constructed using the point coordinates function, which describes the angle of the tangent to the line of the image intensity level. In this case, the field angle sets the direction, which is perpendicular to the vector of the image gradient, and the gradient, in turn, corresponds to the color changes from white to black.

If I (x, y) is the brightness of the light in the image, then the direction field φ (x, y) is given by the following equation:

$$\mathrm{tg}\varphi(x,y) = -(\partial I(x,y)/\partial x)/(\partial I(x,y)/\partial y), \quad (5)$$

where the angle φ (x, y) specifies the direction that is perpendicular to the gradient vector.

Next, filter matrices are calculated that correspond to all possible directions of lines in the range from 0 to 255. After that, a two-dimensional convolution with the Gabor filter kernel at the point (x, y) is performed on the image. In this case, the Gabor core corresponds to a given local angle of the line direction.

In image processing, the Gabor filter is commonly used for edge extraction, object outline detection, texture feature extraction, fingerprint image area extraction, local direction extraction, and other purposes [4, 5]. In this work, different orientations of the Gabor filter are used to improve the image of the fingerprint.

5. Wavelet transform

The main challenge in each type of image processing is to find an efficient representation that allows it to be displayed in a compact form. In modern theory and practice of signals in spectral analysis, signals of a special type are used - wavelets. The works [6, 7] present the decomposition of the image and the extraction of its features for the classification of aircraft images based on the application of the Haar wavelet transform and a multilayer neural network. In this paper, the Haar and Daubechies wavelet transforms are used to extract features of a fingerprint image.

In addition, according to the research results presented in the review [9], the choice of a particular wavelet basis has an insignificant effect on the texture analysis of images. Therefore, when choosing a wavelet basis in this case, the main criterion is the time and complexity of the transformation.

Wavelet analysis methods do not require splitting the image into small blocks, since the required localization properties are incorporated into the wavelet system [10].

6. Fingerprint classification method

In this paper, a method is proposed for classifying fingerprint images by types of papillary patterns based on the use of the Gabor filter, wavelet transform and a neural network. The functional diagram of the proposed method is shown in figure 1.

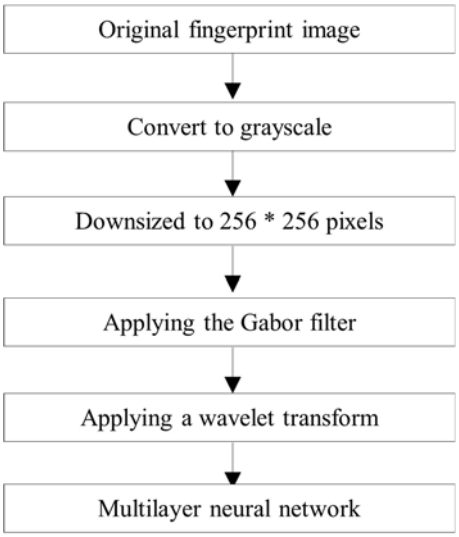

Figure 1 - Functional diagram of the proposed method of classification of fingerprints

The proposed method uses the Haar and Daubechies wavelet transforms to extract features of the fingerprint image. To evaluate the efficiency of feature extraction, 5th and 6th level wavelet transforms are used. A neural network with 192 inputs for the 5th level wavelet transform was created. The number of hidden neurons for this network varies from 200 to 250. For the 6th level wavelet transform, a neural network with 48 inputs was created, for which the number of hidden neurons varies from 80 to 120. Both networks have 7 outputs in accordance with the number of categories fingerprint classification.

7. Experiments

To test the algorithms, a part of the FVC2006 fingerprint database [8] is used, containing 9 images of each category for training (total 9 × 7 = 63 images), and 14 images of each category for testing (total

14 × 7 = 98 images). The results of comparing the efficiency of feature extraction are shown in Figure 2 and 3. Analysis of the above results shows that the algorithm using the Daubechies wavelet transform gives better results than the algorithm based on the Haar wavelet.

We also compared the performance of the algorithm using the Gabor filter with the algorithm without using this filter, Figure 4 and 5. The above results show that the algorithm using the Gabor filter performs better than the algorithm without this filter.

8. Conclusions

1. Proposed and described algorithms for classification of fingerprint images by types of papillary patterns, based on the use of the Gabor filter, the Haar wavelet transform, Daubechies and a multilayer neural network.

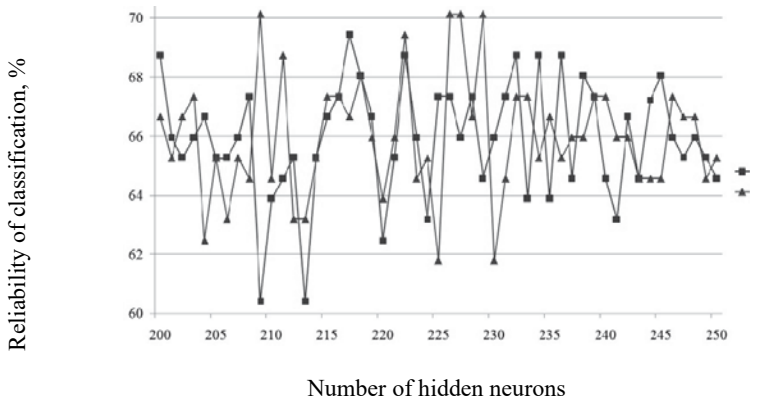

Figure 2 - The result of comparing the efficiency of the algorithm based on the application of a five-level wavelet transform: -Daubechie; - Haara

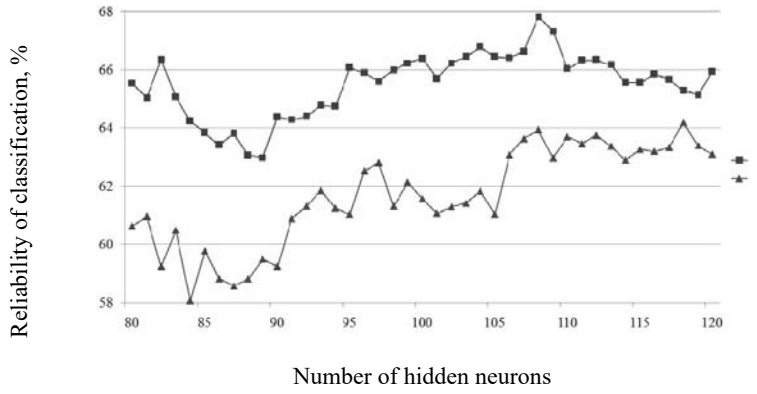

Figure 3 - The result of comparing the effectiveness of the algorithm based on the application of the six-level wavelet transform: - Daubechie; - Haara

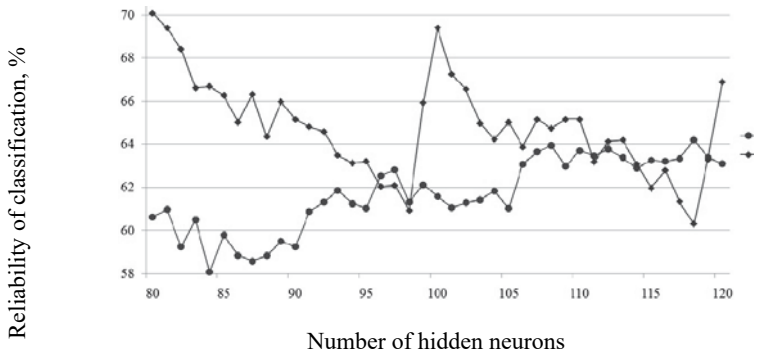

Figure 4 - The result of comparing the efficiency of the algorithm based on the application of the six-level Haar wavelet transform and: - with the Gabor filter; - without Gabor filter

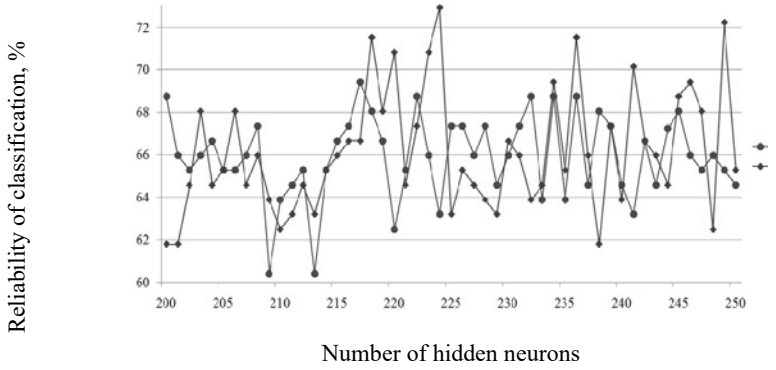

Figure 5 - The result of comparing the efficiency of the algorithm based on the application of the five-level Daubechies wavelet transform and: - with the Gabor filter; - without Gabor filter

2. Based on the analysis of the results of numerical experiments, it has been established that the algorithm based on the combined application of the Gabor filter, the five-level Daubechies wavelet transform and the multilayer neural network has the best reliability of classification of fingerprints.

Applying the Gabor filter on the fingerprint image sharpens lines, detects edges, and removes noise and distortion. However, the disadvantage of this method is the high computational complexity of the algorithm.

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САУСАҚ ІЗІ БОЙЫНША КЛАССИФИКАЦИЯЛАУҒА АРНАЛҒАН АЛГОРИТМДЕР

Аннотация. Қазіргі уақытта жеке тұлғаны танудың биометриялық әдістері тану технологияларына айналуда. Биометриялық сәйкестендіру жүйелерінің дәстүрлі тәсілдерге қарағанда артықшылығы, адамға тиесілі сыртқы объект емес, адамның өзі анықталады. Саусақ іздері арқылы жеке тұлғаны сәйкестендірудің ең көп таралған технологиясы, ол әр адам үшін папиллярлық өрнектің бірегейлігіне негізделген. Соңғы жылдары тану жүйесінің дәлдігін жақсарту үшін көптеген алгоритмдер мен модельдер пайда болды. Саусақ іздерін жіктеудің заманауи алгоритмдері (әдістері) талданады. Габор сүзгісі, толқындық Хаар, Добеши түрлендірулері және көп қабатты нейрондық желі негізінде саусақ іздерінің түрлері бойынша саусақ іздерінің суреттерін жіктеу алгоритмдері ұсынылған. Ұсынылған алгоритмдерге сандық және эксперименттік зерттеулер жүргізілді. Габор сүзгісін, бес деңгейлі толқындық түрлендіруді және көп қабатты нейрондық желіні бірлесіп қолдануға негізделген алгоритмді қолдану, саусақ іздерін тиімді жіктеуге мүмкіндік беретіні көрсетілген.

Түйін сөздер: саусақ ізінің жіктелуі, Габор сүзгісі, вейлетт түрлендіру, нейрондық желілер.

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АЛГОРИТМЫ КЛАССИФИКАЦИИ ОТПЕЧАТКОВ ПАЛЬЦА

Аннотация. В настоящее время биометрические методы распознавания личности становятся все более актуальными технологиями распознавания. Преимущество биометрических систем идентификации, по сравнению с традиционными подходами, заключается в том, что идентифицируется не внешний объект, принадлежащий человеку, а сам человек. Наиболее распространена технология идентификации личности по отпечаткам пальцев, которая основана на уникальности для каждого человека рисунка папиллярных узоров. В последние годы появилось много алгоритмов и моделей для повышения точности системы распознавания. Проанализированы современные алгоритмы (методы) классификации отпечатков пальцев. Предложены алгоритмы классификации изображений отпечатков пальцев по типам отпечатков пальцев на основе фильтра Габора, вейвлет - Хаара, преобразований Добеши и многослойной нейронной сети. Проведены численные и экспериментальные исследования предложенных алгоритмов. Показано, что использование алгоритма, основанного на совместном применении фильтра Габора, пятиуровневого вейвлет-преобразования Добеши и многослойной нейронной сети, позволяет эффективно классифицировать отпечатки пальцев.

Ключевые слова: классификация отпечатков пальцев, фильтр Габора, вейвлет-преобразование, нейронные сети.

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CLASSIFICATION OF PEOPLE BY PSYCHOLOGICAL PERSONALITY TYPES BASED ON THE HISTORY OF CORRESPONDENCE

Abstract. Temperament is a set of innate tendencies of the mind associated with the processes of perception, analysis and decision-making. The purpose of this article is to predict the psychotype of individuals based on chat stories and follow the Keirsi model, according to which the psycho type is classified as a craftsman, guardian, idealist and mind. The proposed methodology uses a version of LIWC, a dictionary of words, to analyze the context of words and uses supervised learning using KNN, SVM, and Random Forest algorithms to train the classifier. The average accuracy obtained was 88.37% for artisan temperament, 86.92% for caregivers, 55.61% for idealists, and 69.09% for rationality. When using the binary classifier, the average accuracy was 90.93% for artisan temperament, 88.98% for caregivers, 51.98% for idealism, and 71.42% for rationality.

Keywords: social networks, ML, NLP, psychotype recognition, Keirsi temperament model, classification.

1. Introduction

Personality defines a set of traits that describe a person's behavior, temperament, and emotions [13]. Personality refers to a set of traits and qualities that form a person's personality. Thus, personality prediction is of interest in the fields of healthcare, psychology, and human resources and has many commercial applications. Several studies have examined the relationship between a person's social media behavior, personality types, and psychological illnesses such as depression and post-traumatic stress Hall [17].

Social networks consist of various types of social sites, including traditional media such as Newspapers, radio and television, and non-traditional media such as Facebook, Twitter, Telegram, etc. social networks [3] Analysis is the process by which patterns can be analyzed and extracted from social media data [13]. In this context, this article develops a system for predicting the psychotypes of Telegram personalities using data in Russian [12]. The temperament model used was introduced by David Keirsey and divides temperament into four categories: guardian; idealist; craftsman; rational. For this purpose, we used the TECLA Framework, which is suitable for working with Russian-English texts. In addition, the LIWC (Linguistic Inquiry and Word Count) dictionary will be used to display contextual analysis of words by temperament [16].

This article is written as a representation on the second section, David Keirsey's substrate model used by TECLA, and section III describes the structure of TECLA. The fourth section presents the methodology and results achieved, and finally, the fifth section summarizes the results and discusses future prospects.

2. Model number Keisey

Temperament is a set of innate tendencies of the mind associated with the processes of cognition, a set of individual psychophysiological features of the individual, analysis and decision-making [1]. People are looking for success, happiness, love, pleasure, etc. In different ways and with different intensity, so they have different types of temperament [5].

Temperament is marked by its history in the sentences of the four humors described by Hippocrates, which underlie the four theories of humor for interpreting human health and disease States [5]. According to this theory, Galen (190 ad) 250 modeled the first typology of temperament [6].

The American psychologist David Keirsey directed the study of temperament to behavior, paying attention to choice, patterns of behavior, unity and consistency. According to Keirsey, psychological type is defined by the drive and interest that motivate us to live, act, move, and play roles in society [12][7] [1 Keirsey].

Artisans are usually impulsive, tend to say what comes to mind and do what suits them. Guardians talk primarily about their duties and responsibilities, as well as how well they comply with the law. Idealists usually act with a clear conscience, a pragmatic mind, behave effectively to achieve their goals, and sometimes ignore rules and customs when necessary [8][11].

Keirsi's temperament can be obtained by comparing the results of the MBTI (Myers-Briggs type indicator) test, a total of 16 psychological types [7][1][17] that classify users according to four parameters. Psychological type is an attitude as an abbreviation consisting of Latin letters starting with E and I (extroverted and introverted). S and N represent sensation and intuition, the process of perception. The letters T and F represent thinking and feeling, usually using logical reasoning, think first and feel later; and J and P represent judgment and perception, that is, relationships that reflect a person's style in the outside world.

Comparison of MBTI with the Keirsi model is performed using the Myers-Briggs classification of abbreviations, as shown in table-1 [7].

Table-1: Classification model psychotic personality of Karsi for MBTI

Keirsey	**Myers-Briggs**			
Artisan	ESTP	ISTP	ESFP	ISFP
Guardian	ESTJ	ISTJ	ESFJ	ISFJ
Idealist	ENFJ	INFJ	ENFP	INFP
Rational	ENTJ	INTJ	ENTP	INTP

3. The TECLA Framework

The TECLA framework (temperature classification framework) was developed by Lima and de Castro [11][12] to provide a modular classification tool.

Psycho is based on the models Carsi and Myers-Briggs [11]. Built in a modular format, it provides greater independence at each stage of the process and allows you to combine and test different technologies in each module [11]. Figure 1 shows the TECLA modules described in detail below.

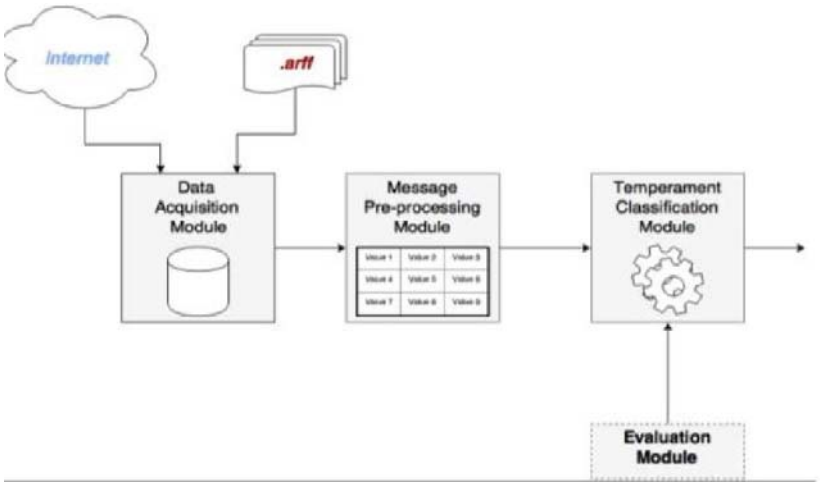

Figure 1 - structure of the TECLA structure

• Data collection module: retrieves information from users to be classified, including data, identities and users, user tokens, and a set of user messages.

• Message preprocessing module: processes data by creating a matrix of objects (meta base) represented by meta properties. TECLA information is divided into two categories: grammar and behavior. Behavioral categories use information from Telegram, such as the number of messages, the number of subscribers, followers, favorites, and the number of times users were added to bookmarks. Grammatical categories use information from LIWC, MRC, Taggers, or oNLP [12].

• Module classification of psychological type: psychological type identification of users of social networks. The classification is performed on the models Carsi using a series of classifiers.

• Evaluation module: used to quantify infrastructure performance. In the version proposed in this technical article, TECLA is adapted to work with text written in Russian-English, and uses information provided by LIWC [12].

4. Methodology and results

The descriptions that will be described in this section correspond to the modular structure of the TECLA framework. First, we will explain how each module of the framework was implemented and what the result of its calculations is.

The collection of data. To test this work, we used data from an Excel file in which we collected data (the message and some attributes) from Telegram, available in Russian, and which is provided by the research center [19] for computational linguistics and psycholinguistics (CLiPS). The data set consists of: user ID; data ID; other data ID; validated data ID; MBTI results (Myers-Briggs type indicators); and gender. Data was recorded using the Telegram API [20] in the following form: each given user, the number of users, the number of favorites, and the total number of messages [10] from all users.

The source database consists of 256 user IDs. In this universe, 222 user IDs could not be collected due to an access denial, resulting in there are 213 valid user IDs left. Table 2 provides a descriptive analysis of the database based on the David Keirsey model.

Figure 2 shows the distribution of the user's psychotype. An idealistic temperament is a dominant temperament that makes up a total of 44% of the database.

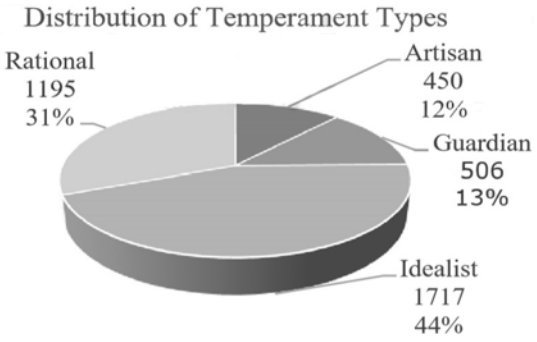

Figure 2 - Distribution of individuals according to temperament

Preprocessing and categorical analysis. At this stage, the application text is prepared. This is part of a classification algorithm consisting of special characters, spaces, numbers, symbols, URLS, tokenization, and stopword removal [4]. After that, we applied the word set technique to indicate the importance of each attribute (token) by weighing each token based on TF-IDF [2].

Another way to organize your documents is to use dictionaries such as the Language Inquiry Word Count (LIWC), which allow you to group words into psychologically relevant categories. LIWC was created by Dr. James Pennebaker to investigate the relationship between language and personality [9][15]. This is a text analysis tool that organizes documents into categories, assigning each word a corresponding category.

Using THE liwc dictionary, we calculated the frequency of words by temperament. The goal is to present the most frequently used word categories for each temperament, as shown in table 3. According to the first analysis, rational temperament usually has a higher average category frequency, which results in the guardian psychotype being taken.

In the second analysis, all substrates are more often found in the following categories: functional words, such as: for, no, very and others; pronouns such as: I, my, me and others; as well as verbs such as:

signs, occurrences and others; socialization, which is a social process, such as user storytelling and others; cognitive category gear mechanism [16]; relativity, rotation, exit and others. There are users who tend to write and hide their identity and tend to submit articles that can Express behavior and show greater awareness and logical thinking.

Another analysis showed that the ppron category for rational and idealistic temperament stands out. And ipron, present, ready, keepers and rational temperament.

This category belongs to the linguistic dimension, which tends to write more articles, pronouns, modal verbs, etc. the Category of people is more often found with an idealistic and rational temperament and tends to write about people. Influence categories are more common among guardians and idealists, and users tend to Express positive, negative, and other emotions. Finally, the admission category has a higher average frequency of temperaments of artisans and caregivers who tend to write about the body, health, and others.

The frequency of words is low, and the categories "Future", "Family", "Anxiety, vision", " Health», "Death, ""Consent," and "filler" have the same value for all temperaments.

Table 3 - Average frequency of LIWC categories by substrate.

Category	Artisan	Guardian	Idealist	Rational
funct	5,22	5,31	5,30	5,39
pronoun	1,85	1,86	1,91	1,93
ppron	1,21	1,22	1,25	1,26
i	0,39	0,36	0,42	0,41
we	0,04	0,04	0,04	0,03
you	0,66	0,70	0,66	0,68
shehe	0,64	0,67	0,65	0,67
they	0,12	0,13	0,13	0,13
ipron	1,22	1,25	1,24	1,27
article	0,77	0,80	0,78	0,81
verb	1,87	1,88	1,88	1,91
auxverb	0,67	0,69	0,68	0,70
past	0,42	0,43	0,43	0,43
present	1,12	1,13	1,12	1,15
future	0,08	0,08	0,08	0,08
adverb	0,48	0,50	0,50	0,50
preps	1,48	1,52	1,46	1,49
conj	0,91	0,90	0,92	0,93
negate	0,24	0,25	0,25	0,25
quant	0,59	0,60	0,61	0,62
number	0,14	0,14	0,15	0,15
swear	0,71	0,71	0,72	0,73
social	2,16	2,17	2,21	2,24
family	0,04	0,04	0,04	0,04
friend	0,11	0,10	0,10	0,09
humans	1,11	1,11	1,15	1,14
Affect	1,08	1,10	1,09	1,08
Posemo	0,70	0,72	0,71	0,69
negemo	0,35	0,34	0,36	0,36
anx	0,05	0,05	0,05	0,05
anger	0,14	0,13	0,14	0,15
sad	0,17	0,16	0,17	0,17
cogmech	4,06	4,14	4,12	4,18
insight	0,72	0,73	0,74	0,75

cause	0,48	0,50	0,49	0,50
discrep	0,68	0,68	0,69	0,70
tentat	0,98	0,99	1,00	1,02
certain	0,38	0,39	0,39	0,39
inhib	0,53	0,55	0,54	0,55
incl	1,40	1,42	1,40	1,41
excl	0,79	0,80	0,80	0,82
percept	0,78	0,79	0,80	0,79
see	0,26	0,26	0,26	0,26
hear	0,18	0,17	0,18	0,18
feel	0,31	0,32	0,31	0,31
bio	0,71	0,69	0,72	0,71
body	0,32	0,31	0,31	0,32
health	0,13	0,13	0,13	0,13
sexual	0,21	0,20	0,21	0,21
ingest	1,08	1,10	1,06	1,06
relativ	2,30	2,36	2,28	2,31
motion	0,76	0,76	0,74	0,76
space	0,98	1,01	0,97	0,99
time	0,98	1,02	0,96	0,96
work	0,23	0,25	0,23	0,24
achieve	0,46	0,49	0,46	0,47
leisure	0,31	0,32	0,31	0,31
home	0,06	0,06	0,06	0,05
money	0,29	0,30	0,29	0,31
relig	0,08	0,09	0,09	0,08
death	0,06	0,06	0,06	0,06
assent	0,13	0,13	0,13	0,13
nonfl	0,26	0,27	0,26	0,27
filler	0,03	0,03	0,03	0,03

Classification. During the experiment, 4% of the total data set was randomly selected and used because of the size of the processed matrix and the availability of computing resources. To perform substrate classification, we used the following classifiers available in Scikit-learn [14]. KNN; SVM; and random forest. Each temperament is divided into binary problems, as suggested by Lima and de Castro [12]. For testing, cross-validation of folders 6 and 10 was used, and accuracy, accuracy, recall, and F-measures were calculated. For the KNN classifier using K-nearest neighbor feature classification, K = 1, K = 2, K = 3, and cosine similarity were used to determine neighbors. The tests were divided into liwc [19] and TF-IDF [20] dictionary.

Table 2 - telegram users ' Temperament and data (A = artisan, G = guardian, I = idealist, R = rational)

	A	G	I	R	Total
Users	450	506	1.717	1.195	3.868
Datas_Statuses_Count	12.343.807	15.648.860	65.593.286	45.198.150	138.784.103
Data _Base	674.211	738.755	2.570.646	1.751.624	5.735.236
Friends	168.893	225.371	825.969	640.529	4.012.741
Favorites	1.768.903	2.371.924	10.006.749	6.683.984	1.860.762
Contact_num	292.413	423.549	1.497.093	1.799.686	4.012.741

5. LIWC

Table 4 shows the results of testing the 10-fold launch of 6 folders in TECLA. The values shown in bold represent the best average accuracy and F measurements obtained by the classifier for each temperature.

For the artisan's temperament, the KNN algorithm with K = 1 gave an average accuracy of 80.44% and an F-measure of 88.91%. The better the performance, that is, the more accurate the function markup, the better is the SVM algorithm with an average accuracy of 88.37%, followed by a random forest with an average accuracy of 87.95%. SVM had better average accuracy and 100% responsiveness, while Random Forest had better accuracy than SVM.

As for the guardian's temperament, the most obvious prediction comes from the SVM algorithm with an average accuracy of 86.92% and a measure of F. This was followed by a 93% random forest and an average accuracy of 86.32%. The lowest average accuracy (78.36%) was found in KNN with K = 1.

SVM showed the best results even with an ideal and reasonable temperament.

The idealistic substrate had an average accuracy of 55.61%, an F measurement of 71.46%, a rational substrate of 69.09%, and an f measurement. These two substrates exceeded the average accuracy and were suitable for marking objects .50%. Overall, the SVM has the highest accuracy for all temperaments, but for artisan and guardian temperaments, Random Forest showed an average accuracy very close to SVM.

6. TF-IDF

Table-5 shows the results of cross-checking the execution of 10 folders 10 times in a TECLA environment. The values shown in bold represent the best average accuracy and the results of the F measurement obtained using the binary classifier for each temperature. Artisan temperament achieved high average accuracy (90.93%) with KNN, K = 3 and F-measurement of 95.09%, which makes the results obtained by KNN reliable (K = 3). The accuracy is 88.35%. SVM had the highest average accuracy for sentinel temperament, but in this case KNN for K = 3 performed very poorly. One hypothesis about this low value is an imbalance in the database, so when you increase the number of neighbors, the algorithm cannot label objects. For the idealistic temperament, SVM and KNN were practical (K = 3). For rational temperament, the best performance was 82.85% of the average accuracy for the KNN algorithm with K = 2. Once again, SVM turned out to be the algorithm that showed the best average performance among those tested.

Table 4 - Accuracy (Acc), precision (Pre), re-call (Rec), and F-measurement (M-F)
for 4 media using 6 folders and 10 replays.

	LIWC	1NN	2NN	3NN	Random Forest	SVM
Artisan	Acc	**80,44% ± 0,71%**	87,62% ± 0,37%	87,62% ± 0,37%	**87,95% ± 0,16%**	**88,37% ± 0,00%**
	Pre	88,79% ± 0,14%	88,47% ± 0,07%	88,47% ± 0,07%	88,41% ± 0,06%	88,37% ± 0,00%
	Rec	89,10% ± 0,87%	98,86% ± 0,44%	98,86% ± 0,44%	99,39% ± 0,15%	100,00% ± 0,00%
	M-F	88,91% ± 0,47%	93,37% ± 0,23%	93,37% ± 0,23%	**93,58% ± 0,09%**	**93,82% ± 0,00%**
Guardian	Acc	**78,36 ± 0,62%**	85,67% ± 0,10%	85,74% ± 0,10%	**86,32% ± 0,11%**	**86,92% ± 0,01%**
	Pre	87,05% ± 0,07%	86,94% ± 0,04%	86,94% ± 0,04%	87,03% ± 0,06%	86,92% ± 0,00%
	Rec	88,22% ± 0,76%	98,27% ± 0,09%	98,36% ± 0,09%	99,02% ± 0,11%	100,00% ± 0,01%
	M-F	87,61% ± 0,43%	92,25% ± 0,06%	92,30% ± 0,06%	92,63% ± 0,06%	**93,00% ± 0,01%**
Idealist	Acc	54,97% ± 0,46%	54,97% ± 0,46%	**52,57% ± 0,61%**	54,27% ± 0,40%	**55,61% ± 0,01%**
	Pre	56,80% ± 0,27%	56,80% ± 0,27%	57,88% ± 0,57%	56,67% ± 0,26%	55,61% ± 0,01%
	Rec	79,44% ± 0,80%	79,44% ± 0,80%	54,18% ± 0,97%	75,65% ± 1,04%	100,00% ± 0,00%
	M-F	66,19% ± 0,33%	66,19% ± 0,33%	55,86% ± 0,67%	64,76% ± 0,49%	**71,46% ± 0,02%**
Rational	Acc	**59,12% ± 0,58%**	65,82% ± 0,49%	87,62% ± 0,37%	66,62% ± 0,26%	**69,09% ± 0,03%**
	Pre	69,72% ± 0,21%	69,27% ± 0,13%	88,47% ± 0,07%	69,74% ± 0,14%	69,10% ± 0,01%
	Rec	72,17% ± 1,20%	90,84% ± 1,16%	98,86% ± 0,44%	91,38% ± 0,40%	99,97% ± 0,04%
	M-F	70,85% ± 0,65%	78,57% ± 0,47%	74,78% ± 0,27%	79,09% ± 0,19%	**81,71% ± 0,03%**

Table 5 - Accuracy (Acc), Precision (Pre), Recall (Rec), and F-measure (M-F) for four temperaments using 10 folders and 10 iterations

	TF-IDF	1NN	2NN	3NN	Random Forest	SVM
Artisan	Acc	87,31% ±3,01%	90,25% ± 0,09%	**90,93% ± 0,06%**	87,69% ± 0,07%	**88,35% ± 0,07%**
	Pre	87,31% ± 3,01%	90,25% ± 0,09%	90,93% ± 0,06%	87,69% ± 0,07%	88,35% ± 0,07%
	Rec	99,00% ± 3,00%	100,00% ± 0,00%	100,00% ±0,00%	100,00% ± 0,00%	100,00% ± 0,00%
	M-F	92,56% ± 2,99%	94,73% ± 0,07%	**95,09% ±0,06%**	93,25% ± 0,08%	**93,60% ± 0,07%**
Guardian	Acc	88,98% ± 0,06%	85,08% ± 0,09%	**27,13% ± 3,73%**	88,25% ± 0,07%	**90,93% ± 0,08%**
	Pre	88,98% ± 0,06%	85,08% ± 0,09%	16,27% ± 3,25%	88,25% ± 0,07%	90,93% ± 0,08%
	Rec	100,00% ± 0,00%	100,00% ± 0,00%	19,00% ± 3,00%	100,00% ± 0,00%	100,00% ± 0,00%
	M-F	94,04% ± 0,05%	91,68% ± 0,11%	17,50% ± 3,16%	93,55% ± 0,13%	**95,15% ± 0,06%**
Idealist	Acc	52,40% ± 2,14%	51,98% ± 0,10%	**61,05% ± 0,08%**	54,42% ± 3,29%	**61,04% ± 0,12%**
	Pre	48,14% ± 1,05%	51,98% ± 0,10%	61,05% ± 0,08%	50,12% ± 5,65%	61,04% ± 0,12%
	Rec	90,00% ± 0,00%	100,00% ± 0,00%	100,00% ± 0,00%	88,00% ± 8,72%	100,00% ± 0,00%
	M-F	62,12% ± 0,99%	67,74% ± 0,20%	**75,13% ± 0,27%**	**63,32% ± 6,78%**	**75,08% ± 0,34%**
Rational	Acc	65,52% ± 1,43%	**71,42% ± 0,10%**	70,80% ± 0,11%	65,60% ± 1,82%	68,21% ± 0,06%
	Pre	62,18% ± 0,72%	71,42% ±0,10%	70,80% ± 0,11%	65,40% ± 2,41%	68,21% ± 0,06%
	Rec	90,00% ± 0,00%	100,00% ±0,00%	100,00% ± 0,00%	99,00% ± 3,00%	100,00% ± 0,00%
	M-F	73,16% ± 0,50%	**82,85% ±0,27%**	82,51% ± 0,27%	78,21% ± 2,63%	80,70% ± 0,013%

7. Conclusion

Temperament affects how we perceive the world and react to it. Understanding temperament is very important in our lives and is important for correctly positioning ourselves in the market. In General, you can determine your temperament using a test such as the Myers-Briggs type indicator (MBTI). The hypothesis of this study is that only with the help of data obtained from a person's social networks, it is possible to passively determine their psychotype. To do this, we used a database containing MBTI results from Telegram users. These data were used to create a model for predicting temperament. Documents (data) are a RUSSIAN liwc dictionary, in which words are grouped by category. Word frequency calculations were performed to show the categories most commonly spoken by artisans, keepers, idealistic and rational psychotypes. In this analysis, you can determine the user's email trends, perception, among other things, related to the topics that are most identified. The data was structured using LIWC and TF-IDF. For classification via LIWC, the best accuracy results were obtained for the temperament of the artisan and guardian trained with SVM. For TF-IDF, the highest average accuracy was for artisan, guardian, and idealist temperament, and the SVM algorithm was also highlighted. For expressions using TFIDF, the best average accuracy was observed for the artisan and guardian temperament of the KNN (K = 3) and SVM algorithms.

As a future work, we plan to conduct a case study using the TECLA framework with a database of a set of volunteer users, so that the data can be used to train TECLA by answering the MBTI test form and sharing a social profile. Make a frame and sort it by temperament. Another improvement is to examine the content of the document to find out how much the imbalance base hinders obtaining these results, to understand why the accuracy of the classifier is low and whether processing of an unbalanced class is required.

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АДАМДАРДЫ ХАТ АЛМАСУ ТАРИХЫ НЕГІЗІНДЕ ПСИХОЛОГИЯЛЫҚ ТҰЛҒА ТҮРЛЕРІ БОЙЫНША ЖІКТЕУ

Аннотация. Темперамент дегеніміз – қабылдау, талдау және шешім қабылдау үдерісіне байланысты ақыл-ойдың туа біткен тенденцияларының жиынтығы. Мақаланың мақсаты – әлеуметтік желілердегі қарым-қатынас негізінде жеке адамның психотипін болжау және Кейрси моделіне сүйену, соған сәйкес психотип шебер, қамқоршы, идеалист және ақыл ретінде жіктеледі. Ұсынылған әдістемеде LIWC нұсқасы, сөз жиынтығы, сөз контексін талдау үшін KNN, SVM және Random Forest алгоритмдерін бақылау арқылы классификатор оқытуды көздейді. Темпераментпен жұмыс істеу үшін орташа есеппен алынған дәлдік қолөнершілерге 88,37%, тәрбиешілерге 86,92%, 55,61% идеалистер мен рационалдылық үшін 69,09% дәлдікті құрайды. Екілік жіктеуішті қолданған кезде орташа дәлдік қолөнершінің темпераменті үшін 90,93%, тәрбиешілер үшін 88,98%, идеализм үшін 51,98% және ұтымдылық үшін 71,42% құрады.

Түйін сөздер: әлеуметтік желілер, ML, NLP, психотипті тану, Кейрси темпераментінің моделі, классификация.

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КЛАССИФИКАЦИЯ ЛЮДЕЙ ПО ТИПАМ ПСИХОЛОГИЧЕСКОЙ ЛИЧНОСТИ НА ОСНОВЕ ИСТОРИИ ПЕРЕПИСКИ

Аннотация. Темперамент – это совокупность врожденных склонностей ума, связанных с процессами восприятия, анализа и принятия решений. Цель этой статьи – предсказать психотип людей на основе чатов и следовать модели Кейрси, согласно которой психотип классифицируется как ремесленник, опекун, идеалист и ум.

Предлагаемая методология использует версию LIWC, набор слов для анализа контекста слов и использует контролируемое обучение с использованием алгоритмов KNN, SVM и Random Forest для обучения классификатора. Средняя полученная точность сотавила 88,37% для темперамента ремесленника, 86,92% – для воспитателей, 55,61% – для идеалистов и 69,09% – для рациональности. При использовании бинарного классификатора средняя точность составила 90,93% для темперамента ремесленника, 88,98% – для воспитателей, 51,98 – для идеализма и 71,42% – для рациональности.

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INFORMATION SYSTEM FOR PEOPLE WITH HEARING IMPAIRMENT

Abstract. The article presents the development of an information system for recognizing voice into text for people with hearing impairments, which makes it possible to improve the quality of life and interaction in society with other people. The device, software, functional blocks and subsystems of the information system are described. Examples of possible application and placement of the system in various spheres of public life are given. One of the types of implementation of the voice recognition information system is described. The development and creation of prototypes of a device for people with hearing impairments is considered. In the course of the research, the Google Speech Api technology was selected for speech recognition. In addition, this article presents a software and hardware complex that allows you to translate speech into text and then display it on the screen. Arduino UNO-based devices were chosen to achieve the goal. All information is processed on the smartphone of people with hearing impairments, which is sent to the device via Bluetooth with Arduino.

Keywords: information system, Google Speech Api, Arduino UNO, microcontroller, Ethernet, display, board, bluetooth, connector, port.

1. Introduction. Nowadays, it is impossible to develop various areas of human activity without the widespread use of computer technology and the creation of information systems. Information processing in such systems has become an independent scientific [1-2] and technical direction. In the modern world, information has become one of the most important resources, and information systems (IS) have become a necessary tool for virtually everyone, including people with disabilities.

Modern world information technologies have determined the direction of adaptation of people with disabilities. There are more than 360 million people with hearing impairments in the world community. In various countries, active research and development is underway to create information systems for the hearing impaired. Many scientific papers have focused on the use of neural networks to recognizing gestures. There are also gloves based on the Arduino Uno microcontroller for the hearing impaired. It is a bulky and inconvenient device, it is only at the design stage (no mass production), there is no text scoring, it is displayed only on the OLED screen.

The rapid process of miniaturization of electronics leads to the emergence of a new class of devices - wearable electronics, which is becoming the most relevant trend of our time. Mobile solutions can help transform speech and sound into visual representations for people with hearing impairments. However, where handheld phones pose problems, displays can facilitate further communication through privately written text, hands-free use, increased mobility, and socially acceptable interactions.

The progress in the field of augmented reality, which led to the creation of prototypes of augmented reality glasses - GoogleGlass and MicrosoftHololens, is especially bright and interesting [3-4]. Applications using these devices appear every day and are shown at the latest company exhibitions. The advent of augmented reality devices was a new step in the development of technology. Many companies managed to release analogs of these devices.

Another breakthrough was the emergence of an open unified universal digital platform Arduino, which made it possible to make a real prototype of the device. This platform includes a digital processor, a

programmer from a computer, and a development environment. The platform is open, which has allowed the emergence of a huge number of devices compatible with it - from the simplest sensors, screens to complex Ethernet boards, WiFi, etc.

Based on the knowledge gained, the capabilities of existing augmented reality devices were considered. The existing universal microcontrollers and devices interfaced with them, as well as writing programs for such devices, have been studied.

Using the Arduino [5-6] universal controller allows you to make a prototype of such devices. Using the open architecture of the controller allows you to write a universal platform for the device that makes life easier for people with hearing impairments.

2. Methods.

When researching this topic, the implementation of speech recognition and speech-to-text conversion, as well as the output of the received text to the device screen, were considered. The first part of the implementation consists of speech recognition and conversion to text.

The study examined some of the methods used in speech recognition.

Pre-emphasis. Different signals differ in volume. To bring audio to the same form, it is necessary to normalize the signals and filter them with a high-pass filter to reduce noise. Pre-emphasis is a filter for speech recognition tasks. It boosts high frequencies, which improves noise immunity and gives more information to the acoustic model.

Framing. The original signal is not stationary. It is divided into small intervals (frames), overlapping with each other, which are considered stationary. A Hann window function is applied to each frame to flatten the ends of the frames to zero.

Fourier. Fast discrete Fourier transform. The Fourier transform allows you to decompose the original stationary signal into a set of harmonics of different frequencies and amplitudes. This operation is applied to the frame, hence it transforms the frequency representation. We apply the Fourier transform to all frames, the spectral representation is formed and the power of the spectrum is calculated.

Log mel filterbank. Numerous scientific studies have shown that a person recognizes low frequencies better than high ones, and the dependence of his perception is logarithmic. Therefore, a convolution of N-triangular filters with one in the center is applied to the power spectrum. As the filter increases, the center shifts in frequency and increases logarithmically at the base. This allows you to capture more information in the lower frequencies and compress the representation of the high frequencies of the frame, subsequently the data is logarithm [7].

The second part of the implementation of the text output to the screen.

To study the principle of operation of the Arduino device with a universal control board, a number of experiments were considered to study the programming of universal controllers. For the hardware part, devices with certain functional properties were selected (table 1).

Table 1 - Functional components of the created device

№	Name	Main settings
1	Microcontroller board	Arduino Uno
2	Display	16×2, Integrated controller WS0010
3	Bluetooth	Module HC-05
4	Connecting wires / connectors	JST connector with wire (male-female kit), wire length 100mm
5	USB cable	A –B
6	Android device	Smartphone
7	IDE Arduino	Software environment

In the course of the research, the Google Speech Api technology was selected for speech recognition. Speech recognition works for 80 languages. Recognition of speech on the air through a microphone or audio recordings from files up to 2 minutes is possible. Numerous formats are supported, including FLAC, AMR and PCMU. Speech API technology can be embedded in any programming language. In this work, the Python language was chosen for this. The system provides the recognized text instantly in the process.

The recognition process is divided into several stages:

• Signal analysis. At this stage, the system sends the received request to the server. This is where the process of clearing interference and noise takes place. The next process is the compression of the received sound, it is divided into fragments, which is 25 milliseconds long. The divided fragments are passed through the acoustic model. For later recognition, this model determines which sounds have been pronounced.

• In the stage of signal recognition, the reference pronunciations stored in the acoustic model are compared with the speech fragments of the recording. Using machine learning, the system selects variants of spoken words and their context. As a result, it collects presumed words from sounds.

• The last step is to convert the signal to text. Using the language model, the system determines the word order and matches unrecognized words by context. The information obtained at these stages goes to the decoder. Therefore, with the most probable sequence of words, the decoder combines data from the acoustic and language models, converts them into text [8].

For programming the Arduino, the standard C ++ programming language was used (the AVRGCC compiler is used). Of course, there are several other development environments and several programming languages (Sketch, Basic), aimed mainly at beginners. We used the C ++ language and the ArduinoIDE device driver packages available on the Internet with an example of the program code [9-10].

To interact with the Arduino with a 16x02 LED display, the LiquidCrystal.h library was required, which includes a variety of commands to control the monitor.

On the Arduino Uno board, at the top are pins numbered from 0 to 13. These are digital pins, usually various LEDs are connected to them. However, pin number 13 is responsible for the operation of the built-in LED on the board and serves, most often, to check its operability. By specifying the pin number in the sketch, we can work with the device that is connected to it. For this we use the necessary functions: pinMode, DitalWrite [11-12]. The PinMode () function is used to customize this very pin. All pins on the board can work as inputs and outputs. By default, all pins are inputs, but the LED needs an output signal as it receives an operating command and voltage. The PinMode (pin, mode) function consists of two values. These are pin - pin number and mode - input / output mode (INPUT / OUTPUT). Further, the loop itself is written in the void loop () function. After determining the contact, as an output, you can set it to a high or low state, this is 0 or 5 volts of voltage [13].

We change the state of the output signal using the digitalWrite (pin, level) function. It also has two meanings. This pin is the pin number (for example, our LED is connected to pin A0) and level is the output signal level: it can be low (HIGH) or high (LOW).

The use of the delay (1000) function serves to set the delay in the program code between the execution of various actions (since the controller cannot simultaneously perform several actions, but performs them sequentially). The function itself specifies the time of this very delay in milliseconds (1000ms = 1s).

Before assembling all the devices, a program code was entered on the Arduino Uno board that will translate speech into text and output it to a 16x2 Led Display. The program code was previously written in the Arduino IDE software (an overview of the program was described earlier). To enter the code, the board was connected to a computer via a USB port, which also serves as a power supply for the Arduino UNO.

To implement the device, the Arduino board must be connected to a power source. Here, the power source is a USB cable from the Arduino UNO coming from the computer, as well as from the wall power supply that is connected to the connector. I also uploaded the code to the Arduino board via USB. You should not use a power supply greater than 20 volts as this will overwhelm your Arduino. The recommended voltage for most Arduino models is 6 to 12 volts. The necessary ports were installed in the software environment, corresponding to the hardware, only after installing the input and output ports, the program code is loaded and launched.

Physically, it serves as a wireless intermediary, transferring data between the Arduino and any smartphone. The application is available for both Android and IOs operating systems. After connecting the two boards, the Led Display was connected to the Arduino, then the HC-05 Bluetooth module [14].

The connection diagram is shown in figure 1.

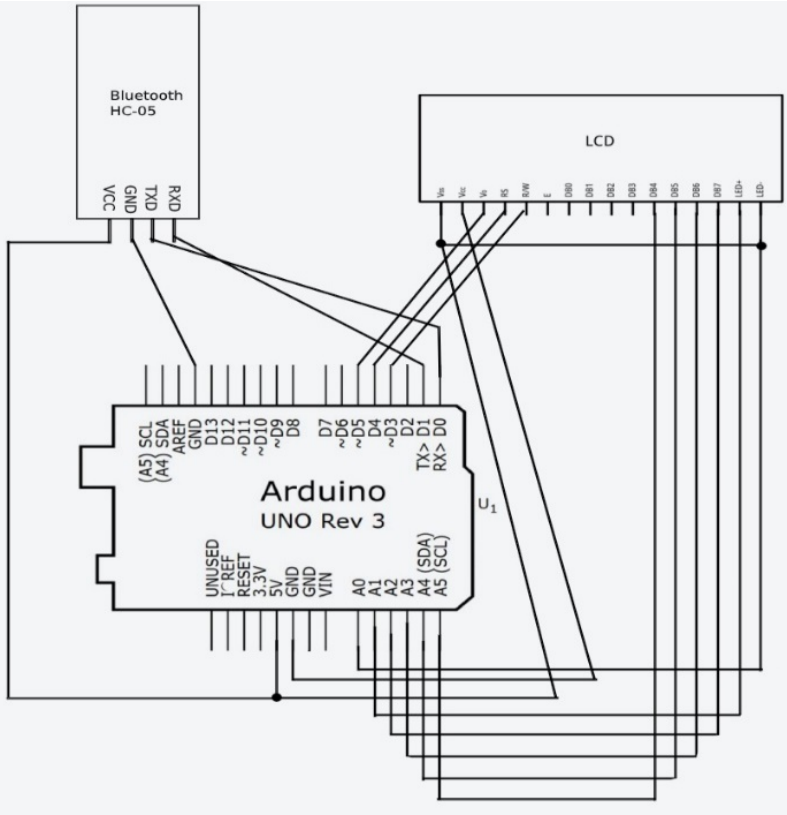

Figure 1 – Layout diagram of the device

Pin A0 is connected to pin 16 of Led Display.
16th pin of LED -> 1st pin of LED Display
2nd pin Led Display -> + 5V Arduino Uno
3rd pin of Led Display -> GND Arduino Uno
4th Pin Led Display -> 5th Pin Arduino Uno
5th Pin Led Display -> 4th Pin Arduino Uno
6th Pin Led Display -> 3rd Pin 1Sheeld
Connection diagram of the Bluetooth module HC-05 to 1Sheeld
RXD pin Bluetooth HC-05 -> TXD pin Arduino Uno
TXD pin Bluetooth HC-05 -> RXD pin Arduino Uno
GND pin Bluetooth HC-05 -> GND pin Arduino Uno
VCC pin Bluetooth HC-05 -> 5V pin Arduino Uno

Therefore, when the required boards have been connected, the device is operational as the program code was previously entered. In this project, an Android smartphone was selected and the OneSheeld application was downloaded. The device and the application communicate through the HC-05 Bluetooth module [15].

4. Conclusions. Given that at the current stage of the project we decided to focus on the implementation of the application and its interaction with the interface, new implementations were inserted into it at a later stage, but we cannot fail to mention this due to the usefulness of these resources. We will refer to the final stage of the project implementation: changes in the application interface, improvement of the usability of the Android device by the end user.

As a result, there were studies of ways to implement speech recognition developed on the Google Speech API technology. In the course of the research, the methods and stages of speech-to-text reproduction were considered.

This article is the result of research that studies and explores the possibilities of automation using Arduino[18]. Built with inexpensive resources such as Arduino and other devices, and an Android app to facilitate socialization of people with disabilities, this app will certainly make its own difference in their lives. However, this prototype is not intended for commercial use. The main goal is to help people with hearing impairment, however, and in the future this solution can be easily implemented.

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ЕСТУ ҚАБІЛЕТІ НАШАР АДАМДАРҒА АРНАЛҒАН АҚПАРАТТЫҚ ЖҮЙЕ

Аннотация. Мақалада есту қабілеті бұзылған адамдарға мәтінді дауыстан тануға арналған ақпараттық жүйенің даму жағдайы ұсынылған, бұл өмір сүру сапасын жақсартуға және қоғамдағы басқа адамдармен өзара қарым-қатынас жасауға мүмкіндік береді. Ақпараттық жүйе құрылғысы, бағдарламалық жасақтама, функционалды блоктары мен ішкі жүйелері сипатталған. Жүйені қоғамдық өмірдің түрлі саласында қолдануға және орналастыруға мысалдар келтірілген. Дауысты танитын ақпараттық жүйені енгізу түрлерінің бірі сипатталған. Есту қабілеті төмен адамдарға арналған құрылғы прототиптерін жасау және құру жолдары қарастырылады. Зерттеу барысында сөйлеуді тану үшін Google Speech Api технологиясы таңдалды. Сонымен қатар, бұл мақалада сөйлеуді мәтінге аударуға, содан кейін оны экранға шығаруға мүмкіндік беретін бағдарламалық-аппараттық кешен ұсынылған. Осы мақсатқа жету үшін Arduino UNO негізіндегі құрылғылар таңдалды. Барлық ақпарат есту қабілеті бұзылған адамдардың смартфонында өңделеді, ол Arduino көмегімен Bluetooth арқылы құрылғыға беріледі.

Түйін сөздер: ақпараттық жүйе, Google Speech Api, Arduino UNO, микроконтроллер, Ethernet, дисплей, тақта, Bluetooth, коннектор, порт.

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ИНФОРМАЦИОННАЯ СИСТЕМА ДЛЯ ЛЮДЕЙ С НАРУШЕНИЕМ СЛУХА

Аннотация. В статье представлена разработка информационной системы распознавания голоса в текст для людей с нарушениями слуха, позволяющей повысить качество жизни и взаимодействия в обществе с другими людьми. Описаны устройство, программное обеспечение, функциональные блоки и подсистемы информационной системы. Приведены примеры возможного применения и размещения системы в различных сферах общественной жизни. Описан один из видов реализации информационной системы распознавания голоса. Рассматривается разработка и создание опытных образцов устройства для людей с нарушениями слуха.

В ходе исследования была выбрана технология Google Speech Api для распознавания речи. Кроме того, в данной статье представлен программно-аппаратный комплекс, позволяющий переводить речь в текст и затем выводить ее на экран. Для достижения этой цели были выбраны устройства на базе Arduino UNO. Вся информация обрабатывается на смартфоне людей с нарушениями слуха, который передается на устройство по Bluetooth с помощью Arduino.

Ключевые слова: информационная система, Google Speech Api, Arduino UNO, микроконтроллер, Ethernet, дисплей, плата, Bluetooth, разъем, порт.

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NUMERICAL SOLUTION OF TWO-DIMENSIONAL PROBLEMS OF THERMOVISCOELASTICITY

Abstract. This paper considers the numerical implementation of two-dimensional thermoviscoelastic waves. The elastic collision of an aluminum cylinder with a two-layer plate of aluminum and iron is considered. In work [1] the difference schemes and algorithm of their realization are given. The most complete reviews of the main methods of calculation of transients in deformable solids can be found in [2, 3, 4], which also indicates the need and importance of generalized studies on the comparative evaluation of different methods and identification of the areas of their most rational application. In the analysis and physical interpretation of numerical results in this work it is also useful to use a priori information about the qualitative behavior of the solution and all kinds of information about the physics of the phenomena under study. Here is the stage of evolution of contact resistance of collision – plate, stress profile.

Keywords: two-dimensional thermoviscoelastic waves, stability of the difference scheme, convergence of the solution of the difference problem, indenter, deformation, tensor, stresses.

Introduction. To test the numerical method proposed in [1], we consider the elastic collision of an aluminum cylinder of unit radius with a two-layer plate made of aluminum ($h_1 = 0{,}75$) and iron ($h_2 = 0{,}25$).

Figure 1 shows the normal voltage distribution σ_z (figure 1, a) and vertical speed υ (figure 1, b) on the axis of symmetry, at the points where the wave motion up to the moment of time $t = 1{,}0$ is one-dimensional (self-similar). The information is presented in dimensionless form, where the linear dimensions are related to the thickness of the plate h, time – to $\frac{h}{a}$ (a – velocity of propagation of longitudinal waves in aluminum), stresses are divided by $\rho \cdot a^2$, and velocities – by a. The solid curve corresponds to the results of calculations with a step $\Delta h = 0{,}02$, solid with a point – $\Delta h = 0{,}01$; the dashed line refers to the Lax-Wendroff Scheme at $\Delta h = 0{,}02$; the dashed line is the exact solution.

It can be seen from the graphs that with a sufficiently large number of integration nodes, the first-order accuracy scheme for a strong gap gives a fairly clear and steep stress and velocity profile. The convergence of difference solutions is monotonic, which allows their refinement by means of Richardson extrapolation [5]. The "smearing" zone of the jump decreases proportionally to the decrease Δh, and at $\Delta h = 0{,}02$ it practically disappears, the numerical solution coincides with the exact one. The results presented here are consistent with the data of [6].

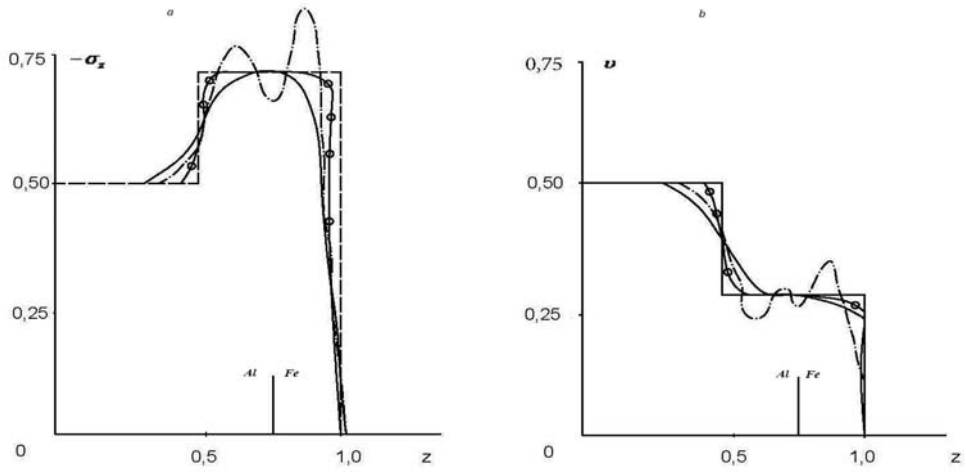

Figure 1(a, b) - distribution of normal stress $-\sigma_z$ and vertical velocity υ

The non-monotonicity of the second-order accuracy scheme generates very significant oscillations in the vicinity of the front, which are increasingly amplified as the waves reflect from the outer boundaries of the plate. With decreasing grid spacing, the amplitude of oscillations decreases, while the width of the zone of "spreading" at the same time narrows. Note that non-monotonicity scheme occurs only before front. Oscillations are absent after the front. The amplitude of the oscillations in the vicinity of the jump can be minimized by introducing a specially selected viscosity, however, as shown by Lax and Wendroff, it is impossible to get rid of these oscillations at all. In addition, the introduction of artificial viscosity reduces the accuracy of the difference scheme in the areas of smoothness of the solution. In some cases, the attribution of different viscosities when they disappear can lead to different limit solutions [7]. The advantages of high accuracy schemes, which include the Lax - Wendroff Scheme, are manifested in the calculation of smooth solutions.

The results presented here clearly illustrate the advantages of a monotone (non-oscillating) scheme for the calculation of jump motion. Countable phenomena, manifested in the through account of discontinuous (generalized) solutions by schemes of increased order of accuracy without special allocation of features, significantly complicate the analysis of the wave pattern, especially in cases where the exact location of the discontinuities and their configuration are unknown. In addition, it is hardly advisable to use a high approximation order to compute a solution that does not have the corresponding smoothness. It should also be borne in mind that for any difference scheme, the order of approximation, and hence the convergence of the solution in the areas of the influence of smearing discontinuities in the general case is close to the first [8].

In the contact problem under consideration, the computational domain has a rather complex geometry, so the study of the a posteriori accuracy of the desired functions, especially near the angular points where the stresses may have features, required a special series of test computational experiments to obtain convergent solutions on a sequence of grinding grids. Control of the calculation results was also carried out by calculating the total thermomechanical energy, which should remain unchanged in time and be equal to the kinetic energy of the translational and rotational movements originally stored by the stamp. Note that when constructing the difference grid, the partition was chosen so that its nodes do not fall on the contact boundaries (hence, in the angular points). The reduction of the integration step over space makes it possible to determine the numerical solution outside an arbitrarily small neighborhood of singular points (this approach eliminates the need for the averaging procedure of the solution at these points, which is inevitable with other methods).

Figure *2, a* shows the distribution of the contact voltage σ_z that occurs at the time $t = 0{,}25$ of collision of an iron cylinder with a radius of 0.5 on a two-layer plate $0{,}75\,Al$ - $0.25\,Fe$. Curves are obtained at $\Delta h = 0{,}02$ (1); 0,07 (2); 0,005 (3).

It can be seen from the graphs that when the grid thickens, the discrete functions differ slightly and these differences are noticeable only in the diffraction region, where the unsteady field is essentially two-

dimensional. In the zone of uniaxial stress state the calculated value $\sigma_z = -0{,}72$ coincides with the exact solution [9], which is effectively calculated only in the region of one-dimensional wave motion:

$$\sigma_z = -V_0 \frac{\rho_0 a_0 \rho_1 a_1}{\rho_0 a_0 + \rho_1 a_1}.$$

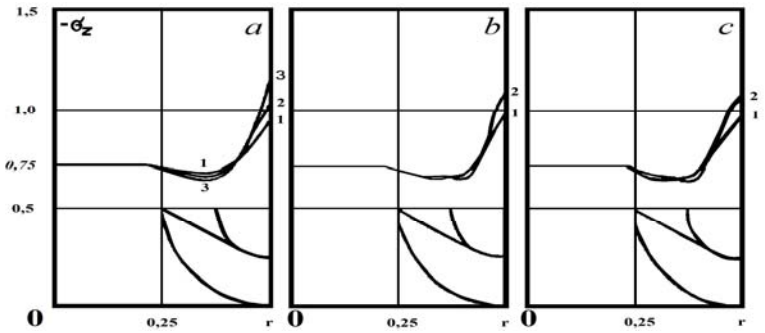

Figure 2(a, b, c) - distribution of the contact stresses $-\sigma_z$ resulting from point-in-time $t = 0{,}25$

Comparative analysis of the compared numerical results indicates their reliability and proximity to the exact solution. On the basis of a posteriori estimates, it can be argued that the individual components of the solution vector are with a relative error of 7 - 10% on the grid with a step $\Delta h = 0{,}02$ in the norm L_2, and the accuracy of determining the mean at the site of contact stresses $\sigma_x = 2\pi \int_0^R \sigma_z(r,o,t) r dr$ is slightly higher: 1 - (-0,588); 2 - (-0,591); 3 - (-0,592).

The imbalance of total energy is only a fraction of a percent on grid 3.

The results of calculations of contact voltage $-\sigma_z$ according to the Lax-Wendroff ($A = 0$) scheme and the scheme with minimal dispersion ($A = 1{,}3$) on grids 1 and 2 reflect figure 2,b,c. Comparison of the curves shows that both schemes give similar grids, in good agreement with the numerical data of the scheme of first order of accuracy ($q^* = A = 0$). The schemes of the increased order of accuracy allow revealing small features of a wave field when distribution of stresses is rather smooth. However, in the area of pronounced discontinuity, the description of wave motion is preferable using a monotone scheme, as evidenced by the results obtained $r = 0$ in (figure 3). The amplitude of false oscillations in the scheme of minimal dispersion is minimized by a special selection of the coefficient on the model problem of collision of semi-infinite plates, for which the exact analytical solution in the form of series of trigonometric functions is known [10, 11].

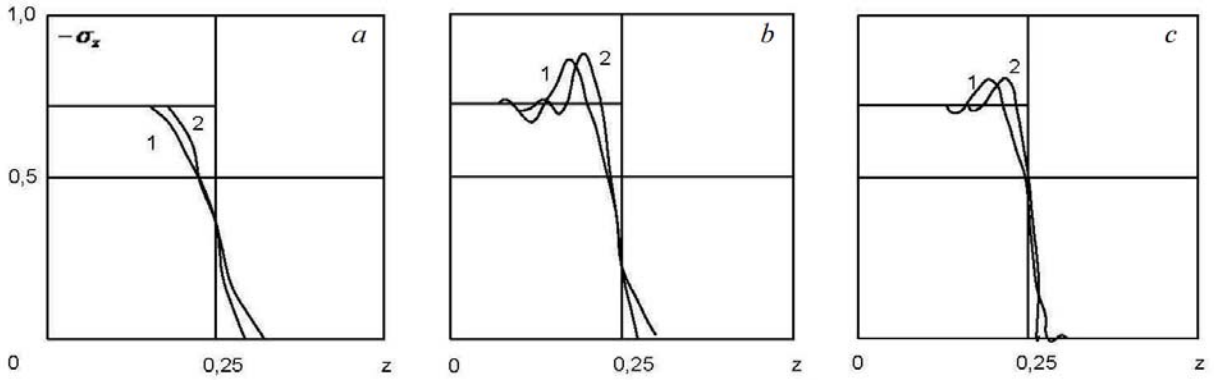

Figure 3 - Description of the wave motion is preferable using a monotone scheme, at $r = 0$

Stress profiles σ_y for dimensionless time moment $t = 0{,}5$ in sections $x : 0(a);\ 0{,}2\ (б);\ 0{,}4\ (в)$ are proved in figure 4. The exact distribution is plotted by a dashed line, the solid curve refers to the scheme proposed in [1], and the dashed line refers to the scheme of the minimum dispersion. The diagrams show that the numerical solutions obtained are close enough to the exact solution, tabulation of which is also associated with some errors, which are inevitable, apparently, due to machine rounding.

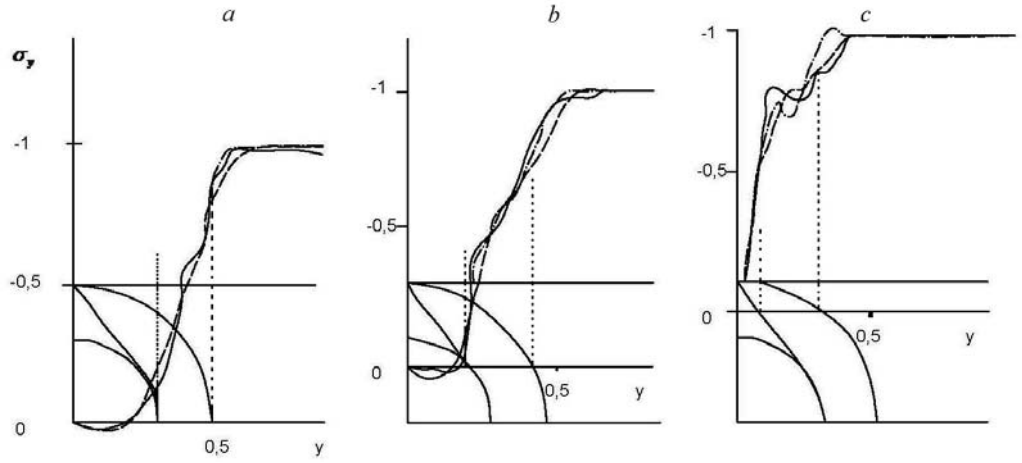

Figure 4 - Stress profiles σ_y for dimensionless instant $t = 0{,}5$ in cross sections by $x : 0(a);\ 0{,}2\,(b);\ 0{,}4\,(c)$

The parametric scheme, which depends on q^* and A and includes schemes of the first and second order of accuracy, allows to calculate the desired solution depending on its local differential properties. In the region of sufficient smoothness of the solution, it is advisable to use a scheme with minimal dispersion, and in the vicinity of jumps or large gradients of the wave field - a monotone scheme. The disadvantage of using the scheme of the second order of accuracy is due to the need for special allocation of contact boundaries, near which interpolation formulas with unilateral derivatives are used. Thus, even within the framework of the approach used, when auxiliary quantities are used to construct a numerical algorithm, it is not possible to construct a homogeneous difference scheme of an increased order of accuracy. Numerous calculations carried out by the parametric scheme have shown that its stability is always provided under the following conditions

$$\tau\left(\frac{1}{\tau_r}+\frac{1}{\tau_z}+\frac{\eta_m}{2}\right)\le 1.$$

Test calculations on grinding grids allowed us to estimate the actual rate of convergence of difference solutions and determine the optimal size of the space-time grid, which achieved acceptable accuracy with minimal machine time. The noted features of discrete solutions are characteristic and take place in the study of other dynamic contact problems with discontinuous boundary conditions.

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ЕКІӨЛШЕМДІ ТЕРМОТҰТҚЫРЛЫ-СЕРПІМДІЛІК ЕСЕБІНІҢ САНДЫҚ ШЕШІМІНІҢ ЖҮЗЕГЕ АСЫРЫЛУЫ

Аннотация. Жұмыста екіөлшемді термотұтқырлы-серпімділік толқыны сандық шешімінің жүзеге асырылуы қарастырылды. Алюминий мен темірден жасалған екіқабатты плитасы бар алюминий цилиндрінің серпінді соққысы қарастырылған.

[1] Жұмыста айырымдық схемасы мен оларды жүзеге асыру алгоритмі келтірілген. Деформацияланатын қатты денелерде өтпелі үдерістерді есептеудің негізгі әдістерінің толық шолу жағдайы [2, 3, 4] көрсетілген, онда түрлі әдістерді салыстырмалы бағалау мәселелеріне және неғұрлым ұтымды қолдану салаларын анықтауға арналған жалпылама зерттеулер қажеттілігі мен маңыздылығы айқындалған.

Жұмыста сандық нәтижелерді талдау және физикалық интерпретациялау кезінде шешімнің сапалық тәртібі туралы априорлы ақпаратты және зерттелетін құбылыстар физикасы туралы барлық ықтимал мәліметтер пайдаланылды. Есептік және эксперименталды деректерді сәйкестендіру шешім дәлдігінің неғұрлым объективті өлшемі болып саналады, оған математикалық модельдің толық адекваттық тексеру жағдайы кіреді.

Түйін сөздер: екіөлшемді термотұтқырлы-серпімді толқындар, айырымдық тізбегінің тұрақтылығы, айырымдық есеп шешімінің жинақтылығы, индентор, деформация, тензор, кернеу.

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ЧИСЛЕННАЯ РЕАЛИЗАЦИЯ РЕШЕНИЯ ДВУМЕРНЫХ ЗАДАЧ ТЕРМОВЯЗКОУПРУГОСТИ

Аннотация. В данной работе рассмотрена численная реализация двумерных термовязкоупругих волн. Рассмотрено упругое соударение алюминиевого цилиндра с двухслойной плитой из алюминия и железа.

В работе [1] приведены разностные схемы и алгоритм их реализации. Наиболее полные обзоры основных методов расчета переходных процессов в деформируемых твердых телах можно найти в [2, 3, 4], где указывается также необходимость и важность обобщающих исследований, посвященных вопросам сравнительной оценки различных методов и выявлению областей их наиболее рационального применения.

При анализе и физической интерпретации численных результатов в данной работе полезно также использовать априорную информацию о качественном поведении решения и всевозможные сведения о физике исследуемых явлений. Сопоставление расчетных и экспериментальных данных служит наиболее объективным критерием точности решения, включающем в себя и проверку адекватности математической модели явлению в целом.

Ключевые слова: двумерные термовязкоупругие волны, устойчивость разностной схемы, сходимость решения разностной задачи, индентор, деформация, тензор, напряжения.

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THE FRACTAL SCALE-INVARIANT STRUCTURE OF A TEMPORAL HIERARCHY IN THE RELAXATION PROCESSES

Abstract. The phenomena of elastic aftereffects during loading/unloading of viscoelastic and capillary-porous bodies, relaxation of their stresses is accompanied by the energy accumulation and dissipation to be taken into account in the theory of oscillations which also considers the behavior of materials when the force is applied to them, the elastic aftereffect and stress relaxation forms ostensibly opposite energy processes that's why the main problem to one is to understand and discovery laws for such aftereffects. The goal of the research to show that the distribution of relaxation time in viscoelastic and capillary-porous media may have a scale-invariant structure and that the indirect confirmation of the scale invariance of relaxation time hierarchy can be the principle of temperature-time superposition according to which the experimental relaxation functions obtained for different temperatures can be combined with each other using the appropriate coordinate axes stretching. We used methods of viscoelastic theory, fractal analysis and methods of mathematical physics. So, in this paper, an attempt has been made to harmonize both these theories and numerous experiments on the destruction of materials described in the academic literature. It is shown that the hierarchy of times determining shear and bulk relaxation in viscoelastic/capillary-porous medium has a fractal structure and it was observed that the presence of time fractality eases the modeling of viscoelastic/capillary-porous bodies resulting in the universal relaxation function of a rather simple kind.

Key words. Aftereffect, internal friction, viscoelasticity, mechanical models, elongation ratio.

Introduction. Hereditary properties of materials have long been studied by experts. For example, faced in 1920s with the fact of elastic aftereffects, the academician A.F. Ioffe [1] described the above phenomenon as follows: "... the result of the effect of this force on the body does not manifest itself entirely at once. For a long time, exposed to a constant force, bending, twisting, tensile it continues becoming gradually weaker. Each effect leaves a trace which can be noticed after a long period of time as the reasons of its emergence disappear. There is something similar to the body's memory experienced in the past". In test machines, the load decrease and keeping the deformation unchangeable is made automatically with the help of special electronic equipment. The water is used as load in such tests. This allows a smooth stress decrease [2].

Turning to researches for energy dissipation under load, i.e., for the theory of internal friction, it can be found that some theories are based on the dependence of oscillations friction on their velocity, other theories are based on the amplitude. Some research papers are based on the M.M. Davidenkov [3] hypothesis. According to it, the energy in the conditions of oscillations application depends on the amplitude and does not depend on the velocity [4]. E.S. Sorokin [5], author of one of these hypotheses, carries out a detailed analysis of research papers on these issues. On the basis of his table containing the comparative characteristics of various theories, he made an important remark that the theory of internal friction is poorly consistent with theories describing the hereditary properties of the materials [6-9].

Moreover, the following tendency is observed: the better a theory reflects hereditary properties, the worse this theory is adapted to describe energy losses due to oscillations.

The goal of the research to show that the distribution of relaxation time in viscoelastic and capillary-porous media may have a scale-invariant (fractal) structure and that the indirect confirmation of the scale invariance of relaxation time hierarchy can be the principle of temperature-time superposition according to which the experimental relaxation functions obtained for different temperatures can be combined with each other using the appropriate coordinate axes stretching.

Materials and methods. Modern technological processes control often requires the modeling of relaxation in reophysically complex media (viscoelastic medium (VEM), capillary-porous bodies (CPB)). Such media are encountered in the production of a wide variety of materials [10-15]. They are extremely important in processes related to oil extraction and transportation [16-18].

Relaxation phenomena in rheophysically complex media are related to the slow development of processes regrouping structural units of different scales. These processes result in deformation changes lag behind the stress change (hysteresis, elastic aftereffect, stress relaxation, etc.) and can be described using the model of elastic bodies with internal friction and viscous bodies with elasticity [10-12,14-15]. Mechanical models of viscoelastic, capillary-porous bodies are helpful for understanding the qualitative characteristics of relaxation phenomena, but their application to the quantitative description of real materials requires the construction of very complex systems consisting of a large number of different springs and viscous elements [19-23].

This research paper shows that the difficulties mentioned hereinabove can be overcome by specifying the structure of time hierarchies which determine the relaxation in rheophysically complex media [24-27]. It is shown that the time fractality allows to simplify the description of relaxation processes resulting in universal relaxation functions of a rather simple form in a wide range of relaxation time [28,29]. It is also shown that in some cases, it is possible to use rheological models with derivatives of fractional order.

Results and discussion. The stress and deformation in viscoelastic and capillary-porous bodies with respect to time. It is necessary to add to the known formula (Eq. 1):

$$\sigma_1 = E \cdot \varepsilon \tag{1}$$

the component taking into account the temporal nature of the stress change (Eq. 2), or (Eq. 3):

$$\sigma_2 = E \cdot \varepsilon \cdot exp\left(-\frac{t}{\tau}\right), \tag{2}$$

$$\sigma = E \cdot \varepsilon + E \cdot \varepsilon \cdot exp\left(-\frac{t}{\tau}\right) = E \cdot \varepsilon\left\{1 + exp\left(-\frac{t}{\tau}\right)\right\}, \tag{3}$$

where σ – body's general stress, E – stress module, ε – elongation ratio (deformation), t – time counted from the moment of the load application, τ – relaxation time.

Elongation ratio (deformation) in the conditions of load application (Eq. 4):

$$\varepsilon = \frac{\sigma}{E \cdot \left\{1 + exp\left(-\frac{t}{\tau}\right)\right\}}, \tag{4}$$

After unloading, the maximum value of elongation ratio is as follows (Eq. 5):

$$\varepsilon_0 = \frac{\sigma}{E \cdot \left\{1 + exp\left(-\frac{t}{\tau}\right)\right\}} - \frac{\sigma}{2E} = \frac{\sigma \cdot \left[1 - exp\left(-\frac{t}{\tau}\right)\right]}{2E \cdot \left[1 + exp\left(-\frac{t}{\tau}\right)\right]} = \frac{\sigma}{2E} \cdot th\left[+\frac{t}{2\tau}\right], \tag{5}$$

The value of ε_0 allows to determine the current value of its elongation ratio after unloading in time t, i.e., to take into account the unloading aftereffect and thus (Eq. 6):

$$\varepsilon(t) = \varepsilon_0 \cdot exp\left(-\frac{t}{\tau}\right) = \frac{\sigma}{2E} \cdot th\left[\frac{t}{2\tau}\right] \cdot exp\left(-\frac{t}{\tau}\right), \tag{6}$$

where t – time running after unloading.

Example 1. The steel wire stretched and rigidly fixed. It is necessary to determine the stress relaxation. Sample data: elastic module E = 196 333 MPa, relaxation time τ = 168.2 s, elongation ratio ε = 0.001 (table 1).

Table 1 – Calculation results of the stresses occurring in the wire and depending on time, i.e., relaxation of stresses

t, s	σ, MPa	t, s	σ, MPa	t, s	σ, MPa
0	392.627	200	256.12	1000	196.66
50	341.89	500	206.26	2000	196.13
100	304.60	900	197.08	3000	196.13

Example 2. The steel sample was stretched to have the stress σ = 300 MPa, module of elasticity E = 196 333 MPa, relaxation time τ = 168.2 s, the sample is unloaded at the time t_p = 1000 s. It is necessary to determine the value of elongation ratio depending on time. The formula (4) allows to determine the value of elongation ratio in the conditions of loading, the formula (5) allows to calculate the unloading moment. Varying in time residual deformation can be found using the formula (6).

Knowing ε_0, one can find the residual deformation $\varepsilon_{residual} = \varepsilon_r$ using the ratio (6). If the ratio (Eq. 7):

$$\frac{\varepsilon_r}{\varepsilon_0} = \sigma \tag{7}$$

is specified, the period of time (t^*) can be found, then the residual deformation will be (Eq. 8):

$$\varepsilon_r = \sigma \cdot \varepsilon_0 \text{ (in periods } \tau). \tag{8}$$

The results for viscoelastic and capillary-porous bodies are presented in table 2.

Table 2 – Results for viscoelastic and capillary-porous bodies

σ	t^*, s	σ	t^*, s	σ	t^*, s
0.1	2.303τ	0.0001	4.210τ	10^{-8}	18.421τ
0.01	4.605τ	0.00001	11.513τ	10^{-10}	23.026τ
0.001	6.908τ	0.000001	13.816τ	10^{-12}	27.631τ

The energy dissipation process when oscillations are applied. The equity (3) which explains the phenomena occurring in the material during its loading-unloading should be used to describe the process in viscoelastic and capillary-porous bodies. Thus, there is a relation between this dependence and the theory of internal friction given in [30-33].

The effect of time on the results of experiments on the tensile of viscoelastic-type materials and capillary-porous bodies. The changing of the destructive stress in time is expressed by the following general formula (Eq. 9):

$$\sigma_t = \sigma_x + (\sigma_0 - \sigma_x) \cdot exp\left(-\frac{t}{\tau}\right), \tag{9}$$

where σ_t – ultimate breaking stress at the time t, where σ_x – ultimate breaking stress at the time $t = \infty$, t – load application time, τ – relaxation time.

Relaxation of stresses in viscoelastic and capillary-porous bodies. Generalized Maxwell model. Considering the generalized Maxwell model representing a set of parallel connected chains composed of a series of sequentially connected springs and a viscous element. The rheology of such a body is determined by the known relations (Eqs. 10-11):

$$\sigma = \sum_{n=1}^{\infty} \sigma_n, \tag{10}$$

$$\varepsilon_n = \varepsilon_n^{(1)} + \varepsilon_n^{(2)}, \tag{11}$$

where ε – body deformation, σ – stress, $\sigma_n = E_n \cdot \varepsilon_n^{(1)} = \eta_n \cdot D \cdot \varepsilon_n^{(2)}$ – stress, E_n, η_n – spring stiffness and viscous resistance coefficient of element n, $\varepsilon_n^{(1)}, \varepsilon_n^{(2)}$ – elongation of the spring n and displacement of viscous element n, $D = \frac{d}{dt}$ – operator of differentiation.

It is assumed that the values E_n and τ_n are determined by the scaling laws having the following form (Eq. 12):

$$\tau_n = \tau_0 \cdot n^{\nu}, \tag{12}$$

After taking the logarithm (12), the following formula can be obtained (Eq. 13):

$$ln\, E_n = ln\, E_0 - n\lambda, \tag{13}$$

Thus, the time-scale invariance should linearly decrease at the same time as n increases.

If $\frac{t}{\tau_0} \to \infty (A \to \infty)$ then asymptotic behavior of this integral is easily determined using Laplace method that leads to an expanded exponential law (Kohlrausch law [29,34]) (Eq. 14), where (Eq. 15):

$$\Phi(t) \approx exp\left[-(t/\tau)^{1/(\nu+1)}\right], \tag{14}$$

$$\tau = (\tau_0 \cdot \lambda^{-\nu}/\nu) \cdot (1 + \nu^{-1})^{1/(\nu+1)}, \tag{15}$$

Thus, the scale invariance of relaxation processes substantially simplifies their description and allows to use a rather simple universal relaxation functions having the form (14). It should be noted that the relaxation function with an exponent equal to (-1/2) can be obtained using Gauss and Bueche molecular theory of viscoelasticity [11]. However, this theory can explain neither the exponent value deviation (which is often observed in practice) nor the origin of the relaxation functions (14). The scale invariance of the relaxation parameters distribution can serve to explain the principle of temperature-time superposition [11] which can be expressed using the following dependence (Eq. 16):

$$\Phi[k(T)t] = k_1(T) \cdot \Phi_0(t), \tag{16}$$

where T_0 – some characteristic temperature, $\Phi(t)$ and $\Phi_0(t)$ – relaxation functions at temperatures T and T_0, k, k_1 – coefficients depending on temperature (Eq. 17):

$$\{k(T_0) = k_1(T_0) = 1\}, \tag{17}$$

Figure 1 presents approximation results of this curve, parameters of which τ and β were determined using methods of the sensitivity theory [35,36]. Apparently, the stress relaxation curve is quite well described by the law of Kohlrausch. For this curve, the parameter β is equal to 0.5.

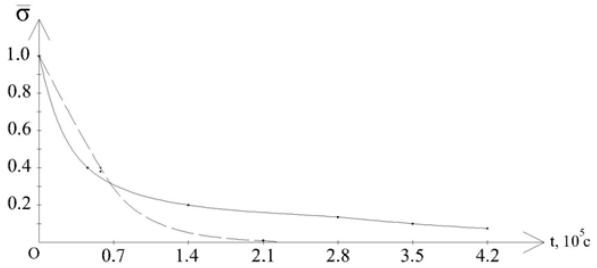

Figure 1 – Relaxation curve approximation

Rheological models of viscoelastic and capillary-porous bodies in fractional derivatives. A viscoelastic/capillary-porous body which can be given using a set of sequentially connected Voigt bodies (chains which consist of parallel connected springs and a viscous element) should be considered now. The stress (Eq. 18) applied to a body at the time $t = 0$.

$$\sigma = \sigma_0 \cdot h(t), \tag{18}$$

Then the deformation rate is determined using the expression (Eq. 19):

$$D\varepsilon(t) = \frac{\sigma_0}{\eta} + \sigma_0 \sum_{n=1}^{\infty} \frac{1}{\eta_n} \cdot exp(-t/\tau_n), \tag{19}$$

By determining the relaxation function $\Psi(t)$ as (Eq. 20), the following result is obtained (Eq. 21):

$$\Psi = \left\{D\varepsilon - \frac{\sigma_0}{\eta}\right\}/\sigma_0, \tag{20}$$

$$\Psi(t) = \sum_{n=1}^{\infty} \left(\frac{1}{\eta_n}\right) \cdot exp(-t/\tau_n), \tag{21}$$

Thus, the time-scale invariance leads to the need to use rheological models in fractional derivatives. It should be noted that such models are entered (on other grounds) in [10,12,35,37].

Relaxation processes in viscoelastic and capillary-porous bodies in conditions of bulk deformation. Considering structural units as viscoelastic elements, the mechanical model given in Figure 2 is proposed to describe the bulk relaxation processes. For this model, the value β_0 characterizes the instantaneous volume compressibility of the medium and the values E_n, η_n $(n = 1, 2, \ldots)$ describe elasticity of structural units and viscosity forces that counteract their movement.

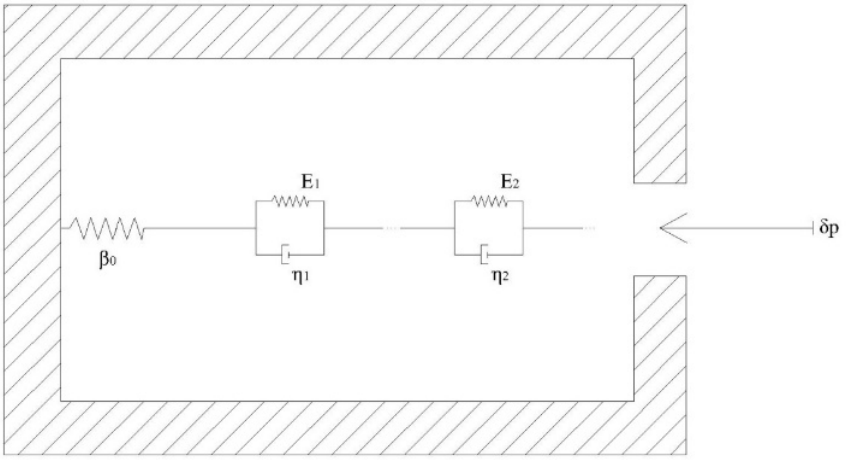

Figure 2 – Mechanical model of volume relaxing body

Similar to the previous cases, it is easy to obtain (Eq. 22):

$$-\delta V(t)/V_0 = \beta_0 \cdot \delta p(t) + \int_0^t \Psi_1(t-\xi) D\delta p(\xi) d\xi, \quad (22)$$

where δV – decrease of medium volume when the pressure is increased by value δp, V_0 – initial volume, $\Psi_1(t) = \beta' \cdot \sum_{n=1}^{\infty} \frac{1}{E_n} \cdot [1 - exp(-t/\tau_n)]$ – relaxation function, $\tau_n = \eta_n/E_n$, β' – quantity determining the volume changing due to the displacement of the structural elements.

Having differentiated (22) with respect to time, the equation the viscoelastic medium (capillary-porous body) state is obtained (Eq. 23), where ρ – medium density:

$$\frac{1}{\rho_0} Dp = \beta_0 \cdot Dp + \int_0^t \Psi(t-\xi) Dp(\xi) d\xi, \quad (23)$$

Thus, the pressure curve should be straightened in coordinates (Eq. 24). The inclination of line can be found with respect to χ.

$$Y(S) = ln\left\{\frac{1}{S} U - 1\right\},\ ln\, S, \quad (24)$$

Equation for relaxing liquid motion. If the motion of a relaxing medium in a pipe (capillary) of radius R is considered then the rheological equation of the medium is presented as follows (Eq. 25):

$$-\frac{\partial v}{\partial r} = \frac{\sigma}{\eta} + \alpha \cdot D^{-\chi} \cdot \frac{\partial \sigma}{\partial t}, \quad (25)$$

where $v(r,t)$ – component of velocity along the pipe axis, σ – shear stress, η – viscosity of medium.

By averaging (25) over the section of the pipe, the following motion equation can be obtained within the frame of the quasi-stationary approximation [38] (Eq. 26):

$$\rho_0 \cdot \left\{\frac{\partial w}{\partial t} + 2aw\right\} = -\left\{\frac{\partial p}{\partial x} + \alpha \cdot D^{-\chi} \cdot \frac{\partial^2 p}{\partial x \partial t}\right\}, \quad (26)$$

where w is average cross-sectional velocity, $2a = 8\eta/(\rho_0 R^2)$, $\frac{\partial p}{\partial x}$ is pressure gradient along the axis of the pipe.

As far as is known, the filtration equation can be obtained by throwing away the inertia term and taking $1/2a = k/\eta$ where now w is filtration rate, k is permeability of the porous (capillary-porous) medium; then it is easy to obtain [39-43] (Eq. 27):

$$Dp + \beta_1 \cdot D^{-\chi'} Dp = \kappa(D^{-\chi} \cdot D + 1) \cdot \left(\frac{\partial^2 p}{\partial x^2}\right), \quad (27)$$

where $\kappa = k/\eta^m \cdot \beta_o$ is thermal conduction coefficient, m is porosity.

Algorithm and method for calculating residual deformations in capillary-porous bodies/materials. The following diagram of the capillary-porous body deformation (figure 3) will be considered.

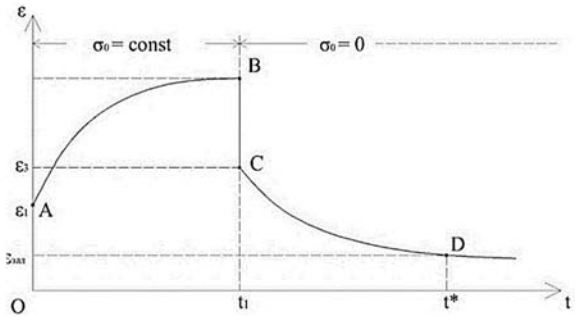

Figure 3 – Diagram of capillary-porous body deformation

The provided below table 3 shows values depending on *n*.

Table 3 – Values depending on *n*

N	$\frac{(t_n - t_1)}{\tau}$
10	2.303
10^2	4.605
10^3	6.908
10^9	20.723
10^{10}	23.026

Consequently, CPBs residual deformation is practically reduced to zero (decreasing by 10^{20}) in about 46τ. Thus, if the flow of visitors to the museum (which has pictures modeled as CPB) creates during the visit time $t = t_1$ the load (temperature and humidity) applied on pieces of art and eventually leading to the deformation of these masterpieces then, after visitors leaving the room, their "deformation effect" on pictures practically falls to zero in time interval $t^* \approx t_1 + 46\tau$ where τ is the relaxation time (average) of CPB located in the museum's premises.

Conclusions. Thus, the distribution of relaxation time in viscoelastic and capillary-porous media may have a scale-invariant (fractal) structure. To confirm this, the spectra of relaxation parameters obtained during experiments carrying out the stretching of polystyrene samples are given in the present paper. It is shown that the indirect confirmation of the scale invariance of relaxation time hierarchy can be the principle of temperature-time superposition.

The present paper shows that in some cases, time fractality can lead to an algebraic relaxation law and, thus, to the need to use rheological models and state equations having fractional derivatives. It is precisely fractional derivatives that can be used for modeling, in particular, bulk relaxation processes. The derived equations of motion of relaxation media in tubes, capillaries, porous media which take into account the time scale invariance of shear and bulk deformation processes are given.

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РЕЛАКСАЦИЯ ҮДЕРІСІНДЕГІ УАҚЫТТЫҚ ИЕРАРХИЯНЫҢ МАСШТАБТЫ-ИНВАРИАНТТЫҚ ҚҰРЫЛЫМЫ

Аннотация. Тұтқыр серпімді және қылтүтіктік кеуекті денені жүктеу/жүксіздендіру барысындағы серпімді соңғы әсер құбылысы, кернеуінің бәсеңдеуі кезінде күштік әсер етуде материалдар беталысын ескеретін тербеліс теориясында да ескерілуі тиіс энергияның жинақталуы мен диссипациясы орын алады. Осы-

ларға қатысты серпімді соңғы әсер мен кернеудің бәсеңдеуі қарама-қарсы энергетикалық үдеріс туды-рады, сондықтан да мұндағы негізгі мәселе осындай салдарды түсіну мен заңды анықтау болып саналады.

Зерттеудің мақсаты – тұтқыр серпімді және қылтүтіктік-кеуекті орталарда релаксация уақытын бөлу масштабты-инвариантық (фракталдық) құрылымға ие бола алатындығын көрсету және түрлі температураға алынған релаксацияның эксперименталды функциясының координата осьтерін сәйкесінше созу арқылы бір-бірін біріктіруге болатын температуралық-уақыттық суперпозиция принципі релаксация уақыты иерархиясының масштабты инварианттылығын жанама түрде растайтындығын көрсету. Тұтқыр серпімділік теориясының әдістері, фракталды талдау және математикалық физика әдістері қолданылды. Мақалада осы екі теория мен академиялық әдебиеттерде сипатталған материалдардың бұзылуына қатысты көптеген эксперименттерді үйлестіру әрекеті жасалды.

. Релаксацияның уақыт иерархиясының масштабты инварианттылығын температуралық-уақыттық суперпозиция принципінің жанама түрде растайтындығы сипатталды. Осыған сай түрлі температураға алынған релаксацияның эксперименталды функциялары сәйкесінше координата осьтерін созу арқылы өзара біріктіріле алатындығы көрсетілді.

Түйін сөздер: соңғы әсер, ішкі үйкеліс, тұтқыр серпімділік, механикалық модельдер, ұзару коэффициенті.

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ФРАКТАЛЬНАЯ МАСШТАБНО-ИНВАРИАНТНАЯ СТРУКТУРА ВРЕМЕННОЙ ИЕРАРХИИ В ПРОЦЕССАХ РЕЛАКСАЦИИ

Аннотация. Явление упругого последействия при нагружении/разгрузке вязкоупругих и капиллярно-пористых тел, релаксация их напряжений сопровождается накоплением и диссипацией энергии, которые необходимо учитывать в теории колебаний, которая также учитывает поведение материалов при воздействии силы. Применительно к ним упругое последействие и релаксация напряжений образуют якобы противоположные энергетические процессы, поэтому основная проблема заключается в понимании и открытии законов для таких последствий.

Цель исследования – показать, что распределение времени релаксации в вязкоупругих и капиллярно-пористых средах может иметь масштабно-инвариантную (фрактальную) структуру и что косвенным подтверждением масштабной инвариантности иерархии времен релаксации может быть принцип температур-временная суперпозиция, согласно которой экспериментальные функции релаксации, полученные для различных температур, могут быть объединены друг с другом с помощью соответствующего растяжения осей координат. Использовались методы теории вязкоупругости, фрактального анализа и методы математической физики. Сделана попытка согласовать обе эти теории и многочисленные эксперименты по разрушению материалов, описанные в академической литературе.

Показано, что косвенным подтверждением масштабной инвариантности иерархии времен релаксации может служить принцип температурно-временной суперпозиции, согласно которому экспериментальные функции релаксации, полученные для различных температур, могут быть объединены между собой с помощью соответствующего растяжения осей координат.

Ключевые слова: последействие, внутреннее трение, вязкоупругость, механические модели, коэффициент удлинения.

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USE OF TWO-STAGE FUEL COMBUSTION TECHNOLOGY TO MINIMIZE HAZARDOUS EMISSIONS AT KAZAKHSTAN TPP

Abstract. Studies have been carried out using numerical modeling methods to determine the effect of the introduction of a two-stage combustion technology (OFA technology) of high-ash Karaganda coal on the characteristics of combustion processes: aerodynamics of flows, temperature and concentration (COx, NOx) fields throughout the entire volume of the combustion chamber of the BKZ-75 boiler at Shakhtinskaya TPP and at the outlet from it. Comparison with the basic regime of combustion of pulverized coal fuel, when there is no air supply through additional injectors (OFA = 0%). To implement the technology of two-stage combustion, various regimes of additional air supply through injectors were chosen: OFA equals 0% (basic version, conventional combustion), 5%, 10%, 15%, 18%, 20%, 25% and 30% of total air volume required for fuel combustion. A comparative analysis of the main characteristics of the heat and mass transfer process in the combustion chamber for the investigated modes is carried out. It is shown that an increase in the volume of additional air supplied through the injectors up to 18% leads to a decrease in the concentration of nitrogen oxide NO by 25% in comparison with traditional combustion. A further increase in the volume of additional air leads to a deterioration in these indicators. The results obtained will make it possible to optimize the combustion of low-grade fuel in the combustion chamber of the BKZ-75 boiler, increase the efficiency of fuel burnout, reduce harmful emissions and introduce a two-stage combustion technology at other coal-fired TPPs.

Keywords: numerical simulation, computational experiment, two-stage combustion, high-ash coal, ecology, temperature, nitrogen oxides.

Introduction. Solid fuel power plants remain one of the main sources of environmental pollution with harmful dust and gas emissions. In this regard, it becomes urgent to develop and introduce combustion technologies with minimal emissions of fly ash, carbon oxides and nitrogen at Kazakhstan coal-fired TPPs. Therefore, the main task of the domestic heat power industry is to create technologies for burning high-ash Kazakh coal, with the help of which it is possible to control the main processes of the formation of harmful dust and gas emissions and control the level of their formation [1-5].

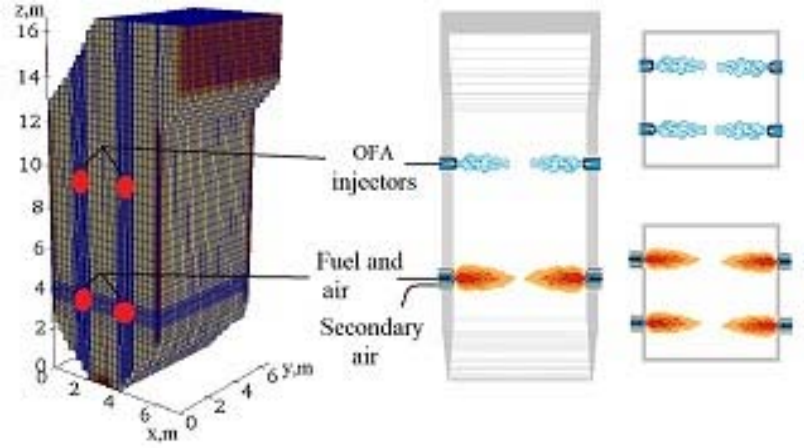
In the context of stricter environmental requirements, the introduction of such environmentally friendly coal technologies will allow in the near future to overcome the shortcomings of Kazakhstan coal-fired TPPs significantly increase their efficiency and ensure a sharp decrease in emissions of harmful substances into the atmosphere. Recently, in the world heat power industry, the most popular are information technologies that allow to model new and modernize existing heat power plants, help to assess the feasibility of launching new environmentally outgoing energy production technologies and their economic efficiency at the stage of design solutions. As a rule, everything new first goes through a series of checks, after which it is put into operation on an ongoing basis. The use of computer technologies for the implementation of environmentally friendly coal technologies is especially effective at the initial

design stage, when several design solutions are being worked out at the same time and a boiler modernization strategy is being determined [6-11].

Currently, various methods are used to minimize harmful dust and gas emissions at coal-fired TPPs, the main of which are: change in combustion technology and purification of gases after combustion. Changes in combustion technology include: the use of modified burners, afterburning of fuel, recirculation of exhaust gases, staged fuel combustion, preparation of low-grade coals for combustion, radiation technologies, combustion of fuel in fluidized bed furnaces, etc. The method of two-stage fuel combustion is one of the most effective methods for reducing the concentration of harmful emissions and, first of all, the most dangerous of them - nitrogen oxides [12-18].

Description of the combustion chamber for conducting computational experiments.

A real energy object was chosen as the object of research: the combustion chamber of the BKZ-75 boiler of the operating Shakhtinskaya TPP (Shakhtinsk, Kazakhstan). A steam boiler with a capacity of 75 t/h burns high-ash Karaganda coal (ash content 35.10%), is equipped with four pulverized coal burners, two burners from the front and from the rear in one tier. A more detailed description of the boiler combustion chamber, mathematical model, solution method, application package is given in the following works [19-26]. The general view of the combustion chamber of the BKZ-75 boiler (figure 1a) and the arrangement of burners and injectors for the implementation of the technology of two-stage fuel combustion (figure 1b) is shown in figure 1a [27-28].



a) *b)*

Figure 1 – General view of the combustion chamber of the BKZ-75 boiler at Shakhtinskaya TPP (a) and the layout of burners and OFA injectors (b)

The technology of two-stage fuel combustion is carried out by installing secondary and even tertiary holes (OFA-injectors) to supply additional air above the main combustion zone, when a reduction and afterburner zone is formed in the combustion chamber. In general, with the correct organization of staged combustion, it is possible to reduce the content of nitrogen oxides by about 30-40%. Such a decrease in the formation of nitrogen oxides is explained by the formation of combustion zones in the combustion chamber, characterized by an excess of air and a temperature level.

Results. To implement the technology of two-stage combustion, we have chosen different regimes of supplying additional air through OFA-injectors: OFA is equal to 0% (basic version, traditional combustion), 5%, 10%, 15%, 18%, 20%, 25% and 30% of the total volume of air required for fuel combustion. As a result of the computational experiments, the distributions of temperature T and concentration of nitrogen oxide NO were obtained over the entire volume of the combustion chamber, at the outlet from it, and a comparative analysis was carried out for all studied regimes. Figure 2 shows three-dimensional (figure 2a) and two-dimensional (figure 2b) graphs of the distribution of the cross-sectional average temperature T along the height h of the combustion chamber for the studied regimes of additional air supply.

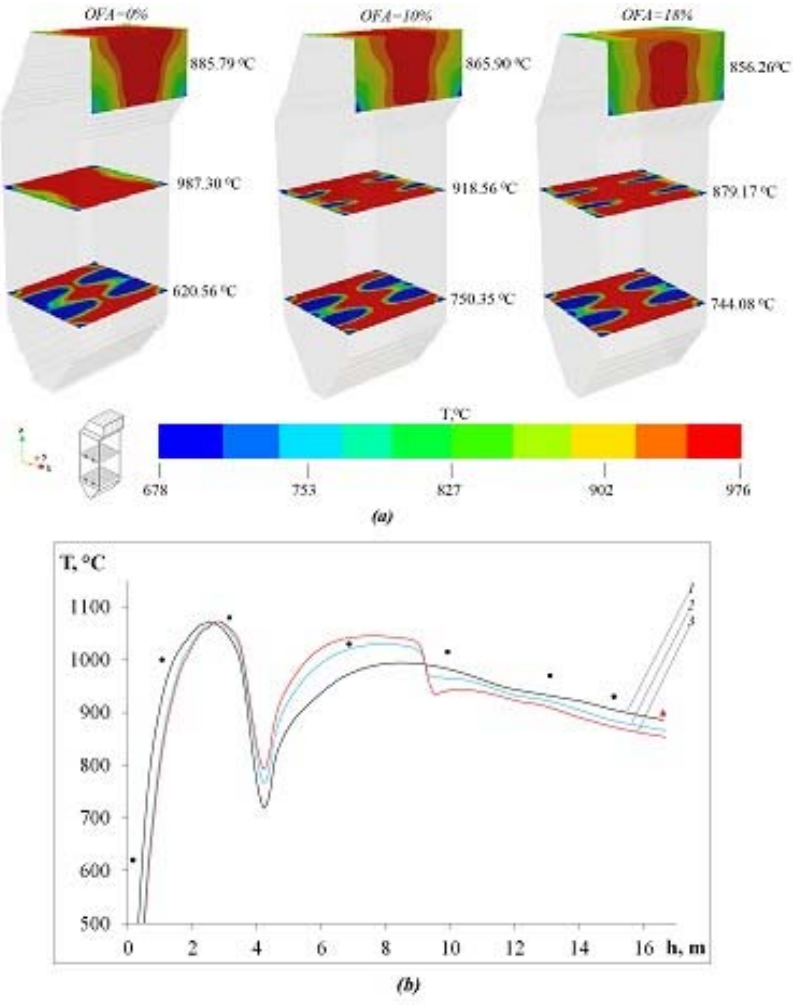


Figure 2 – Three-dimensional a) and two-dimensional b) temperature distribution T along the height h of the chamber of the BKZ 75 boiler at various volumes of air supplied through the injectors:1 – OFA=0%, 2 – OFA=10%, 3 – OFA=18%, ● – CHP experiment [29], ▲ – theoretical value [30]

Analysis of figure 2a shows that with an increase in the volume of air supplied through the injectors, the temperature in the region of the burners (h=4 m) increases: at OFA=10%, T= 750.35^{0}C, at OFA=18%, T= 744.08^{0}C compared with the base case (conventional combustion) when OFA=0%, T=620.56^{0}C. This is due to the fact that when additional air is supplied through the injectors, the area where the burners are located is depleted in oxygen. In addition, this leads to a decrease in the excess air ratio and to an increase in the flame temperature in this zone. On the contrary, more air is supplied in the area of the OFA injectors (h = 9.4 m), chemical reactions are more intense, and the temperature increases in comparison with the temperature in the region of the burner zone: for OFA=0%, T= 987.30^{0}C; OFA=10%, T= 918.56^{0}C and OFA=18%, T= 879.17^{0}C.

This behavior of temperature is clearly seen in figure 2b, which shows its distribution over the height of the combustion chamber of the BKZ-75 boiler at different volumes of air supplied through OFA-injectors. At the outlet from the combustion chamber, we have a further decrease in temperature. Therefore, the average value of the temperature at the outlet from the combustion chamber is for OFA=0%, T=885.79^{0}C; OFA=10%, T=865.90^{0}C and OFA=18% T= 856.27^{0}C. The temperature distribution over the height of the combustion chamber is confirmed by experimental data (figure 2b) obtained directly at the operating Shakhtinskaya TPP [29], and at the outlet from the furnace space, its theoretical value, calculated by the CBTI method [30] for the basic version (OFA=0%). Comparing the results obtained, it can be noted that with an increase in the volume of air supplied through the OFA injectors, a shift in the location of the flame core and an increase in the length of the zone of maximum temperatures are observed (figure 2b, curves 2, 3).

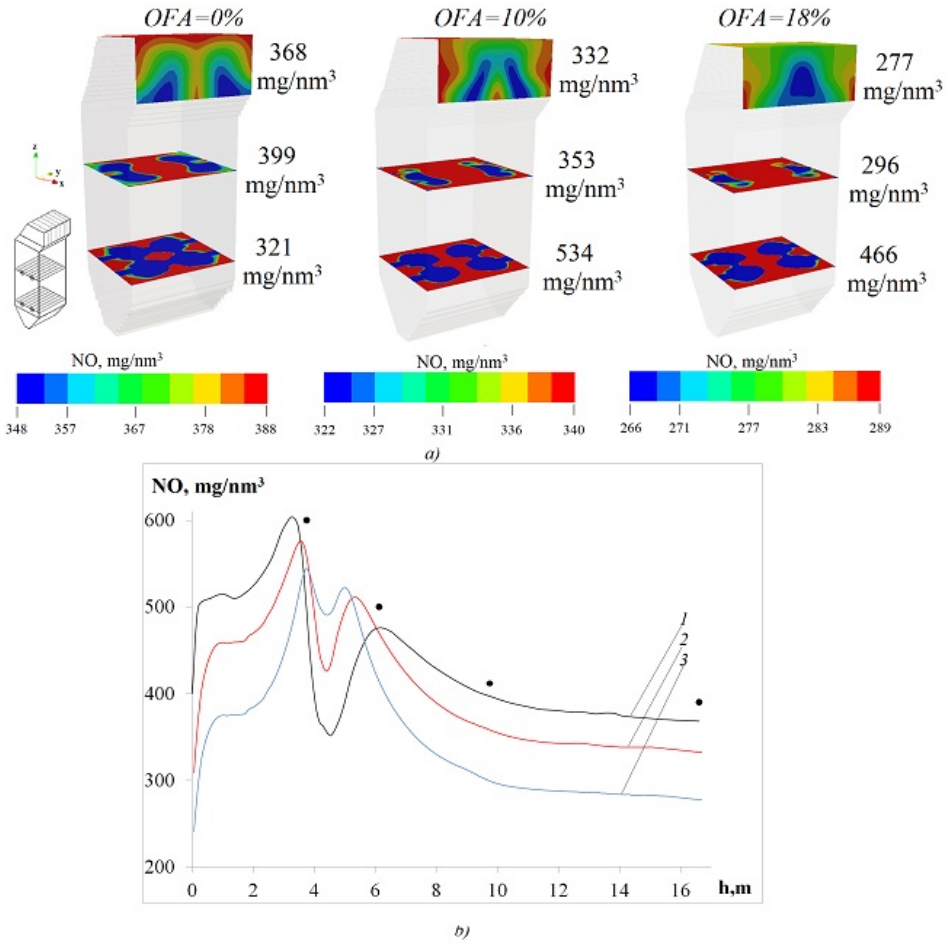


Figure 3 – Three-dimensional (a) and two-dimensional (b) distribution of the concentration of nitrogen oxide NO along the height h of the combustion chamber of the BKZ-75 boiler with different volumes of air supplied through the injectors: *1*–OFA=0%, *2*–OFA=10%, *3*–OFA=18%; ● - experiment at CHP [31]

Figure 3 illustrates the three-dimensional and two-dimensional distribution of the concentrations of nitrogen oxide NO along the height h of the combustion chamber for the studied three cases of application of the two-stage combustion technology. With an increase in the volume of air supplied through the injectors, the amount of nitrogen oxide formed in the area where the burners are located increases (h=4 m) compared to the base case (conventional combustion). So when OFA=0% is 321 mg/nm^3, OFA=10% – 534 mg/nm^3 and OFA=18% – 466 mg/nm^3 (figure 3a).

At the same time, a decrease in the concentration of nitrogen oxide NO is observed in the zone of the location of the injectors at a height of h = 9.4 m when the technology of two-stage combustion is introduced. Here, the average values of the concentration of nitrogen oxide NO for all three cases differ significantly: for the base case OFA=0% the concentration of nitrogen oxide NO is 399 mg/nm^3, at OFA=10% – 353 mg/nm^3 and at OFA=18% – 296 mg/nm^3. This is explained by the fact that in the area of the OFA injectors (h = 9.4 m) a zone enriched with oxygen with a relatively low temperature is created, which leads to a reduced formation of NO from the air (thermal NO_x).

At the outlet from the combustion chamber, with an increase in the volume of air supplied through the injectors, a significant decrease in the concentration of nitrogen oxide no occurs in comparison with the base regime: at ofa=0% – 368 mg/nm^3 (figure 3a and 3b, curve 1), at OFA=10% – 332 mg/nm^3 (figure 3a and 3b, curve 2), at OFA=18% – 277 mg/nm^3 (figure 3a and 3b, curve 3), which is primarily associated with a decrease in temperature in this area of the combustion chamber. All this indicates a significant influence of the technology of two-stage fuel combustion on the distribution of the concentration of solid fuel combustion products in the combustion chamber and at the outlet from it.

Conclusion. Studies have been carried out using 3D computer modeling methods to determine the effect of the introduction of the technology of two-stage combustion of high-ash Karaganda coal on the main characteristics of heat and mass transfer processes: temperature and concentration fields throughout the entire volume of the combustion chamber of the BKZ-75 boiler at Shakhtinskaya TPP and at the outlet from it.

To implement the two-stage combustion technology, various regimes of additional air supply through the injectors were chosen: OFA equals 0% (basic version, conventional combustion) and when 10%, 18% of the total air volume is supplied to the upper part of the combustion chamber. A comparative analysis of the main characteristics of the heat and mass transfer process in the combustion chamber for the investigated regimes is carried out.

It is shown that an increase in the volume of air supplied through the injectors makes it possible to reduce the concentration of nitrogen oxides NO at the outlet from the combustion space. The use of the technology of two-stage combustion in the combustion chamber of the BKZ-75 boiler at the Shakhtinskaya TPP leads to a significant decrease in the concentration of nitrogen oxide NO. In our case, one of the optimal options for reducing the concentration of nitrogen oxides NO at the outlet from the combustion chamber is the use of injectors at OFA=18%.

The results obtained will make it possible to optimize the combustion of low-grade fuel in the combustion chamber of the BKZ-75 boiler, increase the efficiency of fuel burnout, reduce emissions of harmful substances into the environment and introduce a two-stage combustion technology at other coal-fired TPPs.

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ҚАЗАҚСТАНДЫҚ ЖЭО ЗИЯНДЫ ШЫҒАРЫНДЫЛАРДЫ АЗАЙТУ ҮШІН ОТЫНДЫ ЕКІСАТЫЛЫ ЖАҒУ ТЕХНОЛОГИЯСЫН ПАЙДАЛАНУ

Аннотация. Қатты отынмен жұмыс істейтін электр станциялары – қоршаған ортаны зиянды шаң-газ шығарындысымен ластаудың негізгі көздерінің бірі болып қала береді. Азот оксидтерін бәсеңдету бойынша сандық тәжірибелер жүргізу үшін екі сатылы жағу технологиясы арқылы Шахтинск ЖЭО (Шахтинск қ., Қазақстан) БКЗ-75 қазандығының жағу камерасы таңдалды. Қазандықта Қарағанды көмірінің шаңы жағылады, күлі 35,10%, ұшпа 22%, ылғалдылығы 10,6% және жану жылуы 18,55 МДж/кг. Екісатылы жану технологиясын жүзеге асыру үшін инжекторлар арқылы қосымша ауа берудің түрлі режимдері таңдалды: OFA 0% (базалық нұсқа) және 10%, ауаның жалпы көлемінің 18% пештің жоғарғы жағындағы инжекторлар арқылы беріледі.

Жүргізілген сандық эксперимент нәтижесінде БКЗ-75 қазандығының жану камерасының бүкіл көлемі бойынша және шығысында NO азот оксидінің температуралық және концентрациялық өрісі алынды. Зерттелетін режимдерге арналған жану камерасындағы жылу беру үдерісінің негізгі сипаттамаларына салыстырмалы талдау жүргізілді. Инжекторлар арқылы жеткізілетін қосымша ауа көлемінің 18%-ға артуы NO азот оксиді концентрациясының базалық жағдайға (дәстүрлі жану) қарағанда 25%-ға төмендететіні көрсетілген. Алынған нәтижелер БКЗ-75 қазандығының от жағу камерасында төмен сұрыпты отынды жағу үдерісін оңтайландыруға, отынның жану тиімділігін арттыруға, қоршаған ортаға зиянды шығарындыларды азайтуға және басқа да көмір жағатын ЖЭО-да екісатылы жағу технологиясын енгізуге мүмкіндік береді.

Түйін сөздер: сандық модельдеу, есептеу эксперименті, екі сатылы жану, күлі жоғары көмір, экология, температура, азот оксидтері

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ИСПОЛЬЗОВАНИЕ ТЕХНОЛОГИИ ДВУХСТУПЕНЧАТОГО СЖИГАНИЯ ТОПЛИВА ДЛЯ МИНИМИЗАЦИИ ВРЕДНЫХ ВЫБРОСОВ НА КАЗАХСТАНСКИХ ТЭЦ

Аннотация. Одним из основных источников загрязнения окружающей среды вредными пылегазовыми выбросами остаются электростанции, работающие на твердом топливе.

Для проведения численных экспериментов по подавлению оксидов азота с помощью технологии двухступенчатого сжигания была выбрана топочная камера котла БКЗ-75 Шахтинской ТЭЦ (г. Шахтинск, Казахстан). В котле сжигается пыль карагандинского угля, зольностью 35,10%, выходом летучих 22%, влажностью 10,6% и теплотой сгорания 18,55 МДж/кг. Для реализации технологии двухступенчатого сжигания выбраны различные режимы подачи дополнительного воздуха через инжекторы: OFA равно 0% (базовый вариант) и 10%, 18% от общего объема воздуха подается через инжекторы в верхней части топки.

В результате проведенных численных экспериментов были получены температурные поля и концентрационные поля оксида азота NO по всему объему и на выходе топочной камеры котла БКЗ-75. Проведен сравнительный анализ основных характеристик процесса тепломассопереноса в топочной камере для исследуемых режимов. Показано, что увеличение объема дополнительного воздуха, подаваемого через инжекторы, до 18% приводит к уменьшению концентраций оксида азота NO на 25% по сравнению с базовым случаем (традиционное сжигание). Полученные результаты позволят оптимизировать процесс сжигания низкосортного топлива в топочной камере котла БКЗ-75, повысить эффективность выгорания топлива, уменьшить вредные выбросы в окружающую среду и внедрить технологию двухступенчатого сжигания на других углесжигающих ТЭЦ.

Ключевые слова: численное моделирование, вычислительный эксперимент, двухступенчатое сжигание, высокозольный уголь, экология, температура, оксиды азота.

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СПОСОБЫ ЗАЩИТЫ АППАРАТУРЫ СОТОВОЙ (МОБИЛЬНОЙ) СВЯЗИ ОТ ЭЛЕКТРОМАГНИТНЫХ ВОЗДЕЙСТВИЙ

Аннотация. При электромагнитных воздействиях (ЭМВ) достаточного уровня возможно временное нарушение функционирования, нарушение обработки, передачи и хранения информации в аппаратуре сотовой связи. Рассмотрены возможные проблемы электромагнитной совместимости (ЭМС) мобильного телефона и базовой станции (БС) сотовой связи при воздействии электромагнитных излучений (ЭМИ) от других источников и их негативное влияние на функционирование. Энергия высокой частоты (ВЧ) электромагнитного поля (ЭМП) после прохождения защитного корпуса может оказывать воздействие на приборы экранированной радиоэлектронной аппаратуры (РЭА), поэтому описаны возможные отрицательные последствия от воздействия высокоэнергетических ЭМП на РЭА. Приведены возможные при определенных условиях негативные последствия от влияния скин-эффекта, воздействий электростатического разряда и электромагнитных импульсов на электронные устройства. Показано, что конструкционный метод защиты РЭА от влияний внешних электромагнитных факторов состоит в снижении собранной и переданной энергии ЭМП путем улучшения конструкции, размещения и монтажа оборудования. Приведены компоненты некоторых вендоров для систем 5G, устойчивые к внешним помехам, а также отмечены возможности снижения уровня излучения сотового телефона. Обоснована необходимость комплексного подхода к решению проблем ЭМС, состоящего в использовании конструкционных, схемотехнических и структурно-функциональных методов обеспечения ЭМС. Стартовой площадкой для запуска систем связи следующего поколения станут существующие сети 2G/3G/4G. Инфраструктура мобильных операторов должна быть готова к внедрению стандарта 5G. Общая структура сети связи следующего поколения 5G показана на рисунке. Она включает в себя три уровня: сеть доступа; фиксированную сеть; интеллектуальную сеть.

Новый стандарт 5G (Fifth Generation) будет работать на более высоких рабочих частотах, по сравнению с предыдущими поколениями. Из-за загруженности электромагнитного спектра на частотах ниже 6 ГГц базу сетей 5G будут составлять системы беспроводного радиодоступа, работающие на частотах 30–100 ГГц, то есть в нижней полосе диапазона экстремально высоких частот EHF (Extremely High Frequency), 30–300 ГГц.

Ключевые слова: базовая станция, сотовый телефон, электромагнитная совместимость, электромагнитные воздействия, электромагнитные помехи, электромагнитные поля.

Введение. Функционирование средств сотовой связи сегодня происходит в условиях сложной сигнально-помеховой обстановки, обусловленной ростом количества излучающих радиоэлектронных средств и преднамеренных помех [1]. Анализ современного уровня эволюции беспроводной связи свидетельствует о том, что возможно появление локальных областей со сложной ЭМО, которая обусловлена различными техногенными событиями. Проблемы электромагнитной стойкости аппаратуры сотовой связи актуальны в связи с ее расширяющимися возможностями (одновременно с ее значительным усложнением), а также с тем, что все больше функций выполняются с использованием изделий микроэлектроники, IT-оборудования, вычислительной техники. За период эксплуатации оборудования сотовой связи могут происходить изменения электромагнитной обстановки (ЭМО), в которой функционирует РЭА, могут появиться изменения условий

помехоустойчивости из-за внедрения новых технологий или реализованной модернизации аппаратуры.

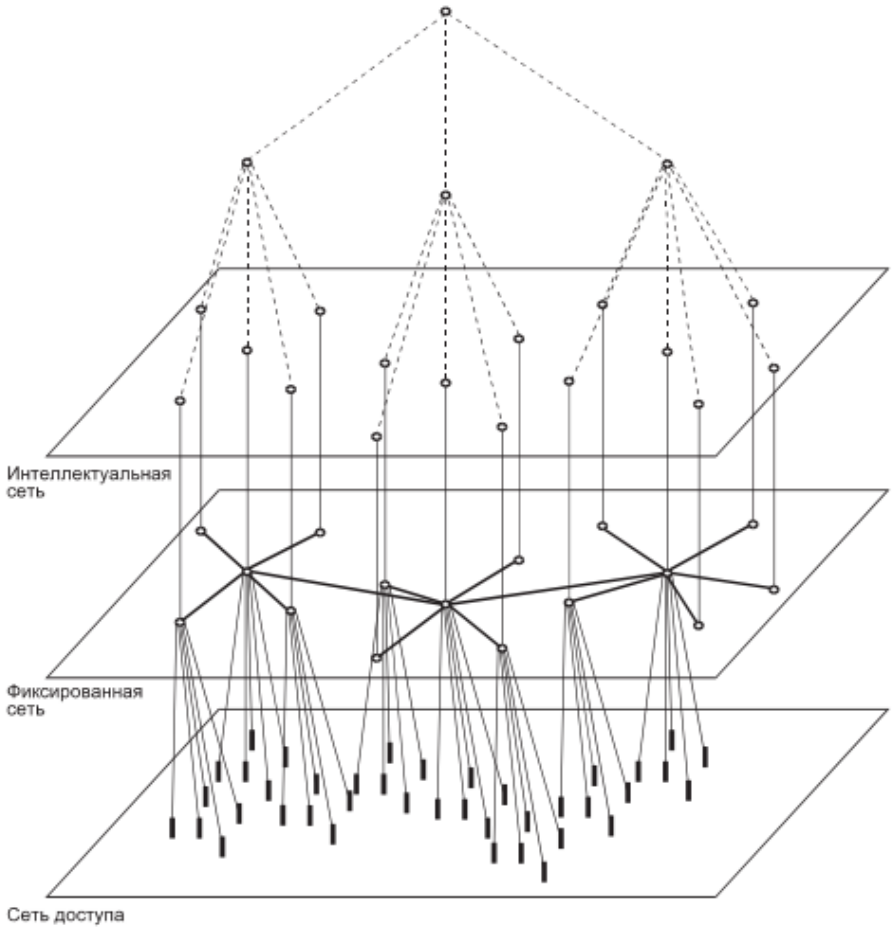
На данный момент Международная электротехническая комиссия (МЭК) определяет ЭМС как способность оборудования или системы удовлетворительно работать в данной ЭМО без внесения в нее какого-либо недопустимого электромагнитного возмущения.

При облучении внешним ЭМП аппаратура сотовой связи должна функционировать в штатном режиме и отвечать требованиям электромагнитной стойкости и безопасности эксплуатации в условиях воздействия электромагнитных факторов различного происхождения.

Основная часть. Радиопередатчики базовой станции излучают электромагнитные волны через передающие антенны в окружающую среду в целях передачи информации, поэтому они служат функциональными источниками помех. Аппаратура БС сотовой связи может быть подвержена влиянию внешних ЭМВ, в результате это проявляется в виде сбоев или нарушений их работоспособности. Учитывая роль сотовой связи в повседневной жизни в ее системы (устройства, электронные компоненты), необходимо заложить способность эффективно работать при мощных электромагнитных волнах (ЭМВ). Наложение излучений разных стандартов (2G-4G) и радиотехнологий с разными вариантами частот и модуляции сигналов, относящихся к разным поколениям, формирует многочастотный спектральный состав радиоизлучений в окружающей среде.

Совершенствование систем мобильной связи приводит к развитию новых возможностей при приеме, обработке и передаче информации. Данный процесс усложняет составные части систем мобильной связи.

Стартовой площадкой для запуска систем связи следующего поколения станут существующие сети 2G/3G/4G. Инфраструктура мобильных операторов должна быть готова к внедрению стандарта 5G. Общая структура сети связи следующего поколения 5G показана на рисунке. Она включает в себя три уровня: сеть доступа; фиксированную сеть; интеллектуальную сеть.



Архитектура сети 5G

Наиболее интенсивно для сотовой мобильной связи сейчас используются диапазоны УВЧ, СВЧ и активно осваивается диапазон миллиметровых волн КВЧ (таблица). Разработки вопросов следующего поколения беспроводной связи 6G стартовали с вопросами пропускной способности, обеспечения кибербезопасности передаваемой информации, ценовой конкурентноспособности услуг по сопоставлению с предыдущим. Беспроводная связь субтерагерцового диапазона волн 90300 ГГц обладает быстродействием.

Используемые диапазоны частот для действующих и перспективных систем мобильной связи

UHF	SHF	EHF	THF
Ультравысокие (УВЧ)	Сверхвысокие(СВЧ)	Крайне высокие (КВЧ)	Гипервысокие
100 см – 1 см		10–0,1 мм	
300–3000	3–30	30–300	300–3000
МГц	ГГц		

Новый стандарт 5G (Fifth Generation) будет работать на более высоких рабочих частотах, по сравнению с предыдущими поколениями. Из-за загруженности электромагнитного спектра на частотах ниже 6 ГГц базу сетей 5G будут составлять системы беспроводного радиодоступа, работающие на частотах 30-100 ГГц, то есть в нижней полосе диапазона экстремально высоких частот EHF (Extremely High Frequency), 30-300 ГГц. Большими ресурсами пропускной способности, обеспечивающими: достижение высокой скорости передачи данных; транзитную передачу со скоростями более 100 Гбит/с; общедоступные киоски доступа в Интернет с расширенными возможностями; технологию прямой связи между устройствами D2D communications (Device-to-Device) малой дальности.

Переход рабочих частот аппаратуры в гигагерцовую область вызывает потенциальную уязвимость аппаратуры от внешних ЭМВ и требует более тщательного подхода к проектированию конструкции: следует снизить проникновение ЭМП через возможные апертуры в корпусе аппаратуры, а также не допускать распространения излучаемых ЭМП в процессе работы аппаратуры во внешнюю среду [2]. С этой целью необходимо обеспечивать качественную экранировку корпуса аппаратуры для защиты от переизлучений через всевозможные неоднородности корпуса (щели в стыках сопрягающихся частей, отверстия под соединители, вентиляционные отверстия).

Основными рецепторами, воспринимающими влияние ЭМП, служат соединительные провода, в том числе дорожки печатных плат, на которых наводятся электрические помехи, вызывающие отказы приборов. Непосредственное воздействие ЭМП на электронные компоненты, как правило, не приводит к каким-либо деструктивным эффектам. Обычно сложная ЭМО характеризуется полями с напряженностью 100 В/м и более в диапазоне частот работы современных сетей мобильной связи.

В современных сетях сотовой связи БС управляют выходной мощностью мобильного телефона, который уже давно стал альтернативой компьютеру. При регулировании выходной мощности БС стремится поддерживать уровень принимаемого сигнала от сотового телефона в оптимальных пределах. Уровень излучения телефона будет снижаться до минимального значения, обеспечивающего требуемое качество связи. В работе [3] приводятся краткие сведения о компактном энергоэффективном оборудовании, минимизирующем излучение сотового телефона с 1 Вт (максимальная мощность передатчика современных смартфонов) до 1 мВт и не требующем никаких дополнительных приложений и настроек. В данную систему входит: приемная антенна, устанавливаемая внутри помещения; блок усиления-переизлучения и узконаправленная передающая антенна, расположенная вне предела помещения.

Важным показателем производительности антенны мобильного телефона служит ее усиление в направлении БС. Ориентация телефона и направление на башню БС могут существенно различаться, телефон должен иметь возможность излучать с максимальной интенсивностью в любом направлении [4]. В технологиях 1G-4G основной луч БС рассеивался в пространстве и устройства работали на «энергии рассеяния». В антенном модуле мобильного телефона 5G устанавливается активная фазированная решетка, формирующая «луч» (складываемый из нескольких), сфокусированный непосредственно на приемном устройстве. Управление диаграммой направленности

данной антенной решетки возможно, если измерить эквивалентную изотропно-излучаемую мощность EIRP (Equivalent Isotropical Radiated Power) по всем возможным направлениям. EIRP – коэффициент усиления мощности передающей антенны в определенном направлении, на которую умножается мощность, поступающая в антенну с передатчика.

В диапазоне миллиметровых частот от 30 до 300 ГГц потери в тракте передачи должны быть компенсированы высоким коэффициентом усиления антенны, интегрированной в передающий блок. Архитектура передающей антенны с множественными передающими элементами минимизирует толщину антенны, сохраняя при этом стабильность коэффициента усиления антенны во всей полосе пропускания и управляя уровнями боковых лепестков. Для соединения сетевых систем 5G разрабатываются фотонные компоненты и радиочастотные фильтры [5].

Антенна PA740 компании Taoglas обладает расширенной полосой частот LTE (Long Term Evolution) и новыми диапазонами, обеспечивающими функциональность 5G (высокую производительность и надежность, точное позиционирование, отслеживание местоположения и пр.) [6]. Возможность точного высокоскоростного подключения, малого времени ожидания, стабильной передачи данных и вычислений в реальном времени зависит от надежности антенны. Корпорация Skyworks разработала переключатель настройки апертуры 5G-антенны – SKY5^{TM}-9269-702LF, имеющий размеры 1,6x1,6x0,45 мм и очень низкое значение сопротивления во включенном состоянии (1,4 Ом), способный переносить типичное напряжение тока в 80 В [7].

Как правило, корпус РЭА изготавливается из металла, в связи с этим он выполняет роль защиты, снижающую уровень поля, проникающего внутрь устройства. Непрерывность корпуса по всему объему занимаемой аппаратуры (при толщине от 1 мм и более) обеспечивает уменьшение напряженности вторичных ЭМП внутри корпуса до значения, гарантирующего отсутствие сбоев в функционировании РЭА. Поле, проникающее в устройство, воздействует на электронные компоненты и соединительные провода. Критичным фактором, нарушающим функционирование РЭА при внешних ЭМВ, служит энергия ЭМП, способная приводить к возникновению токов и напряжений в чувствительных компонентах, достаточных для возникновения структурного разрушения или сбоев типовых электрических (конденсаторы, резисторы и т.д.) и электронных компонентов, в том числе изделий с высокоинтегрированной электронной компонентной базой (микропроцессоры, системы на кристалле и другие). Для типовых компонентов необратимые отказы возникают, если уровень аккумулированной энергии внутри корпуса достигнет значений 10^{-4}–10^{-7} Дж [8]. С целью снижения опасности для чувствительных элементов по возможности необходимо обеспечить дополнительную локальную защиту от энергии ЭМП посредством внутренних металлических корпусов, содержащих эти элементы.

Скин-эффект, возрастающий с ростом частоты в ВЧ диапазоне воздействующего излучения, может значительно снизить прошедшее через корпус ЭМП. Но его влияние значительно только при квазистационарном условии, когда длина волны воздействующего излучения много больше размеров корпуса [9]. На резонансных частотах эффективность экранирования снижается, прошедшее через корпус ЭМП не будет существенно ослабляться с ростом частоты. Определяющим моментом здесь служит соизмеримость длины волны с характерными размерами корпуса. В данном случае влияние скин-эффекта будет перекрываться резонансными процессами, приводящими к снижению или росту экранирующего эффекта корпуса с увеличением частоты.

Электростатический разряд (ЭСР) – источник излучаемых электромагнитных помех в виде импульсных электрического и магнитного полей, представляющих опасность для интегральных микросхем (ИМС) и полупроводниковых приборов (ППП) [10]. ЭСР могут возникать вблизи ИМС и ППП на дистанциях, соизмеримых с длиной канала разряда. При этом величина значений излучаемых электромагнитных помех могут достигать значительных уровней и индуцировать на внутренней металлизации ИМС и ППП напряжения и токи, при которых происходит деградация функциональных характеристик или необратимые изменения, провоцирующие отказ. ЭСР может происходить в пространстве между: неравномерно заряженными участками поверхностей диэлектриков, заряженными участками поверхности или объемными зарядами диэлектрика и электропроводными поверхностями [11].

Воздействие электромагнитных импульсов на электронные устройства при определенных условиях может привести к некоторым эффектам, например [12]:

– отказам некоторых элементов (при высоких уровнях воздействующего ЭМП);

– переходу активных элементов в режим насыщения (вследствие индуцированных в электрических проводниках электромагнитными импульсами помех. После прекращения действия этих помех, компоненты возвращаются в нормальное состояние).

– ошибкам при передаче цифровых данных из-за деградации канала передачи данных при высокой частоте повторения деструктивного воздействия на цифровые устройства. Увеличение частоты повторения помехи может привести к повышению ее средней мощности.

На практике внешние связи между оборудованием могут видоизменяться из-за присутствия экранирующих и диэлектрических материалов, а также взаимного размещения мешающего и восприимчивого оборудования, в особенности кабельных соединений. Заземляющие/экранирующие плоскости или усиливают мешающий сигнал благодаря отражению, или уменьшают его за счет поглощения [13].

Сейчас размеры кристалла ИМС в сотовом телефоне достигли нанометровых топологий, составляющих приблизительно 1–2 мм, размер корпуса – десяток/несколько десятков мм, а размеры печатной платы составляют около 100 мм. Чем плотнее расположены все элементы системы, тем выше удельная производительность в пересчете на единицу энергопотребления. Однако снижение размеров топологических элементов и рост плотности их размещения обостряет существующие проблемы, такие как проблемы теплоотвода, а также влияние крайне малых воздействий – буквально масштаба одного-двух электронов – возрастает очень заметно.

Актуальные флагманские мобильные процессоры – сложные однокристальные системы, включающие: восемь ядер различной мощности (например: 4 слабых, но энергоэффективных (для решения простых задач, экономя батарею); 4 мощных с повышенными тактовыми частотами (для ресурсоемких задач, например, игры с трехмерной графикой); графический ускоритель; контроллер оперативной памяти; модули беспроводной связи 3G/4G, Wi-Fi, Bluetooth и навигации GPS (Global Positioning Satellite); видеоэнкодер [14]. Современные мобильные SoC (System-on-a-Chip) оснащены ядрами центрального процессора CPU (Central Processing Unit), графическим ускорителем GPU (Graphics Processing Unit), модемом LTE, модулями для иных беспроводных сетей, а во флагманских решениях SoC имеются специализированные вычислительные блоки для работы с задачами искусственного интеллекта и машинного обучения и др.

Таким образом, в аппаратуре сотовой связи появляются ИМС все большей степени интеграции и функциональной сложности, многослойные печатные платы (в том числе платы высокой плотности), усложняется монтаж высокотехнологичной аппаратуры. Поэтому наряду с проблемой обеспечения ЭМС, возникают проблемы обеспечения целостности сигнала (связанные с качеством сигнала в системе) и целостности питания (охватывающие вопросы конструирования системы распределения питания, отвечающей жестким требованиям к целевому полному сопротивлению) [15].

Samsung (Корея) и TSMC (Тайвань) осваивают новые технологические процессы производства мобильных процессоров (7 нм, 5 нм). 5 нм – следующий большой технологический шаг. Это позволит увеличить плотность транзисторов примерно в полтора раза. Меньший, более современный технологический процесс позволяет разработчику вместить больше транзисторов в своём решении, что серьёзно влияет на потенциал производительности, а также позволяет сделать компромисс производительность/энергоэффективность куда более гибким. Новые техпроцессы позволяют сделать решения не только мощнее/энергоэффективнее, но часто ещё и компактнее. Увеличение производительности и быстродействия процессоров дает возможность без проблем загружать более ресурсоемкие приложения [16]. Однако более быстродействующие системы генерируют более высокочастотные помехи.

Типовое мобильное радиоустройство как источник электромагнитных помех излучает поле с пиковым значением напряженности до 100 В/м в диапазоне 1,8–2,0 ГГц в зависимости от его напряжения и расстояния [17]. Оно может наводить высокочастотные помехи на другие электронные устройства, даже если мобильные устройства находятся вне рабочей полосы другого электронного устройства.

При необходимости обеспечить наилучшую защиту электронного устройства от электромагнитных помех требуется проанализировать его показатель EMIRR (*rejection ratio* – коэффициент подавления электромагнитных помех), выраженную в дБ, который является одним из важных параметров, позволяющих определить помехоустойчивость электронного устройства.

Итак, сегодня проблема исследования и обеспечения электромагнитной совместимости систем сотовой связи приобретает актуальность в силу следующих основных причин:

– повышение плотности компоновки электронных, радиоэлектронных и электротехнических систем, а также уменьшение габаритных размеров систем;

– наличие в составе оборудования сотовой связи одновременно устройств, работающих в широком диапазоне частот (до нескольких ГГц), напряжений и токов;

– рост количества ЭМВ в системах сотовой связи, способных нарушать функционирование электронных, радиоэлектронных и электротехнических систем;

– повышение быстродействия и уменьшение уровней сигналов, обрабатываемых цифровыми элементами электронных средств, приводящее к снижению их помехоустойчивости;

– при проведении исследований не в полной мере учитываются реальные условия эксплуатации технических систем, учитывающие ЭМО в местах эксплуатации оборудования.

Общие направления для обеспечения ЭМС включают [18]:

– уменьшение связи источника и рецептора помехи через излучение (в частности, путем экранирования, надлежащей компоновкой);

– уменьшение емкостной и индуктивной связи источника и рецептора эдектромагнитной помехи;

– применение конструкционных, схемотехнических и структурно-функциональных методов, а также рациональную трассировку кабелей;

– уменьшение гальванической связи источника и приемника помехи.

Конструкционные способы обеспечения ЭМС основаны на рациональном размещении оборудования, экранировании. Схемотехнические методы защиты – целенаправленное изменение структуры отдельных схем или введение в них дополнительных элементов для ослабления электромагнитных влияний на нормальное функционирование. Схемотехнические методы обеспечения ЭМС могут включать, например, использование элементов оптоэлектроники, симметрирование. Структурно-функциональные методы состоят в: применении корректирующих кодов; выборе оптимальной структуры сигнала и т.д. Для снижения гальванической связи наиболее эффективно применение схемотехнических методов обеспечения ЭМС, в частности фильтрации, служащей первым заслоном электромагнитным помехам.

При проектировании топологии интерфейсов/разъемов следует уделять должное внимание характеристикам ЭМС системы в целом. Все устройства должны пройти испытания на ЭМС, которые гарантируют работоспособность в требуемых условиях эксплуатации. Зная предельно допустимые условия эксплуатации системы, можно выявить соответствующие проблемы на ранних этапах проектирования и решить их, не дожидаясь создания опытного образца [19].

Обсуждение. Устройства, основанные на передаче радиосигналов, необходимо рассматривать с точки зрения генерации ими электромагнитных помех и устойчивости самого оборудования к внешнему воздействию излучения от других приборов [20]. Новые поколения БС сотовой связи работают в гигагерцовом диапазоне частот, поэтому важным аспектом становится учет требований по ЭМС при их проектировании и разработке. ЭМС устройств сотовой связи – это их функционирование с требуемыми техническими характеристиками в условиях электромагнитного взаимодействия его технических систем и внешних ЭМВ. Имеет место потенциальная уязвимость РЭА от внешних ЭМВ, обусловленная не только электромагнитным воздействием источника помехи на рецептор, но и их взаимодействием (когда источник параллельно является и приемником). Необходимо разработать различные решения по методам обеспечения ЭМС (например, базовые методы, основанные на фильтрации и экранировании) и оптимизировать проектные решения. Учет «кумулятивного эффекта» при одновременном воздействии помех, ЭМИ радиопередатчиков, других внешних ЭМВ позволит предотвратить сбой в работе аппаратуры сотовой связи.

Выводы. На работу аппаратуры сотовой связи особое влияние оказывают электромагнитные помехи различного происхождения. Радиоэлектронные средства (системы, электронные компоненты, устройства) могут быть как источником, так и рецептором электромагнитных помех, то есть объектом, подвергающимся влиянию ЭМИ другого устройства. Одним из основных звеньев в гарантировании ЭМС аппаратуры служит разработка качественной конструкции оборудования, эффективно экранирующей чувствительные блоки аппаратуры от всех электромагнитных полей и

помех, действующих извне. Экранирующее действие корпуса ограничивается отверстиями, служащими каналами проникновения поля внутрь устройства.

Основные пути проникновения ЭМВ в аппаратуру БС сотовой связи служат: антенные системы, проникновение через корпус и отверстия в корпусе (ЭМП наводятся в линии связи и воздействуют на антенно-фидерные тракты, информационные интерфейсы, цепи электропитания и заземление). Для правильного функционирования системы важен оптимальный выбор компонентов, ограничивающих выбросы напряжения и защищающих входные каскады от ЭСР.

При проектировании конструкции аппаратуры сотовой связи следует снижать проникновение внешних дестабилизирующих ЭМВ (полей излучений соседних радиотехнических средств и передающих устройств, СВЧ-излучений, ЭСР) через всевозможные апертуры в корпусе. Корректная топология печатной платы, экранирование - необходимые условия для соответствия требованиям стандартов ЭМС. Качественное исследование с целью обеспечения ЭМС приведет к возможности добиться требуемых технических характеристик, а также обеспечить соблюдение нормативных документов. ЭМС – совокупность взаимосвязанных проблем (структурно-функциональных, схемотехнических, пр.) комплексного характера. Рассмотренные методы позволяют решать круг задач, связанных с работой аппаратуры сотовой связи в условиях сложной ЭМО. Результаты исследования можно использовать в задачах обеспечения радиоэлектронной борьбы и ЭМС РЭА.

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METHODS FOR PROTECTING THE EQUIPMENT OF CELLULAR (MOBILE) CONNECTION FROM ELECTROMAGNETIC IMPACT

Abstract. Under electromagnetic impact (EMI) of a sufficient level, temporary disruption of functioning, processing, transmission and storage of information in cellular equipment is possible. Possible problems of electromagnetic compatibility (EMC) of a mobile phone and a base station (BS) of cellular connection under the influence of electromagnetic radiation (EMR) from other sources and their negative impact on functioning are considered. The energy of the HF electromagnetic field (EMF) after passing through the protective case can affect the devices of shielded radio electronic equipment (REE), therefore, the possible negative consequences of the impact of high-energy EMF on the REE are described. Possible negative consequences under certain conditions from the influence of the skin-effect, the effects of electrostatic discharge and electromagnetic pulses on electronic devices are given. It is shown that the constructional method of protecting REE from the effects of external electromagnetic factors consists in reducing the collected and transmitted EMF energy by improving the design, placement and installation of equipment. Components of some vendors for 5G systems that are resistant to external interference are given, and the possibilities for reducing the radiation level of a cell phone are noted. The necessity of an integrated approach to solving EMC problems is substantiated, which consists in the use of structural, circuitry and structural-functional methods of EMC provision.

The new 5G (Fifth Generation) standard will operate at higher operating frequencies compared to previous generations. Due to the workload of the electromagnetic spectrum at frequencies below 6 GHz, 5G networks will be based on wireless radio access systems operating at frequencies of 30–100 GHz, that is, in the lower band of the extremely high frequency range EHF (Extremely High Frequency), 30–300 GHz.

Key words: base station, cell phone, electromagnetic compatibility, electromagnetic influences, electromagnetic interference, electromagnetic fields.

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ҰЯЛЫ (МОБИЛЬДІ) БАЙЛАНЫС АППАРАТУРАСЫН ЭЛЕКТРОМАГНИТТІК ӘСЕРЛЕРДЕН ҚОРҒАУ ТӘСІЛДЕРІ

Аннотация. Ұялы байланыс құралдарында ақпаратты сақтау және таратуда электромагнитті әсерлерден (ЭМӘ) өңдеудің уақытша бұзылуы болуы мүмкін. Ұялы телефонның және ұялы байланыстың базалық станциясының (БС) электромагниттік үйлесімділігінің (ЭМҮ) басқа көздерден электромагниттік сәулеленудің

(ЭМС) әсер етуіндегі мүмкін проблемалары және олардың жұмысына теріс әсері қарастырылады. Қорғаныс корпусынан өткеннен кейін электромагниттік өрістің (ЭМӨ) жоғары жиілікті (ЖЖ) энергиясы экрандалған радиоэлектрондық аппаратураның (РЭА) аспаптарына әсер етуі мүмкін, сондықтан РЭА-ға жоғары энергетикалық ЭМӨ әсерінің ықтимал теріс салдары сипатталған. Белгілі бір жағдайларда скин – эффектінің, электростатикалық разряд пен электромагниттік импульстардың электронды құрылғыларға әсер етуінен болатын жағымсыз салдарлар келтірілген. РЭА-ны сыртқы электромагниттік факторлардың әсерінен қорғаудың құрылымдық әдісі жабдықтың құрылымын, орналасуын және орнатылуын жақсарту арқылы жиналған және берілген ЭМӨ энергиясын азайту болып табылады. Сыртқы кедергілерге төзімді 5G жүйелеріне арналған кейбір сатушылардың компоненттері келтірілген, сонымен қатар ұялы телефонның сәулелену деңгейін төмендету мүмкіндігі көрсетілген. ЭМС қамтамасыз етудің құрылымдық, сұлбалық және құрылымдық-функционалдық әдістерін қолданудан тұратын ЭМС мәселелерін шешуге кешенді тәсілдің қажеттілігі негізделген. Ұялы байланыс операторларының инфрақұрылымы 5G стандартын енгізуге дайын болуы тиіс.келесі буын 5G байланыс желісінің жалпы құрылымы суретте көрсетілген. Ол үш деңгейден тұрады: кіру желісі; тіркелген желі; интеллектуалды желі.

Жаңа 5G стандарты (Fifth Generation) алдыңғы буындарға қарағанда жоғары жұмыс жиіліктерінде жұмыс істейді. Электромагниттік спектрдің 6 ГГц жиіліктен төмен жүктелуіне байланысты 5G желілерінің негізі 30-100 ГГц жиіліктерінде жұмыс істейтін сымсыз радио қол жетімділік жүйелері арқылы құрылады, яғни, өте жоғары жиілік диапазонының төменгі жолағында EHF (Extremely high Frequency), 30-300 ГГц.

Түйін сөздер: базалық станция, ұялы телефон, электромагниттік үйлесімділік, электромагниттік әсерлер, электромагниттік кедергі, электромагниттік өрістер.

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DEVELOPMENT OF AN AUTOMATED PHOTOVOLTAIC SYSTEM WITH WIRELESS MONITORING

Abstract. The work is devoted to the development of an efficient photovoltaic installation with automated wireless monitoring based on the LabView software. Long-distance communication technology - LoRa was used to wirelessly transmit data on the output characteristic states of the photovoltaic installation, storage battery and built-in sensors. This module operates at 433 MHz and transmits small data packets with low power consumption. This makes the stand-alone system energy efficient compared to similar wireless installations. The graphical software LabView was chosen to monitor the state of the developed system. The paper shows a block diagram of an automated wireless system, an operational algorithm of the external transmitting part of the installation, as well as electrical circuits of the transmitting and receiving control units. As a result of the work, a photovoltaic system with an automated wireless monitoring system and graphical data display was developed. The developed automated complex is more efficient and easy to use in comparison with other systems.

Key words: Wireless monitoring, solar panel, battery, current and voltage sensor.

Introduction. With the rapid development of wireless communication technologies through the use of microcontrollers and other communication devices, many industrial processes are controlled by automated systems, which in turn reduce human effort. Automated systems are managed and monitored via wired and wireless communication networks.Wireless automated systems - a complex of software and hardware that enables computer systems and communication devices to function without human intervention. The operations of an automated system are part of the automatic control of a system in which the processes are fully automated with support for control loops and special logic [1-3].

The use of wireless automated systems saves labor, time and money, increasing the accuracy of the work performed. This increases the availability, performance, and reliability of the services provided. Today, the use of such installations in photovoltaic systems is one of the most promising areas. Wireless monitoring is considered an important aspect to monitor the stability and performance of a photovoltaic system. The photovoltaic monitoring system can be used in solar-powered cars, solar-powered buses, solar-powered trains, etc. [4].

In the articles [5,6], the authors designed the design of a simple, cost-effective and low-power wireless monitoring system for photovoltaic installations. XBee RF modules were chosen as wireless receiving and transmitting devices. Also, based on the ZigBee and LoRa wireless modules, research works were carried out for online monitoring of the photovoltaic system [7-11].

The software of the automated system is an important part of this research work. In scientific articles [12-17], monitoring systems based on LabView software were developed. The authors claim that the LabView program can accurately monitor the state of sensors in real time.

Analyzing these materials, we can say that all the developed systems are aimed at improving energy efficiency, reducing the proportion of human intervention in the workflow.

This article presents an automated system of photovoltaic installations with wireless monitoring based on LabView software. The LoRa wireless module was chosen to build the communication network. As a

result of the research work, an automated photovoltaic system with wireless monitoring was built, and an algorithm for the operation of the General system was developed. Experimental data on the effectiveness of the developed system were obtained.

Design of an automated photovoltaic system with wireless monitoring.

Block diagram of an automated system with wireless monitoring. The block diagram of an automated system with wireless monitoring is shown in figure 1. The photovoltaic installation (1) is controlled through the control unit (2). Control electronic unit contains a programmable logic controller, where the algorithm of operation of the general installation is loaded. The generated electrical energy is stored in the battery pack (3). The batteries are charged using the battery charge controller. At the output of the solar panel, as well as at the output of the battery charge controller, an ammeter and voltmeter (4) are installed, which measure the output electrical characteristics of the devices, transmits data to the microcontroller (5).The microcontroller, in turn, after processing all the received data, sends the data todispatcher via the wireless module LoRa E32 (6). At the receiving part of the dispatcher device also has a wireless module E32 LoRa (8). The communication channel between the receiver and the transmitter (7) is publicly available on the territory of the Republic of Kazakhstan. The wireless receiving module is directly connected via a USB 2.0 cable to a personal computer (9), where you can monitor the overall operation of the installation using LabView software.

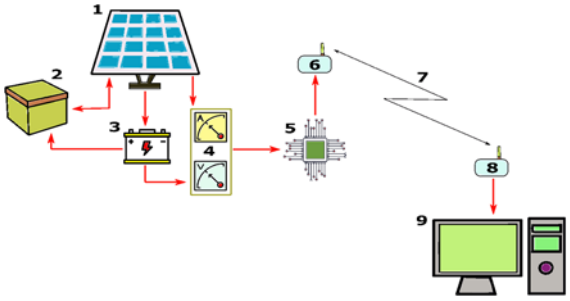

Figure 1 – Structure of the automated wireless monitoring system

Control electronic unit of the system. Figure 2 shows the electronic components of the transmitting and receiving parts of the automated wireless monitoring system. Figure 2 a shows an 8-bit Atmega328PU (1) microcontroller, which uses the developed algorithm to control all electronic components in the device. The unit is powered by a 12 V battery (4), via a voltage stabilizer LM7805 (3). The output electrical values of the solar panel (8) and the battery charge controller (7) are measured through an ACS712 ammeter (5) and a voltmeter made on the basis of a voltage divider (6). The data received from the sensors is processed in the microcontroller and sent to the dispatcher via the LoRa E32 (2) wireless module.

Figure 2 b shows the electrical diagram of the receiving part (dispatcher) of the system. Here, the LoRa E32 wireless module (2) and the Atmega328 PU microcontroller (1) are connected to the personal computer via USB 2.0 (3) cables.

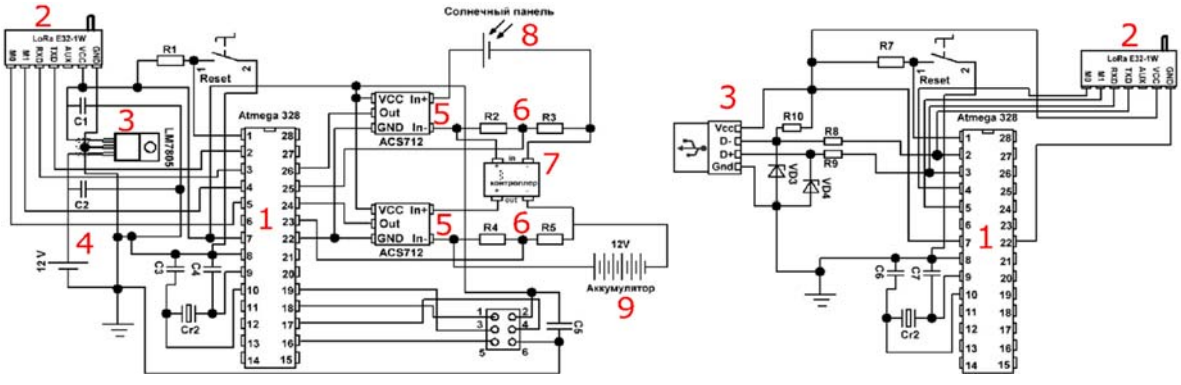

Figure 2 – Electronic components of an automated wireless monitoring system: a) transmitting part; b) receiving part

Algorithm of the general system operation. Figure 3 shows the algorithm of the automated wireless monitoring system.

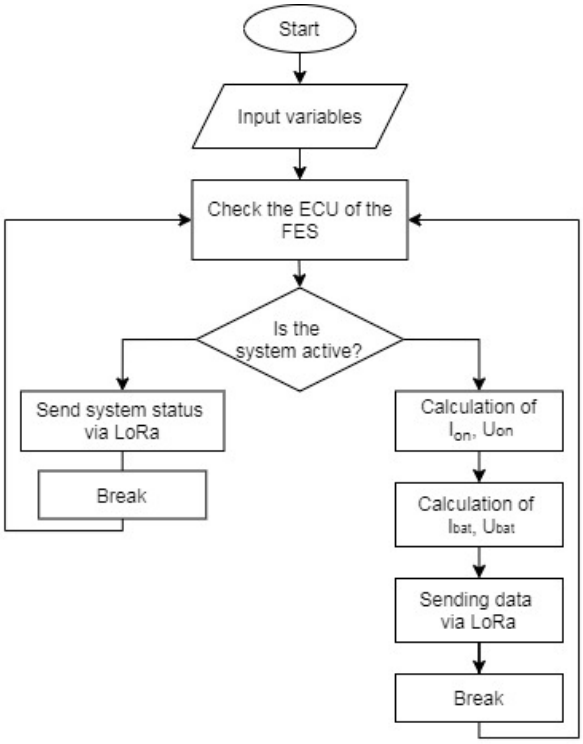

Figure 3 – Algorithm of operation of the automated wireless monitoring system

The built-in microcontroller works according to the specified software algorithm. At the first stage of the system operation, the microcontroller enters the operating mode. Next, enter the desired i/o ports of the microcontroller and variables. After that, the controller checks the activity of the electronic control unit (ECU) of the photovoltaic system (FES). If the system has not yet been activated, the controller sends a packet about the disabled state of the system and goes into sleep mode for a certain time. And if the system has switched to operating mode, the microcontroller takes measurements using the installed sensors and sends them to the dispatcher via the LoRa E32 wireless module. Then the microcontroller goes into sleep mode for a certain time.

Results and discussion. The monitoring interface of the automated wireless photovoltaic system was built on the basis of the LabView graphical software. As a result of the experiment, the electrical characteristics of the solar panel and battery were obtained and displayed on the dispatcher's monitor. Figure 4 shows the interface (front panel) of a wireless automated system.

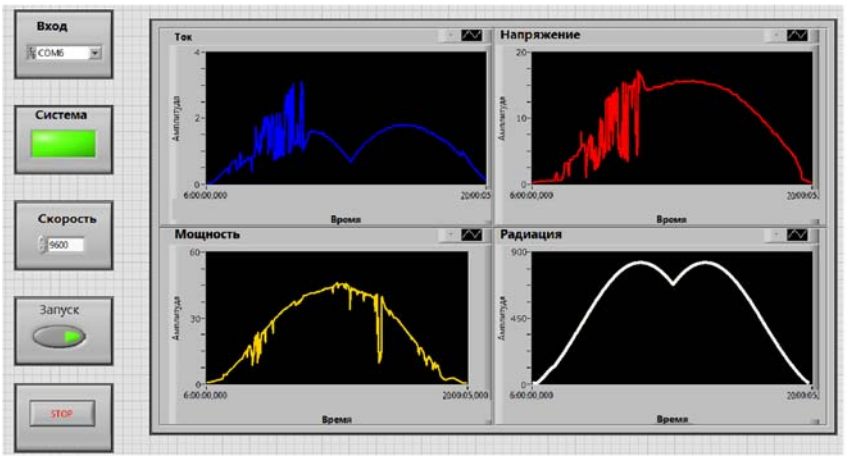

Figure 4 – Wireless monitoring system interface

The main window contains the input port, where you can select the port number of the computer connected to the external device. If the system is activated, the monitor indicator will turn green. Next, the speed of information exchange between the device and the computer is set. Below are the locking buttons for starting and interrupting the system. On the right side of the monitor are graphical indicators that show the electrical characteristics of the system: the current and voltage of the solar panel, the power of the solar panel, and the level of solar radiation W/m^2.All data obtained as a result of the experiment will be automatically saved in text format on the local PC.

Figure 5 shows the graphical (virtual) elements of the LabView program connected between (block diagram).

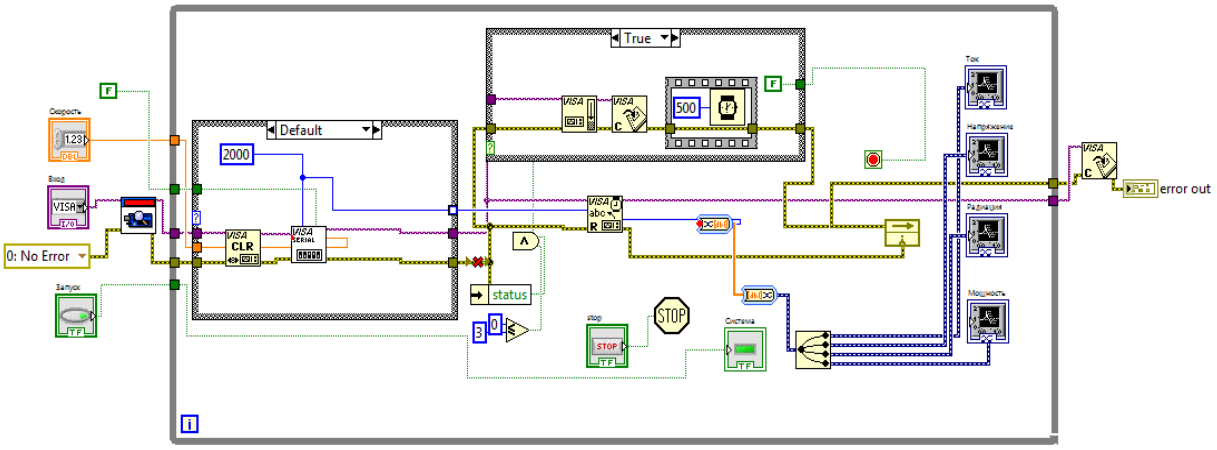

Figure 5 – Block diagram of LabView program

Separate graphs from the LabView program are shown below. Figure 6 shows a graph of the current and voltage generated at the output of a photovoltaic panel during one day. Here, the red line indicates the voltage, and the blue line indicates the current of the photovoltaic panel.

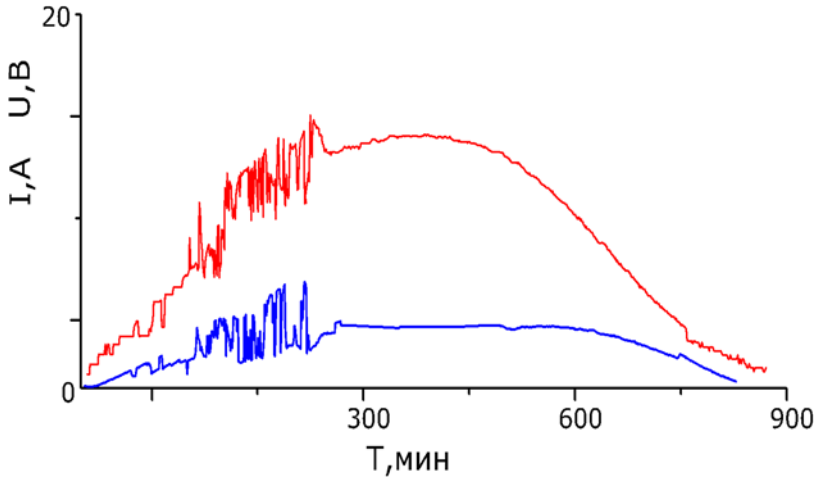

Figure 6 – Graph of the current and voltage of the photovoltaic panel

Figure 7 shows a graph of solar radiation over a single day. Since our radiation sensor is mounted on a single-axis tracker, you can see from the graph that in the middle of the day, the energy decreases due to the height of the sun coordinate location.

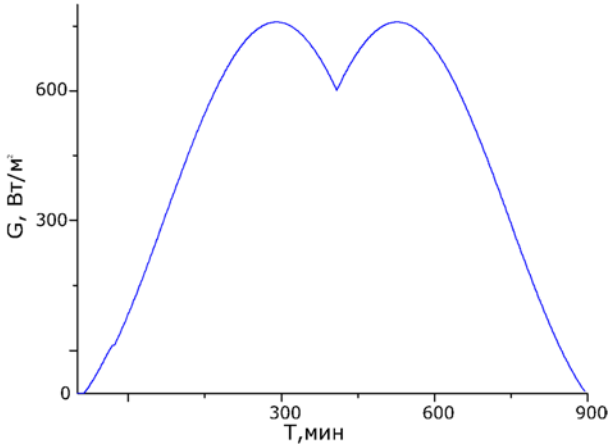

Figure 7 – Graph of solar radiation

Conclusion. During the research work, an automated wireless monitoring system for the photovoltaic system was developed and manufactured using an interface based on the LabView software. Data on the generation of solar energy and solar radiation during the day were obtained in the form of graphs in the LabView environment. The developed automated system reduces human involvement in the monitoring process and is easy to use. Installed electronic components consume a small amount of energy.

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СЫМСЫЗ МОНИТОРИНГ НЕГІЗІНДЕГІ АВТОМАТТАНДЫРЫЛҒАН ФОТОЭЛЕКТРЛІК ЖҮЙЕ ЖАСАУ

Аннотация. Ғылыми жұмыс LabView бағдарламалық жасақтама негізінде құрылған автоматтандырылған сымсыз бақылауы бар тиімді фотоэлектрлік қондырғыны әзірлеуге арналған. Фотоэлектрлік қондырғының шығыс сипаттамасын, аккумуляторлы батареяның және орнатылған сенсорлы құрылғылар күйін сымсыз байланыс жүйесі арқылы жіберу үшін LoRa ұзақ қашықтықтағы байланыс технологиясы қолданылды. Бұл модуль 433 МГц жиілікте жұмыс істейді және электр қуатын азырақ тұтыну арқылы шағын деректер пакетін жібере алады. Бұл ұқсас сымсыз қондырғылармен салыстырғанда автономды жүйені энергияны үнемдейді.

Әзірленген жүйенің күйін бақылау үшін LabVIEW графикалық бағдарламалық жасақтама таңдалды. Жұмыста автоматтандырылған сымсыз жүйенің блок-схемасы, қондырғының сыртқы ақпарат тарату бөлігінің жұмыс алгоритмі, сондай-ақ басқару блоктары, қабылдау-тарату бөлігі, электр схемалары көрсетілген.. Жұмыс нәтижесінде автоматтандырылған сымсыз бақылау жүйесі және деректерді графикалық түрде көрсететін фотоэлектрлік жүйе жасалды. Сондай-ақ, бір күн ішінде фотоэлектрлік панельдің шығысында пайда болатын күн радиациясы, ток және кернеу графиктері алынды. Әзірленген автоматтандырылған кешен басқа жүйелермен салыстырғанда тиімдірек және қолдануға оңай. Автоматтандырылған кешен адамның мониторинг үдерісіне қатысуын азайтады. Орнатылған электрондық компоненттер аз мөлшерде энергия тұтынады.

Түйін сөздер: сымсыз мониторинг, күн панелі, аккумулятор, ток пен кернеу құрылғылары.

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РАЗРАБОТКА АВТОМАТИЗИРОВАННОЙ ФОТОЭЛЕКТРИЧЕСКОЙ СИСТЕМЫ С БЕСПРОВОДНЫМ МОНИТОРИНГОМ

Аннотация. Работа посвящена разработке эффективной фотоэлектрической установки с автоматизированным беспроводным мониторингом на основе программного обеспечене LabView. Для осуществление беспроводной передачи данных состояний выходной характеристики фотоэлектрической установки,

аккумуляторной батареи и встроенных датчиков использовалась технология связи на большие расстояния – LoRa. Данный модуль работает на частоте 433 МГц и передает небольшие пакеты данных с невысоким энергопотреблением. Это делает автономную систему энергоэффективной по сравнению с аналогичными беспроводными установками.

Для мониторинга состояние разработанной системы было выбрано графическое програмное обеспечение LabView. В работе показана блок-схема автоматизированной беспроводной системы, алгоритм работы внешней передающей части установки, а также электрические схемы приемо-передающей части блоков управления. В результате работы была разработана фотоэлектрическая система с автоматизиро-ванной беспроводной системой мониторинга и графическим отображением данных. Также были взяты отдельные графики солнечной радиации, тока и напряжение, генерируемое на выходе фотоэлектрической панели в течение одного дня. Разработанный автоматизированный комплекс по сравнению с остальными системами является более эффективным и простым в использовании. Автоматизированный комплекс снижает вовлеченность человека в процесс мониторинга. Установленные электронные компоненты потребляют незначительное количество энергии.

Ключевые слова: беспроводной мониторинг, солнечная панель, аккумулятор, датчики тока и напряжение.

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АСТЫҚТЫ КЕПТІРУДІҢ ҚАРҚЫНДЫ ЭНЕРГИЯ ҮНЕМДЕУ ӘДІСІ

Аннотация. Астықты кептіру және ылғалды жою әдісі әзірленді, ол термодинамика теңдеуімен сипатталған пайда болатын жылу процестерін алуға және өңдеуге негізделген. Бұл әдіс аз зерттелген және жоғары қуатты жиілік түрлендіргішін (бірнеше жүз киловаттқа дейін) және жиілікті (бірнеше жүз кГц-ке дейін) өндіру технологиясының айтарлықтай жетілмегендігіне байланысты аз қолданылған. Бірақ қазіргі уақытта индукциялық жылытуға арналған жабдық дамып келе жатыр және оны дәстүрлі қыздыру әдістерімен салыстырғанда кептіру қондырғыларында қолдану жақсырақ. Астықты кептірудің ұсынылған индукциялық әдісі, онда астық материалы кептіру білігі арқылы ауырлық күші арқылы өтеді. Тәжірибелік зерттеулер жүргізу үшін транзисторлы – тиристорлы құрылғы жасалды, ол басқару блогынан, жиілік түрлендіргіштен, бет шнегі геликоидты шанақтан, индуктор орамасынан, ылғал өлшегіштен тұрады. Деректерді алу және өңдеу алгоритмі MATLAB бағдарламалық ортасында жасалды. Жиіліктің одан әрі жоғарылауымен шығын коэффициенті өзгермейді, сондықтан біздің құрылғы ГГц диапазонында жұмыс істейтінін ескере отырып, шығын коэффициенті тұрақты болады, яғни 0,6 тең. Сондықтан астық ылғалдылығының шығын коэффициентіне әсерін зерттеген кезде жиілік өлшеу дәлдігіне әсер етпейді деп сеніммен айта аламыз. Алынған жылу мөлшері, дәнді ішіндегі ылғал оның ылғалдылығының жоғарылауымен ериді. Алғаш рет инженерлік мағынада алынған Максвелл формуласы ылғалмен алынған астықтың жылуын есептеуге жарамды болды. Барлық қондырғының өзіндік құнын төмендету қарапайым индукциялық жылытқыштарды әзірлеуге және енгізуге жүгінуді талап етеді, бұл өзекті мәселе.

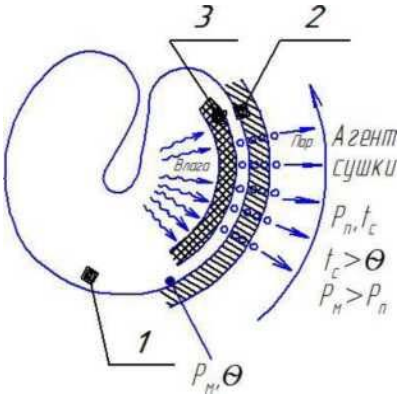
Түйін сөздер: астықты кептіру, электромагниттік индукция, шығарылатын жылу мөлшері, Максвелл формуласы.

Фазалық өзгерістер болған кезде жылу және электромагниттік толқындармен сәулелену процестерінде, ыстық беттермен, астықты кептіру теориясының негізі – қыздырылған газдармен әрекеттесу кезінде жылу мен ылғалдың берілу заңдылықтарына негізделген [3].

Астықты кептіру процесі, кез-келген дымқыл материалдар сияқты, тек термофизикалық ғана емес, сонымен қатар ылғалдың материалмен байланыс формасы шешуші рөл атқаратын технологиялық процесс. Астықты кептіру процесін зерттеу материал ішіндегі ылғалдың қозғалу құбылыстарын, будың пайда болуын және ылғал буларының астық бетінен қоршаған ауаға таралуын қарастырумен шектелуі мүмкін. Бұл процесс негізінен кептіру процесінің механизмін ашады. Астықты кептіру, жылыту және салқындату – бұл астықтың температурасы мен ылғалдылығының, сондай-ақ уақыт өте келе жылу мен ылғал ағындарының тығыздығының өзгеруімен бірге жүретін процестер. Астықта кептіру кезінде температура мен ылғалдың градиенті пайда болады, оның әсерінен дән ішіндегі жылу мен ылғал ауысады, жылу және көлемдік кернеулер пайда болады.

Жалпы жағдайда, кептіру кезінде астықтан ылғалды кетіру механизмі схемалық түрде келесідей ұсынылуы мүмкін (1-сурет).

Белгілі бір параметрлері бар кептіру агенті дымқыл дән бетінде қозғалады. Кептіру агентінен жылу конвективті түрде дымқыл дәнге беріледі; оның беті қызады және бетіндегі ылғалдың бір бөлігі буланып кетеді. Нәтижесінде, дәннің қалыңдығында ылғалдылық, температура мен қысым айырмашылықтары пайда болады, оның әсерінен ылғал үнемі буланып кететін жерге жеткізіледі.



1-сурет – Астықты кептіру кезіндегі ылғалды жою тетігінің схемасы: 1 – дәні; 2 – шекаралық қабат; 3 – булану аймағы

Бу молекулалары шекара қабаты арқылы таралады және кептіру агентімен сіңеді. Астық бетінен ылғалды кетіру процесінің міндетті шарты – оның бетіндегі $p_м$ және $p_п$ кептіру агентіндегі ішінара қысым арасындағы айырмашылықтың болуы.

Ылғал дән бетінен буланбайды, бірақ дәннің шеткі бөлігінде орналасқан 3-ші аймақтан буланады. Сонымен қатар, бұл аймақтың жағдайы өзгеріссіз қалады: ол біртіндеп ішіне жылжиды (тереңдейді). Булану аймағын тереңдетудің басталуын көптеген зерттеушілер астықтан байланысты ылғалды кетірудің басталуымен байланыстырады. Булану аймағын тереңдету кезінде дәнді беті құрғаған, қорғаныс факторы жоқ, сондықтан оны жоғары температураға дейін қыздыруға болады.

Жылу мен ылғалдың берілуінің күшеюі кептіруді тездетуге ықпал етеді, бірақ кернеудің жоғарылауы астық сапасының нашарлауына әкелуі мүмкін-жарықтардың пайда болуы, жарылу, дәнді дақылдардың шығуының төмендеуі және т.б. сондықтан кептірудің оңтайлы режимін орнату маңызды [4].

Астықты кептіру кезінде жылу беру жылу берудің жалпы заңдарына бағынады және оның ерекше жағдайы болып табылады. Теориялық негізі үшін қызмет етеді бір теориясы жылумассаалмасу. Негізінде бұл теория процестер жылу тасымалдау және ылғал астық сипатталуы мүмкін аналитикалық. Мұндай сипаттама кез-келген уақытта кез-келген астықтың немесе астық қабатының температурасы мен ылғалдылығын анықтауға, олардың градиенттері мен уақыт өзгерісін табуға, жылу мен ылғал ағындарының тығыздығын есептеуге, осы процестердің одан әрі дамуын болжауға мүмкіндік береді. Сонымен қатар, астық пен астық қабатындағы процестерді математикалық сипаттау кезінде белгілі бір қиындықтар туындайды, өйткені астық құрылымы мен құрамы жағынан гетерогенді. Нәтижесінде астықтың әртүрлі бөліктері әртүрлі өткізгіштікке ие және анизотропты қасиеттерге ие, яғни әртүрлі бағыттардағы әртүрлі өткізгіштік.

Кептірілген дәннің ішіндегі ылғалдың жалпы түрде қозғалу заңын (1) келесі қатынас арқылы білдіруге болады:

$$\boldsymbol{i} = \boldsymbol{k}\nabla\Pi, \tag{1}$$

мұнда i – ылғал ағынының тығыздығы; $\mathbf{k}$ – материалдың физикохимиялық қасиеттеріне байланысты ылғал берудің кинетикалық коэффициенті (пропорционалдылық коэффициенті); $\nabla\Pi$ – ылғал беру потенциалының градиенті (процестің қозғаушы күші).

Ылғал өткізгіштік және жылу – ылғал өткізгіштік құбылыстарын ескере отырып, ішкі ылғалдың берілуінің негізгі заңын келесідей жазуға болады:

$$i = i_u + i_T = -kp_0\nabla u - \boldsymbol{k}p_0\nabla T, \tag{2}$$

$$i = -\boldsymbol{k}p_0(\nabla u - \nabla T), \tag{3}$$

мұнда i, i_u және i_T – ылғал ағынының тығыздығына сәйкес, ылғал концентрациясының градиенті мен температура градиентінің әсерінен туындаған жалпы, кг/(м^2·сағ); $\boldsymbol{k}$ – материалдың ылғал өткізгіштік коэффициенті, м^2/ сағ; $\boldsymbol{\delta}$ – материалдың өткізгіштік коэффициенті, град$^{-1}$; p_0 - мүлдем құрғақ материалдың тығыздығы, кг/м^3; ∇u – ылғал концентрациясының градиенті, кг/(құрғақ зат кг), ∇T - температура градиенті, град./м.

Жылу-ылғал өткізгіштік коэффициенті$\boldsymbol{\delta}$= $\nabla u/\nabla T$ температура градиентінде денеде ылғал концентрациясының қандай градиенті пайда болатындығын көрсетеді 1 град./м. Формулалардағы "–" белгісі (2, 3) мұны көрсетеді i_u и i_T бір бағытқа а∇u және ∇T қарама-қарсы жағына жіберілді [5].

Егер ылғал концентрациясының градиенті ∇u және температура градиенті ∇T қарама-қарсы бағытта бағытталған болса, материалдың сыртқы қабаттарының ылғалдылығы ішкі қабаттарға қарағанда аз (және температура керісінше), онда ∇u және ∇T формулаларда (2,3) қарама-қарсы белгілер болады, ал ылғалдың жалпы ағымының бағыты ылғалдың қарқынды ағынын тудыратын

градиентпен анықталады. Ылғал ағынының бағыты көбінесе ылғал концентрациясының градиентімен анықталады, температура градиенті материал ішіндегі ылғалдың ылғалды қабаттардан аз ылғалды қабаттарға ауысуына қосымша қарсылық тудырады. Бұл құбылыс, мысалы, кептірудің конвективті әдісімен байқалады.

Жылу берудің байланыс әдісімен температура градиенті негізгі болып табылады және кептіру процесінің негізгі сипаттамасы.

Инфрақызыл сәулелермен кептірудің радиациялық әдісімен ылғал мен жылу өткізгіштігі де әртүрлі бағытта бағытталған, бірақ кептіру процесі басқаша жүреді. Кептірудің бастапқы кезеңінде материалдың бетін тез және қатты қыздыруға байланысты жылу ылғал өткізгіштігі ылғал өткізгіштікке қарағанда анағұрлым қарқынды, сондықтан ылғал жылу ағымы бағытында қозғалады. Ылғалдың концентрация градиентінің жоғарылауын тудыратын ылғалдың бетінен орталыққа ауысуы ылғалдың өткізгіштігінің "ингибиторлық" әсерін біртіндеп арттырады және, сайып келгенде, тепе-теңдік күйіне әкеледі-жылу өткізгіштік толығымен ылғал өткізгіштікпен теңестіріледі. Осы сәттен бастап Орталық қабаттардың ылғалдылығы тұрақты болып қалады, ал кептіру булану аймағын біртіндеп тереңдете отырып, материалдан ылғалдың буланuы арқылы жүреді.

Жоғары жиілікті токтармен электрлік кептіру әдісімен (жылу ағыны материалдың ішкі қабаттарынан бетіне қарай жылжиды) температура градиенті мен ылғал концентрациясының градиенті бір бағытта бағытталған, сондықтан ылғал мен жылу өткізгіштікке байланысты ылғал ағындары сәйкес келеді, бұл кептіру жылдамдығының едәуір артуына әкеледі.

Кез-келген материалдың жылу қасиеттері оның жылу физикалық сипаттамалары бойынша анықталады: нақты жылу сыйымдылығы, жылу өткізгіштік, температура өткізгіштігі және жылу сіңіру коэффициенті (жылу белсенділігі).

Осылайша, астықты кептіру процесінде астық беті мен қоршаған орта арасында жылу-ылғал алмасу, сондай-ақ оның ішіндегі жылу мен ылғалдың қозғалысы жүреді. Сыртқы ылғал алмасу астық бетіндегі және қоршаған ортадағы будың ішінара қысымының айырмашылығына байланысты. Астықтың ішкі қабаттарынан ылғалдың бетіне ауысуы оның құрылымы мен қасиеттеріне байланысты, бұл өз кезегінде ылғалдың астықпен байланыс формаларына байланысты. Ішкі қабаттардан ылғал, әдетте, жылу ағынымен бір уақытта немесе көбінесе кері бағытта оның бетіне ауысады. Жылу-ылғал алмасу заңдылықтарын біле отырып, астықты кептірудің жоғары сапалы процесін осы процестің минималды энергия шығындарымен қамтамасыз етуге болады. Қазақстанда астық өндірісін арттыру астықты сақтау технологиясын дамытпай және жетілдірусіз мүмкін емес.

Астық дайындау жағдайларының өзгеруіне, оның элеваторлар мен астық қабылдау кәсіпорындарына түсу қарқынының төмендеуіне қарамастан, астықтың едәуір бөлігі әлі де оның сапасына зиянды әсер ететін өте қатаң температуралық режимдерде кептіріледі.

Жалпы мақсаттарға, шығындарды азайтуға және астық сапасын жақсартуға сүйене отырып, астықты кептіру технологиясының тиімділігін арттыру жөніндегі маңызды міндеттерді кептіру объектісі ретінде астық қасиеттерін зерттеуді кеңейте отырып, кептіру процесінің кинетикалық заңдылықтарын орнату, кептірілетін астықтың технологиялық қасиеттерін басқару негіздерін құра отырып, энергия мен ресурстарды үнемдеу әдістерін дамыта отырып, ғылыми негізде ғана сәтті шешуге болады.

Жылу кептіру тірі организм ретінде астықтың бүкіл биологиялық жүйесіне қатты әсер етеді. Өзгерістердің бағыты мен тереңдігі қолданылатын кептіру технологиясына байланысты және оң немесе теріс салдары болуы мүмкін.

Астықты кептіру кинетикасы туралы бытыраңқы әдеби деректер оның технологиялық қасиеттерінің өзгеруіне байланысты емес. Кептіру технологиясының тиімділігін бағалауда кептірілген астық сапасының көрсеткіші көптеген жағдайларда маңызды емес. Кептірудің қолданыстағы температуралық режимдері және кептірудің бір цикліндегі астық ылғалдылығын төмендетудің шекті мәндері кептіру процесінің кинетикасының заңдылықтарына байланысты қатаң реттеледі. Астықты жылыту және кептіру жылдамдықтарының өзара байланысының сандық сипаттамалары жоқ. Кептіру ұзақтығы оны қыздыру жылдамдығын есепке алмай, астық ылғалдылығының берілген төмендеуі негізінде ғана есептеледі. Шахта түріндегі кеңінен қолданылатын кептіргіштерде кептіру кезінде астық қабатының қалыңдығы бойынша біркелкі емес қыздыру туралы деректер жоқ.

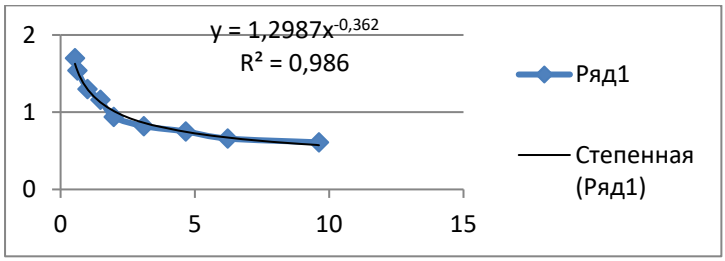
Ауылшаруашылық өндірісінің тәжірибесінде Астықты кептіру процесін күшейту үшін әртүрлі әдістер қолданылады: электроактивті ауаны пайдалану, астықты алдын-ала жылыту, қайта өңдеу

режимдерін қолдану, кептіру аймағын вакуумдау, кептіру камерасының газ құрамын өзгерту және басқалар. Олардың ішінде жақында ультра жоғары жиілікті (микротолқынды) магнит өрісі жиі қолданылады. Біздің елде Астықты кептіру кезінде микротолқынды өрістерді пайдалану тәжірибесі жинақталған. Нәтижесінде ауылшаруашылық кәсіпорындарында қолданылатын қолданыстағы өнеркәсіптік кептіргіштерді жетілдіруге мүмкіндік беретін қондырғылар жасалды. Сондай-ақ, тұқым себу алдындағы өңдеу үшін микротолқынды өрістерді қолдану зерттелді.

Мақала авторлары астықты жоғары жиілікті токтармен кептіру тәжірибетерін жүргізді. Жоғары жиілікті кептіру кезінде жылу беру ультра жоғары (2000–2500 мГц) жиіліктің электр тогының өрісі арқылы жүзеге асырылады, бұл Максвелл теориясының нәтижесі, "электромагниттік индукция жиілігі неғұрлым жоғары болса, соғұрлым қыздырылған денеге жылу тез беріледі". Сондықтан ультра жоғары жиілікті (микротолқынды) токтарды қолдану әлдеқайда тиімді өсімдік тектес ылғалды материалдар диэлектриктер болып табылады және жартылай өткізгіштердің қасиеттеріне ие. Оларға электролит иондары, электрондар, диполь моменттері бар полярлы және полярлы емес диэлектриктердің молекулалары кіреді. Электромагниттік өрісте дипольдер өріс бойымен осьте орналасады. Айнымалы электромагниттік өріске түсіп, олар өрістерді ұстануға тырысып, тербелмелі қозғалыстар жасайды.

Зерттеу материалдары мен әдістері. Осы ережелер негізінде астықты кептіру үшін жиіліктің өзгеруін пайдалану бойынша тәжірибе жасалды және жүргізілді. Тәжірибетің мақсаты өзгермелі тәуелсіз факторлармен астықты кептіру қисықтарын алу болды. Астықтың бастапқы ылғалдылығы тәуелсіз факторлар ретінде қабылданды (W, %), астықтың диэлектрлік тұрақтысы, генератордың жиілігі (ω, Гц), шығын коэффициенті.

Болашақта астықтың бастапқы ылғалдылығының жеткілікті жоғары болуына қарамастан, кептіру процестің барлық кезеңінде ылғалдың булану жылдамдығының төмендеуімен, астықтың үнемі өсіп келе жатқан температурасымен жүреді, бұл алынған кептіру қисықтарының сипатында көрінеді, тәжірибе нәтижесінде Excel бағдарламасының көмегімен өңделген әртүрлі жиіліктердегі шығындар коэффициенті арасындағы байланыс алынды (2-сурет).



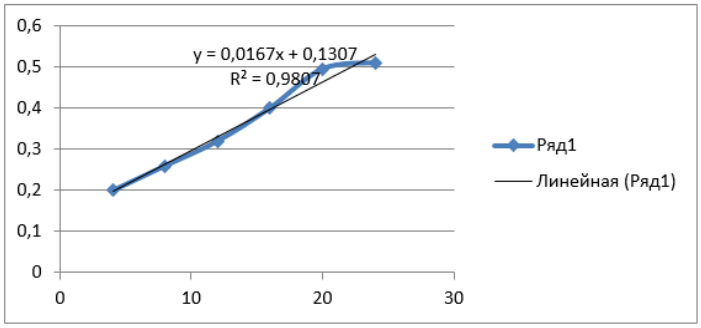
2-сурет – Әр түрлі жиіліктегі шығындар коэффициенті арасындағы байланыс

Ылғал астыққа (12%) әсер ету кезінде шығын коэффициентінің тәуелділігін талдай отырып, оның әртүрлі жиіліктерінде ең алдымен, конкордацияның жоғары коэффициенті 0,986 екенін атап өткен жөн, бұл астық ылғалдылығын жылытуға жұмсалған жиілік пен энергия арасындағы қатаң функционалдық байланысты көрсетеді. Алынған тәуелділікті зерттей отырып, біз 0-ден 120 МГц-ке дейінгі диапазонда бұл қисық монотонды түрде төмендейтінін, содан кейін 0,6 деңгейінде асимптотацияланатынын байқаймыз. Мұнда біз жиіліктің одан әрі жоғарылауымен шығын коэффициенті өзгермейді деген өте маңызды қорытынды алдық, сондықтан біздің құрылғы ГГц диапазонында жұмыс істейтінін ескерсек, шығын коэффициенті тұрақты болады, яғни 0,6. Сондықтан астық ылғалдылығының шығын коэффициентіне әсерін зерттеген кезде жиілік өлшеу дәлдігіне әсер етпейді деп сеніммен айта аламыз. Келесі тәжірибе ылғалдылықтың жоғалу коэффициенті өзгерген кезде жүргізілді, Excel көмегімен өңделген мәліметтер тәжірибе нәтижесінде астықты кептіру қисығы алынды (3-сурет).

Нақты диапазондағы астық ылғалдылығынан шығын коэффициентін 5-тен 25%-ға дейін өзгерту бойынша тәжірибе жүргізу. Біз бұл тәуелділіктің қатаң функционалдық тәуелділікті көрсететін 0,98 конкординг коэффициентімен таза сызықтық екенін көреміз. Бұл функция сызықтық теңдеумен жуықталады

$$k \cdot tg\sigma = 0{,}016W + 0{,}13 \qquad (4)$$

осы жерден біз дәнді ішіндегі ылғал алатын жылу мөлшері оның ылғалдылығының жоғарылауымен жоғарылайды. Бұл дымқыл астықты қыздырудың электромагниттік принципінің жоғары тиімділігін көрсетеді-ең алдымен дәннің өзі емес, дәндегі қыздырылған ылғал. Егер кептірудің басқа кез-келген принциптерін қарастыратын болсақ, онда көп бөлігі астықты қосудың сыртқы денелерін жылытуға жұмсалады, бұл биологиялық жағынан мүлдем қажет емес.



3-сурет – Жоғалту коэффициентінің астық ылғалдылығына тәуелділігі

Ақыр соңында, Максвелл формуласын алмастыра отырып, ылғалдылық арқылы шығын коэффициентін жақындатып, біз Максвелл теңдеуінің инженерлік түсіндірмесін аламыз.

Алынған тәуелділіктер нәтижесінде 1 м^3 материалдан (Q) бөлінетін жылу мөлшерін 5 формула бойынша анықтауға болады:

$$Q = 0{,}555 \cdot E^2 \cdot \omega \cdot (0{,}13 + 0{,}016W), \quad (5)$$

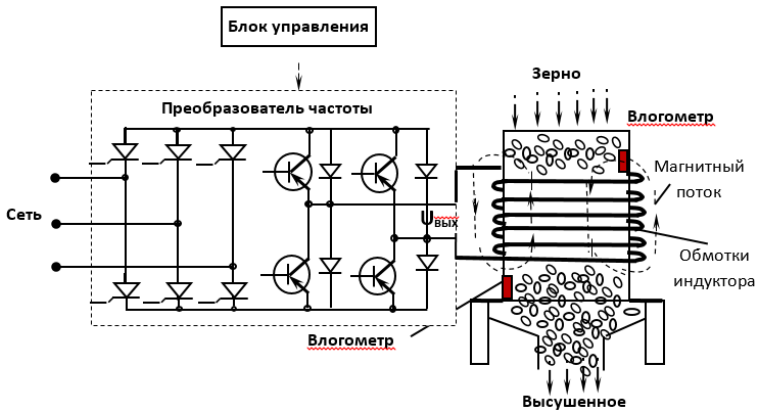
мұнда E^2 – электромагниттік кернеу; ω – микротолқынды генератордың жиілігі; W – астықтың ылғалдылығы.

Үшінші тұжырым: біз алғаш рет инженерлік мағынада қолданылған Максвелл формуласын 3 параметрге байланысты ылғалмен алынған дәннің жылуын есептеу үшін алдық:

- электромагниттік кернеу;
- сәулелену жиілігі;
- астықтың өзіндік ылғалдылығы.

Ұсынылған жұмыс өңделген материалдағы бірнеше көздерден микротолқынды диапазонның электромагниттік өрісінің таралуын зерттеуге бағытталған.

Қолданыстағы технологияларға балама ретінде жоғары жиілікті электромагниттік өрісті пайдалану ұсынылады, ол атмосфераға зияны жоқ, сонымен қатар дәстүрлі әдістердегідей бетіне қарағанда қыздырылған жылудың (дәннің) ішкі бөлігіне тікелей әсер етеді, ал астық ылғалдылығының жоғарылауымен ПӘК артады. Осы мақсатта біз микротолқынды транзисторлы – тиристорлы генераторды ұсынамыз, ол магнетрон генераторынан айырмашылығы жоғары, өйткені магнетрон талшығын қыздыру үшін энергияның көп бөлігі жұмсалмайды (4-сурет).



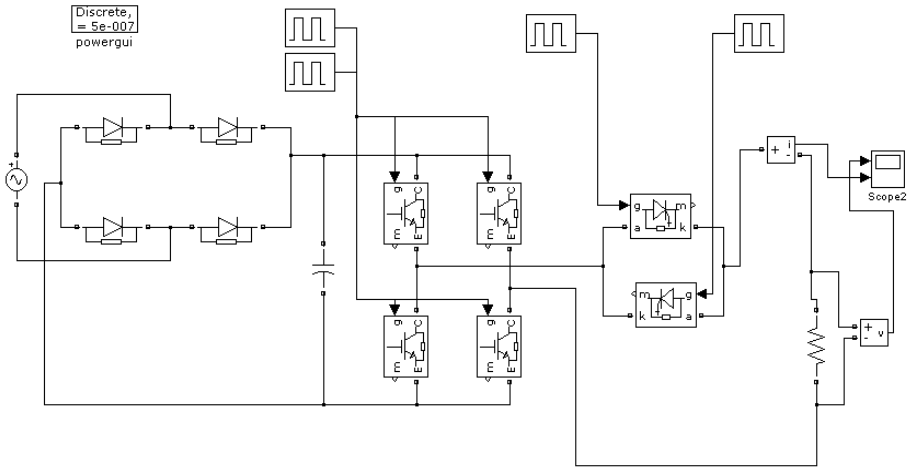
4-сурет 4 – Бет шнегі геликоидальды микротолқынды қондырғының сұлбасы

Астық диэлектриктен цилиндрлік тізбекке геликоидальды бұрандалы бет арқылы беріледі, онда бұранданың көтеру бұрышы әрқашан үйкеліс бұрышының ағымдағы мәніне сәйкес келеді. Мысалы, бірінші кезеңде ылғал астық бұрандалы бетке "жабысып" қалады, содан кейін кебу кезінде үйкеліс коэффициенті төмендейді және астық баяу келесі деңгейге ауысады. Осылайша, осы жұмыс төменгі бөлігінде қажетті ылғалдылық дәні түседі.

Соңғы жылдары техникалық-экономикалық көрсеткіштері жоғары индукциялық жылытқыштар үшін өндірістік жиілікті электр энергиясын түрлендірудің жоғары тиімді және энергияны үнемдейтін жүйелеріне, сондай-ақ өндіруге аз материалдық және қаржылық шығындарға қажеттілік пайда болды [1,2,3].

Түзеткіш пен инвертор жиілік түрлендіргішін білдіреді. Трансформаторды бастапқы тізбекте қолдану бүкіл индукциялық жылытқыштың құнын күрт арттырады, бұл массаның өсуіне әкеледі. Жиілік түрлендіргіштері [4,5] белгілі, онда кернеуді төмендету үшін трансформаторлар қолданылады. Мақсатымыз төмендеткіш трансформатор пайдаланылмайтын жиілік түрлендіргішін құру.

Толық талдау үшін MatLab R12 v. 6.0 ортасында модельдеу жүргізілді, бұл пакет кез-келген күрделіліктегі математикалық есептеулерді шешуге, электрлік және электрондық тізбектердегі процестерді кәсіби талдауға және модельдеуге, өлшеу және тәжірибе нәтижелерін статикалық өңдеуге, сонымен қатар графиктерді алуға арналған. Модельдеу кезінде Simulink Library Browser және SIM Power Systems кітапханасы пайдаланылды [6]. 5-суретте таза белсенді жүктеме кезінде бір фазалы транзисторлы – тиристорлы инверторды модельдеу схемасы көрсетілген.



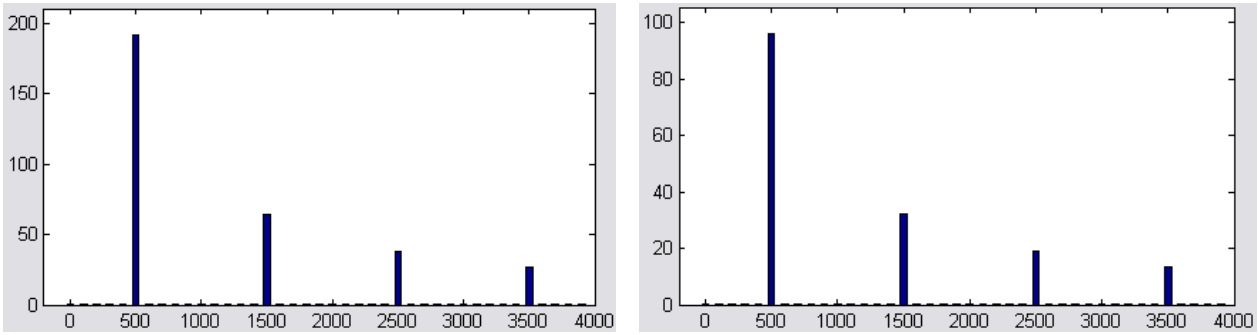
5-сурет – Транзисторлы – тиристорлы турлендіргіштің жиілігін модельдеу схемасы

Модельдеу нәтижелері 5-суретте таза белсенді жүктеме кезінде көрсетілген. Суреттен көрініп тұрғандай, таза белсенді жүктеме кезінде жүктемедегі кернеу мен ток айқын көрінеді. Транзистор-тиристор жиілік түрлендіргішінің жұмыс принципі расталады. 6-суретте белсенді индуктивті жүктеме кезінде модельдеу нәтижелері көрсетілген. Суреттен көрініп тұрғандай, жүктемедегі кернеу мен ток айқын көрінбейді және кернеу шығарындылары пайда болады, бұл транзистор – тиристор жиілік түрлендіргішінің жұмысына өте нашар әсер етеді.

7, 8-суретте белсенді индуктивті жүктеме кезіндегі жиілік түрлендіргішінің жүктемесіндегі кернеудің гармоникалық талдауы көрсетілген, бұл 500 Гц негізгі гармоника айқын, ал басқа гармониканың жеткілікті мәні бар екенін көрсетеді.

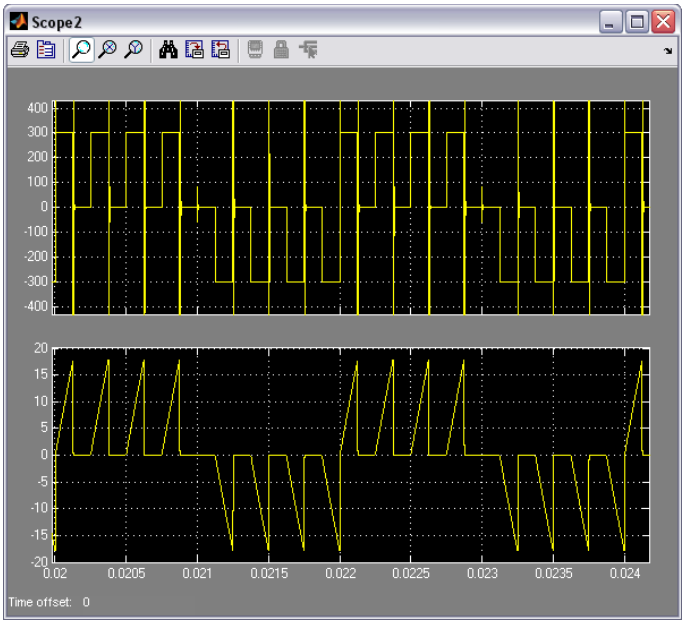
Индукциялық энергияны енгізудің ерекшелігі - құйынды токтардың ағу аймағының кеңістіктік орналасуын реттеу мүмкіндігі. Біріншіден, құйынды токтар индуктор қамтыған аймақта жүреді. Дененің жалпы көлеміне қарамастан индуктормен магниттік байланыста болатын дененің бөлігі ғана қызады. Екіншіден, құйынды токтардың айналым аймағының тереңдігі, демек, энергияның бөліну аймағы, басқа факторлардан басқа, индуктордың ток жиілігіне байланысты (төмен жиіліктерде жоғарылайды және жиіліктің жоғарылауымен төмендейді). Әр процесс үшін (беткі қатаю, қыздыру арқылы) ең жақсы технологиялық және экономикалық көрсеткіштерді қамтамасыз ететін оңтайлы жиілік диапазоны бар. Индукциялық қыздыру үшін 50 Гц-тен 5 МГц-ке дейінгі жиіліктер қолданылады.

6-сурет – Таза белсенді жүктеме кезінде трансистисторлы – тиристорлы жиілік түрлендіргішті модельдеу нәтижелері

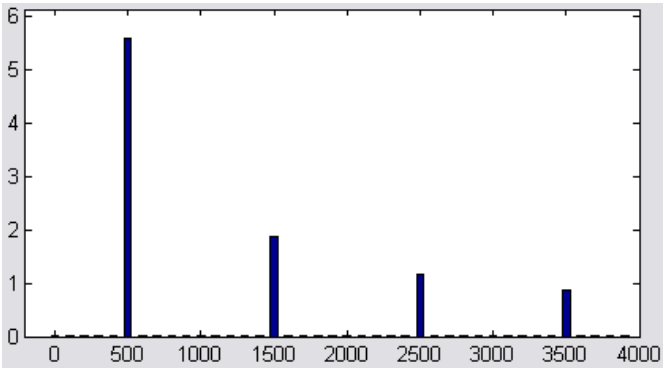


а *б*

7-сурет – Белсенді жүктеме кезіндегі кернеуді (а) және токты (б)гармоникалық талдау



8-сурет – Белсенді индуктивті жүктеме кезіндегі жиілік түрлендіргішін модельдеу нәтижелері



9-сурет – Белсенді индуктивті жүктеме кезіндегі токтың гармоникалық талдауы

Индукциялық жылытудың артықшылықтары төменде келтірілген.

1. Электр энергиясын тікелей қыздырылған денеге беру өткізгіш материалдарды тікелей жылытуға мүмкіндік береді. Бұл жағдайда жанама әсер ететін қондырғылармен салыстырғанда қыздыру жылдамдығы артады, онда өнім тек бетінен қызады.

2. Электр энергиясын тікелей қыздырылған денеге беру байланыс құрылғыларын қажет етпейді. Бұл автоматтандырылған өндірістік өндіріс жағдайында, Вакуумдық және қорғаныс құралдарын пайдалану кезінде ыңғайлы.

3. Беттік әсер ету құбылысына байланысты максималды қуат қыздырылған өнімнің беткі қабатында шығарылады. Сондықтан, шыңдалған кезде индукциялық қыздыру өнімнің беткі қабатын тез қыздыруды қамтамасыз етеді. Бұл салыстырмалы түрде тұтқыр ортада бөліктің бетінің жоғары қаттылығын алуға мүмкіндік береді. Беттік индукциялық сөндіру процесі өнімді қатайтудың басқа әдістеріне қарағанда тезірек және үнемді.

4. Индукциялық қыздыру көп жағдайда өнімділікті арттыруға және еңбек жағдайларын жақсартуға мүмкіндік береді. Индукциялық балқыту пештері, индукциялық пеш немесе құрылғы трансформатордың бір түрі ретінде қарастырылуы болады, онда бастапқы орам (индуктор) айнымалы ток көзіне қосылған, ал екінші орам-қыздырылған дененің өзі болып табылады.

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INTENSIVE ENERGY SAVING METHOD OF GRAIN DRYING

Abstract. The method of drying of grain and removal of moisture which is based on receiving and processing of arising thermal processes described by the thermodynamics equation is developed. This way was a little studied and was less often applied because of considerable imperfection of the production technology of the converter of frequency of big power (to some hundred kilowatts) and frequencies (to some hundred kHz). However, at present the equipment for induction heating gained big development and its application on drying installations in comparison with traditional ways of heating more preferably. Offered induction way of drying of grain where the grain material passes through drying mine by gravity. For carrying out pilot studies, it is developed the transistor–thyristor device, which consists of the control unit, the converter of frequency, the bunker with the screw in it that has helix surface, inductor windings, and a hydrometer. The algorithm of receiving and data processing is developed in the MATLAB software. At further increase in frequency the coefficient of losses won't change, therefore, considering that our device works in GHz range coefficient of losses will be constant, i.e. equal 0,6. Therefore when studying influence of humidity of grain on coefficient of losses we can consider with confidence that frequency doesn't influence the accuracy of measurements. The amount of heat received by moisture in a weevil increases with increase in its humidity. It is a first time when the Maxwell's formula is suitable for calculating a heat taken from grain moisture. Reduction in specific cost of all plants demands the appeal to development and introduction simple on a design of induction heaters that is an actual problem. Agricultural production, unlike other types of production, possesses a

considerable resource – the reserved energy in a biological object. Thus, use of information approach to the description of reactions of biological objects on external influence allows to develop electrotechnologies for increase of productivity, productivity of the grain drying equipment, decrease in power consumption of process of drying of grain.

Keywords: grain drying, electromagnetic induction, the amount of generated heat, the Maxwell formula.

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ИНТЕНСИВНЫЙ ЭНЕРГОСБЕРЕГАЮЩИЙ МЕТОД СУШКИ ЗЕРНА

Аннотация. Разработан способ сушки зерна и удаления влаги, который основан на получении и обработке возникающих тепловых процессов, описанных уравнением термодинамики. Этот способ был мало изучен и реже применялся из-за значительного несовершенства технологии производства преобразователя частоты большой мощности (до несколько сотен киловатт) и частоты (до несколько сотен кГц). Но в данное время оборудование для индукционного нагрева получило большое развитие и его применение на сушильных установках по сравнению с традиционными способами нагрева более предпочтительно. Предлагаемый индукционный способ сушки зерна, где зерновой материал проходит через сушильную шахту под действием силы тяжести. Для проведения экспериментальных исследований разработано транзисторно – тиристорное устройство, которое состоит из блока управления, преобразователя частоты, бункера, в котором находится шнек с геликоидной поверхностью, обмотки индуктора, влагомер. Алгоритм получения и обработки данных разработан в среде MATLAB. При дальнейшем увеличении частоты коэффициент потерь не изменится, следовательно, учитывая, что наше устройство работает в ГГц диапазоне, коэффициент потерь будет постоянным, т.е. равным 0,6. Поэтому при изучении влияния влажности зерна на коэффициент потерь мы можем с уверенностью считать, что частота не влияет на точность измерений. Количество тепла, получаемое влагой внутри зерновки, возрастает с увеличением его влажности. Впервые получена прикладная в инженерном смысле, формула Максвелла, пригодная для расчета тепла полученного влагой зерна. Снижение удельной стоимости всей установки требует обращения к разработкам и внедрению простых по конструкции индукционных нагревателей, что является актуальной проблемой.

Ключевые слова: сушка зерна, электромагнитная индукция, количество выделяемого тепла, формула Максвелла.

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