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Effective Thermal Characteristics Synthesis Microlevel Models in the Problems of Composite Materials Optimal Design

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Abstract. The composite materials optimal design problem which taking into account the thermal characteristics is the part of an actual structural design task. A wide range of variety of such material structures and the complexity of modeling some physical phenomena (such as the phenomenon of those structures effective characteristics percolation threshold appearing) requires a high level of detail in physico-mathematical models. Here, in this paper, were analyzed the role and place of physico-mathematical microlevel models in problems of composite materials optimal design. The methods of such materials representative volume elements construction within the model calculations, which are the key step in the modeling of complex structures variety, also were analyzed. Basing on the usage of finite element method for modeling of stationary heat conduction and elasticity linear problems was proposed the combined formalization of coupled thermoelasticity problems simulation method in complex structured composite materials, which is especially useful when used in engineering applications which provide a high level of abstraction. Basing on the analogy method and theory of similarity were developed the complex structured composite materials microlevel models, which allow one to synthesize and then re-use in the problems of composite materials optimal design, such effective thermal characteristics as thermal conduction coefficient, Young's modulus, Poisson's ratio and temperature coefficient of linear expansion. This gives the ability to avoid of classical complex mathematical homogenization processes or real experiments. The method and models were successfully implemented by using of high-performance parallel and distributed computing technologies in heterogeneous computing environments, as evidenced by the simulation results.

Key words: composite materials, optimal design, microlevel models, finite element method, coupled problems, multiphysics problems.

INTRODUCTION

The composite materials (CM) optimal design problem which taking into account the thermal characteristics [1] is the part of an actual structural design task. Volumes of research in this field are growing every year, as evidenced by the increase in the number of published papers. A wide range of variety of such material structures [2] and the complexity of modeling some physical phenomena (such as the phenomenon of those structures effective characteristics percolation threshold appearing) requires a high level of detail in microlevel physico-mathematical models. To solve the described problems is appropriate to use numerical modeling techniques, such as finite element method.

In this paper, one has gotten the further development of numerical microlevel effective thermal characteristics synthesis models of composite materials with complex structure. Basing on the usage of finite element method for modeling coupled thermoelasticity problems and analogies method were developed microlevel models of composite materials. Models allow one to synthesize effective thermal characteristics such as thermal conduction coefficient, Young's modulus, Poisson's ratio and temperature coefficient of linear expansion. The main difference from other models is combined formalization of coupled multiphysics problems, which allows one to simultaneously take into account boundary conditions in the form of heat flows, surface loads, given surface temperatures and movements, if they are present. This approach is especially useful when used in engineering applications which provide a high level of abstraction. The models successfully implemented by technologies of high-performance parallel and distributed computing, which opens the possibility of direct effective usage in problems of CM optimal design.

THE ANALYSIS OF RECENT RESEARCHES AND PUBLICATIONS

Microlevel composite materials models

Composite materials or composites – materials composed from two or more components, and have specific properties that are different from the properties of their component sum [3]. There are two fundamentally different approaches of building models in the tasks of CM analysis or synthesis – consideration of material as a system of interacting elementary physical component, and consideration of material as some abstract continuous environment. The combination of both approaches in the model allows one to define the structural element order relative to the entire CM system. Under this order, any CM model can be attributed to such classes as empirical, structural, microlevel [4, 5]. The most promising in terms of research, automation, and further practical use, is the microlevel models class that allows one to describe irregularities of base elements, and gives the ability to describe real physical and spatial CM structures most adequately. Models of this class are using numerical methods for solving problems of analysis such as finite element method [6 – 8], thus, allow one to cover almost the entire range of phenomena known to modern science. Here the analysis of physical processes is considered in the so-called representative volume element (RVE) [4, 9]. Determination of its size is usually carried out by a series of numerical experiments [10].

In general case, CM optimal design algorithm, which is considering microlevel models, consists of the following stages:

1. Pre-design phase [11]:
   - select the model parameters that vary (components, structure formation options),
   - set the ranges of variation (maximum or minimum allowable concentrations of components, ranges of acceptable characteristics),
   - select optimal criteria (a set of characteristics that should be optimal – minimum or maximum, depending on the specific task).
2. Optimization phase:
   - formulate optimization problem, basing on pre-design phase,
   - problem solving:
     - build representative volume element (model of the CM structure),
     - do the model analysis by physico-mathematical problems numerical simulation,
     - basing on the results, synthesize a set of model effective characteristics,
     - check optimality criteria (selected effective characteristics), stop or continue the search, depending on the result.
3. The result – solution with optimal (for specific task) characteristics.

Representative volume element construction

Unlike the mathematical models and homogenization methods for constructing effective field as a superposition of each composite material constituent element contribution (e.g. Hashin polydisperse model [18]), microlevel models involve the construction so-called representative volume element (RVE) – usually a volume $\Omega \subset \Re^3$ of heterogeneous material, sufficiently large to describe it statistically, i.e. to effectively include a sampling of all microstructural heterogeneities that occur in the composite.

Another definition that is used in this paper and doesn't consider possible statistical fluctuations – the smallest composite material volume $\Omega \subset \Re^3$, for which macroscopic representation of spatial characteristics is sufficiently accurate model of effective response on corresponding outer influence [10]. In construction of the RVEs under problems of CM optimal design is convenient enough to use the cellular structure models [9], in the form of a large number of regular voxel-cells that simultaneously represent a regular finite-element discretization. Advantages of approach include:

- simplicity and relatively small number of computations in discretization [14, 15];
- the possibility of direct usage of domain decomposition methods for calculations and corresponding effective implementation on devices with big number of computing nodes [6];
- universality, which allow one to construct in one way such composite material complex structure models, as a model of random scalar fields, random cellular models, models with deterministic inclusions, and the combination of these models with the ability to build functional transition layers.

Construction of the RVE is the task of composite materials structure modeling that prior to physical processes analysis in these materials [12]. Classically, the heterogeneous systems microlevel model differential balance equations that describe physical processes, consider the structure of the CM as a combination of component material characteristics that are represented by equations coefficients and topology of the material, which is described by the integration borders where these equations are defined. Pair:

$$(\Omega, \mathbf{D}) = \bigcup_p \left(\Omega_p, \mathbf{D}_p\right), \tag{1}$$

where: $\mathbf{D}_p$ – the set of characteristics of p-th component, and Ω_p – corresponding geometric area, i.e. its topology; completely describes the composite material microlevel structure model. By using this formalization, the RVE can be conveniently presented as a cubic matrix of scalar intensities, i.e. cells that accept scalar values in a certain range, for example from 0 to 1. With a large number of cells, by defining the intensities intervals as a separate composite phases Ω_p and giving them an appropriate characteristics set $\mathbf{D}_p$, it is possible to construct the model of complex structure (Fig. 1).

OBJECTIVES

The main objectives of this paper are: development of complex structured composite materials microlevel models basing on multiphisics problems numerical simulation by finite element method, which gives the ability to avoid of classical complex mathematical homogenization processes or real experiments; as the consequence, development of materials effective thermal characteristics synthesis models that can be used in the problems of composite materials optimal design.

COMPOSITE MATERIALS ANALYSIS BASING ON PHYSICO-MATHEMATICAL PROBLEMS NUMERICAL SIMULATION

The stationary heat conduction linear problem

Numerical simulation of stationary heat conduction problems in CM RVEs is the basis which allows one to synthesize the effective thermal conduction coefficient λ_{eff}. A standardized [19, 20] λ_{eff} finding method of some material sample with thickness d is taken as the starting point:

$$\lambda_{eff} = \frac{d \cdot q}{\Gamma_q \Delta T} = \frac{d \cdot q}{\Gamma_q (T_{\Gamma_q} - T_\infty)}, \tag{2}$$

where: heat flux $\partial T / \partial \mathbf{n} = q$, i.e. Neumann boundary condition on a RVE side $\Gamma_q \subset \Re^2$, and outer environment temperature T_∞, i.e. Dirichlet boundary condition on the opposite RVE side $\Gamma_{T_\infty} \subset \Re^2$, are known. In fact, there are no boundary conditions on other sides – they are, so-called, "floating" sides ($\partial T/\partial \mathbf{n} = 0$):

$$\begin{cases} \mathcal{L}(T(\mathbf{x})) = 0 \Rightarrow \lambda \dfrac{\partial^2 T}{\partial x^2} + \lambda \dfrac{\partial^2 T}{\partial y^2} + \lambda \dfrac{\partial^2 T}{\partial z^2} = 0, \\ \ell_q(T(\mathbf{x}))\Big|_{\Gamma_q} = q \Rightarrow \dfrac{\partial T}{\partial \mathbf{n}}\Big|_{\Gamma_q} = q, \quad \mathbf{n} \perp \Gamma, \\ \ell_{T_\infty}(T(\mathbf{x}))\Big|_{\Gamma_{T_\infty}} = T_\infty \Rightarrow T\Big|_{\Gamma_{T_\infty}} = T_\infty. \end{cases} \tag{3}$$

It should be noted that the temperature field must be uninterrupted between the composite phases. It is necessary to specify, so-called, fourth type boundary conditions, also called as ideal contact. However, with the further numerical problem simulation by finite element method, this condition is automatically satisfied by the finite-element basis consistency requirement [13], and visibly not specified.

Approximate test solution can be built as:

$$T(\mathbf{x}) \approx \tilde{T}(\mathbf{x}) = \sum_{j=1}^{M} T_j \varphi_j(\mathbf{x}), \tag{4}$$

where: T_j – unknown temperature at RVE cells that should be found; φ_j – some simple polynomial basis function.

Putting the test solution into boundary value problem, gives residuals:

$$\mathcal{L}(\tilde{T}(\mathbf{x})) = R^{\Omega}(\mathbf{x}) \neq 0, \quad \ell_q(\tilde{T}(\mathbf{x}))\Big|_{\Gamma_q} = R^{\Gamma_q}(\mathbf{x}) \neq q,$$
$$\ell_{T_\infty}(\tilde{T}(\mathbf{x}))\Big|_{\Gamma_{T_\infty}} = R^{\Gamma_{T_\infty}}(\mathbf{x}) = T_\infty, \tag{5}$$

note that the last residual is exactly matched.

The best approximation of the true solution $T(\mathbf{x}) \in \mathcal{H}^\infty(\Omega)$ is an orthogonal projection $\tilde{T}(\mathbf{x})$ into subspace $C^1 \subset \mathcal{H}^\infty(\Omega)$ that is defined by functions φ:

$$\left\langle R^{\Omega}(\mathbf{x}), \varphi_i^{\Omega}(\mathbf{x}) \right\rangle + \left\langle R^{\Gamma_q}(\mathbf{x}), \varphi_i^{\Gamma_q}(\mathbf{x}) \right\rangle = 0,$$
$$i = 1, 2, \ldots, M, \quad \varphi_i^{\Omega} = -\varphi_i^{\Gamma_q}, \tag{6}$$

or:

$$\iiint_{\Omega} \varphi_i^{\Omega}(\mathbf{x}) \left[\sum_{j=1}^{M} T_j \mathcal{L}(\varphi_j(\mathbf{x})) \right] d\Omega +$$
$$+ \iint_{\Gamma_q} \varphi_i^{\Gamma_q}(\mathbf{x}) \left[\sum_{j=1}^{M} a_j \ell(\varphi_j(\mathbf{x})) - q \right] d\Gamma = 0, \quad 1 \le i, j \le M. \tag{7}$$

Smoothness C^1 of the test solution is minimum permissible, because in the original equation are presenting maximum second order derivatives.

Resulting expression can be rewritten in a weak form, and thus one can weaken the requirements for basis functions smoothness ($\varphi \in C^1 \Rightarrow \varphi \in C^0$). For example, by using the rule of integration by parts and divergence theorem, last expression can include Neumann boundary conditions, which are natural for it ($\varphi_i^{\Omega} = -\varphi_i^{\Gamma_q}$):

$$\left[\iiint_{\Omega} \left[\frac{\partial \varphi_i}{\partial x}\frac{\partial \varphi_j}{\partial x} + \frac{\partial \varphi_i}{\partial y}\frac{\partial \varphi_j}{\partial y} + \right. \right.$$
$$\left. \left. + \frac{\partial \varphi_i}{\partial z}\frac{\partial \varphi_j}{\partial z} \right] dxdydz \right] T_j = -\iint_{\Gamma_q} q \varphi_i d\Gamma. \tag{8}$$

Let change notation to known stiffness matrix and loads vector $[\mathbf{K}]\{\mathbf{u}\} = \{\mathbf{f}\}$ (brackets – matrix; braces – vector).

Let split RVE $\Omega \subset \Re^3$ into tetrahedral finite elements (i.e. simplex elements) $\Omega_i \subset \Omega \subset \Re^3$, $i = 1, 2, \ldots, P$.

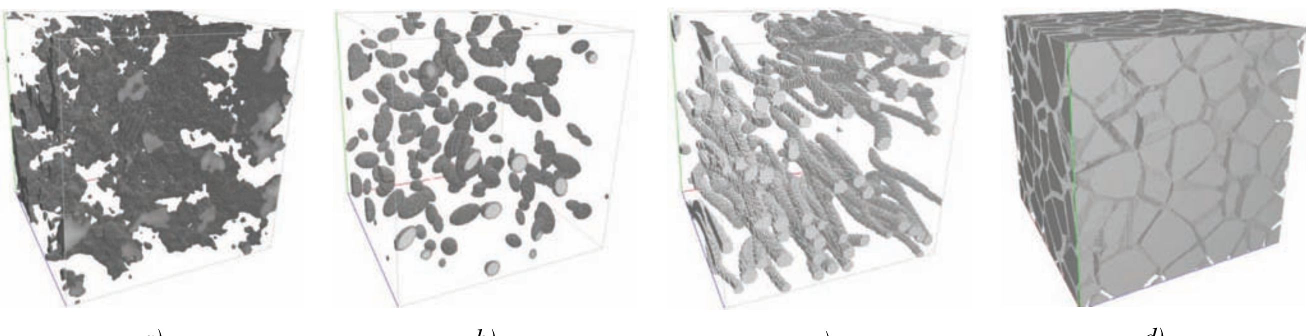
Using the simplex elements is permissible since such basis is C^0 smooth and easily consistent with neighboring (temperature will be uninterrupted between elements). For this is using a simple template method in which every four adjacent RVE cells form a cube, which can be divided into six tetrahedrons.

Now all "local" stiffness matrices $[\mathbf{K}]_i$ and load vectors $\{\mathbf{f}\}_i$ should be found. For linear simplex finite element basis functions are its barycentric coordinates:

$$\lambda_i \sum_{j=1}^{4} T_{i,j} N_{i,j}(\mathbf{x}) = \lambda_i \left[N_{i,1} \; N_{i,2} \; N_{i,3} \; N_{i,4} \right] \cdot$$
$$\cdot \left\{ T_{i,1} \; T_{i,2} \; T_{i,3} \; T_{i,4} \right\}^{\mathbf{T}} = [\mathbf{N}]_i \{\mathbf{u}\}_i, \tag{9}$$

where:

$$[\mathbf{N}] = \begin{bmatrix} 1 & x & y & z \end{bmatrix} \begin{bmatrix} 1 & x_1 & y_1 & z_1 \\ 1 & x_2 & y_2 & z_2 \\ 1 & x_3 & y_3 & z_3 \\ 1 & x_4 & y_4 & z_4 \end{bmatrix}^{-1}. \tag{10}$$



a) b) c) d)

Fig.1. Example of representative volume elements in the form of a 256x256x256 elements matrix that represents composite materials microlevel structure models: a) scalar random fields; b) random ellipsoid particles; c) fibers; d) cellular structures

The boundary of any tetrahedron is a triangle – 2D simplex. Here can be found each local load vector, for example, for firs three nodes of tetrahedron:

$$\{\mathbf{f}\}_i=\iint_{\Gamma_q}[\mathbf{N}]^{\mathrm{T}}q\,d\Gamma=q\int_{\Gamma_q}\begin{Bmatrix}N_1\\N_2\\N_3\\0\end{Bmatrix}d\Gamma=$$
$$=q\int_0^1\int_0^{1-N_1}\int_0^{1-N_1-N_2}\begin{Bmatrix}N_1\\N_2\\N_3\\0\end{Bmatrix}\left|[\mathbf{Jac_N x}]\right|dN_3dN_2dN_1=q\frac{(\Gamma_q)_i}{3}. \quad (11)$$

If finite element doesn`t contain boundary triangle, its load vector will be empty – local boundary value problem is not correct i.e. "floating", and can't be solved without considering neighbor problems. To take into account Dirichlet boundary conditions is enough to modify the local system of equations, taking border nodal temperature equal to the given T_∞, i.e. exactly satisfy the residual $R^{\Gamma_{T_\infty}}$.

After recording weak form (8), its weak operator can be expressed in matrix form:

$$[\mathcal{L}]=\nabla(.)=\begin{bmatrix}\frac{\partial}{\partial x}&\frac{\partial}{\partial y}&\frac{\partial}{\partial z}\end{bmatrix}^{\mathrm{T}}. \quad (12)$$

As a result each local problem can be written as:

$$\left[\iiint_{\Omega_i}\left([\mathcal{L}][\mathbf{N}]_i\right)^{\mathrm{T}}[\mathbf{D}]_i\left([\mathcal{L}][\mathbf{N}]_i\right)dxdydz\right]\{\mathbf{u}\}_i=\{\mathbf{f}\}_i,$$
$$[\mathbf{D}]_i=\begin{bmatrix}\lambda_i&0&0\\0&\lambda_i&0\\0&0&\lambda_i\end{bmatrix}. \quad (13)$$

Values of each matrix $[\mathbf{D}]_i$ depends on which subarea Ω_p is located the finite element. Expression $[\mathcal{L}][\mathbf{N}]_i$ gives 3x4 matrix that contains only constants:

$$[\mathbf{K}]_i\{\mathbf{u}\}_i=\{\mathbf{f}\}_i,$$
$$[\mathbf{K}]_i=\left([\mathcal{L}][\mathbf{N}]_i\right)^{\mathrm{T}}[\mathbf{D}]_i\left([\mathcal{L}][\mathbf{N}]_i\right)\Omega_i. \quad (14)$$

When all local stiffness matrices and load vectors are found, they should be assembled into global SLAE, which describes initial boundary value problem (3). The solution can be conveniently found by conjugate gradient stabilized (to computational errors) method.

The stationary elasticity linear problem

Elasticity problem numerical simulation in CM RVEs allows one to synthesize effective Young's modulus E_{eff} and Poisson's ratio μ_{eff}. Together with the previous, this problem is the basis for the coupled thermoelasticity problem. Young's modulus can be found as:

$$E_{eff}=\frac{d\cdot f_x}{\Gamma_{\mathbf{f}}\Delta u_x}=\frac{d\cdot f_x}{\Gamma_{\mathbf{f}}(u_{x\mathbf{f}}-u_{x\infty})},\quad f_y,f_z=0, \quad (15)$$

where: $u_x,u_y,u_z=\mathbf{u}$ – mechanical displacements along coordinate axes x,y,z; $f_x,f_y,f_z=\mathbf{f}$ – components of the surface loads, i.e. Neumann boundary condition on a RVE side $\Gamma_f\subset\Re^2$; $u_{x\infty}$ – known starting displacement along chosen axis, i.e. Dirichlet boundary condition on the opposite RVE side $\Gamma_{u_\infty}\subset\Re^2$. Note that components $u_{y\infty}$ and $u_{z\infty}$ are no imposed in fact.

Poisson's ratio describes object transverse resizing under described conditions:

$$\mu_{eff}=\frac{\Delta u_y}{\Delta u_x}=\frac{\Delta u_z}{\Delta u_x}. \quad (16)$$

According to the classical linear elasticity theory [21, 22], there is a connection between displacements and deformation – strain tensor:

$$[\boldsymbol{\varepsilon}]=\begin{bmatrix}\varepsilon_x\\\varepsilon_y\\\varepsilon_z\\\gamma_{xy}\\\gamma_{xz}\\\gamma_{yz}\end{bmatrix}=\begin{bmatrix}\partial u_x/\partial x\\\partial u_y/\partial y\\\partial u_z/\partial z\\\partial u_x/\partial y+\partial u_y/\partial x\\\partial u_x/\partial z+\partial u_z/\partial x\\\partial u_y/\partial z+\partial u_z/\partial y\end{bmatrix}=[\mathcal{L}]\{\mathbf{u}\},$$
$$[\mathcal{L}]=\begin{bmatrix}\partial/\partial x&0&0\\0&\partial/\partial y&0\\0&0&\partial/\partial z\\\partial/\partial y&\partial/\partial x&0\\\partial/\partial z&0&\partial/\partial x\\0&\partial/\partial z&\partial/\partial y\end{bmatrix},\quad\{\mathbf{u}\}=\begin{Bmatrix}u_x\\u_y\\u_z\end{Bmatrix}. \quad (17)$$

According to Hooke's law relationship between the strain tensor and the stress tensor is expressed through the environment characteristics matrix:

$$[\boldsymbol{\sigma}]=\left(\sigma_x\ \sigma_y\ \sigma_z\ \tau_{xy}\ \tau_{xz}\ \tau_{yz}\right)^{\mathrm{T}}=[\mathbf{D}][\boldsymbol{\varepsilon}]=[\mathbf{D}][\mathcal{L}]\{\mathbf{u}\}, \quad (18)$$

where:

$$[\mathbf{D}]=G\cdot\begin{bmatrix}A&B&B&0&0&0\\B&A&B&0&0&0\\B&B&A&0&0&0\\0&0&0&C&0&0\\0&0&0&0&C&0\\0&0&0&0&0&C\end{bmatrix},$$
$$G=E/(1+\mu)/(1-2\mu),\quad A=1-\mu,\quad B=\mu,\quad C=(1-2\mu)/2. \quad (19)$$

Let consider the boundary value problem:

$$\begin{cases}\mathbf{u}(\mathbf{x})=\{u_x(\mathbf{x})\quad u_x(\mathbf{x})\quad u_z(\mathbf{x})\},\quad \mathbf{x}=\{x,y,z\}\in\Omega,\\ \mathcal{L}(\mathbf{u}(\mathbf{x}))=0\Rightarrow\begin{cases}\partial\sigma_x/\partial x+\partial\tau_{xy}/\partial y+\partial\tau_{xz}/\partial z=0\\\partial\tau_{xy}/\partial x+\partial\sigma_y/\partial y+\partial\tau_{yz}/\partial z=0,\\\partial\tau_{xz}/\partial x+\partial\tau_{yz}/\partial y+\partial\sigma_z/\partial z=0\end{cases}\\ \ell_{\mathbf{f}}(\mathbf{u}(\mathbf{x}))\big|_{\Gamma_{\mathbf{f}}}=\mathbf{f}\Rightarrow\begin{cases}\sigma_x l_x+\tau_{xy}l_y+\tau_{xz}l_z&=f_x\\\tau_{xy}l_x+\sigma_y l_y+\tau_{yz}l_z&=0\\\tau_{xz}l_x+\tau_{yz}l_y+\sigma_z l_z\big|_{\Gamma_{\mathbf{f}}}&=0\end{cases},\\ \ell_{\mathbf{u}_\infty}(\mathbf{u}(\mathbf{x}))\big|_{\Gamma_{\mathbf{u}_\infty}}=\mathbf{u}_\infty\quad\Rightarrow\quad u_x\big|_{\Gamma_{\mathbf{u}_\infty}}=u_{x\infty}.\end{cases} \quad (20)$$

In matrix form the basic equation takes the form:

$$\mathcal{L}(\mathbf{u}(\mathbf{x}))=0\Rightarrow[\mathcal{L}]^{\mathrm{T}}[\mathbf{D}][\mathcal{L}]\{\mathbf{u}\}=0. \quad (21)$$

Let construct an approximation by finite element method, similar to the previous heat conduction problem. One gets the weighted residuals equation:

$$\begin{aligned}&\iiint_{\Omega_i}[\mathbf{N}]_i^{\mathrm{T}}\left([\mathcal{L}]^{\mathrm{T}}[\mathbf{D}]_i[\mathcal{L}]\{\tilde{\mathbf{u}}\}_i\right)d\Omega-\\&-\iint_{\Gamma_{\mathbf{f}i}}[\mathbf{N}]_i^{\mathrm{T}}\frac{\partial\{\tilde{\mathbf{u}}\}_i}{\partial\mathbf{n}}d\Gamma+\iint_{\Gamma_{\mathbf{f}i}}[\mathbf{N}]_i^{\mathrm{T}}\mathbf{f}_i d\Gamma=0.\end{aligned} \tag{22}$$

It can also be reduced to a weak form that includes Neumann boundary conditions:

$$\begin{aligned}&\left(\iiint_{\Omega_i}\left([\mathcal{L}][\mathbf{N}]_i\right)^{\mathrm{T}}[\mathbf{D}]_i\left([\mathcal{L}][\mathbf{N}]_i\right)d\Omega\right)\{\mathbf{u}\}_i=\\&=\iint_{\Gamma_{\mathbf{f}i}}[\mathbf{N}]_i^{\mathrm{T}}\mathbf{f}_i d\Gamma.\end{aligned} \tag{23}$$

Unlike the previous problem, the matrix of basis functions is sparse. For simplex elements it can be written as:

$$[\mathbf{N}]=\left[[\mathbf{M}]_1,[\mathbf{M}]_2,[\mathbf{M}]_3,[\mathbf{M}]_4\right],\quad [\mathbf{M}]_k=\begin{bmatrix}N_k&0&0\\0&N_k&0\\0&0&N_k\end{bmatrix}, \tag{24}$$

wherefrom the expression $[\mathcal{L}][\mathbf{N}]$ for all elements can be written as:

$$[\mathcal{L}][\mathbf{N}]=\left[[\mathbf{M}]_1,[\mathbf{M}]_2,[\mathbf{M}]_3,[\mathbf{M}]_4\right],\quad [\mathbf{M}]_k=\begin{bmatrix}b_k&0&0&c_k&d_k&0\\0&c_k&0&b_k&0&d_k\\0&0&d_k&0&b_k&c_k\end{bmatrix}^{\mathrm{T}}, \tag{25}$$

$$\begin{bmatrix}1&x_1&y_1&z_1\\1&x_2&y_2&z_2\\1&x_3&y_3&z_3\\1&x_4&y_4&z_4\end{bmatrix}^{-1}=\begin{bmatrix}a_1&a_2&a_3&a_4\\b_1&b_2&b_3&b_4\\c_1&c_2&c_3&c_4\\d_1&d_2&d_3&d_4\end{bmatrix}.$$

Last expression again contains only constants and that's why the local 12x12 stiffness matrix finding is a trivial task (14). Finding of the local loads vectors differs from the previous case in part that the vector expands to 12 elements – three load components per node, each of which should be multiplied by one-third of that tetrahedron side area.

When all local stiffness matrices and load vectors are found, they should be assembled into global SLAE, which describes initial boundary value problem (20).

The solution can be conveniently found by conjugate gradient stabilized method.

THE MAIN RESULTS OF THE RESEARCH

The coupled thermoelasticity problem

Coupled problems are multiphysics problems and usually can be solved in two steps – firstly separately one finds a temperature field, and then a displacement field, which based on temperature, or vice versa, depending on given boundary conditions [23].

Here, basing on previously described linear stationary heat conduction and elasticity problems, is proposed the combined numerical model of thermoelasticity problem simulation in composite materials with complex structure, that unlike to traditional, gives the ability to take into account boundary conditions in the form of heat flows, surface loads, given surface temperatures and movements, if they are present. Combination is made by using a single differential matrix operator.

This approach is especially useful when used in engineering applications which provide a high level of abstraction, e.g. FEMLab/COMSOL or FreeFem++ [24].

Coupled thermoelasticity problem numerical simulation allows one to synthesize an effective thermal conduction coefficient λ_{eff} and temperature coefficient of linear expansion α_{eff} (LCTE).

The LCTE describes a thermal expansion within solid materials, according to which the linear sizes and body shape are changing by body temperature change under fixed environment pressure. In the general case LCTE can be found as:

$$\alpha_{eff}=\frac{1}{d}\frac{\Delta u_x}{\Delta T}, \tag{26}$$

with given heat flux q (Neumann b.c. on $\Gamma_f\subset\Re^2$) and outer environment temperature T_∞ (Dirichlet b.c. on the opposite side $\Gamma_{u_\infty}\subset\Re^2$). In addition, all displacement components $u_x=u_y=u_z=0$ on $\Gamma_{\mathbf{u}_\infty}$, and transverse displacements $u_y=u_z=0$ on flanks, should be limited, leaving the ability to deform in only one direction.

Let build the numerical model. In every point within RVE are unknown a value of temperature and displacements along coordinate axes:

$$\mathbf{u}(\mathbf{x})=\{T\ u_x\ u_y\ u_z\}^{\mathrm{T}}.$$

Let combine strain tensor and temperature gradient into single tensor:

$$\begin{aligned}&[\boldsymbol{\varepsilon}]=\left\{q_x\ q_y\ q_z\ \varepsilon_x\ \varepsilon_y\ \varepsilon_z\ \gamma_{xy}\ \gamma_{xz}\ \gamma_{yz}\right\}^{\mathrm{T}}=\\&=\left\{\frac{\partial T}{\partial x}\ \frac{\partial T}{\partial y}\ \frac{\partial T}{\partial z}\ \frac{\partial u_x}{\partial x}\ \frac{\partial u_y}{\partial y}\ \frac{\partial u_z}{\partial z}\right.\\&\left.\frac{\partial u_x}{\partial y}+\frac{\partial u_y}{\partial x}\ \frac{\partial u_x}{\partial z}+\frac{\partial u_z}{\partial x}\ \frac{\partial u_y}{\partial z}+\frac{\partial u_z}{\partial y}\right\}^{\mathrm{T}}=[\mathcal{L}]\{\mathbf{u}\},\end{aligned} \tag{27}$$

where: $[\mathcal{L}]$ – given problem differential operator matrix (in weak form), which is equal to:

$$[\mathcal{L}]=\begin{bmatrix}A&B&C&0&0&0&0&0&0\\0&0&0&A&0&0&B&C&0\\0&0&0&0&B&0&A&0&C\\0&0&0&0&0&C&0&A&B\end{bmatrix}^{\mathrm{T}} \tag{28}$$

$$A=\partial/\partial x,\quad B=\partial/\partial y,\quad C=\partial/\partial z.$$

Let combine the relation between strain tensor and stress tensor (Hooke's law) and between temperature gradient and heat flow (Fourier law) by single environment characteristics matrix:

$$[\mathbf{D}]=\begin{bmatrix} \lambda & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & \lambda & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & \lambda & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & A & B & B & 0 & 0 & 0 \\ 0 & 0 & 0 & B & A & B & 0 & 0 & 0 \\ 0 & 0 & 0 & B & B & A & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & C & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & C & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & C \end{bmatrix}, \quad (29)$$

$$A = E(1-\mu)/(1+\mu)/(1-2\mu),$$
$$B = \mu E/(1+\mu)/(1-2\mu), \quad C = E/2+2\mu.$$

Given problem balance differential equations can be written as:

$$[\mathcal{L}]^{\mathrm{T}}[\mathbf{D}][\mathcal{L}]\{\mathbf{u}\}+\{\mathbf{X}\}=0, \quad (30)$$

where: $\{\mathbf{X}\}$ – inner heat sources or inner forces. By known LCTE α of the body components, can be found the inner forces:

$$X=\frac{\alpha E}{1-2\mu}\frac{\partial T}{\partial x}, \quad Y=\frac{\alpha E}{1-2\mu}\frac{\partial T}{\partial y}, \quad Z=\frac{\alpha E}{1-2\mu}\frac{\partial T}{\partial z}. \quad (31)$$

In other side, the material is warming under influences of the stress – it is equivalent to presence of the inner heat source that is equal to:

$$Q=\frac{\alpha E}{1-2\mu}\frac{\partial u_x}{\partial x}+\frac{\alpha E}{1-2\mu}\frac{\partial u_y}{\partial y}+\frac{\alpha E}{1-2\mu}\frac{\partial u_z}{\partial z}, \quad (32)$$

wherefrom:

$$\{\mathbf{X}\}=\{Q \quad X \quad Y \quad Z\}^{\mathrm{T}}=[\mathcal{L}]^{\mathrm{T}}[\mathbf{J}]\{\mathbf{u}\}, \quad (33)$$

where: $\{\mathbf{J}\}$ – matrix in form:

$$[\mathbf{J}]=\frac{\alpha E}{1-2\mu}\begin{bmatrix} 0 & 0 & 0 & 1 & 1 & 1 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}^{\mathrm{T}}. \quad (34)$$

Now can be written the weighted residual equation:

$$\iiint_{\Omega_i}[\mathbf{N}]_i^{\mathrm{T}}\left([\mathcal{L}]^{\mathrm{T}}[\mathbf{D}]_i[\mathcal{L}]\{\tilde{\mathbf{u}}\}_i\right)d\Omega+$$
$$+\iiint_{\Omega_i}[\mathbf{N}]_i^{\mathrm{T}}\left([\mathcal{L}]^{\mathrm{T}}\left([\mathbf{J}]\{\tilde{\mathbf{u}}\}_i\right)\right)d\Omega- \quad (35)$$
$$-\iint_{\Gamma_{\mathbf{f}i}}[\mathbf{N}]_i^{\mathrm{T}}\frac{\partial\{\tilde{\mathbf{u}}\}_i}{\partial\mathbf{n}}d\Gamma+\iint_{\Gamma_{\mathbf{f}i}}[\mathbf{N}]_i^{\mathrm{T}}\mathbf{f}_i d\Gamma=0,$$

which can be reduced to the weak form by including Neumann boundary conditions:

$$\left(\iiint_{\Omega_i}\left([\mathcal{L}][\mathbf{N}]_i\right)^{\mathrm{T}}[\mathbf{D}]_i\left([\mathcal{L}][\mathbf{N}]_i\right)d\Omega-\right. \quad (36)$$
$$\left.-\iiint_{\Omega_i}[\mathbf{N}]_i^{\mathrm{T}}\left([\mathcal{L}]^{\mathrm{T}}[\mathbf{J}][\mathbf{N}]_i\right)d\Omega\right)\{\mathbf{u}\}_i=\iint_{\Gamma_{\mathbf{f}i}}[\mathbf{N}]_i^{\mathrm{T}}\mathbf{f}_i d\Gamma.$$

As in the previous case, the matrix of basis functions is 4x16 sparse matrix. Expression $[\mathcal{L}][\mathbf{N}]$ for all elements can be written as:

$$[\mathcal{L}][\mathbf{N}]=\left[[\mathbf{M}]_1,[\mathbf{M}]_2,[\mathbf{M}]_3,[\mathbf{M}]_4\right],$$

$$[\mathbf{M}]_k=\begin{bmatrix} b_k & c_k & d_k & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & b_k & 0 & 0 & c_k & d_k & 0 \\ 0 & 0 & 0 & 0 & c_k & 0 & b_k & 0 & d_k \\ 0 & 0 & 0 & 0 & 0 & d_k & 0 & b_k & c_k \end{bmatrix}^{\mathrm{T}}. \quad (37)$$

The second term of stiffness matrix describes the inner heat force sources. For simplex elements it can be found same as loads vector, basing on tetrahedron barycentric coordinates, with the difference that the result should be multiplied by a quarter of the tetrahedron volume:

$$\iiint_{\Omega_i}[\mathbf{N}]_i^{\mathrm{T}}\left([\mathcal{L}]^{\mathrm{T}}[\mathbf{J}][\mathbf{N}]_i\right)d\Omega=\frac{\Omega_i}{4}\frac{\alpha E}{1-2\mu}\cdot$$

$$\cdot\begin{bmatrix} [\mathbf{M}]_1 & [\mathbf{M}]_2 & [\mathbf{M}]_3 & [\mathbf{M}]_4 \\ [\mathbf{M}]_1 & [\mathbf{M}]_2 & [\mathbf{M}]_3 & [\mathbf{M}]_3 \\ [\mathbf{M}]_1 & [\mathbf{M}]_2 & [\mathbf{M}]_3 & [\mathbf{M}]_3 \\ [\mathbf{M}]_1 & [\mathbf{M}]_2 & [\mathbf{M}]_3 & [\mathbf{M}]_3 \end{bmatrix}, [\mathbf{M}]_k=\begin{bmatrix} 0 & b_k & c_k & d_k \\ b_k & 0 & 0 & 0 \\ c_k & 0 & 0 & 0 \\ d_k & 0 & 0 & 0 \end{bmatrix}. \quad (38)$$

Finding of the local loads vectors differs from the previous case in the part that vector expands to 16 elements, four components (heat flux + loads) per node, each of which should be multiplied by one-third of that tetrahedron side. When all local stiffness matrices and load vectors are found, they should be assembled into global SLAE, which describes initial boundary value problem (30).

The feature of this problem is that the differential operator and according SLAE are asymmetric, thanks to the contribution of inner heat and force sources. Since this term in the expression of stiffness matrix is standing with a minus sign, one can make sure that the system and its differential operator always be positively defined and bounded (doesn't give infinity under integration). These properties are sufficient for the convergence of computational model. An important difference in the practical realization is the impossibility of usage such approximate SLAE solving method as conjugate gradient method that may be used only for symmetric systems. However, in this case, can be used the biconjugate gradient stabilized method, which is a generalization of the previous.

Effective thermal characteristics synthesis

Approximate solution of physico-mathematical problems in the complex structured CM RVEs allows one to synthesize their effective characteristics, i.e. to do the homogenization procedure by numerical simulation. For this can be used thermoelectricity analogy method and theory of similarity [16, 17, 25 – 27]. Let consider the problem of non-stationary heat conduction described by parabolic equation:

$$c\rho\frac{\partial T}{\partial\tau}=\lambda\nabla^2 T, \quad (39)$$

where: specific heat capacity c [J/kg°C], when [J = kg·m²/s²]; density ρ [kg/m³]; heat conduction coefficient λ [W/m°C], when [W = kg·m²/s³]; time τ [s]; distance x, y, z, or, ignoring the differential operator, some characteristic distance l [m] and temperature T [°C]. Let find the similarity criterion by reducing the equation to non-dimensional:

$$\pi_1 = \frac{\lambda \frac{T}{l^2}}{c\rho \frac{T}{\tau}} = \frac{\lambda\tau}{c\rho l^2}, \quad [\pi_1] = \mathrm{kg^0 m^0 s^0 C^0} = 1. \tag{40}$$

This criterion is known as Fourier criterion. To determine the next criterion it can be used the Robin boundary conditions (Newton-Richman), i.e. temperature driving force:

$$\lambda \frac{\partial T}{\partial \mathbf{n}}\bigg|_\Gamma = \xi \Delta T|_\Gamma, \tag{41}$$

where: ξ – heat transfer coefficient [W/m^2°C]. Let reduce the last equation to non-dimensional:

$$\pi_2 = \frac{\alpha T}{\lambda \frac{T}{l}} = \frac{\alpha l}{\lambda}, \quad [\pi_2] = \mathrm{kg^0 m^0 s^0 C^0} = 1. \tag{42}$$

This criterion is known as Biot criterion.

Now, the electric conduction problem, which describes the commutation in some electrical device, can be considered. This problem is also determined by parabolic equation [28, 29]:

$$c\frac{\partial U}{\partial \tau} = \sigma \nabla^2 U, \tag{43}$$

where: σ – specific electrical conductivity [m^{-3}kg^{-1}s^{3}A^2]; c – electric capacity per volume [F/m^3 = A^{2}s^{4}kg^{-1}m^{-5}]; U – electric potential [m^{2}kg^{1}s^{-3}A^{-1}]. The corresponding similarity criteria for this equation are:

$$\pi_1 = \frac{\sigma \frac{U}{l^2}}{c\frac{U}{\tau}} = \frac{\sigma\tau}{cl^2}, \quad \pi_2 = \frac{\zeta U}{\sigma \frac{U}{l}} = \frac{\zeta l}{\sigma}. \tag{44}$$

By the selection of model (43) parameters, in which its similarity criteria are respectively the same for all of original (39) similarity criteria, the problems be similar and analogical. This condition is easy to perform in numerical mathematical models. Expansion the analogy on stationary problem is trivial.

Let consider the modification process of continuous system to its discrete analog. To ensure the unambiguousness of the conditions and matching of third similarity theorem [25], it is necessary to analyze the geometric properties of both systems. It can be considered the linear two-dimensional simplex elements in the problem of stationary heat conduction, for example. Stiffness matrix describes the relation between element nodes:

$$[\mathbf{K}] = \iint \left([\mathcal{L}][\mathbf{N}]\right)^{\mathrm{T}} [\mathbf{D}] \left([\mathcal{L}][\mathbf{N}]\right) d\Omega. \tag{45}$$

It can be noted that coefficients of gradients matrix $[\mathcal{L}][\mathbf{N}]$ have direct geometric meaning – element side projections on the coordinate axes:

$$\begin{gathered}[\mathbf{K}] = \frac{1}{2\Omega}\begin{bmatrix} b_1 & c_1 \\ b_2 & c_2 \\ b_3 & c_3 \end{bmatrix} \begin{bmatrix} \lambda & 0 \\ 0 & \lambda \end{bmatrix} \frac{1}{2\Omega} \begin{bmatrix} b_1 & c_1 \\ b_2 & c_2 \\ b_3 & c_3 \end{bmatrix}^{\mathrm{T}} \Omega = \\ = \frac{\lambda}{4\Omega}\begin{bmatrix} b_1^2 + c_1^2 & b_1 b_2 + c_2 c_2 & b_1 b_3 + c_1 c_3 \\ b_1 b_2 + c_1 c_2 & b_2^2 + c_2^2 & b_2 b_3 + c_2 c_3 \\ b_1 b_3 + c_1 c_3 & b_2 b_3 + c_2 c_3 & b_3^2 + c_3^2 \end{bmatrix}.\end{gathered} \tag{46}$$

The triangle area can be written by the last matrix coefficients, e.g. by taking a first node as the basis:

$$2\Omega = \begin{vmatrix} 1 & x_1 & y_1 \\ 1 & x_2 & y_2 \\ 1 & x_3 & y_3 \end{vmatrix} = \begin{vmatrix} x_2 - x_1 & y_2 - y_1 \\ x_3 - x_1 & x_3 - y_1 \end{vmatrix} = \begin{vmatrix} c_3 & -b_3 \\ -c_2 & b_2 \end{vmatrix}. \tag{47}$$

By repeating these steps for the other nodes one gets:

$$2\Omega = b_1 c_2 - b_2 c_1 = b_1 c_3 - b_3 c_1 = b_2 c_3 - b_3 c_2. \tag{48}$$

Taking into account the last expression, relationship between element nodes can be expressed by conductivities Y, or inverse to them values – resistors R:

$$\begin{aligned} [\mathbf{K}]_{1,2} = [\mathbf{K}]_{2,1} = Y_{1,2} = \frac{1}{R_{1,2}} = \frac{1}{2}\lambda \frac{b_1 b_2 + c_1 c_2}{b_1 c_2 - b_2 c_1}, \\ [\mathbf{K}]_{1,3} = [\mathbf{K}]_{3,1} = Y_{1,3} = \frac{1}{R_{1,3}} = \frac{1}{2}\lambda \frac{b_1 b_3 + c_1 c_3}{b_1 c_3 - b_3 c_1}, \\ [\mathbf{K}]_{2,3} = [\mathbf{K}]_{3,2} = Y_{2,3} = \frac{1}{R_{2,3}} = \frac{1}{2}\lambda \frac{b_2 b_3 + c_2 c_3}{b_2 c_3 - b_3 c_2}. \end{aligned} \tag{49}$$

The local stiffness matrix now can be written as:

$$[\mathbf{K}] = \begin{bmatrix} -Y_{1,2} - Y_{1,3} & Y_{1,2} & Y_{1,3} \\ Y_{1,2} & -Y_{1,2} - Y_{2,3} & Y_{2,3} \\ Y_{1,3} & Y_{2,3} & -Y_{1,3} - Y_{2,3} \end{bmatrix}. \tag{50}$$

The resulting matrix is nothing else than a combination of diagonal conductance matrix and Boolean connections matrix from the node potential method – the electrical circuits analysis method that uses SLAE, where nodal potentials are unknown [29]. In matrix form this SLAE can be written as:

$$[\mathbf{A}][\mathbf{Y}][\mathbf{A}]^{\mathrm{T}}\{\mathbf{U}\} = -[\mathbf{A}](\{\mathbf{J}\} + [\mathbf{Y}]\{\mathbf{E}\}), \tag{51}$$

where: $[\mathbf{A}]$ – connections matrix (nodes to the edges incidence matrix); $[\mathbf{Y}]$ – diagonal conductance matrix; $\{\mathbf{U}\}$ – unknown nodal potentials; $\{\mathbf{J}\}$ – electric power sources; $\{\mathbf{E}\}$ – voltage source. By using the analogy, this system can be reduced to:

$$\begin{gathered} [\mathbf{K}]\{\mathbf{u}\} = \{\mathbf{f}\}, \quad [\mathbf{K}] = [\mathbf{A}][\mathbf{Y}][\mathbf{A}]^{\mathrm{T}}, \\ \{\mathbf{f}\} = -[\mathbf{A}](\{\mathbf{J}\} + [\mathbf{Y}]\{\mathbf{E}\}). \end{gathered} \tag{52}$$

Where, one concludes that the elements of the analogy between physical processes are directly embedded in the linear finite element basis functions – they reflect the parameters of resistance/conductivity for similar discrete systems. If one considers the elasticity problem, stiffness matrix describes the behavior of simplex element where each edge of which is idealized spring with stiffness coefficient analogical to discrete mechanical system. And so on for other similarities, including multiphysics problems.

After numerical simulation of thermo-mechanical processes in RVE the resulting potential field on chosen volume sides can be inhomogeneous. To determine the effective characteristics it can be used described analogy method, i.e. analogy with parallel or serial conductivities connection [12, 26]. It is shown [16] that under the usage of simplex elements an effective heat conduction coefficient can be found as:

$$\lambda_{eff} = \frac{d \cdot q}{\Gamma_q (T_{\Gamma_q} - T_\infty)} = \frac{q}{\Gamma_q} \sum_{j=1}^{P_{\Gamma_q}} \frac{3(\Gamma_q)_j}{\sum_{i=1}^{3} \left(T_{qi,j} - T_\infty\right)}. \quad (53)$$

Extending this formalization to similar mechanical and coupled thermo-mechanical problems, one can get the expressions for effective thermal characteristics synthesis of complex structured composite materials microlevel model. For elasticity problem:

$$E_{eff} = \frac{d \cdot f_x}{\Gamma_{\mathbf{f}} (u_{x\mathbf{f}} - u_{x\infty})} = \frac{f_x}{\Gamma_{\mathbf{f}}} \sum_{j=1}^{P_{\Gamma_\mathbf{f}}} \frac{3(\Gamma_\mathbf{f})_j}{\sum_{i=1}^{3} \left(u_{x\mathbf{f}i,j} - u_{x\infty}\right)},$$

$$\mu_{eff} = \frac{\Delta u_y}{\Delta u_x} = \frac{\sum_{k=1}^{P_\Gamma} \left| u_{y_1 k} - u_{y_2 k} \right|}{\Gamma_\mathbf{f}} \sum_{j=1}^{P_{\Gamma_\mathbf{f}}} \frac{3(\Gamma_\mathbf{f})_j}{\sum_{i=1}^{3} \left(u_{x\mathbf{f}i,j} - u_{x\infty}\right)}, \quad (54)$$

where: u_{y_1} and u_{y_2} – transverse displacements on RVE flanks. For coupled thermoelasticity problem:

$$\alpha_{eff} = \frac{1}{d} \frac{\Delta u_x}{\Delta T} = \frac{1}{d} \sum_{j=1}^{P_{\Gamma_\mathbf{f}}} \frac{\sum_{i=1}^{3} \frac{u_{x\mathbf{f}i,j} - u_{x\infty}}{T_{\mathbf{f}i,j} - T_\infty}}{3}. \quad (55)$$

Simulation Results

Described models were realized in applied software by C++11 algorithmic language with high-performance parallel and distributed computing technology OpenCL v.1.2, and Qt SDK v.5.4.1. Working OS was Windows 7 Ultimate. Executable was built under x64 by MinGW v.4.9.2. Simulations were done on an ordinary configured PC. On Fig.2 are shown the results of CM effective thermal characteristics synthesis.

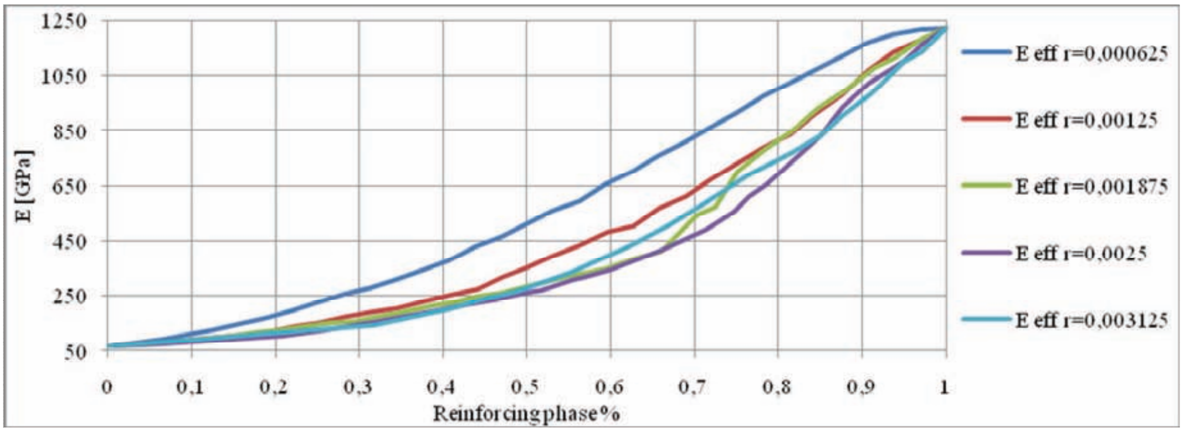


Fig.2.a. Composite materials effective thermal characteristics synthesis results

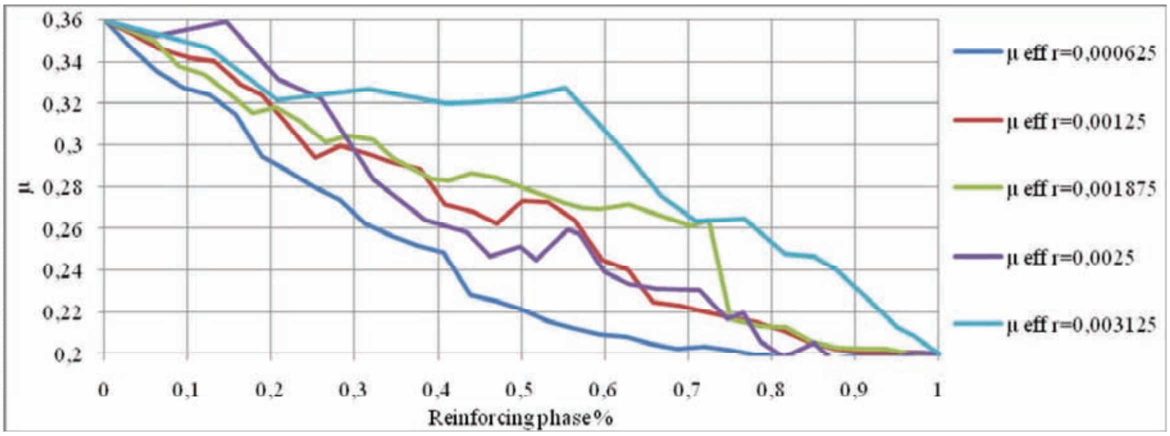


Fig.2.b. Composite materials effective thermal characteristics synthesis results

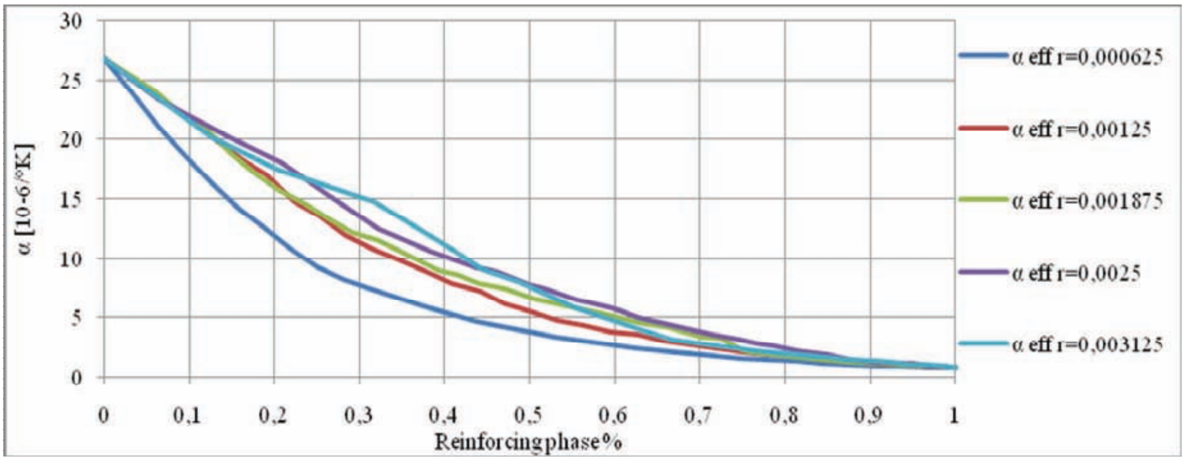


Fig.2.c. Composite materials effective thermal characteristics synthesis results

The CM model is Aluminum matrix with spherical Carbon inclusions with different sizes and concentration. Figure shows the phenomenon of synthesized characteristics percolation threshold appearing.

CONCLUSIONS

The numerical microlevel effective thermal characteristics synthesis models of composite materials with complex structure have gotten the further development:

basing on the usage of finite element method for modeling coupled thermoelasticity problems and analogies method were developed microlevel composite materials models which allow one to synthesize thermal conduction coefficient, Young's modulus, Poisson's ratio and temperature coefficient of linear expansion;

2) the main difference is combined formalization of coupled multiphysics problems, which allows one to simultaneously take into account multiphysics boundary conditions;
3) this approach is especially useful when used in engineering applications which provide a high level of abstraction;
4) the models successfully implemented by technologies of high-performance parallel and distributed computing, which opens the possibility of directly effective usage in problems of composite materials optimal design;
5) the simulation results are shown.

REFERENCES

1. **Gorobets V. and Mendeleyev V. 2012.** Influence of pollutions on the thermal characteristics, heat efficiency and optimal dimensions of tubes with londitudinal fins. EconTechMod, 1(1):35-40.
2. **Balinski A. 2012.** Nanostructure of the soluble sodium silicate in the aspect of basic mechanical characteristic of the moulding sands. EconTechMod, 1(1):3-8
3. **Lubin G. 1982.** Handbook of Composites. New-York: Van Nostrand Reinhold Company Inc.
4. **Narusberh V. and Teters G. 1988.** Stability and optimization of composite shells. Riga: Zynatne. (in Russian).
5. **Jaworski N., et al. 2013.** Research of composite materials optimal design task based on numerical simulation. Proc. of CSIT’2013, 46-48, Lviv.
6. **Jaworski N., et al. 2013.** Architecture of the composite materials distributed heterogeneous computer-aided design system. Proc. of CADSM’ 2013, 440-442, Polyana.
7. **Matthews F., et al. 2000.** Finite element modelling of composite materials and structures. New-York: CRC Press LLC.
8. **Barbero E. 2008.** Finite element analysis of composite materials. New-York: CRC Press LLC.
9. **Torquato S. 2002.** Random Heterogeneous Materials. Microstructure and Macroscopic Properties. New-York: Springer.
10. **Kanit T., et al. 2003.** Determination of the size of the representative volume element for random composites: statistical and numerical approach. Int. Journal of Solids and Structures. 40:3647-3679.
11. **Smerdov A. 2007.** Development of design methods of composite materials and structures for rocket and space technique. Preprint. Moscow: Moscow State University Press. (in Russian).
12. **Jaworski N., et al. 2014.** Thermal Analysis Methods for Design of Composite Materials with Complex Structure. ECS Transactions. 59(1):513-523.
13. **Zienkiewicz O. and Morgan K.** 1983. Finite elements and approximation. New-York: Wiley.
14. **Farmaga I., et al. 2011.** Finite Element Meshing of Composites with Spherical Inclusions. Machine Dynamics Research, 35(3):13-21.
15. **Farmaga I., et al. 2012.** Regular and adaptive algorithms for modelling of spherical inclusions by finite element method. Proc. of TCSET’2012, 505-507, Lviv-Slavske.
16. **Jaworski N., et al. 2012.** Finding Effective Thermal Characteristics of Composite Materials Based on the Analysis of Thermal Conductivities. Bulletin LPNU "Computer Systems of Design: Theory and

Practice", 747:59-65, Lviv.

17. **Jaworski N., et al. 2012.** Development of the Discrete Model of Finding of the Effective Thermal Characteristics of Composite Materials with Complex Structure. Bulletin LPNU "Computer science and information technology ", 744:152-158, Lviv. (in Ukrainian).
18. **Hashin Z. 1962.** The elastic moduli of heteroheneous materials. Journal of Applied Mechanics, 29(1):143-150.
19. **ISO 8301:1991** Thermal insulation. Determination of steady-state thermal resistance and related properties. Heat flow meter apparatus.
20. **Government Standard of Ukraine B B.2.7-105-2000 (GOST 7076-99)** Building materials and products. Method of determination of steady-state thermal conductivity and thermal resistance. (in Ukrainian).
21. **Lurie A. 1970.** Theory of Elasticity. Moscow. (In Russian).
22. **Timoshenko S. and Goodier J. 1979.** Theory of Elasticity. Moscow: Nauka. (In Russian).
23. **Kovalenko A. 1970.** Fundamentals of Thermoelasticity. Kiev: Naukova Dumka. (In Russian).
24. **Jaworski N., et al. 2014.** Finding the Composite Materials Linear Temperature Expansion Coefficient Based on Thermoelasticity Problem Numerical Simulation. Proc. of CADMD'2014, 77-83, Lviv.
25. **Venikov V. 1976.** Theory of similarity and modelling. Moscow: Vysshaia shkola. (in Russian).
26. **Dulnev G. 1984.** Heat and Mass Transfer in Electronic Equipment. Moscow: Vysshaia shkola. (in Russian).
27. **Fedasuk D. 1999.** Methods and tools for thermal design of microelectronic devices. Lviv: LPNU. (in Ukrainian).
28. **Robertson A. and Gross D. 1958.** An Electrical-Analog Method for Transient Heat-Flow Analysis. Jour. of Res. of the Nat. Bureau of Standards, 61(2).
29. **Neumann L. and Demirchian K. 1981.** Theoretical Foundations of Electrical Engineering. Leningrad: Energoizdat. (in Russian).

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Information technology for Ukrainian Sign Language translation based on ontologies

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Abstract. The article discusses an information technology for Ukrainian Sign Language translation based on ontologies. The components of the technology that are based on grammatically augmented ontology are described. New methods and tools for Ukrainian Sign Language translation were developed. These tools can be used for the development of a machine translation system from spoken to sign language and vice versa to facilitate communication between deaf people and those who do not speak sign language.

The experiments for Ukrainian Sign Language translation were conducted. The increase of the percentage of correctly parsed sentences shows the feasibility of using the information technology for Ukrainian Sign Language translation.

Key words: sign language translation, grammatical analysis, grammatically augmented ontology.

INTRODUCTION

Ukrainian Sign Language (USL) is a natural way of communication that is used by people with impaired hearing. Thus a necessity of obtaining information in the form of sign language for this category of people is important. Today there are about 400,000 people with impaired hearing who live in Ukraine. For this category of citizens there are 59 specialized schools, 20 universities (including the National Technical University of Ukraine "Kyiv Polytechnic Institute").

There are educational materials available for deaf people that include video dictionaries of USL, tutoring software, online courses, etc. However, there are no effective tools for machine translation of sign language. The development of information technology for Ukrainian sign language translation is a relevant task. This information technology can be in great social demand; in particular it will provide persons with hearing disabilities with the opportunity to actively engage in communication with people who do not speak sign language.

Sign Language (SL) is a natural language, which is based on a combination of signs [1]. Every sign is performed with one or both hands, combined with facial expressions and body posture. Ukrainian Sign Language is an independent visual-spatial language and has its own grammar that is different from Ukrainian Spoken Language grammar (USpL) [2]. Some features of USL allow parallel transfer of information by performing signs with both hands, using facial expressions and articulations. It is impossible in Ukrainian Spoken Language, where information transfer is linear (word by word).

THE ANALYSIS OF RECENT RESEARCH AND PUBLICATIONS

There are several approaches to sign language translation. The most studied among them are approaches based on statistical models [3, 4], rule-based models [5, 6], data-driven models [7], and ontologies [8 – 10].

Scientists J. Bungeroth and H. Ney studied the statistical approach for German Sign Language (DGS) translation [11]. The translation process consists of gesture recognition, statistical translation, and rendering of a visual avatar.

In [12] a method of statistical machine translation from English text to American Sign Language is described. The components of the method are: a parallel corpus, a decoder for statistical machine translation of English and ASL, and a method for improvement of translation results.

Indian scientists T. Dasgupta et al. [13] have presented a prototype of Text-To-Indian Sign Language (ISL) rule-based translation system. The process of translation consists of five modules: input text preprocessor and parser, LFG f-structure converter, translator based on grammar rules, ISL sentence generator, and ISL synthesizer.

The information technology of rule-based machine translation for Spanish Sign Language was described in [14] (R. San Segundo et al.) The translation system is composed of a speech recognizer (for decoding the spoken utterance into a word sequence), a natural language translator (for converting a word sequence into a sequence of sign language gestures), and a 3D avatar animation module (for playing gestures). The translation process is carried out by using a database of grammar rules of Spanish spoken and sign languages.

Information technology of Polish Sign Language translation based on rules was studied in [15]. The translation process includes syntactic and semantic analysis of the input text, transformation of predicate-argument structure of Polish sentence into predicate-argument structure of SL sentence, and gesture animation.

In [8] an ontology-based machine translation system from Arabic text to Arabic SignWriting in the jurisprudence of prayer domain was developed. The translation process consists of the following modules:

morphological analysis, grammatical transformation and semantic translation using domain ontology. The system produces SignWriting symbols as a result.

Ukrainian scientists Iu. Krak, O. Barmak and Iu. Kryvonos [16] have developed an information technology for bidirectional Ukrainian Sign Language translation. This technology is based on the following processes: calculation of inflection parameters for each word in an input sentence, search and replacement of USpL grammatical constructions with appropriate USL grammatical constructions and replacement of words with appropriate gestures.

The study of known approaches to sign language translation showed that rule-based and ontology-based approaches are the most applicable to Ukrainian Sign Language translation because of lack of big parallel corpora for statistical translation. In order to increase the translation quality an alternative approach based on grammatically augmented ontology was studied.

OBJECTIVES

The article focuses on the development of an information technology for Ukrainian Sign Language translation. The information technology is based on grammatically augmented ontology (GAO) that was introduced in [17]. Methods and tools for Ukrainian Sign Language translation were created. They can be used for the development of machine translation from one language to another, which will facilitate communication between deaf people and people who do not speak sign language.

The process of Ukrainian Sign Language translation is a complex problem, which consists of word sense disambiguation (WSD), parsing sentences in Ukrainian Spoken Language and Ukrainian Sign Language, and applying translation rules.

For the development of the information technology of Ukrainian Sign Language translation the following problems were solved:

1) grammatical analysis of Ukrainian Sign Language,
2) task decomposition of Ukrainian Sign Language translation system,
3) building a system of GAO-based rules for Ukrainian Sign Language translation,
4) development of USL translation methods using GAO,
5) experimental studies and evaluation of results.

THE MAIN RESULTS OF THE RESEARCH

Information technology of Ukrainian Sign Language translation consists of the following processes:

• filling grammatically augmented ontology [18];
• rule-based translation [19, 20] and translation based on grammatically augmented ontology [17];
• testing translation system.

The processes of information technology using a use case diagram is shown in Fig. 1.

A domain specific language (DSL) was developed for filling grammatically augmented ontology of Ukrainian Spoken and Sign Languages. The DSL named GAODL was created to facilitate uniform editing and processing of grammatically augmented ontologies. These ontologies could be created for specific subject areas and lately merged to obtain upper ontologies. The GAODL language contains means for definition of new grammatical attributes, synsets, relations on synsets, predicates and expressions.

Grammatically augmented ontology for "Education", "Nature", "Journey", "State", "Family", "Production", "Profession", "Army", "Theatre", "Culture", and "Hospital" subject areas were built. For this purpose, 1200 words were collected from these subject areas and the meaning of each word was verified using the Ukrainian glossary [21]. The meaning of USL signs was clarified with teachers of Lviv Maria Pokrova Secondary Residential School for Deaf Children because there are no glossaries for USL yet. GAO description was built using the collected words as synsets. Expressions in USpL and USL were added for all verb synsets.

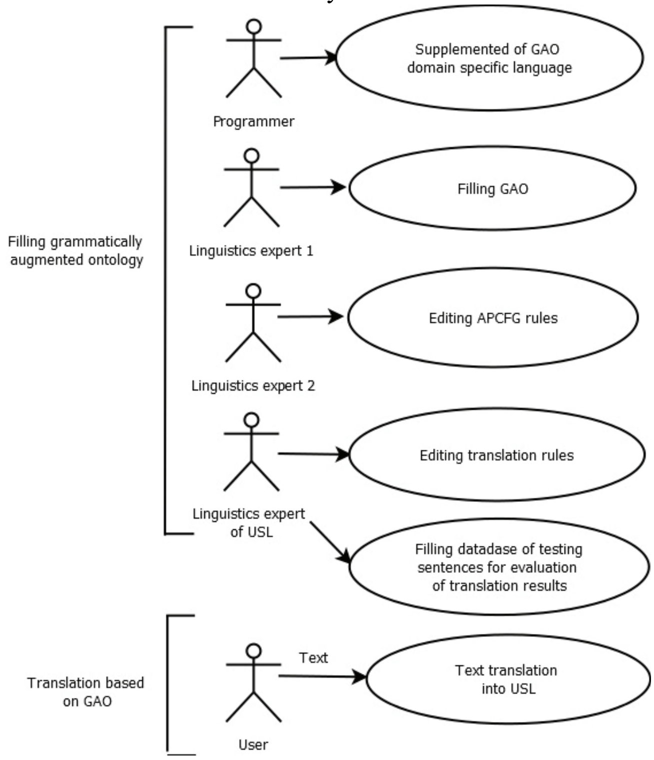

Fig. 1. Use case diagram of information technology of USL translation

Linguistics experts, programmers and experts in Ukrainian Sign Language are involved in the process of filling grammatically augmented ontology.

The possibility of introducing new concepts is implemented by a programmer using a grammatically augmented ontology domain specific language toolchain.

The GAO is filled with the assistance of a linguistics expert. It involves the choice of topics, words, signs, and grammatical constructions. To editing of the APCFG rules involves a linguistics expert as well.

A Ukrainian Sign Language expert is involved in editing database of USL translation rules and filling the corpus of testing sentences for the evaluation of translation results. Users use the translation system for the translation of USpL sentences into USL and vice versa. The evaluation of translation performance is performed by comparing translated sentences with the known translations from the testing sentences database.

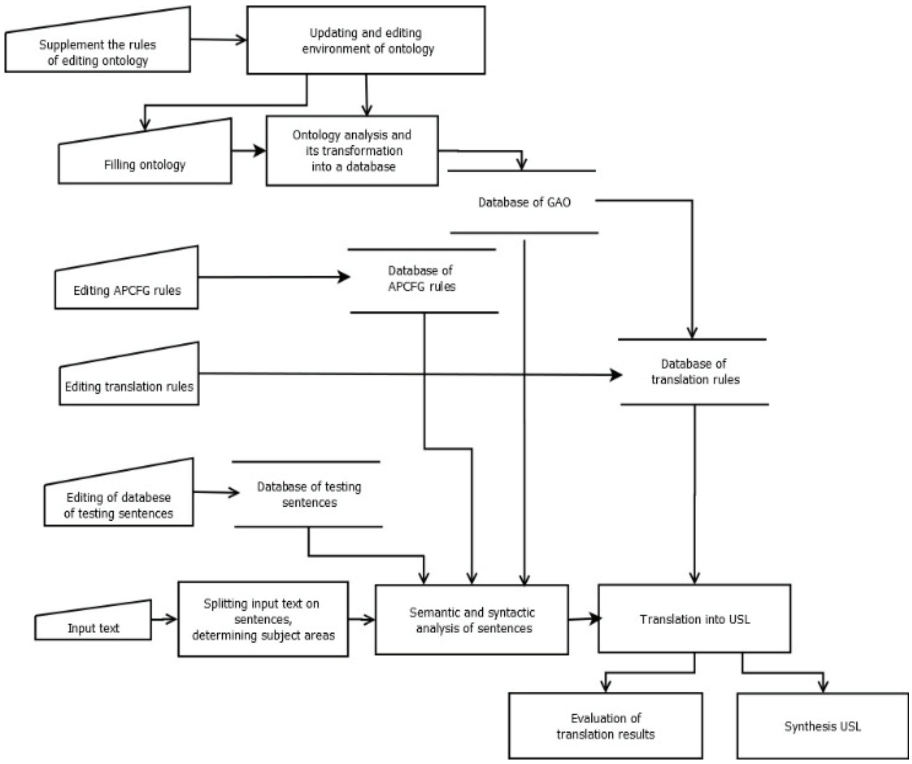

Fig. 2. The scheme of information technology of Ukrainian Sign Language translation based on grammatically augmented ontology

The scheme of the developed information technology for USL translation is shown in Fig. 2. The technology is based on rules that are extracted from grammatically augmented ontology. Then a semantic-syntactic analysis of sentences is performed. The use of grammatically augmented ontology in the first stage of translation enables further semantic-syntactic analysis of sentences and avoids the problem of ambiguous parsing.

The main difference from the known ontology-based approaches is that expressions are stored with ontology using a new domain-specific language GAODL (Grammatically Augmented Ontology Description Language). The use of GAODL facilitates uniform editing and processing of grammatically augmented ontologies. These ontologies could be created for specific subject areas and lately merged to obtain upper ontologies. The GAODL language contains constructions for the definition of new grammatical attributes, synsets, relations on synsets, predicates and expressions. USL signs were represented by glosses for the purpose of translation.

The grammatically augmented ontology is defined in [17] as a tuple:

$$O_G = O,P,E,T,R_p \quad (1)$$

where: O is an ontology, defined as a tuple $O = \langle L,C,F,R_c \rangle$, where $L = \{w_i\}$ is a vocabulary of a subject area, $C = \{c_i\}$ is a set of the subject area concepts, $F \subset L \times C$ – a relation between appropriate terms and concepts, R_c is a set of relations on concepts (hyponymy, hyperonymy, meronymy, holonymy, etc);

$P = \{p_i\}$ is a set of predicates;

$E = \{e_i\}$ is a set of expressions, where each expression $e_i = ((w_1, g_1), (w_2, g_2), \ldots, (w_n, g_n))$ is a tuple of grammatically augmented ontology terms (w_i, g_i);

$T = \{t_j\}$ is a set of parametrized expressions, where $t_j = (e_j, f_j, p_j)$ is a triple of expression e_j, argument positioning function $f_j : \{1,2,\ldots,Len(e_j)\} \to \{0,1,\ldots,N(p_j)\}$, and a related predicate p_j. $Len(e_j)$ denotes the length of tuple e_j, $N(p_j)$ is the number of places of predicate p_j;

R_p is a relation that matches predicates to verb concepts.

For some predicate p_j and some expression e_j argument positioning function $f_j(k)$ was defined to be 0 for the term in position k of the expression e_j that can't be changed without breaking the expression relation to predicate p_j. The value $f(k) > 0$ means that appropriate term in position k represents an argument of the predicate with ordinal number $f(k)$, and it can be replaced with another term from the set of hyponyms of term w_k. If the related predicate has n places and for each $i \in \{1,2,\ldots,n\}$ exists $k \in \{1,2,\ldots,Len(e_j)\}$ such that $f(k)=i$ then expression e_j completely defines predicate p_j. Otherwise, some arguments of the predicate are considered to be undefined in the sentence. They can be either completely unknown or can be devised from the context of speech or from a situation.

The definition of grammatically augmented ontology provided the possibility to express links between concepts, predicates and means of their expression in the form of language constructions.

For example, the predicate $PLAY(a,b,c)$, where a is someone who plays, b is something that is played and c is a musical instrument, can be expressed using expressions $e_1=$ “(somebody) (play) (something) (on something/musical_instrument)”.

In spoken languages the grammatical forms of subject, object, predicate, and complement comply to certain grammatical rules. These rules in the grammatically augmented ontology are defined by grammatical attributes of the expression terms.

These grammatical attributes were divided into 3 groups:

1) attributes that can't be modified (for example, preposition and casus of a complement),

2) attributes that can be freely modified (usually, number and gender of an object),

3) attributes that should be matched (like person and number of a subject or predicate).

Process of translation based on GAO use Affix probabilistic context free grammar (APCFG) [18] parser for parsing sentences and transformation of sentence according to the grammar rules. Fig. 3 shows a block diagram of the translation algorithm based on grammatically augmented ontology.

All experiments were conducted for Ukrainian language and examples below are English equivalents of them. The algorithm for parsing a sentence comprises the following steps:

1. Look up all possible meanings of every word from the sentence.
2. Add base forms for every word and detect its grammatical attributes.
3. Add hypernyms for every meaning of the words.
4. Add all expressions for every verb in the sentence.
5. Parse the sentence using UrkParser.

Consider parsing sentences “The boy plays sonata on the piano” and “The boy plays sonata on a book”. The parsing starts by adding all possible meanings of all words from the sentences, their base forms and all possible hyperonyms (steps 1-3 of the algorithm). GAO relation “hyperonym” is not limited to be a simple tree structure. It can be used to define different groups of words that share some common property. For example:

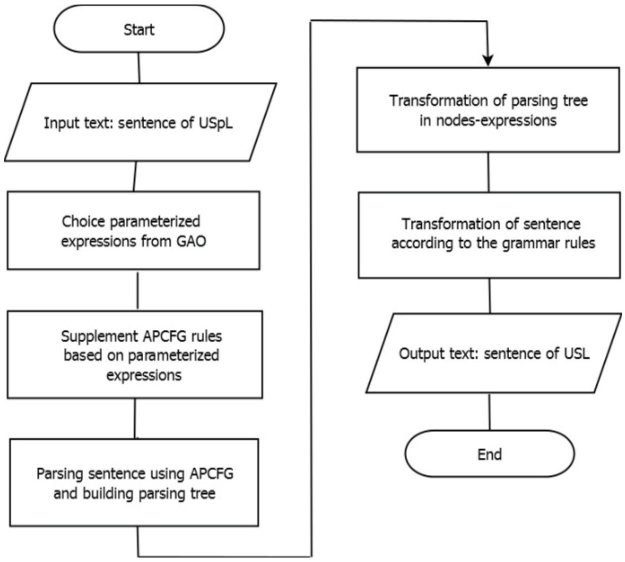

Fig. 3. Algorithm of Ukrainian Sign Language translation based on grammatically augmented ontology

- **Boy** (a youthful male person). Hypernyms: male, male person → person, individual, someone, some body, mortal, soul → organism, being → living thing, animate thing → whole, unit → object, physical object → physical entity → entity.
- **Play** (play on an instrument). Hypernyms: perform → re-create → make, create.
- **Play** (participate in games or sport). Hypernyms: compete, vie, contend.
- **Act, play, represent** (play a role or part). Hypernyms: re-create → make, create.
- **Play** (be at play; be engaged in playful activity; amuse oneself in a way characteristic of children). Hypernyms: act.
- **Play, spiel** (replay (as a melody)) Hypernyms: re-create → make, create.
- **Play** (bet or wager (money)). Hypernyms: play → compete, vie, contend.
- **Play** (pretend to be somebody in the framework of a game or playful activity). Hypernyms: simulate, assume, sham, feign → diss emble, pretend, act.
- **Play** (emit recorded sound). Hypernyms: sound.
- **Play** (put (a card or piece) into play during a game, or act strategically as if in a card game). Hypernyms: deploy → position → put, set, place, pose, position, lay → move, displace.
- **Play, toy** (engage in an activity as if it were a game rather than take it seriously). Hypernyms: act, behave, do.
- **Play** (use to one's advantage) Hypernyms: exploit, work → use, utilize, utilise, apply, employ.
- **Sonata** (a musical composition of 3 or 4 movements of contrasting forms). Hypernyms: classical music, classical, serious music → music genre, musical genre, genre, musical style → expressive style, style → communication → abstraction, abstract entity → entity

- **Piano, pianoforte, forte-piano** (a keyboard instrument that is played by depressing keys that cause hammers to strike tuned strings and produce sounds). Hypernyms: keyboard instrument → musi cal instrument, instrument → device → instrument ality, instrumentation → artifact, artefact → whole, unit → object, physical object → physical entity → entity
- **Book** (a written work or composition that has been published (printed on pages bound together)). Hypernyms: work, piece of work → product, production → creation →artifact, artefact → whole, unit → object, physical object → physical entity → entity.

The next step is to add expressions for these words. Only verb "play" contains an associated expressions, so it is added to the set of APCFG rules:

VP → play <musical_composition>[NP] on <musical_instrument>[NP] (1.1),

VP → play <sport_game >[NP] (1.1),

VP → play_act <actor_role>[NP] in < theatrical performance>[NP] (1.1),

VP → play_with <game >[NP] (1.1),

VP → play_replay <something >[NP] (1.1),

VP → play <wager_money >[NP] (1.1),

VP → play_pretend < playful_activity >[NP] (1.1),

VP → play_emit < recorded_sound >[NP] (1.1),

VP → play_behave < certain_way >[NP] (1.1),

VP → play_manipulate < something >[NP] (1.1),

VP → play_advantage on <somebody_interests> [NP] (1.1),

VP → play on < specific_position> [NP] (1.1).

where: VP means verb phrase, NP means noun phrase and the numbers in braces mean multiplicative weight of the rules. In the conducted experiment all grammatical rules were weighted 1.0 and the weight of all expression rules was set to 1.1. This helped the parser to prefer expressions over the grammatical rules where it was possible.

The results of the experiment with parsing 200 test sentences in USL and USpL language are given in table 1. The percentage of correctly parsed sentences was low when only the grammatical rules were used. This percentage is small especially for spoken language. It was due to the fact that Ukrainian spoken language grammar has flexible word order and word order in sign language is fixed in most expressions.

Table 1. Percentage of correctly parsed USL and USpL sentences

Rule set	Ukrainian Sign Language	Ukrainian Spoken Language
Grammatical rules only	72%	65%
Grammatical rules + rules generated from GAO	91%	90%

The result of parsing the sample sentences is shown in Fig. 4. An expression "play" was used when the first sentence was parsed, thus the weight of the result is 1.1. In the second sentence the expression "play" could not be used because "a book" does not belong to the group of entities "musical_instrument". Thus, the second sentence was parsed using only grammatical rules.

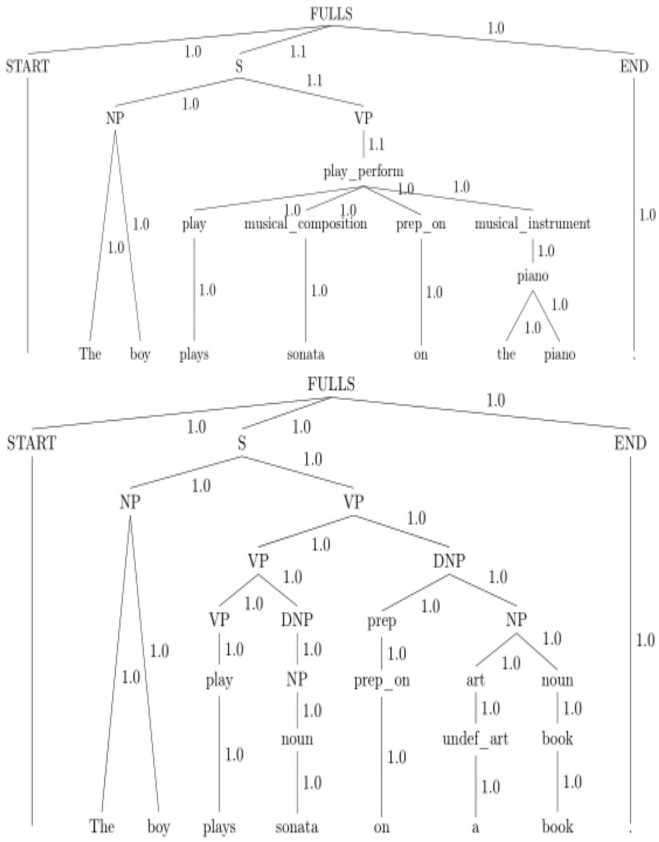

Fig. 4. The result of parsing sentences "The boy plays sonata on the piano" and "The boy plays sonata on a book". FULLS stands for "full sentence", S – a part with major clause, VP – verb phrase, NP – noun phrase, DNP – object or complement.

CONCLUSIONS

Experimental results have confirmed that the information technology for Ukrainian Sign Language translation based on grammatically augmented ontology performed better translation than other information technologies. The use of the developed grammatically augmented ontology for parsing sentences in Ukrainian Spoken and Ukrainian Sign Languages improved the performance of APCFG parser. The major increase in percentage of correctly parsed sentences was achieved for Ukrainian Sign Language. The work is a part of a larger project conducted by authors to tackle the bidirectional Ukrainian Sign Language translation problem.

However, we faced challenges of verification ontology files from different sources, the automation of the process of building GAO ontologies from other known ontologies and large text corpora. Besides, optimal weights for rules generated from GAO expressions and grammatical rules should be determined to achieve better performance of APCFG parser. These challenges will be the subject of further research.

REFERENCES

1. **Kulbida S.V. 2009.** Ukrainian Sign Language as a natural sign system. Sign language and the present: scientific research journal. Tsentrodruk, 218-239. (in Ukrainian).
2. **Adamyuk N.B. and Chepchyna I.I. 2009.** Syntactic features USL: the case of simple sentences. Sign language and the present: Coll. Science. works. Issue 4, 170-191. (in Ukrainian).
3. **Stein D. Dreuw P., Ney H., Morrissey S. and Way A. 2007.** Hand in Hand: Automatic Sign Language to Speech Translation. In Proceedings of Theoretical and Methodological Issues in Machine Translation (TMI-07). Sweden. 214-220.
4. **Lozynska O.V., Melnyk A.S., Davydov M.V. and Nikolsky Iu. V. 2014.** Development of the statistical machine translation system from Ukrainian Sign Language into Ukrainian Spoken Language to support business processes. Electronics and Computer Science, Science and Technology magazine, Kharkiv National University of Radio Electronics. № 1 (60), 35-39. (in Ukrainian).
5. **Safar E. and Marshall I. 2001.** The architecture of an English-text-to-Sign-Languages translation system. In G. Angelova, editor, Recent Advances in Natural Language Processing (RANLP). Tzigov Chark. Bulgaria. 223-228.
6. **Dreuw P., Stein D. and Ney H. 2009.** Enhancing a Sign Language Translation System with Vision-Based Features. Gesture-Based Human-Computer Interaction and Simulation. Lisbonю Portugal Vol. 5085. № 1, 108-113.
7. **Morrissey S. and Way A. 2005.** An Example-based Approach to Translating Sign Language. In Proceedings of the Workshop in Example-Based Machine Translation (MT Summit X). Phuket. Thailand. 109–116.
8. **Almasoud A. M. and Al-Khalifa H. S. 2012.** A Proposed Semantic Machine Translation System for translating Arabic text to Arabic Sign Language. Journal of Software Engineering and Applications. Vol. 5. № 8, 604-612.
9. **Lytvyn V. 2013.** Design of Intelligent Decision Support Systems using Ontological Approach. EconTechMod, An International Quarterly Journal on Economics in Technology, new Technologies and Modelling Processes. Krakiv-Lviv. Vol. II, № 1, 31 – 38.
10. **Lytvyn V., O. Semotuyk and Moroz O. 2013.** Definition of the semantic metrics on the basis of thesaurus of subject area. Econtechmod : an international quarterly journal on economics in technology, new technologies and modelling processes. Lublin. Rzeszow. Vol. 2. № 4, 47-51.
11. **Bungeroth J. and Ney H. 2004.** Statistical Sign Language Translation. Proc. LREC 2004, Workshop proceedings: Representation and Processing of Sign Languages. Lisbon. Portugal. 105–108.
12. **Othman A. and Jemni M. 2011.** Statistical Sign Language Machine Translation: from English written text to American Sign Language Glos. IJCSI International Journal of Computer Science Issues. Vol. 8. № 3, 65–73.
13. **Dasgupta T., Dandpat S. and Basu A. 2008.** Prototype Machine Translation System From Text-To-Indian Sign Language. In Proceedings of the IJCNLP-08 Workshop on NLP for Less Privileged Languages. 19–26.
14. **San-Segundo R., Pérez A., Ortiz D., D'Haro L.F., Torres M.I. and Casacuberta F. 2007.** Evaluation of Alternatives on Speech to Sign Language Translation. Proc. of Interspeech. Antwerp. Belgium. 2529–2532.
15. **Suszczańska N., Szmal P. and Kulików S. 2005.** Continuous Text Translation using Text Modeling in the Thetos System. International Journal of Computational Intelligence. Vol. 1. № 4, 255–258.
16. **Krak Iu., Barmak A. and Kryvonos Iu. 2009.** Computer technology for sign language modeling. Supplement to the International Journal "Information technologies & knowledge". Institute of information Theories and Applications FOI ITHEA. Sofia. Bulgaria. Vol. 3. № 15, 40–48.
17. **Lozynska O.V. and Davydov M.V. 2015.** Mathematical model of grammatically augmented ontology. Visnyk of the National Technical University "KPI". №11 (1120), 102-108. (in Ukrainian).
18. **Project «UkrParser».** Available online at: <https://github.com/mdavydov/UkrParser> (in Ukrainian).
19. **Lozynska O.V., Davydov M.V. and Pasichnyk V.V. 2014.** Rule-based machine translation for translation into Ukrainian Sign Language. International scientific journal "Information Technology and Computer Engineering". Vinnytsya. 11-17. (in Ukrainian).
20. **Lozynska O.V. 2014.** Application of rule-based machine translation for Ukrainian Sign Language translation. Information systems and networks. Visnyk of the Lviv Polytechnic National University. Lviv. № 783, 368-375. (in Ukrainian).
21. **Bilodid I.K. 1970-1980.** Ukrainian dictionary. Kyiv, "Scientific Opinion". Vol. 1-11.

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Analysis and modeling of load parameters of wind power station

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Abstract. The method and the load parameters dynamics simulation algorithm fed to the input of the energy-dynamic wind power station modes management system have been developed. Based on the real data analysis, we obtained dependencies of the management system input data changes for the specific time intervals. Input load parameters were simulated using the developed method. We have obtained data for the neural network training with the justification of changes in active wind power composition. The results are shown in a load parameters table as input management system data and estimated load charts. The results are important for the wind power station management system simulation as they provide higher reliability and accuracy of the results.

Key words: wind power station (WPS), load curve, management system, input load parameters simulation.

INTRODUCTION

Modern industrial WPSs consist of a large number of different types of electrical wind turbines (EWT), and their operation modes are determined by the balance of generated and consumed electricity. These conditions, on both sides, are determined by the random processes, which significantly complicates the energy-dynamic processes control algorithm [12, 15]. This problem becomes particularly relevant in case of WPS operation simultaneously with the electrical distribution network, that is, when it is necessary to ensure implementation of a complex load schedule based on active capacity or other mode parameters [11]. The possibility of power generation by a wind turbine depends on many factors, the most important of which are wind power and the technical condition of the EWT. [1, 9, 18] The capacity of modern WPSs is so high that objective of generating the necessary amount of energy in some periods of time does not require the operation of all existing EWT [20]. So nowadays, an urgent task is to increase the efficiency of certain electrical wind turbines operation within a farm wind [2] in order to increase the period of their operation, optimization of electric-dynamic modes [10]. To study and implement these modes within certain time intervals, required composition of wind turbines is formed. In [3] this issue is addressed by developing each wind turbine usability coefficient at a given time, which makes it possible to substantiate and change the WPS structure. However, the analysis of the energy-dynamic processes management implementation results suggests that one of the possible methods of improving its effectiveness is a preliminary study of the load parameters for specific time intervals in order to enable the situations classification to make a decision on the change in the active composition of wind power station [4, 14, 17].

Therefore, the load parameters dynamics study, development of methods for its simulation to improve the efficiency of wind power station energy-dynamic modes management is a ***critical scientific task.***

The design and operation of electrical systems provides for three types of electric load, reactive load power Q, active load power P and current I. The curve which reflects the change in load over time is called load demand. The load at a given time means its true value determined using measuring devices with low inertia. The value of consumed active and reactive power depends on parameters such as the number, determined power and operation modes of different types of receivers. Power consumption can vary widely throughout the day. The total electrical load that determines the mode of power station operation is changing continuously [5]. This fact is usually reflected using load curves, i.e. charts of electrical unit capacity change over time, which can be smooth, zigzag or stepped curves built in the Cartesian coordinate system, where the vertical axis reflects power, and the horizontal axis - the time during which its change is considered. Load curve which characterizes the change in capacity for one day is called a daily curve [5, 6].

The value of the load for different groups of consumers may differ, but the load curves share some general quantitative estimates – they include the largest and the smallest value of load capacity at a certain time interval. To analyze the data on the capacity use, daily curves for the two typical periods of consumers operation

– in summer and winter – are used. Hence, the highest and the lowest load are distinguished for these periods.

OBJECTIVE

The objective of this work is a preliminary study, extrapolation and simulation of the load parameters dynamics which are fed to the management system input to improve the efficiency of methods and means used to determine a plurality of used electrical wind turbines (EWT) by increasing the reliability of input data.

THE MAIN MATERIAL

The task of obtaining reliable load parameters at the wind power station management system input is very important because to verify the algorithms for analysis, simulation, forecasting, dynamic determination of wind power station composition used in the system developing, it is necessary to submit data with high reliability. At the first step, it is necessary to create and fill a database with the real control input load values which can be obtained from the real daily load curve for the basic consumer groups for the regime days of June and December from the company which provides services to the electricity consumers.

In order to obtain universal data, data on the load dynamics at the administrative unit level - the region rather than at the level of the building, street, district or city were used because at the high level of integration, load curves for different regions will have a high degree of similarity which will allow taking into account the typical change in the load parameters.

Based on the data obtained in [7], we are building region power grid daily load change curves (Figure 1), where —— the load parameters change throughout the day in June 16; - - - the load parameters change throughout the day in December 15; -·-·- the load parameters change throughout the day in June 15; -··- the load parameters change throughout the day in December 21; ······ the load parameters change throughout the day in June 21; —— the load parameters change throughout the day in December 20.

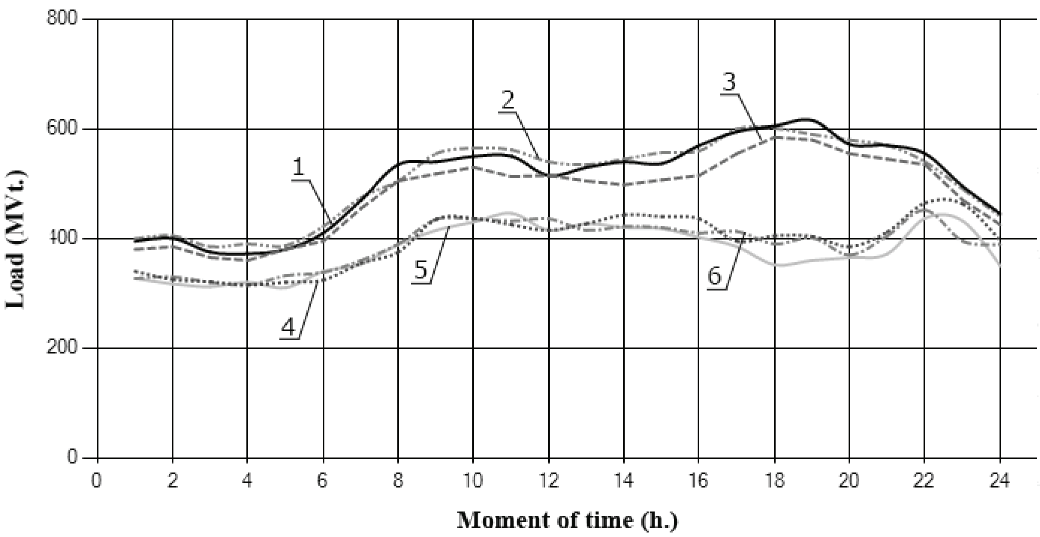

Fig.1. Daily grid load curve in the summer and winter periods

On the vertical axis, you can see load (MW) at time t (h) which is shown on the horizontal axis. The figure shows six curves, curves 1, 2, 3 characterize the load parameters change throughout the day for winter the period while curves 4, 5, 6 show the change throughout the day in the summer period for three consecutive years.

Algorithm and software which allows us to obtain the data change interval and visually display the result in the form of a load curve have been developed [13] for the analysis of input load parameters. Algorithm for determining the load used for the software development can be presented using a block diagram (Figure 2) [19].

The first step is to determine the maximum and minimum capacity in each control point. Mathematically, this step can be represented as follows:

$$P_{\max}(t_j) = \max(P_i(t_j)), \tag{1}$$

$$P_{\min}(t_j) = \min(P_i(t_j)), \tag{2}$$

where: $P_{\max}(t_j), P_{\min}(t_j)$ – the maximum and minimum capacity in t_j time respectively, $j = [0,23]$;

$(P_i(t_j))$ – value of the i-th capacity measurement in t_j time period; $i = [0, n]$ - the number of measurements.

Since the reference data are provided accurate to an hour, it is necessary to extrapolate the maximum and minimum values to improve the reliability of the resulting data.

Discretisation is specified by the software user. Mathematically, extrapolating process [8, 16] can be represented as follows:

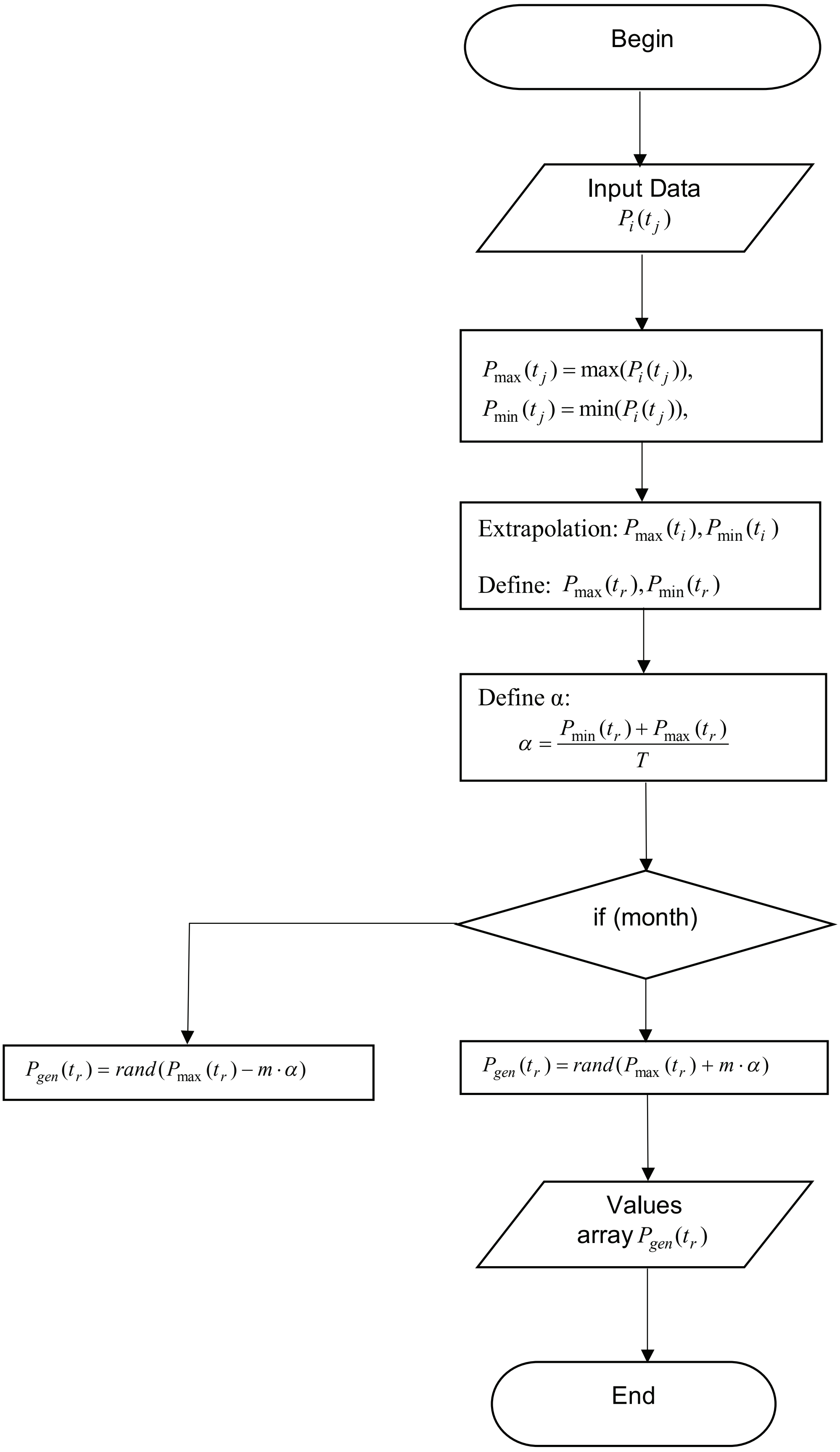

Fig. 2. Block diagram of the algorithm for the wind turbine management system input load analysis

$$P_{\max}(t_r) = \frac{P_{\max}(t_j) + P_{\max}(t_{j+1})}{K} \cdot r, \quad (3)$$

$$P_{\min}(t_r) = \frac{P_{\min}(t_j) + P_{\min}(t_{j+1})}{K} \cdot r, \quad (4)$$

$$r = k \cdot \Delta \quad (5)$$

where: $P_{\max}(t_r)$, $P_{\min}(t_r)$ is the maximum and minimum capacity at the r-th second of time,

r is moment of time for which $P_{\max}(t_r)$, $P_{\min}(t_r)$ is determined,

k is experiment number K= 3600,

Δ is generating discretisation (set by the user).

The next step is to determine the values of the input capacity for experiments in a special range of values. Since the system load parameters are directly proportional to the length of the daylight, which is clearly confirmed experimentally by analyzing measurements of extreme values of instant capacity, to enhance the results reliability, it has been proposed to narrow the range of the spread of values by introducing the correction coefficient α.

The mathematical description of the process is as follows:

$$\alpha = \frac{P_{\min}(t_r) + P_{\max}(t_r)}{T}, \quad (6)$$

where: α is corrective coefficient determined as an average between the maximum and minimum values of capacity, at the T = 6 intervals, i.e. every six months.

$$P_{gen}(t_r) = rand(P_{\max}(t_r) - m \cdot \alpha) \quad (7)$$

or

$$P_{gen}(t_r) = rand(P_{\min}(t_r) + m \cdot \alpha) \quad (8)$$

where: $P_{gen}(t_r)$ is the determined capacity in t_r time period in the adjusted range,

$m = [1,12]$ is serial number of months in the year.

The results of the algorithm operation can be viewed in tabular and graphical mode.

Figure 3 shows the load parameters dynamics curve for 24 hours with a step of 300 seconds.

Figure 4 shows the load parameters dynamics curve over a period of 7 days with a step of 500 seconds.

Figure 5 shows the load parameters dynamics curve for a period of 12 months with a step of 3600 seconds.

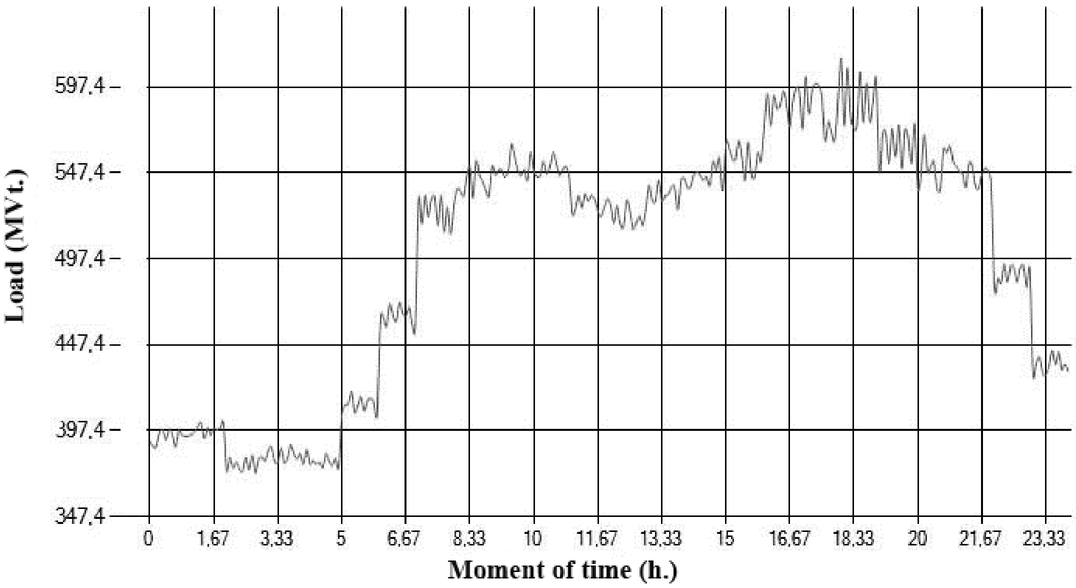

Fig. 3. Load parameters dynamics for 24 hours with the generation interval of 300s

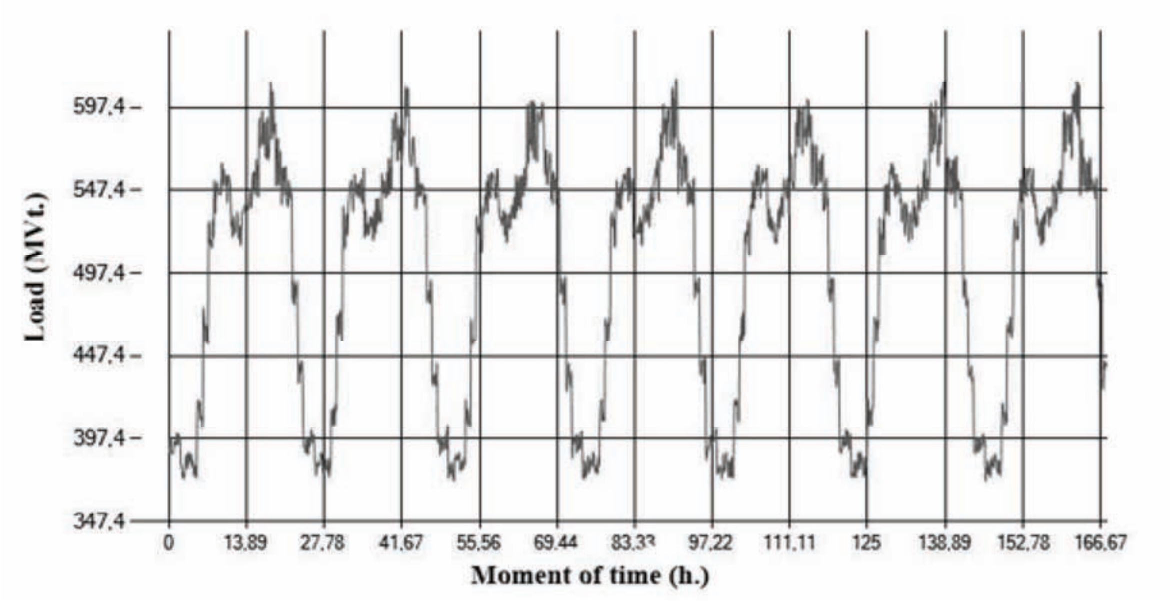

Fig. 4. Load parameters dynamics for 7 days with the generation interval of 500s.

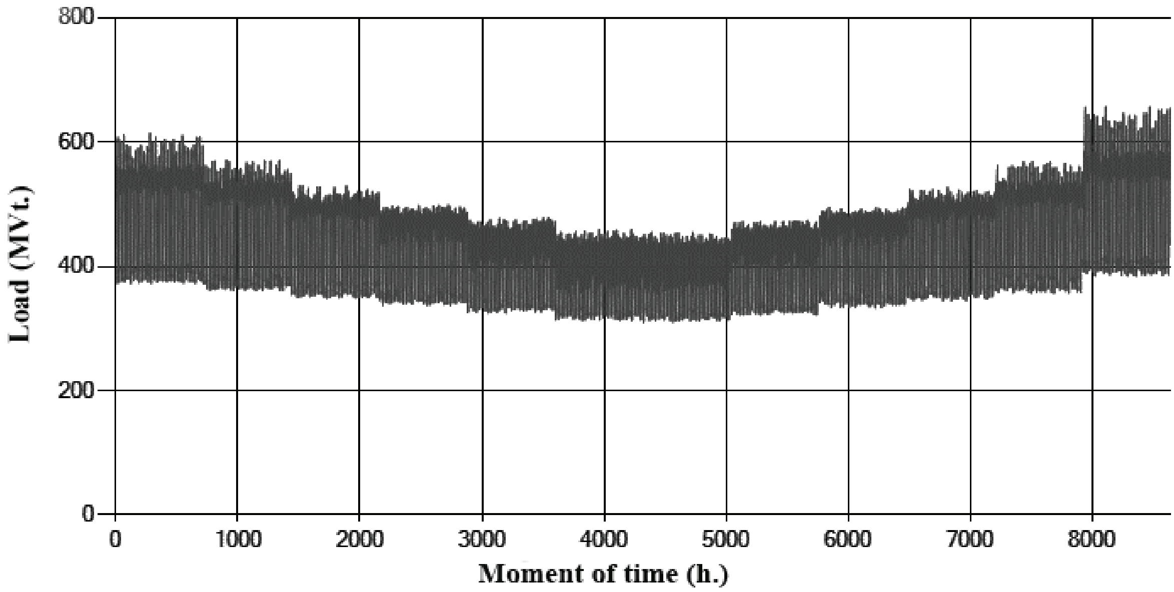

Fig. 5. Load parameters dynamics for 360 days with the generation interval of 3600s.

CONCLUSIONS

Algorithm and software which allows us to determine the real input data change intervals and visually display the result as a load curve have been developed for the analysis of the input parameters of the active power management by WPS. The input values dynamics dependencies for the typical time intervals based on the real data analysis have been obtained [21, 22].

The input load parameters were determined with one second discretisation using the algorithm which can be used to teach the neural networks when justifying active wind power station composition. The specified range of data provides a more detailed description of the input load parameters curve and increases the results reliability.

The results are presented in a table of input load parameters as input data of the management system and calculated load curves. The results are important for the wind power station management system simulation as they provide higher reliability and accuracy of the results.

REFERENCES

1. **Medykovskyy M.O., Shunevych O.B. 2010** Using integer programming for determination of wind power, Modeling and Information Technologies, Kyiv, Vol 57, 230-233 (in Ukrainian).
2. **Medykovskyy M.O., Shunevych O.B. 2010** Multicriteria method for evaluating the effectiveness of wind energy installations, Journal of Engineering Academy of Ukraine. – Kyiv, 2010, Vol. 3-4. 240-245 (in Ukrainian).

3. **Medykovskyy M.O., Shunevych O.B. 2011** Investigation of the effectiveness of methods for determining weight coefficients importance // Journal of Khmelnytsky National University: Coll. scientific-technical. papers. – Khmelnytskyi, 2011, no 5, 176-182 (in Ukrainian).

4. **Medykovskyy M.O., Shunevych O.B. 2009** The method of determining the structure of wind power plants, taking into account the dynamics of load Modelling and Information Technology: coll. science. works. - Kyiv .: IPM NASU. 2009. Vol. 53. 175–181 (in Ukrainian).

5. **Knyazevsky B.A, Lipkin Y.B 1986** Electrical supply of industrial enterprises, Higher School, Moscow, 1986. 400 (in Russian) .

6. **Fedorov A.A., Kamenev V.V. 1984** Fundamentals industrial power, Energoatomizdat, Moscow, 1984. 472 (in Russian).

7. **Oliynyk Y. 2008** Research conjuncture electricity markets of Western Ukraine, NS mowers, LI pipers. Bulletin "Lviv Polytechnic": Logistics, no.6 (23).109-116 (in Ukrainian).

8. **Garkusha N.M., Tsukanov A.V., Horoshanska A.A. 2012.** Models and methods of decision analysis and audit., 2nd ed., Erased. Kyiv, Knowledge, 2012. 591 (in Ukrainian).

9. **Labeysh.V.G. 2003** Alternative and renewable energy sources: Textbook, Sankt-Petersburg, 2003. 25 (in Russian).

10. **Venikov V. A., Zhuravlev V.G., Filippova T.A. 1990** Optimization of power plants and power systems, 2nd ed., Rev. and add. Moscow: Energoatomizdat, 1990. 349 (in Russian).

11. **Shunevych O.B. 2008** Analysis of operating systems for embedded technologies, Technical missing. Lviv, Vol. 2008/1 (27) 2 (28). 40-44. (In Ukrainian)

12. **Shunevych O.B., Medykovskyy M.O.** 2009 Fuzzy logic in simulation mode enerhodynamichnyh, "Signal processing and non-Gaussian processes": II Intern. scientific-practic. conf, 25-29 May. 2009, Cherkasy: Theses. / Cherkas. state technical University. – Cherkasy, 2009. 255-256. (In Ukrainian).

13. **Shunevych O.B. 2009** Features of programming techniques TDD, Automation 2009: 16 Intern. Conf. from the automated control, 22-25 September. 2009, Chernovtsy: Theses. / Mob. nat. Univ. them. Fedkovych. - Chernivtsi.. 405-406. (In Ukrainian).

14. **Medykovskyy M.O., Shunevych O.B. 2010.** Optimal Choice of Wind Turbines Combination Based on Customer's Requirements, "Modern Problems of Radio Electronics, Telecommunications and Computer Science": 10-Intern. scientific-technical conf, 23-27 February. 2010, Lviv-Slavsko: Theses. / Nat. University of "Lviv Polytechnic". 319 (in Ukrainian).

15. **Medykovskyy M.O., Shunevych O.B. 2010** Energy-dynamic modeling processes in renewable energy systems, Automation 2010: 17 Intern. Conf. from the automated control, 27-29 September. 2010, Kharkov: Theses / Kharkiv University of Radio Electronics. - Kharkov. 56-58. (In Ukrainian).

16. **Bondarenko M.F., Bilous N.V. 2004** Computer discrete mathematics, Kharkiv. 438. (in Ukrainian).

17. **Valenkin N.Y. 1975** The popular combinatorics, Publisher 'Nauka', Moskow, 139-140 (in Russian).

18. **Urin V.D, Cutler P.P 1974** Energy performance for optimization of power stations and power grids. Mosow: Energia,. – 136 (in Russian).

19. **Corman T., Charles Leiserson T., Rivest R., Stein C. 2005** Introduction to Algorithms, 2nd ed. Moscow: Williams. 1296 (in Russian).

20. **Gamm A.Z., Kucherov Y.N. 1991** Methods for solving problems in the power of real-time H-SC .- Nauka, 1991. – 272 (in Russian)

21. **Horyński M., Pietrzyk W., Boguta A. 2012** A model of an energy effi cient building automation system, EconTechMod, An International Quarterly Journal on Economics in Technology, new Technologies and Modelling Processes. Krakiv-Lviv, Vol. 1, No 1. 41-47.

22. **B. Kovalyshyn 2012** Theoretical and experimental ground of the fuel energy efficiency improvement by an activation of the burning reaction molecules-reagents, EconTechMod, An International Quarterly Journal on Economics in Technology, new Technologies and Modelling Processes. Krakiv-Lviv, Vol. 1, No 1. 63-67.

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Mobile Information Technologies for Tourism Domain

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Abstract. The paper analyses a number of advanced mobile information technologies in the sphere of tourism. A large volume of information has been processed to determine the main areas of development and improvement of tourism mobile information technologies. Mobile information technologies are built both for tourists and for travel agencies. In this paper, information technologies for individual tourists are laid stress on. These are tourist program guides, augmented reality tourist information systems, gamification traveling systems, tourist location based systems and others. The paper offers description of the available mobile software for trip planning and information support of tourists during a trip. It consists of two chapters: the current studies and existing mobile program algorithmic tools. According to the research outcomes, the authors propose to build a new information system for tourists Mobile Tourist Information Assistant. A set of functional features of this system as an integrated information system relying on mobile applications is proposed. The main principle of the system is EVERYTHING, HERE AND NOW.

Key words: mobile IT, mobile application, information technology, mobile information system, tourism, e-tourism, travel planning, travel information support.

INTRODUCTION

The modern information society is rapidly approaching a new peak of mobile information technology evolution. The use of smartphones and tablets for mobile access to the Internet resources has increased to the level where the number of accesses to them has exceeded the amount of traffic from stationary specialized access tools [1]. According to eMarketer's research, the total number of mobile Internet users in 2013 reached 134 million, and by 2019 this figure will have become twice as large as the number of desktop computer users [2].

The tourist industry is an area which needs the use of mobile information technology for full-scale operation and development. Mobile Information Technologies significantly affect both the behavior of tourists and the whole industry in general [3].

Traditional software products focused on stationary PCs remain important means of information marketing tools and information technology support for tourism businesses. However, tourists are increasingly using their mobile devices (smartphones, tablets) for planning their next trip, studying tourism destinations, booking hotel rooms, etc. [4].

The implementation of the EVERYTHING, HERE AND NOW principle in the tourist information resources is becoming increasingly popular among both tourists and people engaged in tourism.

THE ANALYSIS OF RECENT RESEARCHES AND PUBLICATIONS

Tourist's questions to be answered using up-to-date IT

The tourist industry clearly demonstrates a huge potential for application of mobile information technology.

However, there is still insufficient understanding of the range of methods and tools which can be used by tourists on the move for trip planning and support.

The number of issues to be dealt with during a trip is often underestimated, but they could be successfully tackled with mobile IT.

A tourist trip is naturally divided into several stages, and each of them requires adoption of certain decisions to address a number of specific problems (see Table 1).

Table 1. Information support of decision-making processes at different stages of a tourist trip

STAGES OF THE TRIP	TRIP PLANNING										
						TRIP IMPLEMENTATION					
										AFTER TRIP ENDS	
NEEDS OF THE TOURIST	Choosing tourist destination		transport decision	budget counting	information collection		booking accomodation	tour guide	food	experience exchange	the analisis of the results of the trip
	trip in one city	trip arroud tourist route			general information	detailed information					photo/video archive

A good pre-planned trip will require less effort in the future to overcome different kinds of problems. The main question to be answered before a tourist trip is **"Where?"** A Facebook survey showed that 52% of users claim that photos of their friends travelling significantly affected their decisions on where to go [1].

An equally important question which a tourist faces is **"When?"**, because each tourist destination has certain features and characteristics which should be considered at the planning stage of the trip. The season and the profile of the tourist group must also be considered. Many tourists face these questions when they are actually on their trips, and this entails making operational decisions under extreme conditions often with strict time limits.

One of the first and probably the most important problems encountered by tourists staying in an unfamiliar place is **"What to do?"** Tourism is a specific form of human activity which includes a number of opportunities and choices, such as visits to sites of interest, relaxation, searching and buying souvenirs, etc. Usually, tourists need to make decisions very quickly on a wide range of issues regardless of the type of holiday [5].

Typically these decisions must take into account the time needed to get to the right place and tourists' preferences with regards to tourist attractions. Therefore, the question **"Where?"** arises naturally. Tourists often visit an impressive number of tourist attractions so the travel route has to be optimized. Along with the previous question, the question **"How?"** must also be answered. When visiting certain countries, tourists should be informed about behavior, local customs and rules to avoid unpleasant situations and possible rejection by the local population [5].

Tourists often analyze their progress and the details of their trips and then share experiences with friends, family and relatives when the trip is over. According to the survey, 41% of Facebook users in the UK posted a summary of their trip, 24% of users shared their experiences through social networks and blogs even during the trip and 49% posted their records after returning home [1].

At first glance, quite simple and sometimes trivial questions that arise when planning and implementing a tourist trip after more rigorous analysis can transform into an extensive complex of interrelated problems. This in turn translates them into the category of semi-structured tasks requiring the use of a wide range of special mathematical methods and algorithmic tools to find a solution.

Classes of mobile applications in the sphere of tourism

As a result of the rapid technological development of smartphones, tablets, and other mobile devices, the market for mobile software applications has increased dramatically. Mobile information technology in its functional guidance and complexity of implementation in the field of tourism has reached a new higher level of development. The modern tourist cannot feel comfortable without the support of intelligent information technologies at all stages of a trip. In fact, a large number of new original methods of acquisition, use and distribution of tourist experience have been formed [6].

According to the situation and context, users have different information needs that can be satisfied by using mobile information technology and appropriate computer tools. As a result, mobile software applications developed to cater for a certain stage of a tourist trip must be endowed with specific properties and ensure quality performance of certain functions in order to meet all the tourist's needs [7].

According to the functional content of mobile software applications for the tourism industry they can be divided into the following classes:

- *Trip Planners* – software that the tourist can use to plan the main aspects of the trip (e.g., hotel booking, transport, etc.).
- *Route Planner* – systems which provide for quality planning of travel routes.
- *Tourist information* – the systems providing the user with comprehensive information on various travel destinations. Such systems are commonly used at the planning stage of trips, when a potential tourist collects and analyses data about places to visit during the trip. This information can be presented to the user in the form of text, audio and video files and images.
- *Offline information tourism systems* – travel systems that require a large amount of available memory on a mobile device, since all information is stored in it. They feature a limited volume of information and less detailed data.
- *Service tools of comparison and booking of services* – systems which are used to compare the prices of certain type of services and allow booking hotel rooms, flights, etc.
- *Tourist program guides* – systems which replace human guides by providing information on target destinations on a route. Relevant information in the system can be supplied in the form of static images, text, audio and video formats. In some cases, the system provides recommendations to the user on the routes of viewing of particular places of interest.
- *Dynamic maps* – maps which contain labels with information about each individual object depicted in a dynamic view. The user is able to choose what information is of interest.
- *Systems for tracking the location of transport means* – systems which provide the user with information about the location of a certain type of public transportation such as taxi, bus or train.
- *Geographical digital offline maps* - similar to offline information systems in that they require a large amount of available memory, and they usually require additional downloading of various maps in the context of individual countries and regions.
- *Augmented Reality systems* – tools which provide additional information about the place where the user is located and the objects in view. To do this the user must have a mobile device with a webcam and GPS interface, as augmented reality systems are based on the principles of video and image processing, machine vision algorithms and information about current locations.
- *Location-based systems* – systems which need information about the current geographical location of the

user and, accordingly, the mobile device to ensure good quality functioning.

- *Knowledge-sharing systems* - allow users to share their experiences on the trip. This applies to the trip itself and also to reviews after it is finished.
- *Gamification traveling system* – a system which forms tasks which need to be completed during the trip, or while exploring a specific tourist attraction. Such tasks usually cannot be solved if the tourist is not in the territory of a tourist attraction. In case of solving a task the system provides information about the current location. This information is presented in an interesting and entertaining form.

Current researches of mobile information technologies in the sphere of tourism

The tourism industry is one of the most topical spheres for research today. This is particularly true about an innovative class of systems for mobile information technologies. Scientists are working to develop new tools and methods of submission and processing of tourist information and systems to generate personalized recommendations. Powerful centers of development of advanced mobile information technologies for the tourism industry are The Digital Tourism Think Tank, International Federation of IT and Travel & Tourism, Bournemouth University (United Kingdom), University of Lugano (Switzerland), etc.

Tourist program guides. Travel systems called program guides have become very popular with mobile users. Modern tourists require personalized access to comprehensive travel information in any place they stay and at any time. Mobile application guides have been created to take into account such requirements [8].

One of developments of this type is Latvia.Travel created by scientists who are members of The Digital Tourism Think Tank aimed at tourists who are traveling in Latvia taking into consideration the features of the country. The aim of the mobile application is to give the tourist access to good quality information during the trip. The developers claim that by using the application the user gets much more than expected. Functionally, Latvia.Travel can replace a website containing information about directions, tourist attractions, cafes, restaurants, hotels and events that may be of interest to tourists [9]. The application developer, Didzisom Spruds, confirms that a growing number of users are visiting the site Latvia.Travel using only a mobile device. This is yet another proof of the need to provide travelers with mobile software applications which can support them in their current locations [9].

A mobile information system with similar functionality is Innsbruck.mobile, a mobile travel guide for visitors of the city of Innsbruck. The system provides access to detailed information on tourist facilities, hotels and apartment rentals, current events in the places of tourist stays, places of dining and shopping, etc. At the same time, the system provides recommendations to tourists according to their wishes and preferences via short message service. Developers continue to work on algorithms to generate recommendations and information contents of the system [10].

Another modern mobile information tool is an application to the web site of the Saint Olav's Way (Norway). It contains consolidated information from the website and offers powerful functions for travelers, such as travel planning tools, information storage on a mobile device for off-line access, emergency calls with the transfer of location information, experience exchange (posting information on social media networks) [11].

An integral part of the tourism sector is entertainment. This in turn results in increasing dissemination of travel computer gaming systems. An example of such systems is Peter`s TrevelPlot Porto [12]. This is a computer audio-guide that provides additional interesting tourist information while asking a tourist to complete a specific task, such as "finding treasure". The "legend" the application is based on is the "great treasures" hidden in the city of Porto which must be found by a tourist faster than by his virtual rival. The task successfully completed, the system provides the user with information on tourist places of interest. The described "Legend" is divided into nine chapters and forty-two historical places of interest. Mobile application Peter`s TrevelPlot Porto has received numerous positive reviews from the users [12].

Tourist Augmented Reality systems. The technology of Augmented Reality (AR) is a mobile information technology that is rapidly gaining popularity. Augmented Reality as a technological concept was announced in 1960, but only now there have arisen real opportunities for the development and implementation of this technology. AR is an imaging technology based on information provided in the form of text, video and graphics that overlay the real images of the object taken with a mobile device camera. In other words, AR can complement the representation of surrounding reality through the additional information, thus contributing to a better understanding of surrounding objects [13].

The Augmented Reality technology is used in many spheres of human activity, and one of the most popular in this context is the tourism sector [14].

The overall structure of the tourism augmented reality systems can be represented as the combination of six classes (see Fig. 1). Class Servers is the main class of the system. It contains the functions of processing data received from a user to generate the required information and display this information on your mobile device. Class Smartphone is responsible for receiving data from the user and images from a webcam of his/her mobile device. BackendSystem class is a class that connects Smartphone and Servers classes. This class is responsible for setting the correct connection to the server and transferring the information from the device. Additional classes of the system are TouristLogin, which is responsible for signing in the user, and TouristRegister used to register a new user. These classes are important in case of generating personalized tourist information on the user's location and surrounding objects. The class Form is responsible for establishing communication between the user and the system [14].

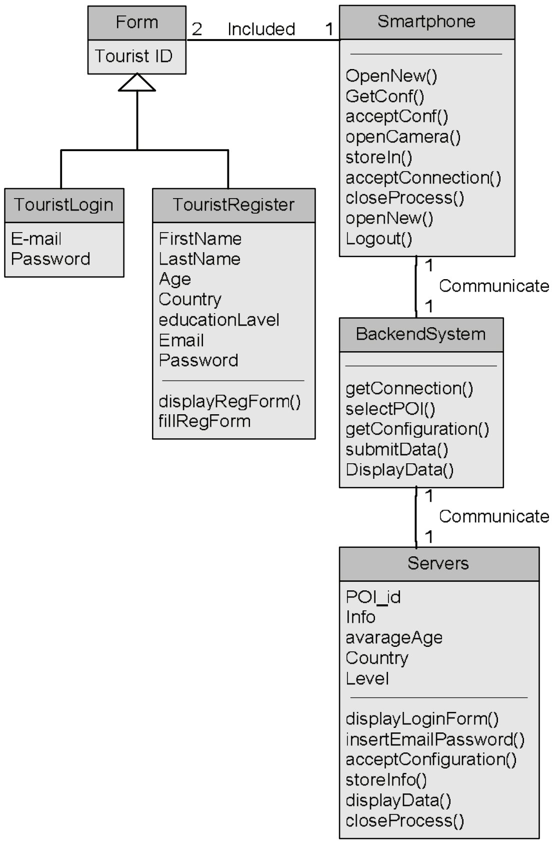

Fig. 1. General structure of augmented reality systems [14]

One of the first Augmented Reality systems for tourist purposes is the system developed based on the information resources of the region of Tuscany (Italy), Tuscany +. The software application offers an interactive guide services in real-time mode to improve traveling conditions with regard to four branches of information contents, including sites of interest, accommodation, food and entertainment [15].

A well-known Augmented Reality system is the mobile software platform MobiAR devised in Android OSE. MobiAR gives offers tourist information about specific cities or objects. Tourists have the opportunity to use application MobiAR on their mobile devices. Using multimedia content, the system informs about the events that occurred in the user's location and provides access to necessary information when planning tour routes [16]. The system consists of subsystems of registration, user configuration, visualization of the map with marking of tourist sites and content generation for each tourist site. The developers have used cloud technology to implement communication between the mobile application and knowledge base [16].

Gaming systems with the feature of augmented reality are popular software in the sphere of mobile information technology in the sector of tourism gamification. They are good motivators of active and cognitive traveling.

An original case of computer augmented reality games is the mobile system TIMEWARP. The main purpose of TIMEWARP is defined as encouraging gamers to actively engage with the city [17]. The game is based on a fairy story *The Elves of Cologne*. The legend tells about elves that helped the city every night, and then suddenly disappeared. The developers of the application have suggested that elves remained in the city but got into time traps and find themselves in their time dimension. The main aim of TIMEWARP is to search elves in different eras using the time window tool, a user mobile device, and return them to real time [25].

Location-based services for tourism domain using GPS tools. Mobile tourist-oriented information technologies form a powerful sector of the market for mobile computer tools with GPS, which in turn generates a new class of technologies – location-based mobile services.

The representative of this class of systems is a mobile recommender system of public transportations PECITAS, established to meet the needs of visitors of Bolzano (Italy). The system provides the user with recommendations on the type and schedules of public transport, which tourists benefit from to move between two points in the city; the start point is the current location of the user. The system generates personalized recommendations based on the knowledge base and taking into account the specific preferences of a particular user. [26]

GPS technology is a convenient tool for the analysis of user behavior and of using the resulting information to provide better professional advice. One of the advanced developments of modern information technologies to get the information on user location is GimToP Toolkit (GTK). To understand the processes of the system, it should be noted that GPS-tracking is a common method of empirical research to obtain information on human behavior. The recorded GPS trajectories make it possible to analyze and to some extent explained the movements of individuals in space and time. GimToP Toolkit (GTK) is a combination of an original methodological approach and data processing technology with GPS. The system combines the data path with user polls obtained by using special mobile applications. Connecting to the server enables survey data processing and interaction with the applications. The system operation results in the information on tourists' behavior, depending on tourist destination and the purpose of the trip [20].

Mobile program algorithmic tools for the tourism industry

Taking on board that the demand for good quality IT tourist products is growing exponentially [27], IT companies have got actively involved into the development of powerful mobile software applications for tourists and travel agencies.

A popular tourist program and algorithmic application for planning a trip is RouteIt [18]. The database of the system contains information about over 1,000 tourist routes, which are divided into 8 categories (historical, corporate, educational, wildlife, shopping, adventure, festival and romantic) and 29 subcategories. The application is functionally focused on meeting the needs of customers who want a virtual tourism trip. The system supports a function of panoramic view of streets via Google Street View. The application supports information sharing by using social networks Facebook and Twitter. In addition, the system allows you to find other tourists that are traveling at the same time in the vicinity of the route chosen by the user [18].

A popular tourist destination mobile software tool to plan and support the implementation of the trip is the mobile travel application TripAdvisor, which contains information about the most popular tourist destinations, places of accommodation, food, entertainment, etc. The user can download information from the free city guides, which then can be used without connecting to the Internet. The system includes current location detection, tourist-guide and the planned route navigation [19].

A mobile application standing out from the variety of trip planners is Minube, which was created to help tourists in choosing a tourist destination and planning a trip. It contains information on about 50,000 international tourist destinations. The information is divided into categories, taking into account the type of the trip. The application allows you to book a hotel and contains information about places to eat [20].

The application Trip Planner developed by Ukrainian programmers is a modern and popular in planning travel routes. The system allows users to create travel routes with a feature of navigation across the path and saving the route. During the formation of the tourist route the system takes into account the choice of appropriate transport solutions [21].

A powerful travel guide is the TourPal system, which provides the user with ample opportunity for travel planning and formation of separate tourist routes. The application provides information on tourist facilities, accommodation opportunities and places to eat. The location of these facilities is marked on the appropriate map. The audio-guide formed by professional tourist guides is a paid feature in this system [22].

The majority of mobile tourist guides and travel planners are created specifically for a special tourist destination. The mobile travel guide Malaysia Trip Planner is the official tourist application for tourists visiting Malaysia. It can be used at the stage of planning the trip and during its implementation. This application contains complete information about tourist sites of Malaysia, interesting events and festivals, places of accommodation and eating, etc. Among others, the application offers such functions as selection of information according to a specific user's preferences and knowledge sharing on social media networks [23]. Table 2 contains data on the comparative characteristics of tourism mobile information systems.

THE MAIN RESULTS OF THE RESEARCH

Mobile tourist information assistant

According to the analysis of the vast array of information sources, it can be stated that none of the currently existing mobile information systems for tourists meets the complex of all the needs and requirements of potential users. The authors of this paper propose to start developing a next generation system Mobile Tourist Information Assistant (MIAT) which will satisfy a wide range of information needs of all tourists in all stages of planning and implementation of a trip.

This system should provide the fulfillment of the following functions:

- helping the user in choosing a tourist destination,
- helping in selecting transportation (to a tourist destination and along the tourist route),
- creation of a tourist route based on a personalized statement,
- assistance in selecting places to eat and accommodation,
- changing the tourist route during a trip,
- providing information to the user before and during a trip:
  - general information about tourist destinations,
  - detailed information on every tourist site:
    - information on the type and specifics of a tourist site,
    - information about the location and opening hours,
    - tourist information in text, photo, audio and video formats,
- user locating,
- user navigation across the tourist route,
- hotel bookings, booking transportation (plane, train, bus), purchasing tickets to cinemas, theaters and museums online,
- creating photo and video archives of the trip with the option to attach additional information to each file (for example, location information, a description of a tourist sites, travel notes, etc.),

Table 2. Comparative characteristics of tourism mobile information systems

Mobile information tourist systems \ Functions	Planning routes	Offline mode	Information on tourist sites	Information about accommodation opportunities	Booking accommodation	Information on places to eat	Information on events and parties	Information on transport	Popular ready-made tourist routes	Paid content	Free content	Connection with social nets	Dynamic maps	Locating and Navigation	Audio-guide	Users mark*
RouteIt	+	-	-	+	-	+	+	-	+	+	+	+	+	+	-	4.3
Malaysia Trip Planner	-	-	+	-	-	-	+	-	+	-	+	+	+	-	-	3.3
Minube	-	-	+	+	+	+	+	-	-	-	+	+	-	-	-	4.2
Планувальник подорожі	+	-	-	+	-	+	-	+	-	-	+	+	+	+	-	3.6
TourPal	+	+	+	+	-	+	+	+	-	+	+	-	+	+	+	3.7
TripAdvisor	+	+	+	+	-	+	+	-	-	-	+	-	+	+	+	4.1

*Users marks are taken from the GooglePlay service [24]

- automatically creating a trip diary, based on data obtained during the trip (photos, videos, notes, user movements),
- posting photos, videos and notes on social networks such as Facebook, Instagram, Vkontakte.

In order to prepare comprehensive proposals on providing personalized recommendations by the system, the user is required to fulfill the procedures of registration and answering a series of questions about his/her preferences, habits, professional activity, marital status, age, etc. It is necessary to obtain the most complete and adequate image of a potential tourist.

This information is subsequently used at various stages of the system operation. Herewith, the system will require information about persons that the user is going to travel with, and data on the time limits of the trip, its maximum duration and approximate budget per person. The user will receive a list of recommended tourist destinations and their details, including, in addition to a general description, information about popular tourist destinations and tourist facilities, the estimated duration of the trip and its minimal budget [28, 29].

After the user selects a tourist destination, the system will offer a list of hotels and apartments which is generated in accordance with the wishes and needs of the user. Prospective tourists will be able to book a room at a selected accommodation facility online.

Another problem to be solved by a tourist with the help of MIAT is transportation. It is assumed that the system will provide the user with information about the cost of a transport solution, depending on the trip duration and accounting for the local estimated fuel prices. In addition, the system will provide opportunities of booking flight, trains and buses, and car rentals.

The user will be able to plan his/her trip in detail. MIAT will offer a list of recommended travel routes generated according to the results of the polls conducted at the beginning of the system operation. The user will be also able to create and modify the route according to his/her preferences at the stage of planning the trip and during its implementation. Any route can be stored on the mobile device and used offline.

While implementing a trip, the tourist will have access to any information about the tourist destination and its attractions. At this stage, according to the user's location, the system will generate recommendations, such as the nearest places to eat, or information about nearby tourist sites, etc.

All photos and videos taken with a mobile device while traveling will be automatically stored in the trip archive, enabling the user to provide additional information and description of the data files, as well as delete unnecessary one at any time. In addition, the user will have the option of making travel notes. The information gathered during the trip can be automatically saved in the user-editable travel diary.

The system provides for experience exchange, offering the option to post photos, videos and notes on social networks such as Facebook, Instagram and Vkontakte.

Table 3 presents the functions of the Mobile Tourist Information Assistant tool grouped according to the stage of the trip.

The basic principle that underlies MIAT is a quality implementation of the slogan EVERYTHING, HERE AND NOW. This intelligent mobile travel system should provide the user with information support in any part of the world and at any time.

So MIAT is a complex of system-integrated mobile program and algorithmic applications which will provide for the effective tourist's information support at all stages of planning and implementation of a tourist trip.

Table 3. Use of MIAT functionality according to the trip stage

	Stages of the trip		
	Trip planning	**Trip implementation**	**Analysis of the results of the trip**
MIAT functions	Help in choosing tourist destination	Locating the tourist	Access to saved photo and video archives
	Help in making transport decisions to a tourist destination	Help in selecting transportation along the planned route	Data sharing on social networks
		Help in renting a car	
	Transport tickets booking (plane, bus, train)	Editing the saved route	Forming the financial report on the trip
		Help in selecting places to eat	
	Planning a tourist route	Booking tickets to museums, theaters, cinemas	
	Accommodation selection and booking	Providing the user with detailed information on tourist sites	Option of evaluating every tourist route, tourist sites, accommodation and eating places on a ten-point scale
	Providing the user with general information on tourist destinations	Navigation along the route	
	Trip cost estimation	Creation of the trip diary and photo and video archive	
		Data sharing on social networks	

CONCLUSIONS

Despite the significant advances in mobile information technologies in tourism, the existing software has so far failed to fully meet the users' needs.

Most mobile tourist information systems still require direct access to the Internet, which is difficult to ensure in many cases. Systems on software tools that do not require direct Internet connection need a robust technical component for effective functioning.

Another drawback is that some of the mobile information systems rely on the information about the current location of the user, and the quality of their operation significantly varies depending on the hardware parameters and weather conditions.

At the same time, it should be emphasized that modern tourism mobile information technologies have a number of important positive qualities. They provide the user information support at all stages of the trip, which includes detailed information on tourist destinations, tourist attractions, places of accommodation and food, entertainment and upcoming events. Studies in the area of formation and provision of tourists with personalized recommendations are under way.

The analysis of the class of mobile information technologies in tourism has allowed distinguishing a number of current scientific and applied problems that should be dealt with in a short term, in particular:

- research of technologies to provide the user with personalized advice during the trip in an offline mode,
- development of mobile systems for planning family trips, taking into account the individual features of tourist groups,
- exploring the technology of smart planning of travel routes and their dynamic adaptation during the trip,
- significant expansion of mobile intelligent information services,
- full-scale implementation of EVERYTHING, HERE AND NOW principle in tourism mobile information technologies.

REFERENCES

1. Tourism in the midst of a mobile revolution, Northernireland tourist board. Intelligent Vision Series, 2012.

2. Growth in Mobile's Share of Ad Interactions Slows, eMarketer. – Available online at: <http://www.emarketer.com/Article/Growth-Mobiles-Share-of-Ad-Interactions-Slows/1012519>.

3. Karanasios S., **Burgess S., Karanasios S., Sellitto C. 2012** A Classification of Mobile Tourism Applications, Global Hospitality and Tourism Management Technologies. – IGI Global, 165-177.

4. Mobile technology for tourism. Tutorial 50: Tourism e-kit. – ATDW, 2011. – Available online at: <http://www.tourism.vic.gov.au/images/stories/ATDW_EKIT/tourism e kit v7 50.pdf>.

5. Chalmers M. 2003 Tourism and mobile technology. – Available online at: <http://www.dcs.gla.ac.uk/~matthew/papers/ECSCW2003.pdf>.

6. Kennedy-Eden H., Gretzel U. 2012 A taxonomy of mobile applications in tourism, Research online: University of Wollongong. 112.

7. Rubio Aranzabal A., Peraita A.-M., Gil Fuentetaja I., Zugasti S.I., Lamsfus F.C., Alzua-Sozabal A. 2009 A time sensitive classification of tourism-related mobile application. An analysis of the feature of the applications in a travel stage-based framework, Tourgune. – San Sebastian, Spain.

8. Schwinger W., Grun Ch., Poll B., Retschitzegger W., Schauerhuber A. **2005** Context-awareness in Mobile Tourism Guides – A Comprehensive Survey: Kepler University Linz

9. Spruds D. 2014 Latvia's evolution into mobile, Didgital Tourism Think Tank. – Available online at: <http://thinkdigital.travel/best-practice/mobile-tablet-app-latvia>.

10. Zanker M., Hopker W., Fuchs M. 2011 Exploiting Feedback from Users of Innsbruck.mobile for Personalization, Information and Communication Technologies in Tourism. – Wien: Sringer.

11. Visit Greenland's Mobile Hiking Trails – Available online at: <http://thinkdigital.travel/best-practice/mobile-tablet-greenland/>.

12. Ferreira S., Pimenta A.A., Quico C. **2014** Location Based Transmedia Storytelling in Social Media – Peter's TravelPlot Porto Case Study, ENTER 2014. – Available online at: <http://3ws1wk1wkqsk36zmd6ocne81.wpengine.netdna-cdn.com/files/2014/02/enter2014_RN_134.pdf>.

13. Osterlund J., Lawrence B. 2012 Virtual reality: Avatars in human spaceflight training, Acta Astronautica. 139-150.

14. Kounavis Ch.D., Kasimati A.E., Zamani E.D. 2012 Enhancing the Tourism Experience through Mobile Augmented Reality: Challenges and Prospects, International Journal of Engineering Business Management. – Intech, Vol. 4.

15. Tuscany+: the first Augmented Reality tourism application // Around Tuscany. – Available online at: <http://www.turismo.intoscana.it/allthingstuscany/aroundtuscany/tuscany-the-first-augmented-reality-tourism-application/>.

16. Linaza M.T., **Marimon D., Carrasco P., Alvarez R., Montesa J., Aguilar S.R., Diez G. 2012** Evaluation of Mobile Augmented reality Applications for Tourism Destinations, Information and Communication Technologies in Tourism . 260-271.

17. Augmented Reality in Tourism: 10 Best Practices // Didgital Tourism Think Tank. – Available online at: <http://thinkdigital.travel/wp-content/uploads/2013/04/10-AR-Best-Practices-in-Tourism.pdf>.

18. RouteIt Travel Route Guide, Play Market. – Available online at: <https://play.google.com/store/apps/details?id=com.ma.route.activity&hl=ru>.

19. City Guides Catalog // Play Market. – Available online at: <https://play.google.com/store/apps/details?id=com.tripadvisor.android.apps.cityguide.catalog>.

20. Spangenberg T. 2014 Development of a mobile toolkit to support research on human mobility behavior using GPS Trajectories, Thomas Spangenberg: Information Technology Tourism. Springer-Verlag Berlin Heidelberg.

21. Minube: viajes y turismo // Play Market. – Available online at: <https://play.google.com/store/apps/details?id=com.minube.app&hl=es>. (in Spanish)

22. Trip Planner Navigation // Play Market . – Available online at: <https://play.google.com/store/apps/details?id=com.maina.GPSPlacesavervoice>. (in Ukrainian)

23. Travel guide: City Tour Guide, Play Market . – Available online at: <https://play.google.com/store/apps/details?id=com.opentech.tourpal>.

24. Top Holiday Destinations and Attractions in Malaysia, Official website of tourism Malaysia. – Available online at: <http://www.tourism.gov.my/en/es/places#>.

25. Play Market. – Available online at: <https://play.google.com/store>.

26. Herbst I., Braun A.-K., McCall R., Broll W. 2008 TimeWarp: Interactive Time Travel with a Moile Mixed Reality Game, CSIE. – Available online at: <http://www.csie.ntu.edu.tw/~b95055/Mobile%20HCI%2008/p235-herbst.pdf>.

27. Why tourism? World Tourism Organization UNWTO. – Available online at: <http://www2.unwto.org/content/why-tourism.>.

28. Kovalyshyn O., Gabriel Yu. 2014 Development of a management systems model of automatic control by using fuzzy logic, EconTechMod: an international quarterly journal on economics in technology, new technologies and modelling processes. – Lublin ; Rzeszow, 2014. – Vol 3, No 4. 87-91.

29. Fedasyuk D., Yakovyna V., Serdyuk P., Nytrebych O. 2014 Variables state-based software usage model, Econtechmod: an international quarterly journal on economics in technology, new technologies and modelling processes. – Lublin ; Rzeszow, 2014. – Vol. 3, no. 2. 15-20.

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The use of Petri Nets for inclusive education IT-support

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Abstract. The work is devoted to inclusive education process modeling by means of Petri nets with the aim to formalize the requirements to information technology support of such learning. The analysis of mathematical model of the inclusive education process allowed identifying factors of influence on this process. The study of specific interaction of external and internal factors and their influence on the output parameters was carried out, using the analysis of the procedure of educational aim achievement and additional conditions. Petri net of the education process of a person with special needs was developed. The decomposition process of inclusive education in the form of serial and parallel implementation of relevant educational tasks allowed developing functional requirements to a complex information technology of inclusive education support. For the design of information technology for information storage and structuring in the process of inclusive education, a mathematical model of subject domain description formation process was used.

Key words: inclusive education, persons with special needs, Petri nets, parallel processes, information technology.

INTRODUCTION

One of the dominant trends of modern education is the desire to ensure the full development of the personality of persons with special needs and promote their widest socialization through systematic development of inclusive education. The integration of children with special needs in mass educational institutions is a world tendency, inherent in all highly developed countries. The current scientific and practical task is to improve the accessability of educational services for persons with special needs through the development of software for complex modeling of information and technological support of inclusive education.

THE ANALYSIS OF RECENT RESEARCH AND PUBLICATIONS

The research of education of persons with special needs in the world has been going on for more than thirty years. Scientists from Europe, USA and other countries [1-5] laid foundations for the development and establishment of education for this category of persons. There are information technologies abroad that facilitate the work of teachers and methodologists in the formation of individual learning aims and assessing pupils with special educational needs. Also there are open Internet resources for the development of personal communication passports and information resources for persons with special needs containing news of inclusive education and relevant legal information; centers of computer support for persons with special needs are working etc. The theoretical and practical experience as well as the information technology and software developed abroad cannot be automatically applied to the process of education of persons with special needs in Ukraine.

Fifteen-years international cooperation and national projects in the field of inclusive education have allowed Ukrainian specialists to form a theoretical base for the development and implementation of inclusive education. Ukrainian scientists have proposed conceptual components of inclusive education implementation in our country (P. Talanchuk, K. Kolchenko), organizational and methodical approaches to inclusive education implementation were developed (B. Dikova-Favorska, A. Kolupaeva, S. Litovchenko, Yu. Naida) as well as fundamentals of training and methodological support of inclusive education in Ukraine [6 – 8]. The development of information technologies contributes to the dynamic expansion of a range of information and technological tools for the support of the education process of persons with special needs in Ukraine, at the expense of specific tools and technologies that can be customized to perform specific learning tasks [9-11]: specialized application software packages for various data accumulation have been developed; teachers of educational institutions create problem-based software to teach selected topics; there are educational portals of regional and city departments of education; an independent electronic gradebook online service has been created with a focus on educational institutions of CIS countries, whose main function is to organize and keep gradebooks on the Internet; information is available at the websites of psychological, medical and pedagogical commissions, foundations and public organizations.

To ensure adequate working conditions for persons with special educational needs on the basis of works of Lviv Polytechnic National University scientists (V. Pasichnyk, M. Davydov, N. Kunanets [12 – 14]), computer technologies of access to educational information resources have been developed; the system of information and library services is working to provide educational services to users with special needs; basing on modern information technologies a system of remote education of persons with special needs is being actively developed. However, educational process support with modern information technologies is uneven, algorithmic and software tools are usually not systematically related, there is no comprehensive approach to managing the educational environment focused on individuals with special needs.

Modern prospects of the development of inclusive education system in Ukraine are the application of information technologies to support persons with special educational needs. The application of methods of mathematical modeling for the analysis of such complex systems will improve their efficiency and the effectiveness of such education. In the works of foreign researchers S. V. Astanin, G. V. Mayer, V. V. Lomakin, as well as Ukrainian scientists L. Slipchyshyn, O. Cherednichenko and others, mathematical models of management of the education process are presented, but such works do not take into account the specificity of education of persons with special needs [15-19]. Ukrainian scientists have a number of works that are in a way connected with the development of software for certain stages of education of person with special needs. In his works Yu. Nikolsky proposed a model of large amounts of data process analysis. T. O. Dmytrenko adapted the application of the graph theory to solve optimization problems of the curriculum, V. I. Kut has developed a model of distance learning, M. V. Davydov suggested a mathematical software system to identify the elements of Ukrainian sign language [14, 20]. The need for a comprehensive reflection of functional and structural characteristics of the education process of persons with special needs with the consideration of national specificities of this process determines the relevance of this study.

OBJECTIVES

The basis of a comprehensive study of problems related to information and technological support of inclusive education is the development and verification of appropriate mathematical models. The purpose of this article is to determine the paradigm of information technology support of the process of inclusive education on the basis of analysis of the functional model of such a process. The development of information technology mathematical models typical for the process of inclusive education will promote holistic engineering of education information technologies aimed at integrated support of such learning.

THE MAIN RESULTS OF THE RESEARCH

To create a mathematical model of the process of inclusive education we use the principle of "black box"; this approach allows considering the process of inclusive education as a system, whose basic elements are variables at the input and the output of the system and the operators of their transformation.

The factors influencing the process of inclusive education are the following:

- controlled input and unmanageable impact factors that take into account the peculiarities of psycho-physical and intellectual development of the person, basic knowledge, the professional level of inclusive education specialists; the range of factor variation is set by the conditions of educational and extra-educational institutions,
- controlled input and managed impact factors establishing the rules of inclusive education; the range of factor variation is set in regulatory documents, the training content, material and technical, scientific and methodological support, the set of corrective actions etc.,
- output parameters characterize knowledge, skills, competencies and the level of social integration of persons; the range of variation of these parameters is set by the standards of educational and social skills of the inclusive learner.

Internal parameters of the system are, in particular, scientific and methodical, material and technical support of inclusive education process, learning aims and its corrective component, technologies and evaluation methods of educational and social progress of a person with special needs etc.

The mathematical description of inclusive education process in general will be the following:

InclEduSupportSystem(OSID, IER)=PS,

where: *OSID* – an impact factor, considers objective and subjective characteristics of participants in inclusive education; *IER* – an impact factor, establishes the rules for inclusive education; *PS* – the outcome factor reflecting the level of socialization.

Formally, the impact factor *OSID* will be presented as follows:

OSID=(IntegrEval, HRSupport, {ParentsHelp}),

where: *HRSupport* – human resources of inclusive education, *HRSupport=(MedS, PedagS)*, here *MedS=({Psycol(PPFeat)}, {CorMed(PPFeat)})* – medical professionals (psychologists *Psycol* and correctional medicine specialists *CorMed*), *PedagS=({CorPedag(PPFeat)}, {PedHelp(PPFeat)})* – educators (correctional teachers *CorPedag* and teacher assistants *PedHelp*), accompanying inclusive education depending on the nosology *PPFeat* of the person; *{ParentsHelp}* – available parental assistance; *IntegrEval* – integrated evaluation of the person obtained by intellectual data mining, using function *DataAn*: *IntegrEval=DataAn(<RegData>, <DiagnPMPC>, <ParentsInfo>, <PersonInfo>)*, parameters of which are: *<RegData>* – registration data of the person, *<DiagnPMPC>* – the diagnostic results in PMPC, *<ParentsInfo>* – information from parents, *<PersonInfo>* – information from the person.

Formally, the impact factor *IER* will be presented as follows:

IER=(OrgLegActs, EdMetSupport, MatTechSupport, {EdInst(PPFeat)}, {ExtraEdInst(PPFeat)}, {AssessmentRules}),

where: *OrgLegActs* – organizational and legal support of inclusive education, *OrgLegActs=({LegActs(PPFeat)}, {Consult(PPFeat)}, {PublAssoc(PPFeat)}, {SocServ(PPFeat)}, {Sport(PPFeat)}),* here *LegActs* – legislative acts, *Consult* – information of consulting centers, *PublAssoc* – information from public organizations, *SocServ* – help from social services; *EdMetSupport* – educational and methodological support of inclusive education, *EdMetSupport=({IETextbook(PPFeat)}, {IEProgr(PPFeat)}, {IEMet(PPFeat)}),* here *IETextbook* – consolidated special and general education textbooks, *IEProgr* – curriculum, *IEMet* – methodical support of inclusive education depending on the determined features of psychophysical development; *{EdInst(PPFeat)}* – available inclusive institution; *{ExtraEdInst(PPFeat)}* – available inclusive extraeducational institutions; *{AssessmentRules}* – methods of assessment of educational development of persons with special needs; *MatTechSupport* – material and technical support of inclusive education, which depends on the provision of appropriate educational and non-educational institutions: *MatTechSup=MTS(TechSup, MatSup, ArchDes),* where *TechSup=TS(EdInst*, *ExtraEdInst*) – technical support of the education, depending on educational and non-educational institutions, *ArchDes=AD(EdInst*, *ExtraEdInst*) – features of the architectural design of educational institutions.

Formally, the output factor of *PS* is presented:

PS=(EduRes, SocRes),

where: *EduRes* – assessed learning outcomes of the individual education plan *IndEdPlan*: *EduRes=Evl(<IEPlanRes>, {AssessmentRules}, IndEdPlan)*, where *<IEPlanRes>* – the results of the implementation of the individual educational plan *IndEdPlan, {AssessmentRules}* – methods of assessment of learning outcomes, *IndEdPlan=IEPDesign(HRSupport, OrgLegActs, MatTechSupport, {ParentsHelp}); SocRes* – evaluated level of social development of the person, the level depends on the results of the corrective component of inclusive education *CorEduRes*: *SocRes=SR(CorEduRes*).

The analysis of the specificity of interaction between external and internal factors of the system and their impact on output factors lies in studying the functional stages of the education process, and inclusive education is a part of it. According to [21], the implementation of the first phase of education of a person with special needs is the accumulation of data for a comprehensive study of personality by various specialists (psychologists, doctors, teachers) and information from parents. Also on the basis of comprehensive assessment the peculiarities of psychophysical development of a personality are determined. The second phase of education of persons with special needs involves the determination of learning aims of the entity, depending on peculiarities of their mental and physical development. This aim unites form and content of learning with the correctional rehabilitation component. The third stage of education is the selection of appropriate methods and means to achieve learning aims, a fixed set of methods and tools with regard to personal orientation is the individual educational plan (IEP) of the person. The fourth stage of education is the implementation of the IEP, the accumulation of learning outcomes and their assessment.

A phased study of the education process of a person with special needs has allowed identifying its characteristic features: a strict sequence of stages of the investigated process [21, 22] and the need for parallel implementation of some educational tasks within the designated stages of the education process for person with special needs. For formal representation of such requirements Petri nets were applied [23]. The advantages of this mathematical abstraction is the possibility of reflection of causal relationships in complex systems and a visual representation of parallel phenomena and processes in complex systems.

Let us set the Petri net of education process of a person with special needs as a set of positions *P* and transitions *T*, an input function *I* and an output function *O*. The Petri net transitions are events, and positions are conditions in which events occurre. The sequence of educational task realization is reflected by Petri net transition triggering.

Let us define Petri net positions and their content in terms of education of a person with special needs. Position p_0 is interpreted as a requirement of the person concerning the acquisition of education, p_1 is the accumulated registration data, p_2 – diagnostic results at PMPC, p_3 – results of the interview of parents, p_4 – results of the interview of the person, p_5 – comprehensive evaluation of the person, p_6 – established psychophysical development features of the person (PDF), *p7* – forms of learning of the person with PDF, p_8 – the content of inclusive education, p_9 – adapted Curriculum, p_{10} – training and methodological support of inclusive education, p_{11} – logistical support of inclusive education, p_{12} – human resources of inclusive education, p_{13} – a list of inclusive education institutions at the place of residence of the person, p_{14} – a list of extraeducational institutions at the place of residence of the person, p_{15} – organizational and legal support of inclusive education, p_{16} – parents, p_{17} – individual education plan (IEP), p_{18} – the results of implementation of IEP, p_{19} – evaluation of educational achievements, p_{20} – social development evaluation, p_{21} – evaluation of IEP implementation results.

Let us define an appropriate formal notation of Petri net transitions and define their content. t_1 transition is interpreted as the process of identity formation, t_2 is the process of comprehensive assessment of the person, t_3 – the process of comprehensive assessment analysis, t_4 – the process of learning form determination, t_5 – the process of learning content determination, t_6 – the process of agreement of learning aims, *t7* – the process of IEP components formation, t_8 – the process of IEP components agreement, t_9 – the process of IEP implementation, t_{10} – the process of evaluation of the results of IEP implementation, t_{11} – the interpretation process of the results of IEP implementation, t_{12} – the decision-making process of IEP implementation.

Let us set the Petri net analytically – as a set of positions, transitions input and output functions. The set of positions: $P=\{p_0, p_1, p_2, p_3, p_4, p_5, p_6, p_7, p_8, p_9, p_{10}, p_{11}, p_{12}, p_{13}, p_{14}, p_{15}, p_{16}, p_{17}, p_{18}, p_{19}, p_{20}, p_{21}\}$. The set of transitions: $T=\{t_1, t_2, t_3, t_4, t_5, t_6, t_7, t_8, t_9, t_{10}, t_{11}, t_{12}\}$. The input functions set: $I=\{I(t_1)=\{p_0\}, I(t_2)=\{p_1, p_2, p_3, p_4\}, (t_3)=\{p_5\}, I(t_4)=\{p_6\}, I(t_5)=\{p_7\}, I(t_6)=\{p_7, p_8\}, I(t_7)=\{p_9\}, I(t_8)=\{p_{10}, p_{11}, p_{12}, p_{13}, p_{14}, p_{15}, p_{16}\}, I(t_9)=\{p_{17}\}, I(t_{10})=\{p_{18}\}, I(t_{11})=\{p_{19}, p_{20}\}, I(t_{12})=\{p_{21}\}\}$. The output functions set: $O=\{O(t_1)=\{p_1, p_2, p_3, p_4\}, O(t_2)=\{p_5\}, O(t_3)=\{p_6\}, O(t_4)=\{p_7\}, O(t_5)=\{p_8\}, O(t_6)=\{p_9\},$

$O(t_7)=\{p_{10}, p_{11}, p_{12}, p_{13}, p_{14}, p_{15}, p_{16}\}$, $O(t_8)=\{p_{17}\}$, $O(t_9)=\{p_{18}\}$, $O(t_{10})=\{p_{19}, p_{20}\}$, $O(t_{11})=\{p_{21}\}$, $O(t_{12})=\{p_0\}\}$.

Graphically a Petri net that gives you the opportunity to simulate parallel processes in the education of a person with special needs, is given in Fig. 1.

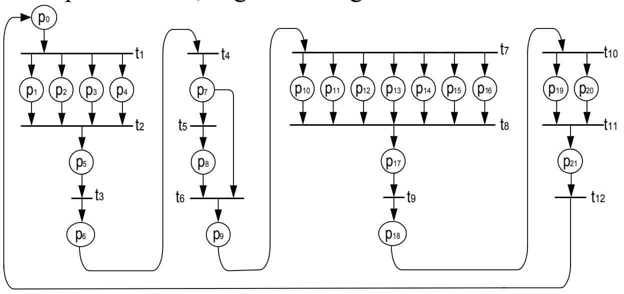

Fig. 1. The Petri net of education process of a person with special needs

Graphic setting of a Petri net is a convenient tool of showing parallel phenomena in the system. For example, the triggering of transition t_1 initiates the execution of parallel educational tasks. Such educational tasks are to obtain a person's identity, results of their diagnosis in PMPC, receiving information from the person and parents in Fig. 1. These tasks are corresponded to positions p_1, p_2, p_3, p_4. The performance of all educational tasks is the triggering condition for transition t_2. The parallel execution of educational tasks of determining the form and the content of education of persons with special needs (position p_7, p_8) allows you to initiate the approval procedure of learning aims (transition t_6). To initiate the agreement procedure for the components of individual educational plan (transition t_8), it is necessary to form appropriate components. The selection of components for IEP formation must occur through simultaneous interaction of all the components of individual educational plan (position p_{10}, p_{11}, p_{12}, p_{13}, p_{14}, p_{15}, p_{16}). To interpret the results of IEP implementation (transition t_{11}), we must simultaneously take into account academic achievement and the development of social skills of the person (positions p_{19}, p_{20}).

Transition t_4 triggering determines the form of learning based on the characteristics of the person's physiological development. In the case of education in a mass school, we are talking about the process of inclusive education, where access to quality education for children with special educational needs is implemented through the organization of their learning in schools through the use of learner-focused teaching methods, taking into account individual characteristics of the educational-cognitive activity of these children. On the basis of the developed Petri net it is convenient to model the process of inclusive education with the help of activity diagrams – an UML diagram, which shows the decomposition process of inclusive education into its component parts according to stages in the form of coordinated, sequential and parallel execution of nested educational tasks (Fig. 2).

The analysis of inclusive education based on the activity diagram allows designing functional requirements to a complex information technology that will be used for inclusive education IT-support. The analysis of functional requirements to a complex information technology have made it possible to design it and thus ensure IT-support of inclusive education.

Table 1 contains the paradigm of information technologies and indicates the status of participants in the process of inclusive education in relation to this information technology (S – the process participant is the source of data for information technology, C – the process participant is the consumer of the results of information technology).

According to Table 1, in the complex information technology of inclusive education support we shall emphasize the following main types of information technology, according to the tasks they perform:

- information storage and structuring – accumulation of identity, pedagogical, psychological, medical data and learning outcomes,

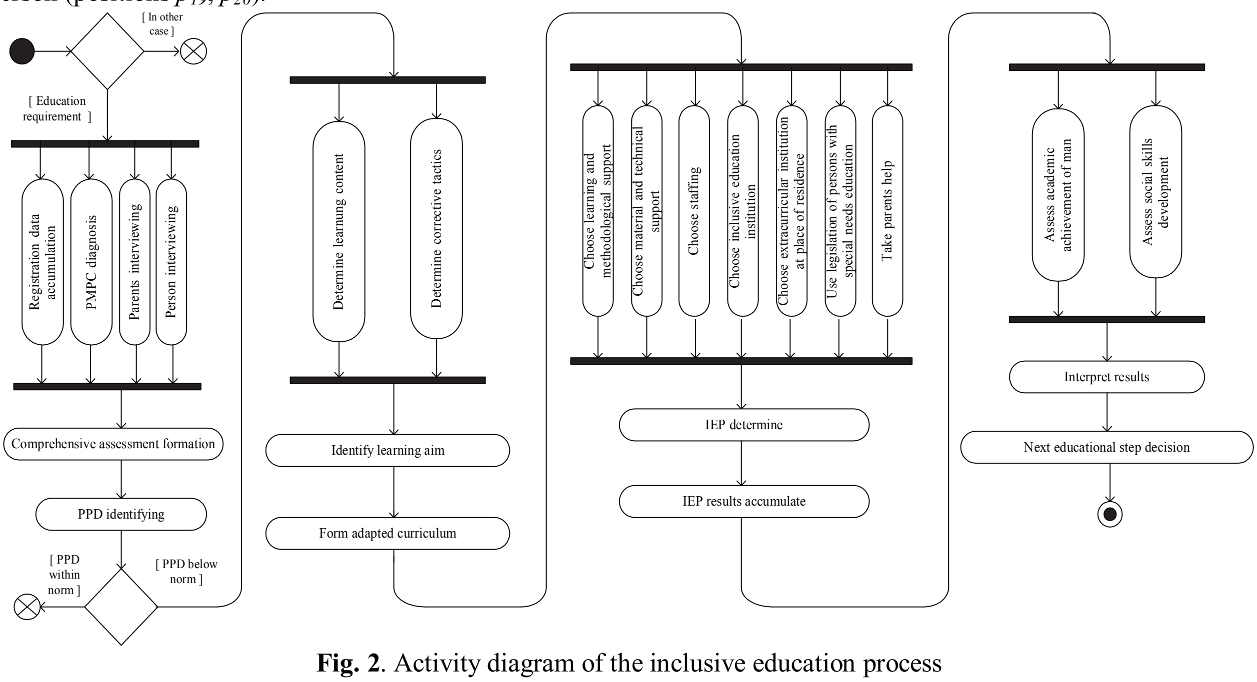

Fig. 2. Activity diagram of the inclusive education process

Table 1. Information technology support of inclusive education and the status of participants

Process participants	Information technology												
	Stage I					Stage II			Stage III		Stage IV		
	The accumulation of ID data	The accumulation of teachers'	The accumulation of psychol.	The accumulation of med. diagnostics	Person's PDF determination	Knowledge level assessment	Social skills assessment	Adapted curriculum	Educational network design	IEP components design	Accumulation of learning results	Knowledge level assessment	Social skills assessment
Person with PDF	S	S	S	S	C	C	C		C	C	S	C	C
PMPC doctors				S	C								
Doctors				S									
Ed. institution doctors					C			C		C	S		C
PMPC psychologist			S		C		C						
Psychologist			S										
Ed. institution psychologist			S		C		C	C		C	S		C
PMPC teachers		S			C	C	C						
Ed. institution teachers		S			C	C	C	C	C	C	S	C	
Extra-ed. institution teachers					C		C	C	C	C	S	C	
Parents	S		S	S	C	C	C		C	C	S	C	C

- data analysis – determination of special needs: personal development and social skills,
- automated knowledge control – assessment of knowledge level of the person,
- learning strategies personification – curriculum adaptation, designing individual education plan with educational needs and opportunities for a particular person taking into account the network of inclusive education institutions.

Information technology that implements information storage and structuring is used at the first and fourth stages of inclusive education. For the design of information technologies for information storage and structuring in the process of inclusive education a mathematical model of the process of subject domain formation is used [24].

The set of subject domain objects is denoted $X=\{x_1, x_2, \ldots, x_n\}$. Each object x_i, $x_i \in X$, is specified by a tuple of its properties $a_i=a(x_i)=(a_1(x_i), a_2(x_i), \ldots, a_{mi}(x_i))$ with the values $v_{ij} \in V_{ai}$, where V_{ai} are determined by the specifics of subject domain objects description. The rules for determining the properties of the set A of objects X rises to uncertainty or redundancy in the formation of subject subject domain. Each object x_i, $x_i \in X$ has the property d, $d_i \in V_d \subset D$, which is a note of its classification [25].

It is appropriate to present the informational description of the subject domain as a decision-making table:

$$T = (X, A \cup \{d\}). \quad (1)$$

The subject domain formation process model is the following:

$$M=(X, A, d, \mu(x,a), \eta(x,d), \Phi(x), \Gamma(a)), \quad (2)$$

where: $\mu(x,a)$: $X{\times}A \rightarrow V_a$ is a function that computes the set of attribute values in the T with the corresponding properties of the object x; V_a – set of values of the function $\mu(x,a)$; $\eta(x,d)$: $X{\times}d \rightarrow V_d$ – is a function that computes the attribute value of the decision d of the object x; V_d – is the set of values of the function $\mu(x,a)$ [24]. The model of the form (2) matches the set of objects X of subject area Π to its description (1).

Uncertainty in the description of the subject domain (1) can be of two types: explicit (when there is no particular attribute value) and hidden (in case of full or partial objects discernment). Redundancy can also be of two types: explicit (in the case of existence of identical objects or attributes) and hidden. Functions $\Phi(x)$ and $\Gamma(a)$ eliminate the obvious redundancy and are defined as follows: $\Phi(x){:}X \rightarrow X'$, where X' is a subset of objects obtained by T object removal; $\Gamma(a){:}A \rightarrow A'$, where A' is a subset of attributes obtained by elimination of redundant attributes from set A.

For the design of information technology for the formation of integrated assessment of a person (accumulation of identification, pedagogical, psychological, medical data) model (2) would be:

$$M_I=(X, A, d, \mu(x,a), \eta(x,d)).$$

The formation of subject domain description lies in defining a set of objects: X – persons with educational needs that were examined, A – properties of objects that are test indicators, d – results of the diagnosis. The functions $\mu(x,a)$, $\eta(x,d)$ are used to compute the values of table attributes. The process model M_I generates the decision-making table:

$$T=(X, \{A_1, A_2, A_3, A_4\} \cup \{d_1, d_2\}),$$

where: d_I is a set of nosology, d_2 is a set of social skills, $d_i \in V_d$.

The specificity of the inclusive education process requires splitting of a set of properties $A=\{A_1, A_2, A_3, A_4\}$ into subsets: A_1 – registration information of the person, A_2 – results of pedagogical diagnostics of the person, A_3 – results of psychological diagnostics of the person, A_4 – results of medical diagnostics of the person.

The emergence of explicite and hidden uncertainty and redundancy associated with the possible lack of certain diagnostic data [25, 26].

A comprehensive analysis of the accumulated data will be used in the next phases of inclusive education to determine psychophysical peculiarities of personality development as well as the level of their social development and progress. Identification of redundant attributes in the analysis of the decision-making table will optimize the process of conducting medical, psychological and educational testing to determine psychophysical development features.

CONCLUSIONS

The study described in this article proposes a model of inclusive education process, which, unlike the existing ones, fully embraces all its components and reflects the current national approach to this type of learning. The use of Petri nets allows formalizing the functional stages of this process and consider its specificity. The authors also suggest that scientific and methodological basis of the creation and use of software for complex information modeling and inclusive education technological support has made it possible to substantiate structural requirements to such software systems. Also the mathematical model of the subject domain formation process is the basis for developing an information technology of information storage and structuring in the process of inclusive education.

Further research will study the possibilities of using a data analysis model in the context of inclusive education, which will improve the data mining technique of integrated evaluation of persons with special needs.

REFERENCES

1. **Bunch G., 2010.** 10 key points of a successful inclusion, autism and developmental disorders. Nr 3, 50-67. (in Russian).
2. **Lorman T., Deppeler D. and Harvey D. 2010.** Inclusive Education. Support Diversity in the Classroom: A Practical Guide. Kyiv, 296. (in Ukrainian).
3. **Malofeev N. and others. 2010.** The concept of a special federal Uniform State Standard for children with disabilities: the main provisions. Defectology. Nr 1, 6-22. (in Russian).
4. **Itterstad G. 2011.** Inclusion – which means that this concept and the challenges facing the Norwegian school, put it into practice? Psychol. Sc. and Ed. Nr 3, 41-49. (in Russian).
5. **Daniels E. and Stafford K. 2000.** Involving children with special needs in the system of secondary classes. Lviv: Nadija, 256. (in Ukrainian).
6. **Kolupaeva A. and Savchuk L. 2011.** Children with special educational needs and the organization of their education. Kyiv : "ATOPOL", 274. (in Ukrainian).
7. **Dikova-Favorska O. 2009.** A person with functional limitations in terms of health issues, education, employment. University of "Ukraine". Zhitomir: Polissya, 364. (in Ukrainian).
8. **Kolupaeva A.A., Naida Y.M., and Sophij N.C. 2007.** Impl. of the evaluation process and the development of individual educational plan. Inclusive school: peculiarities of organization and management. Kyiv, 128. (in Ukrainian).
9. **Kut V.I. 2013.** Information technologies of distance education of persons with disabilities. Thesis for the degree of candidate of technical sciences: 05.13.06 - information technologies. Ternopil, 22. (in Ukrainian).
10. All-Ukrainian Foundation "Step by Step". Available online at: <http://ussf.kiev.ua/> (in Ukrainian).
11. Electronic Journals Service of success. Available online at: <http://emsy.org/> (in Ukrainian).
12. **Kunanets N.E. 2013.** Information and library service for users with special needs: history and modernity. National University "Lviv Polytechnic". Lviv: Galician Publishing Association, 439. (in Ukrainian).
13. **Hodych O., Davydov M. and Nikolskuy Yu. 2011.** Computer gesture recognition, algorithmic approach. Lviv: "Company" manuscript ", 310. (in Ukrainian).
14. **Kut V., Nikolskuy Yu. and Pasichnyk V. 2011.** The mathematical and algorithmic modeling of distance education of persons with disabilities. Computer Science and Information Technology: collection of scientific papers Lviv: Publishing Lviv Polytechnic. Nr 710, 11 3-122. (in Ukrainian).
15. **Maier R.V. 2013.** Cybernetic Pedagogy: Simulation of the learning process. 138. (in Russian).
16. **Astanin S.V. 2000.** Support of the learning process based on fuzzy modeling. Open education, Nr 5, 37-44. (in Russian).
17. **Lomakin V. and Asadullayev R. 2013.** Organization of intelligent control of individual educational trajectories. Scientific statements Belgorod State University. Belgorod: PH «Belgorod», Nr 22 (165), 167-174. (in Russian).
18. **Cherednichenko O.Y., Yanholenko A.V. and Baranov Y. 2014.** The formal architecture of agent system for monitoring the results of scientific activities of higher education. Proc. of the National Technical University "KPI". System analysis, management and information technology. Kharkov: NTU "KPI". Nr 55 (1097), 71-87. (in Ukrainian).
19. **Slipchyshyn L. 2013.** Preparation of vocational schools for future creative professional activities: research results. Pedagogy and Psychology of Professional Education. Nr 2, 99-107. (in Ukrainian).
20. **Dimitrenko T.O. and Jaresko K.V. 2011.** Differentiation and integration in the management of educational institutions. Origins of ped. skill. Pedahogogical science. Nr 8 (1), 31-35. (in Ukrainian).
21. **Shestakevych T.V. and Pasichnyk V.V. 2014.** Structural modeling of processes of inclusive education of persons with disabilities. Information systems and networks. Lviv: LPNU PH, 805, 180-195. (in Ukrainian).
22. **Shestakevych T.V. and Pasichnyk V.V. 2014.** The use of formal grammars in modeling information technology support inclusive education of persons with disabilities. Innovative computer technologies in higher education. Lviv: LPNU PH, 805, 100-106. (in Ukrainian).
23. **Peterson J. 1981.** Petri net theory and the modeling of systems. Prentice-Hall, 290. (in English).
24. **Nicholskyy Y. 2010.** Model process analysis. Computer Science and Information Technology. Lviv: Lviv Polytechnic National University PH, Nr 663, 108-116. (in Ukrainian).
25. **Zavaliy T.I., Nicholskuy Y. and Shestakevych T.V. 2008.** Intelligent analysis of psychological testing. Lviv: Lviv Polytechnic National University PH, Nr 631, 113-138. (in Ukrainian).
26. **Voronkova A. and Zelenkina K. 2013.** Situation modeling of interaction between enterprises of the region and cross-border industrial clusters. EconTechMod, 2(3):71-77.

Defining Duration of Driver Reaction Time Components Using the NeuroCom Complex

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Abstract. The research defines components of driver reaction time under different conditions. The duration of a latent period and time of respective response to a stimulus are determined. It is traced how driver reaction time depends on the complexity of the situation the driver was exposed to. With the help of the NeuroCom complex, computer program and processing of video recordings, the main components of driver reaction time were defined to be information in-flow to the cerebral cortex, detection and recognition of a stimulus, making a right decision and respective reaction. The obtained results can be used for determining dynamic gauge and braking distance of a vehicle, which, in its turn, influences the road safety.

Key words: driver reaction time, latent period, functional state.

INTRODUCTION

The reliability of drivers to a large extent depends upon the speed and accuracy of their respective responses to stimuli (jamming on the brakes, wheel turning, gear shifting, etc.), particularly under the conditions of fast motion [1 – 3]. The probability of a right decision under such conditions depends on the influence of the functional state (FS) of a driver on objective quantitative indicators which characterize the process of perception of the road conditions. Driver reaction time is one of such indicators [4]. In most cases, braking distance of a vehicle as a result of an emergency brake application depends on the driver reaction time. Therefore, study of this psychomotor response and possibilities to reduce it taking into account driver’s FS is of a great importance for road safety improvement [5].

THE ANALYSIS OF RECENT RESEARCHES AND PUBLICATIONS

The reaction time of a driver is an important indicator of his/her professional activity. The studies [6-7] have established that processing of the information by a driver is not a passive reflection of statistical signal characteristic but an active search for problem solving, particularly in the field setting.

Standards of driver reaction time vary between different countries. In European countries, driver reaction time equals 0.75 s when calculations are related to the traffic in cities or towns, and 2.5 s when they are carried out in the countryside [8]. In Ukraine, excellent drivers apply emergency braking with the reaction time of 1.16 s [9]. The reaction time also depends on the intensity of driver’s attention, i.e. on the degree of attention strain for perception of complex and simple road situations. Under the conditions of city traffic, when attention intensity is quite high, the driver reaction time is significantly lower. Czech and Slovak researchers believe that, when the application of brakes is prepared to, the driver reaction time is 0.6-0.7 s, and when attention of a driver is distracted, the reaction time increases to 1.1-1.7 s [10-12].

Reactions can be simple or complex. A simple reaction means the ability to respond quickly and unambiguously to a signal which is known in advance. The time of a latent period of a simple motor response to a signal is 0.2 s [13]. A complex reaction is connected with the choice of a needed action from a range of possible ones. It requires much more time. It is believed that the average time of a complex reaction of a driver is 0.8-1.0 s. This time can vary from 0.4 to 1.5 s [5].

OBJECTIVES

Driver reaction time is a manifestation of a complex mental process. Understanding, prognostication and managing this reaction is possible only when psychophysiological mechanisms of the integral perceptual experience are revealed. When driver’s response to stimuli is studied without taking into account his/her FS, it is impossible to explain such factors as varied time of response to the same signal, change of a reaction with time or lower values of the reaction time when a driver is considerably tired as compared to the periods of his/her optimal productivity [6].

However, know only driver reaction time is not sufficient. The important role is attributed to the time of making an adequate decision (the latent period), which largely depends on a driver's FS. Therefore, psychophysiological characteristics of a driver have to be taken into account in the research. This will enable defining the duration of components of driver reaction time. For this purpose, it was decided to use the NeuroCom complex [14], which on the basis of electroencephalogram (EEG) records allows describing excitatory and inhibitory processes in the cerebral cortex if a person is exposed to different kinds of stimuli.

THE MAIN RESULTS OF THE RESEARCH

The profession of driver is always connected with dangerous situations when the time of sensorimotor reaction plays an essential role. A driver does not only have to perceive great amount of information but also analyze it quickly and, consequently, make right decisions and perform a respective action [15].

Methodologically, there are two difficulties in studying driver reaction time [16]:

- determining the moment of zero time reference, that is the moment of signal occurrence,
- evaluating the degree of signal unexpectedness for a driver.

Most often the reaction time is understood as the period of time which includes stimulus detection, its recognition, making the decision and taking a respective action [17].

According to modern ideas concerning the mechanism of perception of surrounding signals by a driver, the process of formation of the reaction time generally can be illustrated with a block diagram (Fig. 2). The time span between the moment of signal occurrence and the start of a respective action is the reaction time of a driver.

Experimental research was conducted both in the field and in the laboratory settings. To study the process of information in-flow to a driver in details, the NeuroCom complex has been used. One stage of the experimental part is shown in Fig. 1.

On the basis of electroencephalogram (EEG) records, the complex gives a possibility to characterize excitatory and inhibitory processes in the cerebral cortex when exposed to different kinds of stimuli, define the duration of information in-flow to the cerebral cortex, the time of detection and recognition of a stimulus, and the time needed to make a right decision (fig. 3).

Besides, EEG records enable defining the FS of a driver when the experiment is carried out. The main characteristics of this record are frequency and average amplitude of α, β, θ, δ and γ rhythms [14]:

- alpha rhythm is registered when the driver has closed eyes, relaxed musscles, and is in the quiescent state. This rhythm is blocked with photic stimulation, increased attention and mental workload,
- the amplitude of beta rhythm grows with attention increase, mental strain or emotional arousal,
- gamma rhythm increases with making decisions which require the maximum of concentrated attention,
- low-amplitude (20-30 μV) oscillations of delta rhythm can be registered in the quiescent state during certain forms of stress and prolonged mental work,
- theta rhythm is most expressed during light sleep, hypnoidal state.

Values of frequency and amplitude of EEG rhythms, obtained through the use of the NeuroCom complex, for each type of the experiment are presented in Table 1.

Fig. 1. Registration of EEG recordings while conducting the research

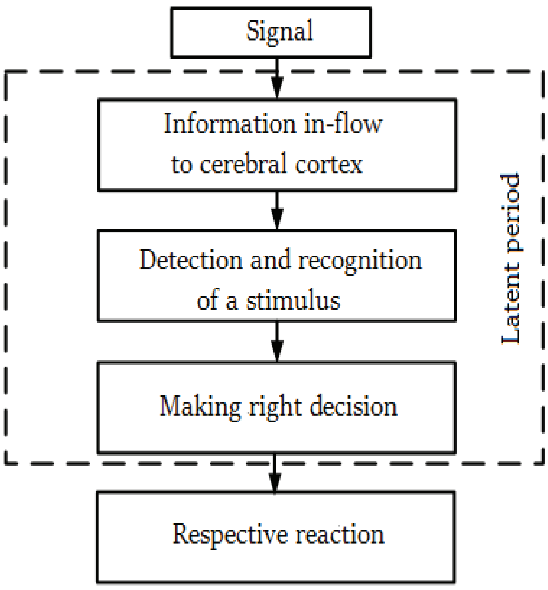

Fig. 2. Block diagram of the formation of driver reaction time

When the tests are underwent in simple and difficult situations, the indicators of α, β, θ, δ and γ rhythms of EEG (see Table 1) increase by 15-20 % on average in comparison to the results of the background test (in the quiescent state).

Comparing the information load in a simple and difficult situation, the indicators of beta, gamma and delta rhythms increase (mental workload, concentration of attention, prolonged mental work), and indicators of alpha and theta rhythms fall down (quiescent state) as the task becomes more complicated.

In order to define the time of driver's simple and complex reaction in the laboratory setting, the previously developed computer program consisting of two tests is used along with the NeuroCom complex. The first test of this program was created on the basis of dangerous situations which occur with drivers behind the wheel. The main goal is to recognize a dangerous situation in a picture which appears among other ones, and respond to it.

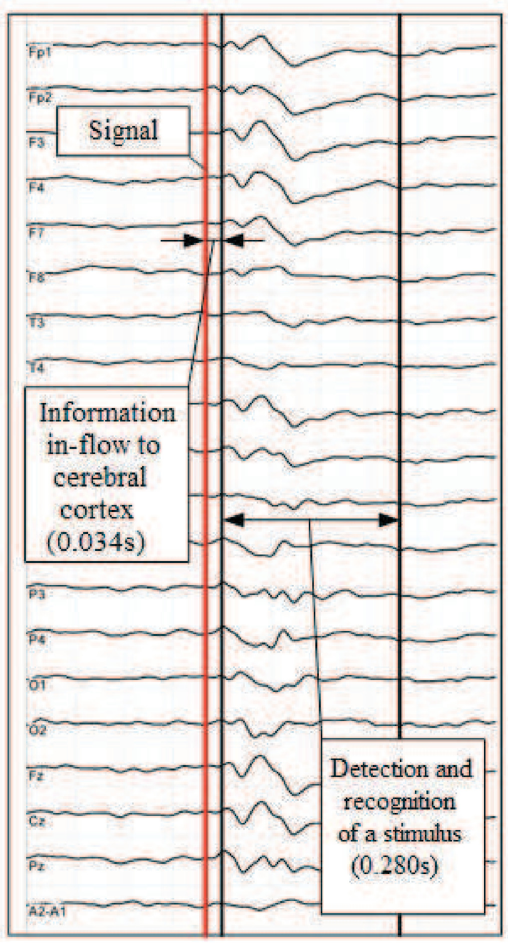

Fig. 3. The fragment of EEG records in the process of defining the duration of driver reaction time components

The second test requires responding with a respective reaction to each signal which is fed onto the screen [16].

Figure 4 depicts the cumulative curve of interval allocation of the latent period (the NeuroCom complex) and driver reaction time (the computer program) in the laboratory setting.

Table 1. Values of frequency and amplitude of EEG rhythms

Type of the experiment	EEG rhythm	alpha	beta	gamma	delta	theta
Background test	Frequency, Hz	9.28	13.67	40.34	0.73	7.81
	Amplitude, μV	23.15	10.58	3.32	15.96	8.42
Completion of the test in simple situations	Frequency, Hz	10.33	18.10	41.22	2.18	7.26
	Amplitude, μV	9.31	11.13	6.92	17.21	8.07
Completion of the test in difficult situations	Frequency, Hz	10.45	19.16	40.62	2.27	6.89
	Amplitude, μV	7.25	12.49	8.05	16.88	6.87

Duration of a latent period in the laboratory setting varies from 0.13 s to 0.79 s when the values of reaction time are between 0.54 s and 1.92 s (see Fig. 4). A fraction of a latent period in the total driver reaction time falls between 26 and 37%. This means that as the situation gets more complicated, the time for detecting, recognizing and making a right decision by a driver increases.

Considering the total reaction time without taking into account difficulty of decision making, the latent period constitutes 30% (0.576 s) on average. Therefore, in some complicated situations the time for making an adequate decision is longer than the reaction time in simple situations.

As a rule, in order to define driver reaction time in situ, the most common methods such as using radio communication, video camera, and taking measurements with the help of an assistant are used [17 – 18]. When the components of the reaction time of a driver behind the wheel were defined, all positive aspects of these methods were taken into account [19, 20].

No special training areas to conduct the research were arranged. All works were carried out on auto-roads. With a car on the move, constant video surveillance of the traffic situation was performed. Drivers were sent different kinds of signals which had to be responded to with a respective reaction. Doing this, the drivers had to adhere to a specified motion mode [4].

This method allows measuring the time of a simple braking reaction (when the traffic light is red) and of a complex situation (when each signal has to be responded to with a respective reaction). Moreover, the complex reaction was connected with memorizing a sequence of signals occurrence (fig. 4).

Statistical distribution of the driver reaction time during real driving is shown in Figure 5.

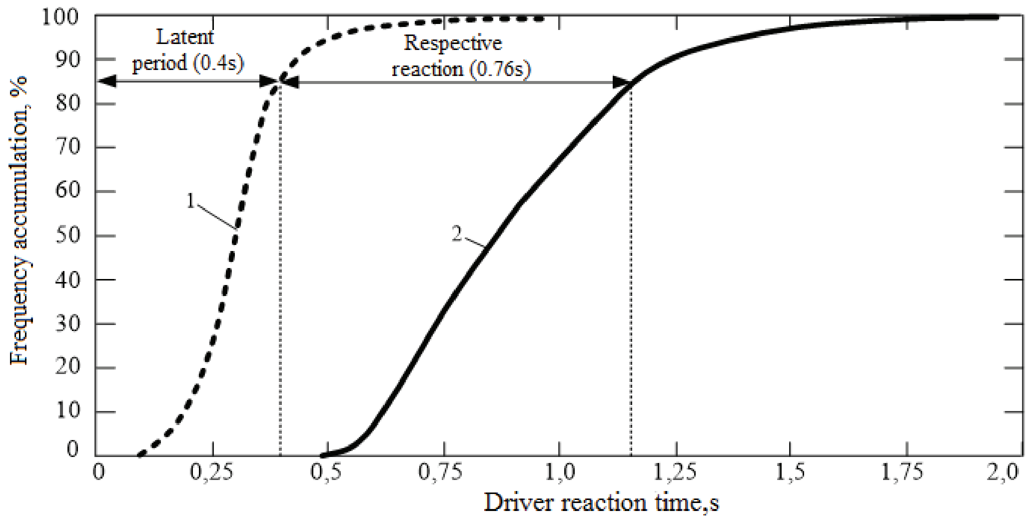

Fig. 4. Cumulative curve of interval allocation of the latent period (curve 1) and driver reaction time (curve 2) in laboratory setting

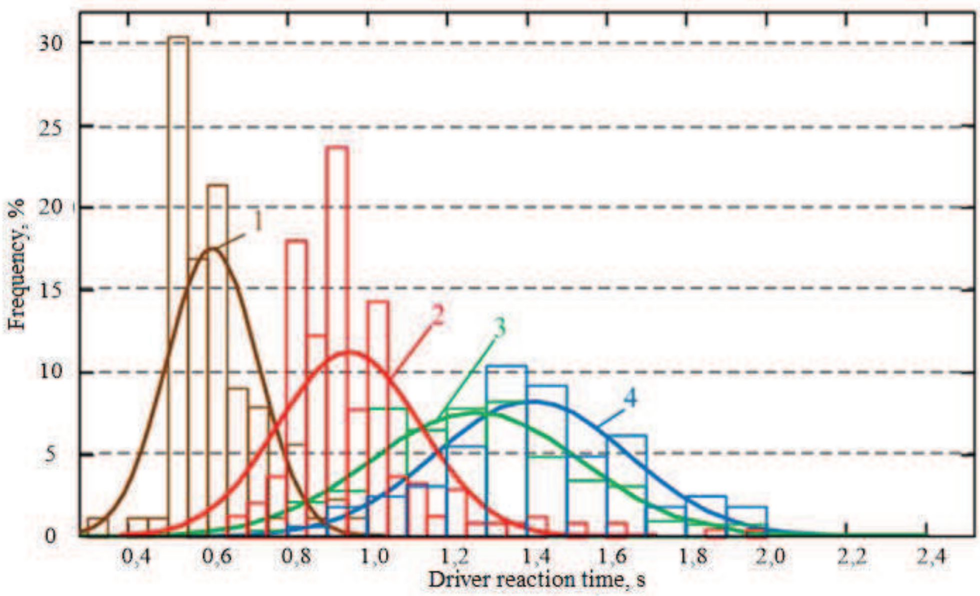

Fig. 5. Histograms of the interval distribution of driver reaction time in simple and difficult situations: 1 – a simple reaction; 2 – a complex reaction during braking; 3 – a complex reaction during wheel turning; 4 – a complex reaction to a recurring signal

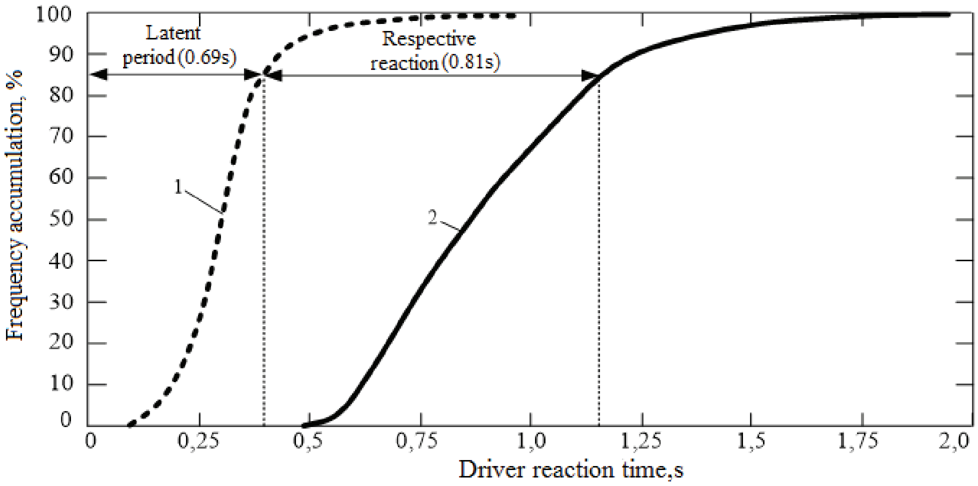

Fig. 6. Cumulative curve of interval allocation of the latent period (curve 1) and driver reaction time (curve 2) in field setting

Table 2. Driver reaction time in various situations

Situation Complexity	Setting	Duration of reaction time components, s				Total reaction time
		Latent period			Respective reaction	
		Information in-flow to cerebral cortex	Detecting and recognizing a stimulus	Making a right decision		
Simple	Laboratory	0.034	0.109	0.127	0.503	0.773
	Field		0.151	0.295	0.710	1.190
Difficult	Laboratory		0.290	0.465	1.131	1.920
	Field		0.312	0.724	1.360	2.430

The time of a simple reaction to brake application is the lowest, and the time of a complex reaction increases as it complicates and, on average, is twice as long as the time of a simple reaction (see Fig. 5).

Plotting the interval distribution of the latent period duration and driver reaction time in the field setting (Fig. 6 revealed that the minimum reaction time of a driver is 0.4 s, and the maximum one is 2.430 s.

In its turn, the time of a latent period in situ varies from 0.25 to 1.07 s. On average, the fraction of a latent period is 45% from the total driver reaction time.

The table below summarizes the duration of components of driver reaction time (Table 2) combining the findings obtained under different conditions using the NeuroCom complex and a number of other means.

According to the research of the reaction time components, the time of information in-flow to the cerebral cortex in different situations is 0.034 s on average. To detect and recognize a stimulus takes on average 0.216 s (15%) of the total driver reaction time, to make a right decision 0.403 s (27%), and to respond respectively 0.926 s (58%). The time of a latent period constitutes on average 41% of driver reaction time (see Table 2).

CONCLUSIONS

The research has allowed assessing variation of driver reaction time depending on the complexity of decision making in the laboratory and field settings. With the help of the NeuroCom complex, computer program and processing of video recordings, the main components of driver reaction time were defined to be information in-flow to the cerebral cortex, detection and recognition of a stimulus, making a right decision and respective reaction. The obtained results can be used for determining dynamic gauge and braking distance of a vehicle, which, in its turn, influences the road safety.

REFERENCES

1. **Romanov A. N. 2002.** Motor Transport Psychology: a study guide for students of higher learning institutions. Moscow: Academy, 224. (In Russian)

2. **Grygorov M.A. and Usatov V.V., 2007**. The Influence of Information and Physical Loading on the State of Physiological Systems of a Driver. Works of Odessa Polytechnic University. Nr 2(28), 53-54. (In Ukrainian).

3. **Rotenberg R.V., 1986.** Basics of Reliability of the System “Driver – Vehicle – Road – Surroundings”. Moscow : Mashynostroenie. 216. (In Russian)

4. **Zhuk M.M. and Kovalyshyn V.V. 2012.** Methodology of Studying the Influence of Driver’s Psychophysiological Characteristics on His/Her Reaction Time In Real Situations Municipal Engineering. Nr 103. (In Ukrainian).

5. **Ignatov N. A., Ilarionov V. A., Koshelev M. V. and Mishurin V. M., 1977.** Training on Car Simulators. Moscow : DOSAAF. 96. (In Russian)

6. **Lobanov E. M. 1980.** Designing of Roads and Organization of Traffic Taking into Account Driver’s Psychophysiology. Moscow : Transport. 311. (In Russian)

7. **Dolia V. K.** Passenger Transportation. Kharkiv : Fort. 504. (In Ukrainian)

8. **Hick W. E. 1952.** On the rate of gain of information. Journal of Experimental Psychology. Nr 1, 11–26. (In English)

9. **Boiko E. I., 1961.** The Human Reaction Time. Moscow : Medicine. 110. (In Russian)

10. **Pistun I. P., Khomyak Y. V. and Khomyak V. V., 2005.** Labour Safety on Motor Transport. Sumy : University book . 374. (In Ukrainian)

11. **Lobanov E. M. 1975**. Driver Reaction Time. Works of the Moscow State Automobile and Road Technical University. Nr 95, 81-110. (In Russian)

12. **Volobuyeva T.V. 2009.** Experimental Verification of Study Model of a Driver in Stressful Traffic Situations. News of Automobile and Road Institute Automobile and road Institute Bulletin. Nr. 2 (9), 199–205. (In Russian).

13. **Krincik E. I. and Mednikov I. F. 1970**. On Mechanisms of Influence of Signal Probability on the Human Reaction Time. Matters of Psychology. Nr 6, 31–46. (In Russian)

14. Electroencephalography Computer System NeuroCom: operation manual. 2008. Kharkiv: Kharkiv National Aerospace University. Kharkiv. 171. (In Russian)

15. **Klinkowstein G. S. and Konoplyanka V. S. 1977.** Traffic Management. Moscow. 56. (In Russian)

16. **Kovalyshyn V.V. 2013.** Speed Rates of Car Movement in the Mountains Taking into Account Psychophysiological Characteristics of a Driver: theses for a Candidate of Sciences: 05.22.01. Lviv 167 c. (In Ukrainian).

17. **Krebelsberg D. 1989.** Transport Psychology: translation from German. Moscow. 367. (In Russian)

18. **Streh Carl M. 1971.** Vigilance: the problem of sustained attention. Oxford e. a. Pergamen Press. Nr 106, 111.

19. **Kovalyshyn O. and Gabriel Yu. 2014.** Development of a management systems model of automatic control by using fuzzy logic, EconTechMod: an international quarterly journal on economics in technology, new technologies and modelling processes. – Lublin ; Rzeszow, 2014. – Vol 3, No 4. 87-91

20. **Fedasyuk D., Yakovyna V., Serdyuk P. and Nytrebych O. 2014.** Variables state-based software usage model, Econtechmod: an international quarterly journal on economics in technology, new technologies and modelling processes. – Lublin ; Rzeszow, 2014. – Vol. 3, no. 2. 15-20

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The Influence of Dynamic Characteristics of Vehicles on the Passenger Car Equivalent and Traffic Delay

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Abstract. The analysis of transportation flow and technical condition of cargo-carrying vehicles and buses has showed the need in the research of its influence on the passing density on signalized intersections. The indicator which reflects this influence is represented by light motor vehicle passenger car equivalent (PCE). The need in determining a passenger car equivalent for differently structured transportation flows is demonstrated not according to the recognized methodology, but according to the one developed by the authors which takes into account both diverse structure and the level of technical condition of road users. The latter one decreases launching dynamics of vehicles which depart from the stop line. The respective passenger car equivalents are determined for such a structure of traffic flow. These calculations differ from already known and normative ones. Due to the simulation (the VISSIM program) of passing at an intersection with the use of calculated passenger car equivalents which take into account the technical condition of vehicles, traffic delays on the main direction were defined as decreased by 7.6% for respective duration of permissive signal on a traffic light.

Key words: passenger car equivalent (PCE), traffic delay, traffic light cycle, saturation flow, vehicle, technical condition, speedup.

INTRODUCTION

Nowadays we can observe rapid growth of the number of vehicles in street and road network (SRN) of cities and towns. The increase in the level of motorization, when SRN, actually, is not expanded and improved, results in problems with traffic management. Oversaturation of urban roads with cars causes queues at intersections, particularly signalized ones, which have low capacity in comparison with other elements. Consequently, drivers and passengers of public transport are additionally irritated, transporters get lower incomes, expenses of individual cars are higher, the ecology of urban air basin is being deteriorated.

It is known that light motor vehicles with high indicators of drag-out dynamics dominate in the urban traffic flows (TF). However, along with these vehicles there is a certain portion of buses and cargo-carrying vehicles with significantly lower indicators. Substantial heterogeneity of TF can be observed both in time (at hours of a day – rash hours or periods between them) and in space (in any transportation district of a city or town). Diversity of vehicles in traffic flows is taken into account with the help of respective PCEs (light motor vehicle ones), in the basis of which there are dynamic dimensions. However, the question with which dynamic characteristics and technical condition those equivalents are determined remains unanswered.

ANALYSIS OF THE LATEST FINDINGS AND SCIENTIFIC PUBLICATIONS

Both Ukrainian and foreign scientists try to find the best possible (by certain criteria) ways of passing at signalized intersections. The majority of them present TF as an ideal (by dynamics and technical condition) total of vehicles. However, reality proves the following: along with light motor vehicles there are buses and cargo-carrying vehicles which have much lower drag-out and speed properties than light motor vehicles. In our view, not to take this into account would be wrong.

In their researches [1-3] the authors point out that, when searching for the optimal managing of traffic light objects, it is necessary to take into consideration dynamic properties of vehicles which mainly determine capacity of signalized intersections. In his work, Kolesnikov O. Ye. considers an accidental character of TF formation, technical properties of a vehicle, and defines the speed, time and disposition of the first car after switching on the green light according to the formulae:

$$V = \frac{V_{\max}}{1 + D \cdot e^{-r \cdot t}}, \tag{1}$$

$$\tau_1 = \begin{cases} 0, & if \quad t \le \Delta T \\ t - \Delta T, & if \quad t > \Delta T \end{cases}, \tag{2}$$

$$S_1 = S_{01} + \int_0^{\tau_1} V_1 d\tau , \tag{3}$$

where: $V_{\max}$ – maximal speed of different vehicle brands, m/s; $D = \frac{V_{\max} - V_0}{V_0}$; V_0 – initial speed, m/s; r – proportionality factor that depends on speed properties of cars, s^{-1}; τ_1 – the duration of movement of the leading car via an intersection, s; t – initial time after switching on the green light, s; ΔT - threshold of time changes t; S_1 – position of a vehicle relative to an intersection at the moment of time τ_1, m; $S_{01} = -5$ – initial position of a car relative to an intersection line when $\tau_1 = 0$, м; V_1 – car speed which depends on the time of traffic reduction at an intersection, m/s.

One of main indicators which is considered in calculation of traffic light cycle parameters is saturation flow. In works [4-5] the attempt has be made in order to take into account the composition of a traffic flow when this indicator is defined. In our view, this assumption is not quite right since saturation flow is an indicator which characterizes SRN. Nevertheless, two adjusting factors included into the formula for calculating saturation flow are provided in the Highway Capacity Manual 2000 [6] (American guidelines for the design of controlled intersections) and take into account the presence of cargo-carrying vehicles in TF and obstacles created by buses.

The main parameter of traffic, which is included into all engineering calculations, is TF intensity. Nowadays there are numerous approaches to defining passenger car equivalent. Among them we can distinguish the following ones: those used in researching TF on road spans between intersections and those used for calculating traffic light cycles at signalized intersections with different types of road crossing [7]. Numerical values of the passenger car equivalent in Ukraine are presented in the Building Code 2.3-4-2007 «Auto-roads» [8]. Values of these equivalents were defined 30 years ago and thus, cannot adequately reflect realities of today's traffic conditions. Many scientists [1-2, 9-10] state that those calculations are unacceptable for defining parameters of traffic light signaling. However, they are used in various investigations connected with designing (improvement) of SRN, management and regulating of traffic, passing intersections by vehicles, etc. For different types of vehicles these coefficients vary from 0.5 to 3.0 (motorcycle – bus).

The investigation of passing signalized intersections is carried out in different countries around the world and there is a number of findings. Thus, scientists Vrubel Yu. A. (the Republic of Belarus) [1] and Sosin Ya. (the Republic of Poland) [11] have gained nearly the same values of passenger car equivalents which differ from the ones defined by the Building Code, particularly concerning motorcycles and cargo-carrying vehicles (the scientists: PCE = 0.6-1.6, the Building Code: PCE= 0.5-2.0), buses and trolleybuses – 1.7-2.0 and 3.0 respectively (the Building Code doesn't provide these data for trolley-buses). The results of investigations carried out in England, Germany [12] and the USA [6] are also known. English scientist Webster F. V. [13], for instance, calculates this PCE within the boundaries of 0.33-2.25; Branston D. [14 – 15] – 0.15-1.68; American researchers [6] suggest mediated value of 2.0. Detailed analysis of findings by these scientists can be found in works [7, 16], and the results concerning calculations of PCEs are presented in table 1.

The following correlation is in the foundation of investigations of PCE for signalized intersections:

$$K_{pce} = \frac{t_i}{t_{lig}}, \tag{4}$$

where: t_i – time span between vehicles of i-type during pass-by of the queue on the green signal of a traffic light, s; t_{lig} – time span between light motor vehicles during pass-by of the queue on the green signal of a traffic light, s.

Modern scientists suggest their own, justified in a certain way, PCEs which, in their view, reflect today's traffic flows in the most adequate way. However, they do not take into consideration changes in drag-out and braking properties of vehicles of different types and duration of service. The attempt to take into account technical and operational characteristics of a vehicle when defining light motor vehicle PCE has been made in [17], however, this methodology concerns road passes, and not signalized intersections.

OBJECTIVE

Despite obtained, so called final, values of light motor vehicle passenger car equivalents for TF which passes a signalized intersection, the issue concerning the technical condition under which these equivalents were defined remains open to investigations. During the operation of cars, the indicators of their drag-out and braking dynamics decrease. Respectively, the presented equivalents cannot adequately reflect the condition of TF which includes worn vehicles. The results of calculations of traffic light cycle indicate formation of excessive queues and increasing of delays on specific approaches to an intersection where there are such vehicles. In this regard, the need to develop the methodology of defining light motor vehicle passenger car equivalents which would take into consideration changes of dynamic properties of vehicles with the growth of their cumulative operational kilometers.

Table 1. Light motor vehicle passenger car equivalent

Vehicle type	Light motor vehicle passenger car equivalent to according to different authors				
	Webster	Branston	Sosin	Vrubel	The Building Code B.2.3-4:2007
Motocycles	0.33	0.15	0.6	0.7	0.5-0.75
Cargo-carrying vehicles with elevating capacity:					
to 2 tons	-	-	-	-	1.5
over 2 to 6 tons	1.75	1.35	1.6	1.4	2
over 6 tons	1.75	1.68	-	-	2.5-3.5
Tractor-trailer units	-	-	2.8	2.3	3.5-6.0
Buses	2.25	1.65	1.7	2.0	3.0
Trolley-buses	-	-	-	2.0	-
Articulated buses (trolley-buses)	-	-	2.8	2.6	-

MAIN RESULTS OF THE RESEARCH

It was previously theoretically grounded and practically confirmed that with the duration of service [18] and increasing of cumulative operational kilometers [19] drag-out and speed properties of cargo-carrying vehicles decrease. It was determined that in five years of intense exploiting they can deteriorate by 25%. This, in its turn, decreases runway speed, particularly initial one during launching from a stop line to the green signal of a traffic light. To calculate PCEs which take into account the influence of this factor the correlation (4) is suggested. Time spans between vehicles (t_i, t_{lig}) were determined according to a regressive model which takes into consideration the counting number of a car in a queue. It is the following for various vehicles:

$$t_{i,\ lig} = \beta_0 + \frac{\beta_i}{n}, \tag{5}$$

where: β_0 – an intercept term of a regressive model which characterizes the value of a time span between vehicles for a respective saturation flow, s; β_i – the parameter of a regressive model which takes into account the deviation of a time span of a vehicle of i-type in the queue from the one typical of saturation flow, s; n – a variable which corresponds to a number of a vehicle in a queue.

To research time spans t_i between vehicles, the VISSIM programmed product designed for microscopic traffic simulation was used. With its help the traffic lane with a stop line (traffic light) was simulated. Firstly, the movement of TF with 100% of light motor vehicles was simulated, then – with 100% of cargo-carrying vehicles (which in the Building Code B.2.3-4:2007 correspond to the carrying capacity of 6-8 tons) with various technical conditions expressed in the simulation through launching speedup which was changed within the limits of 0.25-3.5 m/s^2 in increments of 0.25 m/s^2.

The analysis of obtained results is carried out in the MATLAB program. Using the formula (5), values of time spans between vehicles in all simulated TF were obtained. It was found that the time span of passing by of a queue of light motor vehicles is 1.53 s; of cargo-carrying vehicles it varies from 2.061 s (for vehicles with the speedup of 0.25 m/s^2) to 6.337 s (for vehicles with the speedup of 0.25 m/s^2). As a result, passenger car equivalents which take into account the technical condition of a vehicle were defined (table 2).

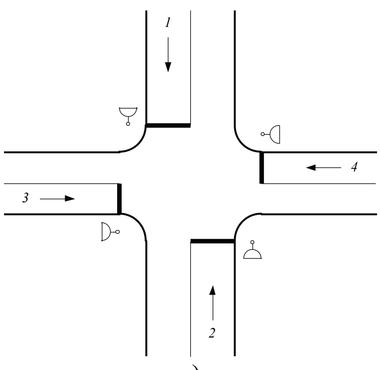
From the information stated above it is evident that PCE according to physical content is not constant but variable in functional dependence on changes of decrease in dynamic properties of cargo-carrying vehicles and buses due to the deterioration of their technical condition. This confirms its physical nature: the lower vehicle dynamics is, the higher value of PCE to a light motor vehicle will be and vice versa.

The suitability of obtained PCEs for use in defining of such an important indicator as traffic delay at a signalized intersection was verified with the help of the VISSIM product. With this aim, first of all, the simulation of a signalized intersection was created (its scheme is depicted in fig.1). Four experiments were carried out: the 1st one – all directions have 1x2 road lanes, the duration of the traffic light cycle is 65 s; the 2nd – the major way has 2x2 road lanes (flows 1 and 2 are shown in fig. 1), and the minor one with 1x1 road lanes (flows 3 and 4 are depicted in fig. 1), the duration of the traffic light cycle is 60 s; the 3rd one is the same as the 2nd one, but with the traffic light cycle of 65 s; the 4th experiment is analogues to the 3rd one, however, with the traffic light cycle of 70 s.

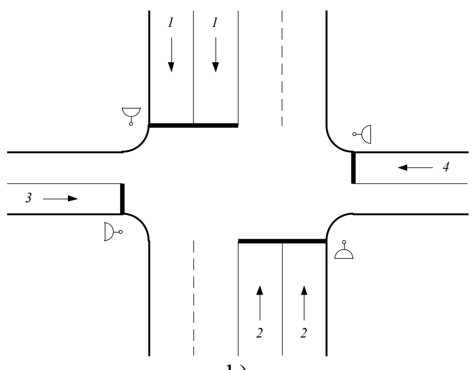
The TF saturation at an intersection was varied from 400 veh./h to 700 veh./h for the major direction (No. 1, 2, table 3) and from 100 veh./h to 300 veh./h for the minor direction (No. 3, 4, table 3) (in increments of 100 veh./h). The structure of TF was also changeable: the portion of cargo-carrying vehicles in the TF in the major direction varied from 25% to 40%, of light motor vehicles – from 75% to 60% respectively, in increments of 5%.

Table 2. Passenger car equivalents which take into account changes of dynamic characteristics (deterioration of the technical condition) of vehicles (cargo-carrying vehicles and buses)

Vehicle speed-up, m/s^2	0.25	0.50	0.75	1.00	1.25	1.50	1.75
PCE	4.14	2.88	2.35	2.04	1.83	1.72	1.63
Vehicle speed-up, m/s^2	2.00	2.25	2.50	2.75	3.00	3.25	3.50
PCE	1.58	1.52	1.47	1.44	1.40	1.37	1.35



a)



b)

Fig. 1. Simulation of a signalized intersection with road lanes 1x1 in all directions (a), 2x2 in the major direction and 1x1 – in the minor one (b)

The major direction was occupied by light motor and cargo-carrying vehicles, the minor one – only by light motor vehicles. To simplify the simulation left wheeling was banned in all ways, and right wheeling flows constituted 8% of incoming intensity. The road lane width in the major direction was 5m, and in the minor one – 3.5m. The calculations of the duration of the green signal of a traffic light were performed using PCE suggested by O. H. Levashev [10] and PCEs which take into account variation of vehicle dynamic properties (deteriorating of their technical condition) (see table 2).

Duration of traffic delays at an intersection was obtained through the simulation of TF in VISSIM. The sample of the simulation for TF which consisted of 75% of light motor and 25% of cargo-carrying vehicles (buses) (the 3rd experiment, with the duration of traffic light cycle of 65s) is shown in table 3 (the results of the first experiment are provided in the work [20]).

The figure 2 depicts the diagrams (traffic intensity in the major direction is 600 veh./h) which reflect decrease in delays in the major direction (fig. 2, a, b, c) and their increase in the minor one (fig. 2, d, e, f).

The analysis of all results of TF simulation obtained in 192 experiments and shown in table 3 has enabled establishing characteristic decrease in the duration of traffic delays in the major direction and their unsubstantial increase in the minor one (fig. 2). Data for the 3rd experiment for fig.2 are framed in bold in table 3. The TF intensity in the major direction was 600 veh./h. It was found that for all 192 variants of combinations of TF intensity in a major and minor directions, the duration of vehicle delays in the former one decreases by 7.6% in comparison, if passenger car equivalents according to Levashev are used. At the same time, it is observed the increase in delays in the minor direction by 7.1%. Total delay of all vehicles at an intersection drops by 3.6%.

Obtained results show that if suggested passenger car equivalents are used for determining the time of displaying green signals, traffic delays in the major direction decrease and in the minor one vice versa, i.e. increase. In our opinion, such a situation can be considered as an acceptable one since it creates an advantage for a major (through) road, which, as a rule, is occupied by much higher amount of public transport. And delays of this transport are not allowed in order to comply with traffic schedules. In the variants of combining N_{maj} and N_{min} for 192 experiments, the former one exceeded the latter one by 1.2-7.0 times.

When obtained results are used, the duration of permissive signals on the major (through) direction of TF movement will need corrections.

CONCLUSIONS

1. The analysis of a structure of traffic flows and technical condition of vehicles proved the necessity of investigating its influence on the dynamics of passing signalized intersections. The indicator which reflects this influence was decided to be light motor vehicle passenger car equivalent.

2. Through the simulation of passing by TF of different structure (light motor and cargo-carrying vehicles, buses) a signalized intersection with a major (through) and minor roads which have different traffic intensity (the former one has higher by 1.2-7.0 times intensity than the latter one) the following data has been obtained: for all 192 variants of combinations of TF in a major and minor directions, the duration of vehicle delays in each experiment decreases by 7.6% on average in comparison, if traditional passenger car equivalents are used. At the same time, the increase in delays on the minor direction by 7.1% is observed Total delay of all vehicles at an intersection drops by 3.6%.

Table 3. Duration of traffic delays according to the results of the simulation

№ ТП	TF intensity in the major direction, N_{maj}, veh./h	TF intensity in the minor direction, N_{min}, veh./h					
		100		200		300	
		Passenger car equivalents					
		acc.to Levashev	suggested	acc.to Levashev	suggested	acc.to Levashev	suggested
		Delay, s					
1	400	8.13	7.72	13.98	13.33	18.35	17.63
2		8.33	7.73	14.75	13.98	19.62	18.68
3		14.82	15.57	9.33	9.92	7.00	7.48
4		13.75	14.42	9.60	10.15	7.85	8.37
1	500	7.00	6.62	13.33	11.78	17.97	16.55
2		6.92	6.33	13.10	11.52	17.60	15.92
3		17.27	18.02	11.13	12.40	8.52	9.63
4		15.83	16.55	11.40	12.65	9.43	10.60
1	600	6.52	5.92	11.60	11.02	16.23	15.38
2		6.37	5.82	11.50	10.95	15.98	15.03
3		18.80	19.57	13.00	13.65	10.18	10.82
4		17.35	18.13	13.33	14.02	11.20	11.78
1	700	6.27	5.60	11.07	10.52	15.65	14.18
2		5.62	5.15	11.13	10.40	15.50	13.97
3		20.37	21.18	14.33	15.07	11.45	12.70
4		18.95	19.73	14.70	15.40	12.43	13.77

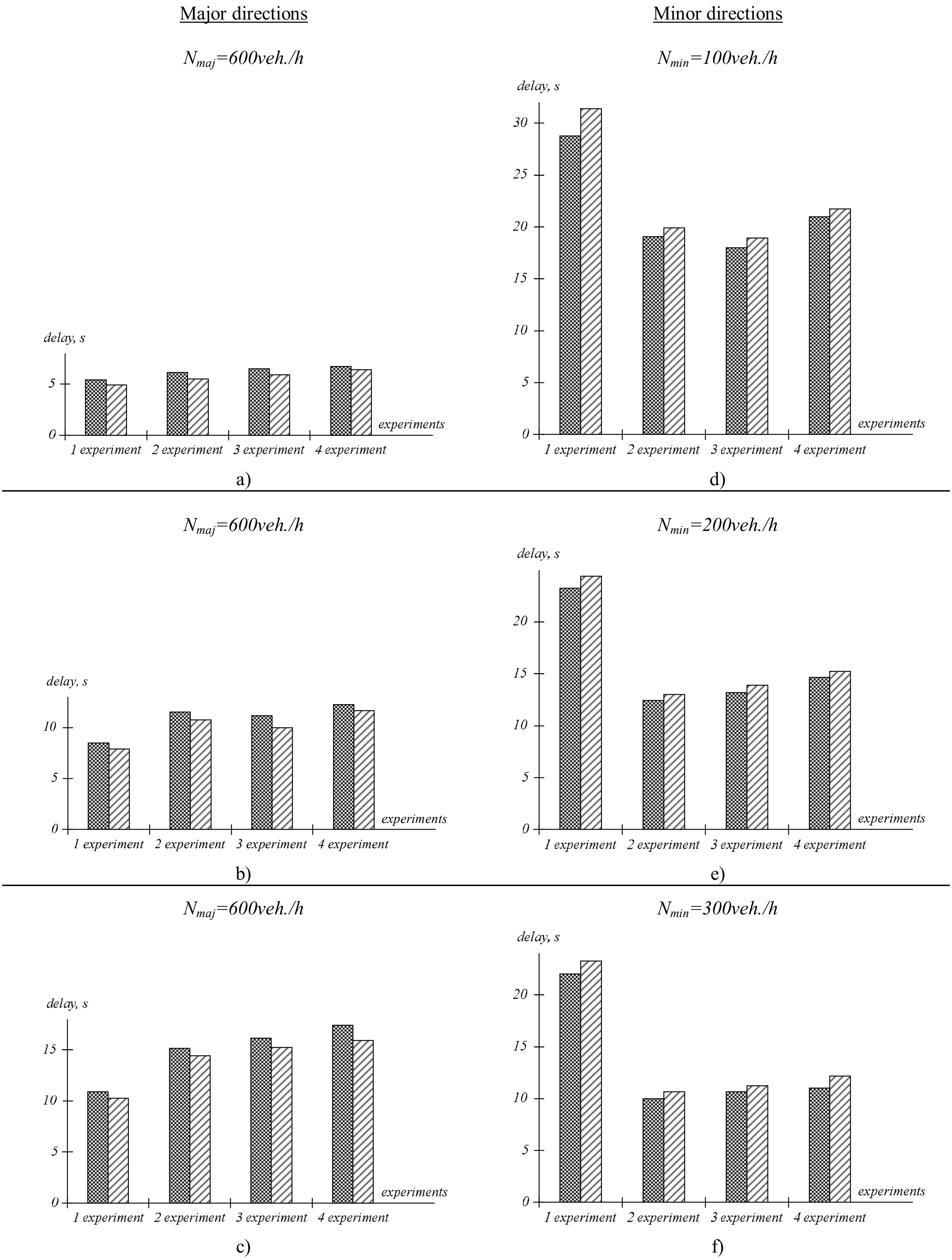


Fig. 2. Changes of the duration of traffic delays in the traffic flow at a signalized intersection consisting of 75% of light motor vehicles and 25% cargo-carrying vehicles and buses: ▩ – using passenger car equivalents according to Levashev; ▨ – using passenger car equivalents which take into account reducing of dynamic properties of a vehicle

REFERENCES

1. **Vrubel Yu. 1996.** Traffic Engineering, part 1. Minsk, 328. (in Russian)

2. **Holub D. 2006.** Method of statistic optimization of traffic light cycles. Vestnik KrTSU: Transport, 43, 332-336 (in Russian).

3. **Kolesnikov O. 2006.** Simulation of the Traffic of Modern Vehicles through Signalized Intersections. Proceedings of OPU, extra issue, 76-79 (in Ukrainian).

4. **Borovskoi A. and Shevtsova A. 2012.** Actual Saturation Flow Depending on the Class of a Light Motor Vehicle. Visnyk DonATA, 2, 4-9 (in Russian).

5. **Malyshev A. 2010.** Considering Transportation Flow Structure When Defining Saturation Flow foe the Traffic Light Regulation. Visti ADI. 1(10). 69-75 (in Ukrainian).

6. **Highway Capacity Manual. 2000.** Washington, TRB, 1134.

7. **Levashov A., Mihailov A. and Holovnykh I. 2007.** Designing Signalized Intersections. Irkutsk, IrTSU, 208 (in Russian).

8. **Auto-roads:** the Building Code B.2.3-4. 2007. Kyiv, 91 (in Ukrainian).

9. **Denysenko O. and Filimonova A. 2010.** Certain Aspects of Defining Light Motor Vehicle Passenger Car Equivalent. Automobile Transport, 26, 115-118 (in Russian).

10. **Levashev A. 2004.** Improving Efficiency of Traffic Management on Signalized Intersections. Thesis of Ph.D. dissertation, 05.22.10. Irkutsk, IrTSU, 17 (in Russian).

11. **Sosin J.A. 1980.** Delays at intersections controlled by fixed cycle traffic signals. Traffic Eng. and Contr., v.21, N.5, 264-265.

12. **Handbuch fuer die Bemessung von Strassenverkehrsanlagen. 2002.** Forshungsgesellschaft fuer Strassenund Verkehrswesen, Koeln (in German).

13. **Webster F.V. and Cobbe B.M. 1966.** Traffic Signals. Road Research Technical Paper, N. 56, HMSQ, London, 111.

14. **Branston D. 1978.** A comparison of observed and estimated queue lengths at oversaturated traffic signals. Traffic Eng. and Contr, v. 19, N. 7, 322 – 327.

15. **Branston D. 1979.** Some factors affecting the capacity of signalized intersection. Traffic Eng. and Contr., v. 20, N. 8-9, 390 – 396.

16. **Abramova L., Naglyuk I. and Ptytsya G. 2012.** Analiz metodiv vyznachennya skladu transportnoho potoku [Analysis of Methods of Defining of Traffic Flow Structure (in Ukrainian)]. Visnuk NTU "HPI", N. 17, 35-41.

17. **Svatko V. 2013.** Methodology of Defining Adjustment Factors to a Light Motor Vehicle Using the Model of Efficient Vehicle. Available online at <http://www.sworld.com.ua/konfer30/1005.pdf> (in Ukrainian).

18. **Fornalchyk Ye. and Hilevych V. 2011.** Influence of the Technical Condition of Vehicles on the Dynamics of Intersection Passing. Eastern-European Journal of Enterprise Technologies, Issue 3/4 (51), 4-6 (in Ukrainian).

19. **Fornalchyk Ye. and Hilevych V. 2013.** Interrelation between the Technical Condition of Buses and Their Speedup Properties during Intersection Passing. Avtoshlyakhovyk of Ukraine, N. 6, 5-7 (in Ukrainian)

20. **Hilevych V. and Mohyla I. 2015.** The Influence of Changes of Vehicle Dynamic Properties on the Value of Passenger Car Equivalent. Proceedings of Ukraine science-theoretical conference "Transport flow problems and course of its solving", 28-30 (in Ukrainian)

21. **Lesiv M., Bun R., Shpak N., Danylo O. and Topylko P. 2012.** Spatial analysis of GHG emissions in eastern polish regions: energy production and residen-tial sector,Econtechmod, vol. 1,n.2,17-24.

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Big Data Model "Entity and Features"

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Abstract. The article deals with the problem which led to Big Data. Big Data information technology is the set of methods and means of processing different types of structured and unstructured dynamic large amounts of data for their analysis and use of decision support. Features of NoSQL databases and categories are described. The developed Big Data Model "Entity and Features" allows determining the distance between the sources of data on the availability of information about a particular entity. The information structure of Big Data has been devised. It became a basis for further research and for concentrating on a problem of development of diverse data without their preliminary integration.

Key words: Big Data, NoSQL, document-oriented database, Big Table.

INTRODUCTION

The term Big Data was introduced by Clifford Lynch, editor of *Nature*, who released a special issue on 3 September 2008 examining what big data sets meant for modern science. He collected information about the phenomenon of explosive growth and diversity of data and technological prospects in the paradigm of probable transition from quantity to quality [1].

Big data is the term increasingly used to describe the process of applying serious computing power – the latest in machine learning and artificial intelligence – to seriously massive and often highly complex sets of information (cited from 4/2013 the Microsoft Enterprise Insight Blog).

Typically Big Data:

- is automatically machine obtained/generated,
- may be a traditional form of data now expanded by frequent and expanded collection,
- may be an entire new source of data,
- is not formatted for easy usage,
- can be mostly useless, although Big Data is collected and its economics is positive,
- is more useful when connected to structured data in corporate enterprise systems (ERPs).

The challenges include capture, curation, storage, search, sharing, transfer, analysis, and visualization

Big Data has many advantages over traditional structured databases. The properties of Big Data enable analysis for the purpose of assembling a picture of an event, person, or other object of interest from pieces of information that were previously scattered across disparate databases. Big Data is a repository for multi-structure data which makes it possible to draw inferences from correlations not possible with smaller datasets.

Despite the fact that the term was introduced in the academic environment, the primary problem was the growth and diversity of scientific data in practical tasks. As of 2009, the term was widely used in the business press, and 2010 saw emergence of the first series of products and solutions related only to the problems of processing of huge data volumes. By 2011, most of the largest providers of information technology for organizations based their business strategies on the concept of big data, including IBM, Oracle, Microsoft, Hewlett-Packard and EMC [1].

Problems arising during processing, interpretation, collection and organization of Big Data appeared in numerous sectors, including business, industry and non-profit organizations. Data sets such as retail customer transactions, weather monitoring, business analysis can quickly outstrip the capacity of the traditional methods and tools for data analysis. There are new methods and tools such as databases NoSQL and map Reduce, natural language processing, machine learning, visualization, acquisition, and serialization. It is necessary to fully understand what happens when we use growing big data and where its role is becoming crucial. Knowing the requirements to the existing methods of system development and data analysis is also important.

ANALYSIS OF RECENT RESEARCHES AND PUBLICATIONS

One of the adapting concepts not only of relational data is NoSQL. Followers of the concept of NoSQL language emphasize that it is not a complete negation of SQL and the relational model, and that the project comes from the fact that SQL is an important and very useful tool, which, however, cannot be considered universal. One of the problems mentioned for classical relational database is the problem of dealing with huge data, projects with a high load and parallel processing. The main objective of the approach is to extend the database if SQL is not flexible enough, and not displace it wherever it performs its tasks.

The NoSQL idea is underlain by the following points:

- non-relational data model,
- distribution,

• open output code,
• good horizontal scalability.

As one of the methodological approaches of NoSQL studies, a heuristic principle is used, known also as the CAP theorem (Consistence, Availability, Partition tolerance – «consistency, availability, resistance to division"), arguing that in a distributed system consistency, accessibility (English: availability, every query is responded to) and resistance to splitting a distributed system into isolated parts cannot be simultaneously provided. Thus, if it is necessary to achieve high availability and stability of the division, the means to ensure consistency of data provided by traditional SQL-oriented database with transactional mechanisms on the principles of ACID are not to be focused on [1].

A non-strict proof of the CAP theorem is based on a simple reflection. Let the distributed system consist of N servers, each of which handles the requests of a number of client applications. While processing a request, the server must ensure the topicality of the information contained in the response to the request being sent, which previously required synchronizing the contents of its own base with other servers. Thus, the server must wait for a full synchronization or generate a response based on non-synchronized data. In the alternative case, for some reasons synchronization involves only some of the servers. In the first case the requirement of availability is not fulfilled, the second one fails to satisfy the requirement of consistency and in the third case resistance to division requirement is not matched.

There are four categories of NoSQL databases.

The first category is *Key-value stores*. These are very simple stores. Actually, they are large cache tables, where each key has its value. Such databases are able to quickly process a huge volume of information, but they are limited in terms of query language (just searching for a key or value). The examples of key-value databases are Dynomite, Voldemort, Tokyo, Redis, etc.

The second category is *Bigtable clones*. Bigtable is a database developed by Google for its own needs. The database is a large three dimensional table comprising columns, lines, and time markers. Such architecture allows it to obtain very high productivity and, moreover, can be easily scaled on many computers. However, it is a non-relational database which does not support many features peculiar to relational databases. In particular, Bigtable lacks complex queries, joining operations function, etc. Google does not promote Bigtable. That is why there are several independently developed clones of this database on the market, including such projects as Hadoop, Hypertable, and Cassandra.

The next category of bases is the *document-oriented databases*. These bases are partially similar to Key-Value bases, but in this case a database knows what constitutes value. Typically, the value is a document or object to the structure of which queries can be made. Examples of such bases are CouchDB and MongoDB.

The fourth category is *databases based on graphs*. These bases are targeted at supporting complex relationships between objects and are based on graph theory. The data structure in such databases is a set of nodes connected by links. In this case nodes and links can have a number of attributes. Neo4j, AllegroGraph and Sones graphDB are the examples of such databases.

There is also the fifth category, but it is not considered to be of NoSQL type. These are *object-oriented databases*. Such databases serve first of all to maintain object-oriented programming paradigms. It is extremely easy to use them in programming languages supporting this paradigm. There are several mechanisms to access data in a NoSQL database.

Restful interfaces. This is an interface similar to HTTP, the main Internet protocol. Within the framework of this approach, each object that can be manipulated is supposed to have its own unique address. Using this address, the marked object can be queried, created, edited and deleted. Meanwhile, no state is stored on the server, which means each query is processed independently of other queries.

The query language different from SQL:

- GQL – Sql-similar language for Google Bigtable,
- SPARQL – semantic Web query language,
- Gremlin – graph traversal language,
- Sones Graph Query Language – Sones Graph query language.

API requests:

- Google Bigtable Datastore API,
- Neo4j Traversal API.

NoSQL can offer a high level of operational readiness, correctness and productivity. Apparently, the main advantage of NoSQL database is productivity. All NoSQL databases surpass relational databases in its niche. If until recently there was only one type of database in all cases – relational database, today the situation has changed. For each particular case, one has to select its data warehouse. Sometimes one has to have several databases simultaneously, in each of which its strongest points are used. For example, in web-applications Mongodb is used as the main data warehouse, and with the help of Redis the user's query caching is organized. As a result, we obtain a very high performance system with a developer-friendly interface. Another important advantage of NoSQL databases is that many representatives of this family of data warehouses are implemented as projects with open source. In general, comparison of SQL and NoSQL is presented in Fig. 1.

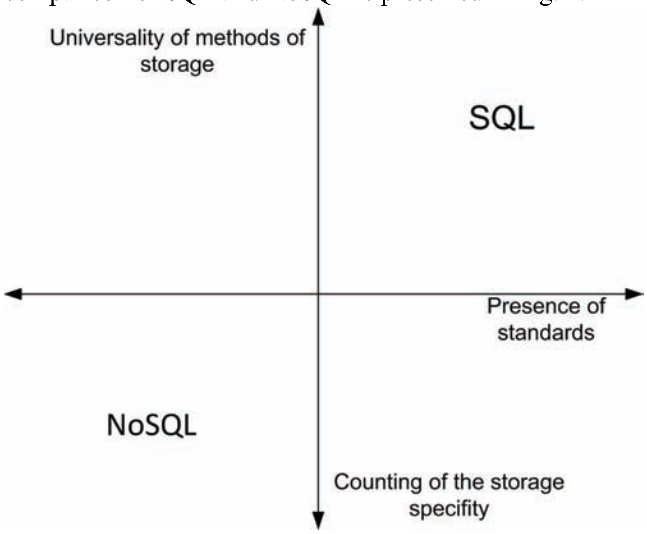

Fig.1. Comparison of SQL and NoSQL

Thus, the existence of different categories of NoSQL databases requires the formal description of data models which are processed by them.

Another comparison of relational database and NoSQL-system is presented in Table 1.

Table 1. Comparison of relational DB and NoSQL-system

Relational DB	NoSQL-system
Structured data	Unstructured data
ACID	Without ACID
Strong data consistence	Fractional data consistence
ETL	Without ETL
Not so fast response	Fast response
Efficiency	Flexibility

The Big Data issues are still not very well delineated, although it is the centre of gravity for business and technology. Analysis of the above-mentioned sources, popular science magazines, and blogs allow identifying the following discussion focuses:

- sources of big data;
- hardware and infrastructure;
- software and storage;
- IT (methods and tools of data processing);
- using big data, business-analysis.

Devices and people can be singled out as sources of data. Examples of the former include national and international projects such as Lange Hadron Collider in CERN, the European Laboratory for Particle Physics, the Large Synoptic Survey Telescope in the north of Chile, Internet things, industry (SCADA, finance, etc.).

The second type of data sources are represented by social networks, health care, retail, personal location data, public sector management, etc.

For data collection and processing it is practicable to use cloud computing technology. Cloud computing is a new paradigm for placing clusters of data and providing different services through a local network or via Internet. Hosting of date clusters allows clients to keep and calculate huge amount of data in a cloud.

On the one hand, when we collect big data, we have an opportunity to support decisions with the help of BI. BI is a set of theories and technologies aimed at data transfer of relevant and useful information for business processes. For example, according to the analyst Tim Swanson, the number of operations made in Cryptocurrency Bitcoin is more than 100 000 [12]. According to the IDC Digital Universe Study, the total amount of global data in 2005 was 130 Exabyte, by 2011 it rose to 1227 EB, and during the 2014 tripled and reached 4.4 ZB (zettabyte is 10^{21} bytes). A forecast made by the same study shows that by 2020 the volume of digital data will increase up to 44 ZB (the annual increase by 40 %) [13].

The size of an individual database increases as fast as that and has passed the petabyte barrier, for instance, for social networks databases. Therefore, online processing of such volumes in a distributed mode is practically impossible (Fig. 2).

Table 2 [1] shows some tools with processing of Big Data with open output code, which are provided by the cloud computing infrastructure. Most of the tools are provided by Apache and produced under the Apache license. These products are grouped depending on the tasks that arise during the processing of big data.

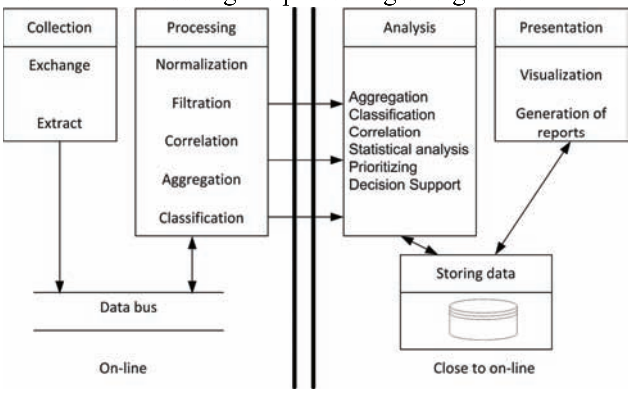

Fig.2. Contrastive description of OLAP and Big Data

Table 2. Tools for working with Big Data [1]

Tools for Big Data	**Description**
Data analysis tools	
Ambari http://ambari.apache.org	Web tool for service delivery, management and monitoring of Apache Hadoop clusters.
Avro http://avro.apache.org	The system of data serialization.
Chukwa http://incubator.apache.org/chukwa	The system for collecting data to manage large distributed systems.
Hive http://hive.apache.org/	Data warehouse infrastructure that provides data aggregation.
Pig http://pig.apache.org	High-level data streams language and executable framework for parallel computing.
Spark http:// spark.incubator.apache.org	Fast and general Hadoop data computer/calculator. It provides a simple and expressive programming model that supports a wide range of applications, including ETL, machine learning, flows processing.
ZooKeeper http:// zookeeper.apache.org/	Highly productive coordinating service for distributed applications
Actian http://www.actian.com/about-us/#overview	Provides storage of raw data and prepares the data for further analysis
HPCC http://hpccsystems.com	Provides rapid transformation, parallel processing for use with Big Data
Tools of Data Mining	
Orange http:// orange.biolab.si	Open source data visualization and analysis for novice and experts.
Mahout http:// mahout.apache.org	Library of facilities of machine learning and data mining
KEEL http://keel.es	Evolutionary algorithm for data mining problems
Social Networking Tools	
Apache Kafka	Platform high bandwidth for data processing in real time
Tools of BI	
Talend http://www.talend.com	Data integration, management, integration of applications , tools and services for Big Data
Jedox http:// www.jedox.com/en	Functions of analysis, reporting, planning
Pentaho http://	Data integration, business

www.pentaho.com	analysis, data visualization, prediction
Rasdaman http:// rasdaman.eecs.jacobs-university.de/	Multidimensional raster data (array) without restrictions on size, availability of query language
Search tools	
Apache Lucene http://lucene.apache.org	Applications for full-text indexing and search
Apache Solr http:// lucene.apache.org/solr	Full-text search, faceted search, dynamic clustering, formats of document of type Word, PDF, spatial search
Elasticsearch http:// www.elasticsearch.org	Distributed text search tool with a web interface and JSON documents
MarkLogic http://developer.marklogic.com	NOSQL and XML database
mongoDB http:// www.mongodb.org	Cross-platform document-oriented database management system with support for JSON and dynamic schemes
Cassandra http:// cassandra.apache.org	Scalability and high availability without compromising performance.
HBase http://hbase.apache.org	Is the Hadoop database, a distributed, scalable, big data store.
InfiniteGraph http:// www.objectivity.com	Distributed Graph Database

OBJECTIVES

Big data is a term used to identify data sets that we cannot cope with using existing methodologies and software tools because of their large size and complexity. Many researchers are trying to develop methods and software tools for data mining or information granules of Big Data.

Big Data features are: work with unstructured and structured information; targeting at faster data processing; leading to the fact that traditional query languages are ineffective while working with data.

The purpose of the article is to formally describe different data models, operations and carriers distinguishing and sharing methods since traditional query languages are ineffective for working with data.

A FORMAL DESCRIPTION OF THE BIG DATA STRUCTURE

A striking example of Big Data is a data set that describes functioning of a region. Therefore, in the end there are:

- a large set of entities: persons, places, organizations (individual and legal), date, natural resources (rivers, forests, lakes), recreational resources (historical monuments, health care), legislative acts and reports,
- huge database features: documents for data mining, ontological terms, data dictionaries, which allow associating certain objects.

On the basis of this information the relations between entities should be established.

Formally, all the objects fall under the following categories [1]:

- *e* – entities,
- *f* – features,
- associations between entities *e* and features *f*.

For instance:

- name *e* is mentioned in *f* document,
- notion *f* appeared in *e* document.

There are also defined:

- set *E* of entities,
- set *F* of features,
- for each *e* and *f* the number of associations between *e* and *f* is designated as $n_{e,f}$.

The total number of entities is determined as |*E*|, the total number of features is determined as potency of sets *F*:|*F*|. Let us also describe:

- for every feature *f* plural $e(f)=\{e\in E : n_{e,f}>0\}$ of all entities associated with *f*,
- for every entity *e* plural $f(ef)=\{f\in EFn_{e,f}>0\}$ of all features associated with *e*.

Let us describe these qualitative representations in the quantitative form.

In similar situations when a few entities are related to a feature, we will use the quantitative representation of information, i.e. the number of binary questions (yes, no) required to find the object we need. In general, if we know that the unknown object belongs to a set consisting of *N*-elements, this set can be divided into halves.

Therefore, the number of objects will be $\frac{N}{2}$. Let us continue this procedure: the second question is asked, for which we will divide the selected half into halves. Thus, after two questions (actions) we will have $\frac{N}{4}$ objects to which the unknown one belongs. After three questions (actions) we will receive $\frac{N}{8}$. Answering *q* binary questions will result in a set of $N\cdot 2^{-q}$ elements that contain the necessary object. Thus, for *N* alternatives the relevant information (the number of binary questions) is $N\cdot 2^{-q}=1$ and therefore equal to $q=\log_2(N)$.

Entities can be described in a similar way. There is |*E*| entity with $\log_2(|E|)$ amount of information. When we know that some entity is associated with a response (we have $|e(f)|$ entity), then the amount of information is equal $\log_2(|e(f)|)$. Therefore, the fact of the relation between the entity and the feature *f* allows reducing the number of questions to $\log_2(|E|)-\log_2(|e(f)|)=\log_2\left(\frac{|E|}{|e(f)|}\right)$. It is similar to the formula defining amount of information.

Besides, the effect of several associations can be described by counting how many additional binary questions we can ask to further know an association with the required entity. Let us start with $n_{e,f}$. Each binary question reduces the number of objects by half; *q* questions reduce the number to $n_{e,f}\cdot 2^{-q}$. We continue to have an association up to the point at which the number of objects becomes ≥ 1. Most q for which we still do not have an association is defined as $n_{e,f} \cdot 2^{-q} = 1$, which, in its turn, is defined as $q = \log_2\left(n_{e,f}\right)$. Adding an additional question is defined as $1 + \log_2\left(n_{e,f}\right)$.

General importance of f features for the entity e is defined as $\log_2\left(\frac{|E|}{|e(f)|}\right)$ with the factor of importance $1 + \log_2\left(n_{e,f}\right)$. The resulting amount of information is defined as:

$$I(e, f) = \left(1 + \log_2\left(n_{e,f}\right)\right) \cdot \log_2\left(\frac{|E|}{|e(f)|}\right). \quad (1)$$

This formula (1) is one of the options in terms of frequency – the so-called inverse document frequency *tf-idf*. For each e-entity we have importance $I(e, f)$ for different features f. It is necessary to normalize the meaning of importance, which looks like cosine normalization:

$$V(e, f) = \frac{\left(1 + \log_2(n_{e,f})\right) \cdot \log_2\left(\frac{|E|}{|e(f)|}\right)}{\sqrt{\sum \left(\left(1 + \log_2(n_{e,f})\right) \cdot \log_2\left(\frac{|E|}{|e(f)|}\right)\right)^2}}. \quad (2)$$

For each e-entity there is weight $V(e, f)$. Thus, as a measure of proximity between two objects E_1 and E_2, we can consider the distance between the corresponding vectors $(V(e, f_1), V(e, f_2), \ldots)$.

In the ordinary Euclidean distance $d(a,b) = \sqrt{(a_1 - b_1)^2 + \ldots}$ squares of differences are added. Thus, for each weight $V(e, f)$, which represents the number of bits, we will have the following equation:

$$d(e_1, e_2) = \sum_{f \in F} \left|V\left(e_1, f\right) - V(e, f_2)\right|. \quad (3)$$

This distance depends on the number of features: for example, if in addition to the documents we store their copies, the distance is doubled. In order to avoid this dependence, the distance $d(e_1, e_2)$ is ordinarily normalized in the range [0,1] through the division by the maximum possible value of this distance.

How can we estimate the largest possible value of this distance? In general, when we do not know the true value of A and B, the two non-negative quantities, and we know only the upper limits of these variables $\bar{a}$, $\bar{b}$, then the largest possible value of the difference $\left|\bar{a} - \bar{b}\right|$ is equal to $\max\left(\bar{a}, \bar{b}\right)$. Then [2, 16]:

- if $\bar{a} \leq \bar{b}$, then $\left|\bar{a} - \bar{b}\right| = \bar{b} - \bar{a} \leq \bar{b}$ that is why, $\left|\bar{a} - \bar{b}\right| \leq \max\left(\bar{a}, \bar{b}\right)$;
- if $\bar{b} \leq \bar{a}$, then $\left|\bar{a} - \bar{b}\right| = \bar{a} - \bar{b} \leq \bar{a}$ that is why, $\left|\bar{a} - \bar{b}\right| \leq \max\left(\bar{a}, \bar{b}\right)$.

In both cases we have $\left|\bar{a} - \bar{b}\right| \leq \max\left(\bar{a}, \bar{b}\right)$.

The limit $\max\left(\bar{a}, \bar{b}\right)$ is reached:

- when $\bar{a} \leq \bar{b}$, if $a = 0,\ b = \bar{b}$;
- when $\bar{b} \leq \bar{a}$, if $a = \bar{a},\ b = 0$.

IV. ASSOCIATION MODELS OF ENTITIES AND FEATURES FOR VARIOUS CATEGORIES OF NOSQL DATABASE

We introduce the concept of model associations between objects and features for different categories NoSQL databases.

The data carrier in the model «key-value», also known as column DB, is described with cortege in the following way:

$$KV = \{< f, e >\}, \quad (4)$$

where: f is the key that takes a unique value in each pair; e is the value that corresponds to this key. Keys can be folded (major or minor), and the value supports unlimited semantics.

The model signature has the following form:

$$O = \langle \pi, \sigma \rangle, \quad (5)$$

where: π is an operation projection by attributes (key or value); σ is a selection of attributes (value selection by key, keys by value, key by ancestors value). These operations refer to the reading category [5, 6].

An example of the column database is **Cassandra**.

The model is used in the system BigTable of Google and was designed for the distributed storage of large volumes of data:

- not a full relational data model,
- dynamic control support of data placement.

The BigTable data model is simple and contains rows, columns and timestamps:

$$BigTable = \{< r, c, t >\}. \quad (6)$$

The address of the documents from the Internet may be presented as the row names in the database of the search engine, and the features of these documents can serve as columns' names (for instance, the content of the document can be stored in column «Content» and the reference to secondary pages in «Anchor»).

Another example is Google Maps that consist of billions of images, and each of the image details a certain geographic area of the Earth. The structure of Google Maps in BigTable is based on the fact that each row corresponds to a single geographic segment, and the columns are the images, from which this segment is built; different columns have the images with different resolutions.

If one-type data is stored in several columns, such columns make a family, due to the BigTable model, which takes the following form:

$$colF = \left\{c_i, c_j \mid dom(c_i) \in T \wedge dom(c_j) \in T\right\} \quad (7).$$

A column family can be first of all used for compressing similar data to decrease volume. A column family is a unit of data access.

The BigTable rows are also important (they can be 64 kilobytes in length). An operation of tag to row is atomic, meaning that no other programme can change the data in the column family of the row until the tag to row of the previous programme is succeeded).

In addition, the rows are easily sortable. An example of the URL-document, after its record has been made reversible, shows how easily all lines are organized as a third level domain name.

The content of web-pages is constantly changing. In order to accommodate these changes, each copy of the data stored in the column is given a time stamp. In BigTable, timestamp is a 64-bit number that can code the date and time as required. For example, a timestamp for copies of web-pages in the column *Contents* will be the creation date and time of such copies. Using timestamps, applications can specify a search in BigTable, for example, of only recent data copies.

Therefore, for the domain of any Google service, its own data map BigTable can be created, which contains any number of rows and a set column families unique for this domain. The inevitable repetitions of data in columns are sorted by timestamps. All this appoints to the complete lack of support of ACID properties.

However, the main advantage of this approach is that such database can be easily divided into independent parts and distributed to a set of servers. Alphabetically sorted lines are shared on ranges called Tablets, or dependent tables. As lines are sorted by a key name in every tablet, it is very simple for client applications to find either the necessary tablet or the necessary line in it.

In this model the key identifies the line containing the data which is stored in one or several sets of columns. Every line can have many values of columns within such sets. The value of each column contains a time tag, which is why some values of compliances between line and column can be within one family of columns.

BigTable is a big and distributed system for such synchronizing objects, due to which a distributed lock service that Google call Chubby has been used instead. Its role in BigTable can be compared with a role of transactions in the usual Database Management System (DBMS). For each tablet-server, Chubby creates a special chubby-file. Due to this file, BigTable Master is always aware of efficient servers. One more chubby-file contains links to the location of the Root tablet with data on the location of all the other Tablets. This file informs the Master which servers are managed by the Tablet.

Undoubtedly, use of Chubby-service in BigTable to some extent solves the problem of data consistency control with a set of remarks in the distributed environment. However, consistency can be of different kinds. BigTable became the first attempt to reach the balance between system productivity, its scalability and consistency of data stored in it. This resulted in the maintenance of the so-called weak consistency, which, in principle, met the requirements of major services working with BigTable.

Fig. 3 shows how the user looks for the tablet [4].

The carrier of object-document model is described by the following cortege:

$$OD = \left\langle \begin{array}{l} f_0, \langle f_1 : e_1, f_2 : e_2, ..., f_n : e_n \rangle, \\ \langle f_1 : d_1, f_1 : d_2, ..., f_{n+l} : d_l \rangle \end{array} \right\rangle, \quad (8)$$

where: f_0 is the identifier of the document; $f_1..f_n$ are the attributes of the document; $e_1..e_n$ are the atomic values of features $f_1..f_n$; $d_1..d_l$ are dispatchers to the other documents, $d_i = e(f_i)$.

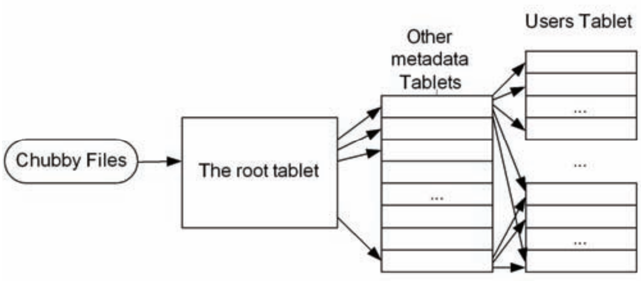

Fig. 3. The hierarchy of tablets

Operations of this model are object.

The operation of determination of element nodes will look as follows:

$$v(f_i) = \{C\} \cup \{od_i \mid i = \overline{1,n}\} \cup \{e(f_i) \mid i = \overline{0, n+l}\}, \quad (9)$$

where: C is a collection of documents od_i

The operation of determination of node values will have the following form:

$$v(f_i) = \{e_{ij} \mid i = \overline{1,n}, j = \overline{0, m+l}\}, \quad (10)$$

where: e_{ij} is the value of attribute f_i.

The relations between carrier elements are also defined.

The relation *element-element* is defined between documents and collection:

$$OD \times C \to EE. \quad (11)$$

Relations *element-attribute* look as follows:

$$f_i \times OD \to EA. \quad (12)$$

Relations *element-tag* are expressed in the following way:

$$f_i \times d_j \to ER. \quad (13)$$

The relations *element-data* are defined as follows:

$$f_i \times e_j \to ED. \quad (14)$$

MongoDB and CouchDB are examples of this type of DBMS.

The graph data model is presented as:

$$O = \langle ID, A, z, r \rangle, \quad (15)$$

where: ID is a set of identifiers, graph nodes; A is a set of labelled directed arcs (p, l, c), $p, c \in ID$; l is line-tag; the record (p, 1, c) means that there is a relation l between nodes p and c; z is a function that displays each node $n \in ID$ in the specific composite or atomic value, $z : n \to v$; V is a special root graph node.

The structure of the XML document which consists of the enclosed element-tags is well-known. Its difference from the graph model considered above generally consists in interpretation of tags: in column tags are used as designation of communications between elements of data schemes and tags are not necessary for designation of an element, and in XML document-focused model it is necessary that each (not text) element of data has an identifying sign. XML is also translated into the tree data structure, which is a specific case of graph model.

In the XML graph model, semistructured data requires specialized types of attributes, such as *ID*, *IDREF* and *IDREFS*. The specified types enable organizing the storage of cross tags in *XML*-elements such as <*eid*, *vahie*=""> (<*the element identifier*, *value*>) and attributes of <*label*, *eid*=""> (<tag, value>) type.

There are several types of *RDF* data as a graph model, including *RDF*/*XML*, *N3*, *Turtle*, *RDF*/*JSON*.

The description of resources in the form of *RDF*-Data sets are defined as a triplet "subject" - "predicate" - "object", that is for the set *U* (*Universal Resource Identifier*, *URI*, unified identifier of resources) these are elements *f*, for the set *B* (*Black nodes*, *empty nodes*), set *L* (*Literal*, *RDF*-literals), $B \in e, L \in e$ the set is defined as (*f*, *e*(*f*), *e*), where *f* is "subject", *e*(*f*) is "predicate" and *e* is "object".

For *RDF*-graph model of data, let $t = (f, e(f), e)$ be an *RDF*-element of data, where $(f,e(f),e)\in(UB)\times U\times(UBL)$; besides, *t* is a key element if it does not contain nodes without identifiers. *RDF*-graph *G* is a $T \supseteq t$ set [3].

Consequently, Big Data includes various models of data [18 – 22]. Therefore, there should be methods of their transformation with the minimum loss of data.

Information structure of Big Data is presented in Fig.4.

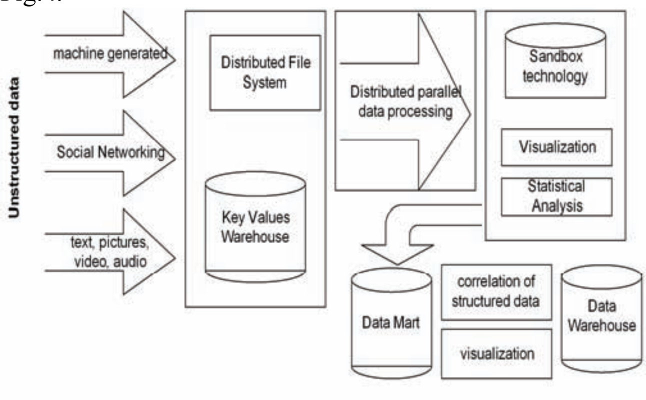

Fig. 4. Information structure of Big Data.

CONCLUSIONS

The article discusses the structure of Big Data. Models of object associations and features of the main data presentations in NoSQL are defined. The information structure of Big Data has been devised. It became a basis for further research and for concentrating on a problem of development of diverse data without their preliminary integration.

REFERENCES

1. **Pedrycz W., and S.-M. Chen. 2015.** Information Granularity, Big Data, and Computational Intelligence, Studies in Big Data 8, DOI: 10.1007/978-3-319-08254-7, Springer International Publishing Switzerland.
2. **Srinivasa, S., and V. Bhatnagar. 2012.** Big data analytics. In: Proceedings of the First International Conference on Big Data Analytics BDA'2012. Lecture Notes in Computer Science, vol. 7678. Springer, New Delhi, 24–26 Dec 2012.
3. **Butakova M.A., Klimanskaya E.V., and Yants V.I. 2013.** Measure of informative similarity for the analysis of semi-structured information. Modern problems of science and education. n. 6; Available online at: <http://www.science-education.ru/113-11307>.
4. **Chang F., Dean J., Ghemawat, S., Hsieh W., Wallach D., Burrows M., Chandra T., Fikes A., Gruber R. 2006.** Bigtable: A Distributed Storage System for Structured Data, Research (PDF), Google.
5. **Papakonstantinov F. and Widom J. 2005.** Object exchange across heterogeneous information sources. 11-th International Conference on Data Engineering (ICDE'05). 251-261.
6. **Feng Z., Hsu W. and Li M. 2005.** Efficient pattern discovery for semi-structured data. 17th IEEE International Conference on Tools with Artificial Intelligence (ICTAI-05). 301-309.
7. **Shakhovska N. 2010.** Software and algorithmic software of data storage and data spaces: monograph; Acting Lviv Polytechnic Nat. University. Lviv: Izd Lviv Polytechnic, 194. (in Ukrainian).
8. **Shakhovska N. 2008.** Features Data spaces modeling. Proceedings of Lviv Polytechnic National University. Lviv: Izd Lviv Polytechnic Nat. Univ, Computer Engineering and Information Technology. 608:145 – 154. (in Ukrainian).
9. **Shakhovska N., Medykovsky M., and Stakhiv P. 2013.** Application of algorithms of classification for uncertainty reduction/ Przeglad Elektrotechniczny. 89(4):284-286
10. **Kut V. 2014.** Consolidated model of remote and consulting center of people with special needs. Proceedings of Lviv Polytechnic National University. Information systems and networks. 783:120–127. (in Ukrainian).
11. **Kushniretska I., Kushniretska O., and Berko A. 2014.** Analysis of information resources integration system of dynamic semistructured data in a Web-environment. Proceedings of Lviv Polytechnic National University. Information systems and networks. 805:162-169. (in Ukrainian).
12. The daily volume of transactions in Bitcoin overcame the barrier of 100 000: Available online at: <http://vkurse.ua/ua/business/ezhednevnyy-obem-tranzakciy-v-bitcoin.html>.
13. Data Growth, Business Opportunities, and the IT Imperatives Available online at: <http://www.emc.com/leadership/digital-niverse/2014iview/executive-summary.htm>.
14. **Shakhovska N., Bolubash Yu, and Veres O. 2015.** Big Data Federated Repository Model. Proc. of CADMS'2015. Lviv: Lviv Polytechnic Publishing. 382-384. (in Ukrainian).
15. **Shakhovska N., Bolubash Y, and Veres O. 2014.** Big data organizing in a distributed environment. Computer Science and Automation. Donetsk. Ukraine. 2(27):147-155. (in Ukrainian).
16. **Shakhovska N. 2011.** Formal presentation of data space as an algebraic system. System Research and Information Technologies. National Academy of Sciences of Ukraine, Institute for Applied Systems Analysis. Kyiv. 2:128 – 140. (in Ukrainian).
17. **Shakhovska N. and Bolubash Y. 2013.** Working with Big Data as indicators of socio-ecological-economic development. Eastern-European Journal of Enterprise Technologies, 2(65):5. (in Ukrainian).
18. **Kalyuzhna N. and Golovkova K. 2013.** Structural contradictions in control system by enterprise as

function of associate administrative decisions. EconTechMod: an International Quarterly Journal on Economics in Technology, new Technologies and Modelling Processes. Krakiv-Lviv, 2(3):33-40.

19. **Magoulas R., and Ben L. 2009** Big data: Technologies and techniques for large scale data, Release 2.0

20. **Kossmann D., Dittrich J.P. 2006** Personal Data Spaces. Available online at: http://www.inf.ethz.ch/news/focus/res_fo cus/ feb_2006/index_DE.

21. **Stonebraker M., Abadi D., DeWitt D. J., Madden S., Pavlo A., and Rasin A. 2012** MapReduce and Parallel DBMSs: Friends or Foes. Communications of the ACM (53:1). 64-71.

22. **Laney D. 2001** 3D Data Management: Controlling Data Volume, Velocity and Variety. Gartner.

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The Model of Correspondence of Passenger Transportation on the Basis of Fuzzy Logic

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Abstract. The article dwells upon possibilities of the implementation of smooth calculation methods for predicting the demand for passenger transportation. The developed model which is based on fuzzy logic successfully solves the problem with traffic assignment – formation of passenger throughput for each traffic route. The model of correspondence takes into account such defining factors as fare on the route, average headway on it and fullness of the vehicle saloon. Different combination of these factors forms attractiveness as a criterion of an optimal route for a prospective passenger. It is determined that the lower saloon fullness, transportation fare and headway, the higher attractiveness is. Using the reasoned criterion, it is possible to allocate the total number of prospective passengers according to each existing route.

Key words: fuzzy logic, transportation correspondence, membership function, basis of fuzzy rules, route attractiveness.

INTRODUCTION

The system of passenger transportation in cities has to be regarded as difficult and changeable one. The initial information used for the development of project decisions concerning improvements of traffic system functioning is the demand of citizens for transportation services. Prediction of the demand for passenger transportation is indispensible part of traffic planning in big cities.

One of the powerful characteristic features of demand due to its resource-intensiveness of calculations is considered to be correspondence of passenger transportation of the citizens. Results of its calculations characterize the mobility pattern on the territory of planning in spatial and quantitative dimensions.

ANALYSIS OF THE LATEST FINDINGS AND SCIENTIFIC PUBLICATIONS

The issue of passenger transportation allocation on a street and road network of a city or town was investigated by a number of scientists [1 – 9]. In their works, the initial information for matrix correspondence evaluation is a number of passengers who gets on and off a vehicle on each stop. The research in this field was carried out mainly for routes of public transport. Among foreign scientists who worked on this subject the following ones can be distinguished: N. Oppenheim, Y. Sheffi, J. Ortuzar, C. Winston, D. Loze, D. Drew and others [10 – 14].

The analysis of scientific publications has defined the requirements for passenger correspondence patterns: flexibility (possibility of additional parameters input in order to take into account traffic situation in cities); universality (possibility to describe different types of road trips); relative simplicity (broad application under various conditions of planning with and without computing technologies) [15, 16].

Models of defining transportation capacity with the use of fuzzy logic are qualitatively distinguished among others in terms of minimizing necessary resources for collecting initial data and simplicity of calculating. Due to their structure, such models represent a “black box” which allows to enter input data, formed in a certain way, and receive outcomes [17].

OBJECTIVE

Since passenger transportations are characterized by ambiguity of information concerning main features of a particular route type and preferences of an active part of the population, the objective of the research is to develop a model of passenger transportation correspondence on the basis of mathematical apparatus of fuzzy logic which enables choosing the most suitable options of a route which at the same time are the most time and cost effective and the most comfortable ones.

MAIN OUTCOMES OF THE INVESTIGATION

In the course of certain investigations [18] the survey of citizens was carried out with the aim to detect factors which do not allow people to satisfy their needs in using public transport. Among them there is transportation fare, headways, boarding denial, saloon fullness, time spent on the way to a stop, necessity in transfers, transportation safety. Outcomes of processed data have shown that passengers belonging to the main population groups are not satisfied, first and foremost, with transportation fare. Other factors that follow in order of importance are: headway, boarding denial, saloon fullness [18].

Taking into consideration the above, for allocation on the routes of transportation of the total number of people who waits to be transferred from point A to point B, it is reasonable to build the model with the initial data concerning total transportation fare, average headway of the vehicle on the route and average fullness of the vehicle. Initial (resulting) data will be attractiveness.

Considering a set of alternative connective routes, each of them corresponds to a particular value which is called attractiveness and depends upon parameters which characterize this route.

Therefore, methodological approach to evaluation of alternative attractiveness (choice of a route option) is considered in this paper:

$$P = f(V, I, N), \tag{1}$$

where: V – transportation fare on the route;
I – average headway on the route;
N – fullness of vehicle saloon.

In order to fulfill the set task there has to be created a database of rules for fuzzy logic with three inputs and one output. The task was to form fuzzy rules for the basis of the control module which, when receiving input signals (transportation fare (*V*), average headway on the route (*I*) and fullness of the vehicle (*N*)), would generate valid (with the least error) output signals (attractiveness of the route (*P*)) [19].

Let us suppose that we know the minimal and maximal value of each signal. According to these data it is possible to define intervals of admissible values. For instance, for input signal of transportation fare on a route (*V*) this interval is denoted as $[V_{\min}; V_{\max}]$ in monetary units.

Similarly let us set an average headway on a route (*I*) as $[I_{\min}; I_{\max}]$ in minutes, for vehicle fullness (*N*) – [0;100] on a percentage base. Accordingly, we choose the interval for an output signal of a fuzzy system – route attractiveness (*P*) [0;10], where 0 means that this route will not be used, 10 – the route will definitely be used.

Let us divide each interval defined in this way into areas which can be of the same or different length. Selected areas will be denoted as *M* (small), *S* (middle), *B* (big). One membership function will be defined for each interval. Fig. 1 depicts allocation of input and output signals into intervals. Each interval is divided into three areas.

Each membership function of input signals has triangular shape. One of the vertices is located in the center of the area and corresponds to the function value of 1. Two other vertices are in the adjacent areas and correspond to the function value of 0. The membership function of the output signal (attractiveness) is circumscribed, for example, by Gaussian curve.

The next step in creating the transportation correspondence model is setting fuzzy rules. To do this we define the degree of data membership in each of highlighted areas.

This membership is expressed by the membership function values of respective fuzzy sets for each data group [19]. The initial information was a testing selection in which the researcher had estimated in grades the degree of attractiveness of suggested routes with different characteristics.

Let us relate data to the areas in which they have the highest degree of membership. For instance, for the route with such characteristics:

$$V = 0{,}1 \cdot V_{\max},\ I = 0{,}4 \cdot I_{\max},\ N = 40\%,\ P = 8$$

it is possible to record the following fuzzy rule (there are 27 of them in total):

$$\begin{aligned}
&(V = 0.1 \cdot V_{\max}, I = 0.4 \cdot I_{\max}, N = 40\%;\\
&P = 8) \Rightarrow V = 0.1 \cdot V_{\max}\,[\max : 1\ in\ M],\\
&I = 0.4 \cdot I_{\max}\,[\max : 0.6\ in\ S],\\
&N = 40\%\,[\max : 0.6\ in\ S],\\
&P = 8\,[\max : 0.9\ in\ B] \Rightarrow\\
&ruleR:\\
&IF\,(V\,is\,M\ AND\,I\,is\,S\ AND\,N\,is\,S)\\
&THEN\ P\,is\,B.
\end{aligned} \tag{2}$$

As a result of processing of these samples some compiled rules appeared to be controversial (e.g. the rule with the same conditions but with different outcomes). Elimination of controversy meant attributing to each of them a degree of verity with further selection of the rule where this indicator is the highest [19].

In this way there were found and discarded 5 pairs of controversial rules. The procedure was carried out according to this formula:

$$SP(R) = \mu_M(V) \cdot \mu_S(I) \cdot \mu_S(N) \cdot \mu_B(P), \tag{3}$$

where: $\mu_M(V), \mu_S(I), \mu_S(N), \mu_B(P)$ is membership degree of the value of fare, headway and fullness of the vehicle in respective areas.

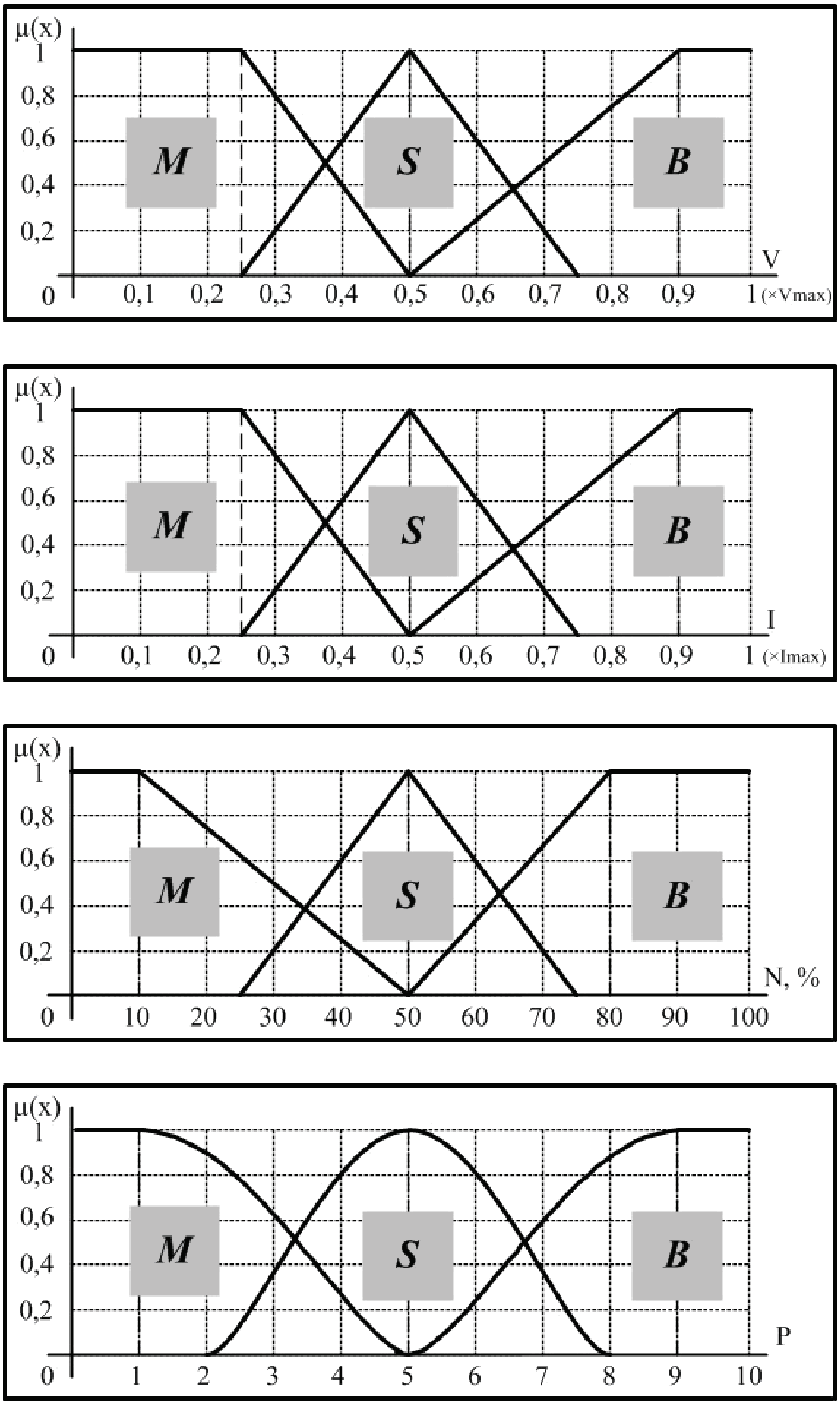

Fig. 1. Space allocation of input and output signals on the area and respective to them membership functions

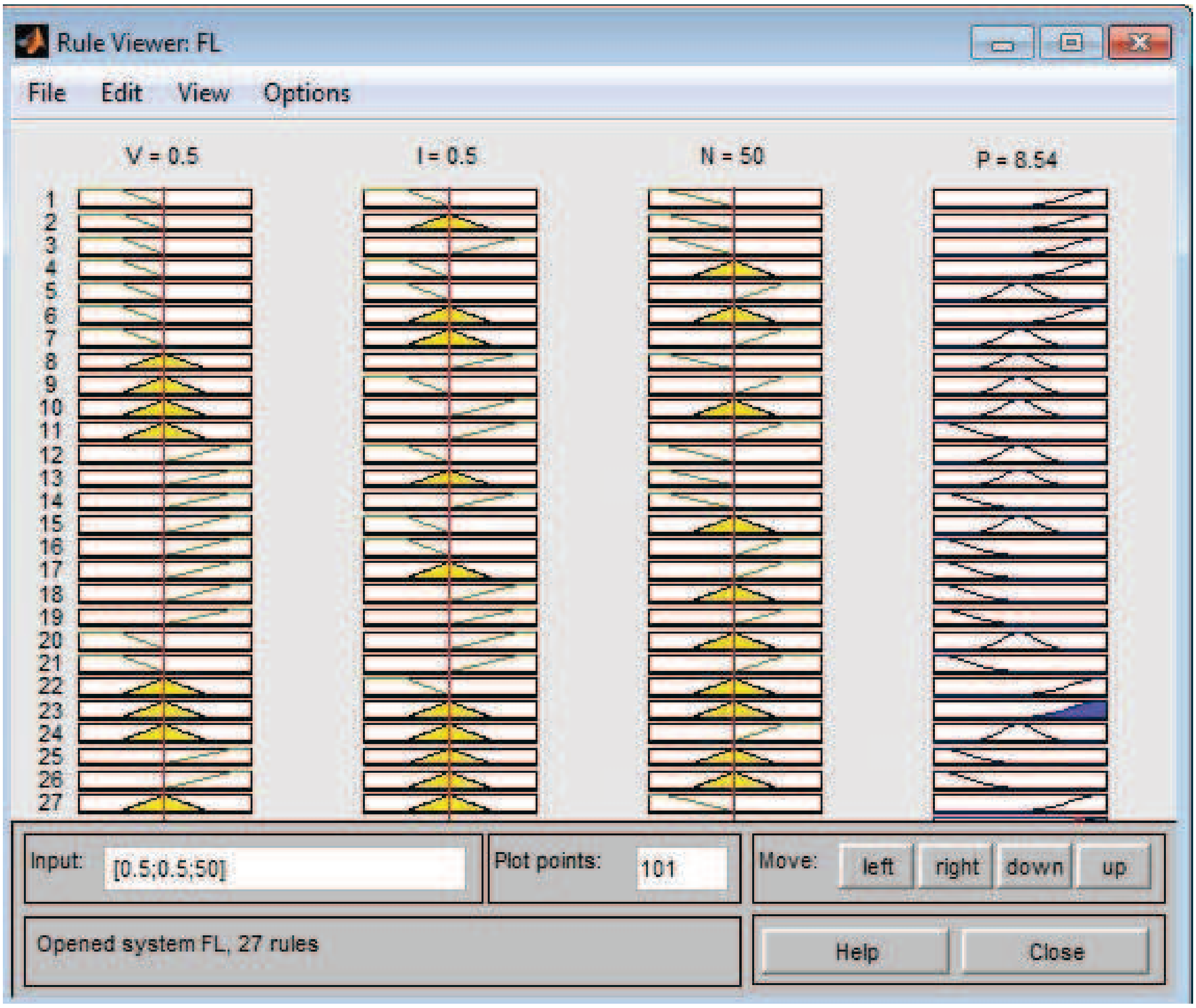

Fig. 2. View window of the rules of fuzzy inferences in MATLAB software environment

Therefore, the whole database of rules consists of 27 fuzzy statements (3 input signals which are divided into three areas). With its help and having used one of defuzzification methods (barycentric method, Center of Area method, left/right modal value method) we gain accurate output value of a fuzzy system, i. e. attractiveness of an option in grades.

Manipulating the data of passenger throughputs between two points among available route options which connect them and attractiveness of such alternatives, it is possible to calculate the number of passengers which will use each of these routes:

$$q_i = \frac{Q}{\sum_{i=1}^{n} p_i} \cdot p_i, \tag{4}$$

where: q_i is a number of passengers which will use i-option;

Q - passenger throughput between two points;

p_i - attractiveness of i-option among total n-number.

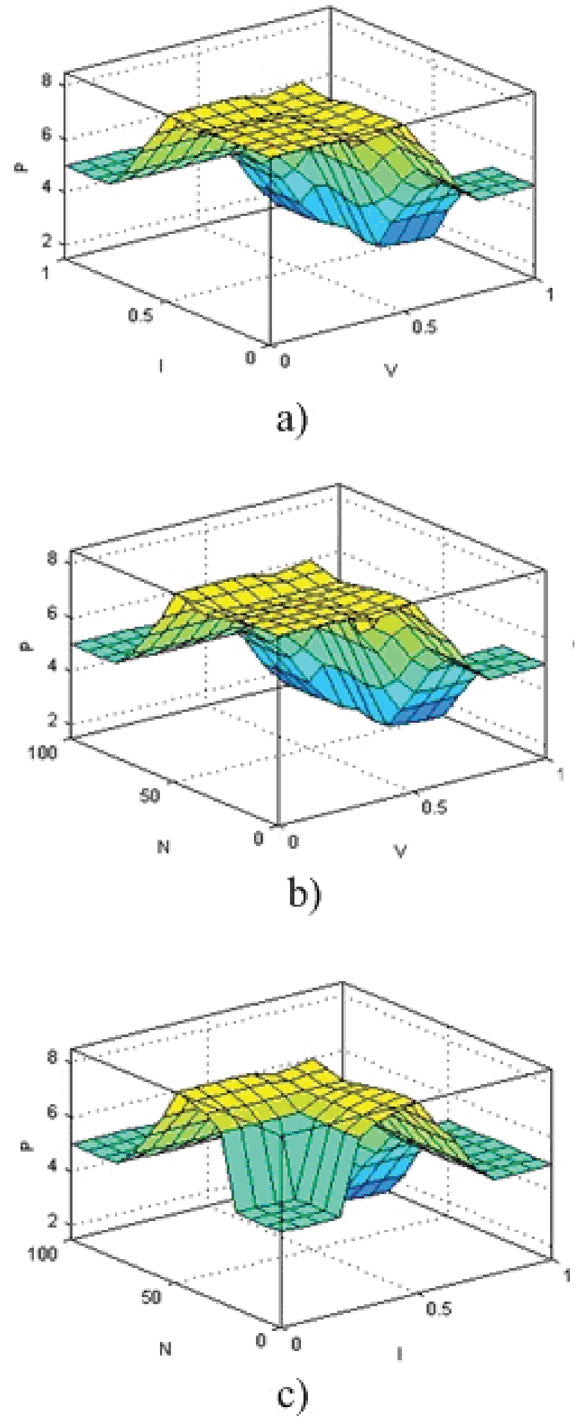

Fig. 3. Response Surfaces in relation to attractiveness level of alternative variants of transportations

The developed model is implemented in MATLAB software environment with the use of Fuzzy Logic Toolbox package [20, 21]. The program uses Mamdani algorithm of fuzzy inference and centroid method of defuzzification (reduction to neatness) [19]. Fig. 2 shows the view window of the rules for fuzzy inferences (red lines depict transportation fare *V*, headway on the route *I* and fullness of a vehicle saloon *N*; in the fourth column the output value, i. e. attractiveness *P*, is calculated automatically).

Dependence of attractiveness of alternative options for passenger transportation on transportation fare and vehicle headway (a), transportation fare and vehicle fullness (b), headway and fullness (c) are depicted as response surfaces in fig. 3.

Therefore, the outcomes of the application of developed correspondence models based on fuzzy logic has proved that they can be used further in forming matrixes of passenger throughput on specific routes. The information from databases of cellular communication on recording of transactions carried out by citizens will also be used.

CONCLUSIONS

Obtained results enabled drawing the fallowing conclusions:

1. The analysis of scientific publications on functioning systems of passenger transportation has revealed main demands to transportation correspondence models.
2. Correspondence models take into account the following defining factors: transportation fare on the route, average headway on it and fullness of a vehicle. Attractiveness of a route type is considered as a defining criterion for the selection of a rational option of transportation.
3. With the help of application of the fuzzy logic method and respective membership functions, the full database of rules (27 in total) for finding attractiveness of alternative route options was established.
4. The transportation correspondence model is implemented in MATLAB software environment with the use of Fuzzy Logic Toolbox package. On the basis of this (as a specific example shows) it is possible to choose optimal options of correspondence allocation on the routes according to their attractiveness.

REFERENCES

1. **Shvetsov V., 2010.** Problems of Transportation Modeling in Traffic Networks. MFTI works. Vol. 4, 169-179. (in Russian).

2. **Brailovskyi N., Hranovskyi B., 1978**. Modeling of Traffic Systems. Moscow: Transport, 124. (in Russian).

3. **Horbachov P. 2009.** New Conception of Modeling Needs of the Population in Commuting. Dnipropetrovsk national university Bulletin. Vol. 27, 210-214. (in Ukrainian).

4. **Horbachov P., 2009**. Modern Scientific Approaches to the Management of Passenger Transport of Fixed-Routes in Cities. Kharkiv, 196. (in Ukrainian).

5. **Zablotskyi H., 1968.** Methods of Calculations of Passenger and Traffic Flows in Cities, Moskow, 92. (in Russian).

6. **Vdovychenko V., 2004.** Functioning Efficiency of Urban Passenger Transportation System. Kharkov, 196. (in Russian).

7. **Liubyi Ye., Horbachov P., Havrylyshyna O., Siromolot A., 2011.** Patterns of Allocation of Transportation Correspondences in Towns. SNU im. V. Dalia Bulletin. Vol. 5 (159), 89-94. (in Ukrainian)

8. **Pohrebniak E., Samoilenko N., 2006.** Analysis of Methods of Forming the Matrix of Transportation Network Correspondences in a City. Kharkov National Academy of City Household. Vol. 69, 121-126. (in Ukrainian).

9. **Hetsovych Ye., Zasiadko D., 2010.** Traffic Zoning of Megalopolises and Estimation of the Routes for Correspondence Realization. Minsk, 26-33. (in Russian).

10. **Norbert Oppenheim, 1995.** Urban Travel Demand Modeling.John Wiley and Sons, 480.

11. **Ortuzar J. de D., Willumsen L., 2006.** Modelling transport. Third edition. John Wiley & Sons Ltd., 499.

12. **Winston C., Small K., 1998**. The Demand for Transportation: Models and Applications [Text]. C.: Univesity of California, 51.

13. **Drew D., 1972.** Theory of Traffic Flows and Their Management M: Transport, 423. (in Russian).

14. **Loze D. (2006).** Modelling of Traffic Supply and Demand for Passenger and Official Vehicles. SPb: SPb. Household Architect.-Build. University, 170-186. (in Russian).

15. **Horbachev P., Dmitriev I., 2012.** Fundamentals of Traffic System Theory. Kharkov, 202. (in Russian).

16. **Ohay V., 1978.** Modeli analiza passazhiropotokov na marshrutah gorodskogo transporta: avtoref. dis. [Models for the Analysis of Passenger Throughputs on Routes of the Public Transport], Tomsk,22. (in Russian).

17. **Bilous A., Demchuk I., 2014.** Analysis Methods and Models of Calculation of Passenger Correspondence Analiz, Eastern-European Journal of Eenterprise Technologies. Vol. 3/3 (69), 53-57. (in Ukrainian).

18. **Krystopchuk M., 2014.** Investigation of Impact Factors on the Allocation of Passenger Correspondences in the Route Network, Scientific notes. Vol.45, Lutsk, 317-322. (in Ukrainian).

19. **Rutkovskaya D., Pylynskyi L., Rutkovskyi L., 2006.** Neural Networks, Genetic Algorithms and Fuzzy Systems, Moscow : Telecom, 382. (in Russian).

20. **Shtovba S., 2007.** Designing of Fuzzy Systems with MATLAB, Moscow :Telecom, 288. (in Russian).

21. **Leonenkov A., 2003.** Fuzzy Modeling in MATLAB and fuzzyTECH Environment, Peterburg: Decision Master, 72. (in Russian).

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VHDL-Ams Model of the Integrated Membrane Micro-Accelerometer with Delta-Sigma (Δσ) Analog-To-Digital Converter for Schematic Design Level

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Abstract. VHDL-Ams model of integrated membrane type micro-accelerometer with delta-sigma (ΔΣ) analog-to-digital converter for schematic design level was developed. It allows simulating movement of the sensitive element working weigh from the applied acceleration, differential capacitor and original signal capacity change, signal digitizing with the help of Delta-Sigma ADC with defined micro-accelerometer structural parameters, and analyzze an integrated device at the schemotechnical design level.

Key words: Micro-Electro-Mechanical Systems (MEMS), micromechanical sensitive element, integrated membrane micro-accelerometer, delta-sigma modulation, pulse-width modulation (PWM), delta-sigma analog-to-digital converter (ADC), one bit digital-to-analog converter (DAC), VHDL-AMS hardware description language, hAMSter software, schemotechnical design level.

INTRODUCTION

Integrated micro-accelerometers (Microelectromechanical inertial sensors) are devices for linear accelerations measuring (static, for example, local Earth gravitational field and dynamic caused by motion or stroke), which appeared due to development of micromachine (MEMS) technologies [1-3]. Nowadays integral micro-accelerometers [2, 4, 6] are widely used in different technology areas such as: car industry, (antiblocking and the antiskiding systems, active suspension bracket systems, theft defense systems), robotics, inertial navigation, domestic appliances (computer manipulators, smart phones, tablets), sports equipment (training equipment, pedometers), geophysical applications, aerospace industry, medical systems, navigation and others. Integrated accelerometers have the following types depending on the acceleration registration way: with the sensitivity axis perpendicular to the integrated device substrate (out-of-plane accelerometers) these include membrane type accelerometers; with plane registration (in-plane accelerometers) - accelerometers which have pectinated design, their sensitivity axis is parallel to the integrated device substrate. Accelerometers are also categorized by the external input acceleration registration mechanism, namely: capacitive, piezoresistive, piezoelectric, magneto-resistive, tunneling, optical, based on heat transfer, based on Hall effect, thermal, interferometric, etc. The membrane accelerometer with capacitive mechanism of external input acceleration registration was chosen for the investigation due to its simplicity, large manufacturing technology scale, high sensitivity and wide range of application.

Depending on the implementation areas companies design and manufacture accelerometers with different technical characteristics [3, 6, 7]. Among these characteristics are the following: measuring range, sensitivity, resolution, size, price – these are only some of the factors that determine their future application. Design and improvement of the integrated micro-accelerometers with the necessary technical and operational characteristics oversee creation of the behavioral models using the following hardware description languages – VHDL-AMS, Verilog-AMS [8 – 12] with the help of specialized software, for example, Virtuoso AMS Designer (developed by American company Cadence Design Systems), SystemVision (by American corporation Mentor Graphics), hAMSter (by Ansoft Corporation), SMASH Mixed-Signal Simulator (by French corporation Dolphin Integration) and others [13 – 18].

Therefore, development of the behavioral patterns using VHDL-AMS and Verilog-AMS languages which intends to describe such complex heterogeneous systems as integral micro-accelerometers is an actual task for their efficient design.

WOKING PRINCIPLE AND MATHEMATICAL MODEL OF THE INTEGRAL MEMBRANE MICRO-ACCELEROMETER

Fig. 1 shows the model of a micromechanical sensitive element (SE) for integrated membrane micro-accelerometer. [2]. micromechanical SE consists of the working weight and elastic elements that connect it with the integrated device substrate (fig. 2). External acceleration displaces the micromechanical sensitive element working weight from the equilibrium position. This displacement magnitude is proportional to the acceleration magnitude and inversely proportional to the elastic elements stiffness. Thus, the input sensor acceleration is converted into displacement of the sensor SE working weight. The cover (lid), lining and working weight from both sides of the integrated device is covered with electrodes, which form differential capacitor binding. The created capacitor capacity changes with the working weight movement caused by the applied acceleration. Further on the capacity changes are logged and can be converted into voltage, frequency, current, or PWM signal with the use of according electric circuits [19]. As a rule, after conversion the signal is digitized using precision ADCs, which subsequently allows its investigation with a specialized microprocessor or microcontroller.

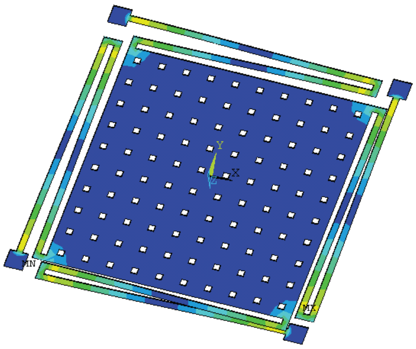

Fig. 1. Model of a micromechanical SE for integrated membrane micro-accelerometer

Movement of the integrated membrane micro-accelerometer can be described with following differential second-order equation:

$$M\frac{d^2x(t)}{dt^2}+D_x\frac{dx(t)}{dt}+K_x x(t)=F_{ext}\ , \quad (1)$$

where: M – sensitive element weight, D_x – attenuation coefficient, K_x – resilience coefficient, $x\ (t)$ –sensitive element movement along the x axis direction. $F_{ext} = M \bullet a_{ext}$, where a_{ext} – external acceleration [20, 21].

Measuring capacitors (C_1, C_2) are used for recording sensitive element movements are shown in Fig. 2. Their capacities vary depending on the external acceleration.

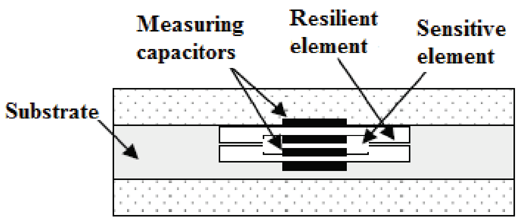

Fig. 2. Schematic view of the MEMS membrane accelerometer design

Capacities C 1 and C 2 of the differential capacitor can be calculated in the following way:

$$C_1=\frac{\varepsilon_0 A}{\delta - x}, \qquad C_2=\frac{\varepsilon_0 A}{\delta + x}, \quad (2)$$

where: A – membrane area; ε_r – dielectric environment penetrability between the capacitor electrodes; ε_0 – dielectric vacuum penetrability; δ – distance between the capacitor plates in case of external acceleration absence $a_{ext} = 0$; x – movement of the SE working weight.

Since:

$$C_1-C_2=\frac{2\varepsilon_0 Ax}{\delta^2-x^2}, C_1+C_2=\frac{2\varepsilon_0 A\delta}{\delta^2-x^2}. \quad (3)$$

Then the output signal value V_{out} is proportional to the carrier frequency and displacement of the SE working weight, when $a_{ext} = 0$ ($c_1 = c_2$, $V_{out} = 0$) and inversely proportional to the working weight displacement:

$$V_{out}=V_{sample}\left(\frac{x}{\delta}\right). \quad (4)$$

THE WORKIN PRINCIPLES AND BASIC TOPOLOGY OF THE DELTA-SIGMA ADC

Delta-Sigma analog-to-digital converters are perfect solution for signals conversion, for example once taken from inertial sensors in a wide range of frequencies from zero to several megahertz with a very high resolution [22 - 26]. Figure 3 shows the basic topology (core) of the Delta-Sigma ADC, it consists of the internal Delta-Sigma modulator consistently joined with the digital filter. Role of the Delta-Sigma ADC input signal is taken by constant or variable voltage. Input signal is signal taken from the integral micro-accelerometer SE. The internal modulator converter, shown in Fig. 3, samples the input signal, transforming it into a discrete output signal, using 1-bit ADC. The modulator converts the analog input signal into a high speed pulses sequence. Units to zeros appear in this pulses sequence corresponds to the input analog voltage size. Modulator actually returns noisy signal. This noise is created by the electrical circuit in the high-frequency region of the output signal spectrum. This enables getting transformation results with high resolution and low noise levels from the digital filter output. At the modulator output the digital filter generates high discretization frequency data from the high-frequency noisy signal. Since now this signal is digital the lower frequencies digital filter can be used for further suppression of high-frequency noise, and the filter/decimator can be applied to reduce data output frequency. Collectively, digital filter/decimator and modulator flow filters create from 1-bit codes slower sequence of multibit codes. Although most of transducers have only one discretization frequency, Delta-Sigma transducers have two: input discretization frequency and output data delivery frequency. The ratio of these two frequencies determines the system decimation coefficient. There is a strong dependence between the decimation coefficient and converter effective capacity [27-29].

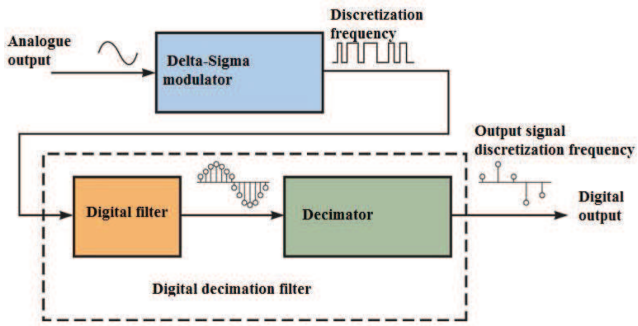

Fig. 3. Basic functional core of the Delta-Sigma ADC – Delta-Sigma modulator and digital filter/decimator

Delta-Sigma converter uses a large number of the modulator generated pulses for creating 1-bit codes sequences. In Delta-Sigma ADC this task is performed by the input signal quantization device of high frequency. In analogue to other quantization devices, Delta-Sigma modulator accepts an input signal and produces a numeric values sequence that reflects the input voltage value. The modulator performance can be observed from both time and frequency ranges. Time range allows illustrating operation principle of the first order modulator (fig. 4). The modulator measures difference between analog input signal and analog DAC reverse output signal. Then the integrator handles the original analog subtraction voltage and passes the signal to the 1-bit ADC. Single ranged ADC converts the integrator output signal into one unit or zero. Using the system stroke generator the ADC sends the 1-bit digital signal to the modulator output, and back by the feedback connection chain to the input of 1-bit DAC.

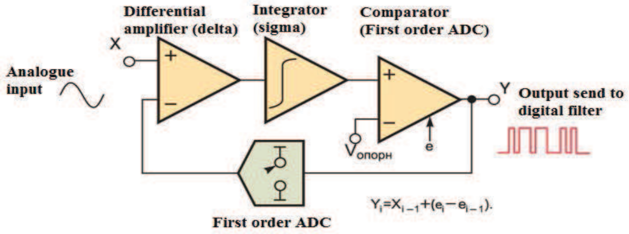

Fig. 4. Presentation of the first order modulator performance in time range

1-bit ADC converts the signal into the source code which also contains noise quantization (ei). Signal at the modulator output equals to the sum of input signal and quantization noise (ei-ei-1). As can be seen form the formula, quantization is represented by difference between the current (ei) and previous (ei-1) modulator faults. The output signal in the time range is a reflection of the input signal in form of pulses sequence with a discretization frequency, fS. If to average the output pulses string the input signal value can be got. The frequency range chart reveals the other side of the process (fig. 5). The time range output signal pulses in frequency range look as the input signal and noise, which has a characteristic shape. The noise characteristics in fig. 5 allow understanding the modulator performance in the frequency range. The noise spectrum at the modulator output is not flat. The most important fact in its frequency analysis is that the modulator generates noise in the high frequencies range making it easier to get high resolution results. The modulator output signal in Fig. 5 shows how modulator quantization noise, starting almost from zero frequency, fast grows and then leveled to maximum values at the of modulator frequency. The double integration with the use of the second order modulator is a better way to minimize low- quantization frequency noise comparing with single integration.

The digital filter suppresses noise and the decimator reduces output data frequency. In Delta-Sigma frequency after the modulator there is digital filter/decimator chain. It collects and filters sequence of 1-bit codes taken from the modulator output. There is an issue in high-frequency noise and high modulator source signal discretization frequency. Since now this signal is digital the digital filter function can be used for noise suppression, and the filter/decimator function can be applied to reduce data delivery frequency. These two functions are often combined into one module. Fig. 6 (a, b, c) shows how the signal passes through the digital filter/decimator. The digital filter performance occurs at the same frequency, as modulator discretization (fig. 6).

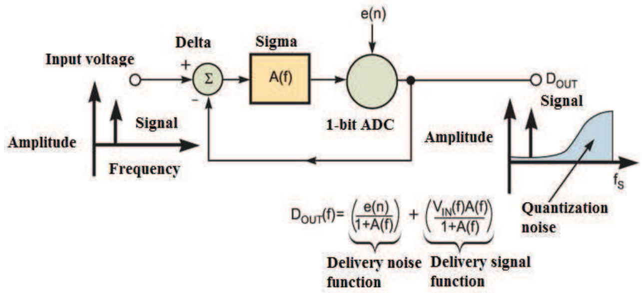

Fig. 5. Noise frequency characteristics are the key to the modulator performance representation at frequency the range

The digital filtering function provides digital representation of the input signal, however the data delivery frequency is still too high for practical application. While it may seem attractive to have a large amount of high quality multi-bit samples, produced with high discretization frequency, most of the data in this array is redundant. The second function of a digital filter/decimator is decimation (thinning). Decimation is frequency reduction of the digital signal delivery to Nyquist system frequency.

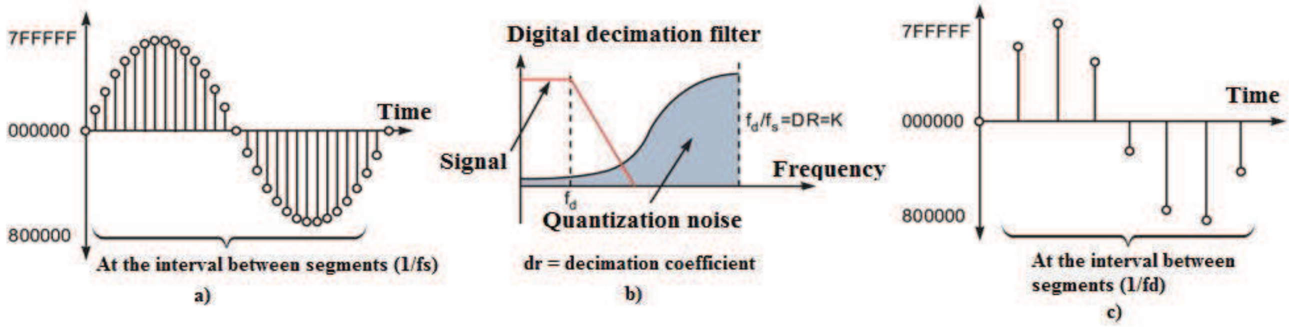

Fig. 6. The digital filtering function provides high resolution of the output data result (a) suppressing high frequency noise (b), the decimation function reduces the data delivery frequency (c)

One of the simple ways to realize decimation is to average 24-bit codes (fig. 6c). Decimator accumulates high resolution data words, averages them, gives averaging result and resets the accumulated data for the next average. More economical way of the decimation function low cost implementation is simple choice of 24-bit words from each K segment without its averaging (K is the decimation or thinning coefficient). Almost all of the Delta-Sigma converters contain averaging filters such as Sinc or FIR-filters (CIX-filter). A lot of Delta-Sigma devices use other filters together with Sinc-filters to ensure two staging decimation. In case of low-speed industrial Delta-Sigma ADC only Sinc filter is typically used. From the frequency range it can be seen that digital filter/decimator carries out only law frequency filtering of the signal (fig. 6 b). Meanwhile this digital filter/decimator suppresses high frequency quantization noise formed by the modulator. After the quantization noise suppression by filtering the signal develops over again in the time range.

VHDL - AMS INTEGRAL MEMBRANE MICRO-ACCELEROMETER WITH DELTA-SIGMA ADC

MEMS Design at the schemotechnical level oversees development of behavioral models. The fact that such models contain data from different areas of science and technology is their characteristic feature. In particular, in the integral membrane micro-accelerometer model contains mechanics, electricians and electronics values. The extension of the standard hardware description language (HDL) VHDL to VHDL-AMS allowed describing digital, analog, and mixed models of devices, which use not only electrical signals but also optical, chemical, thermal, mechanical and others [8-13]. Figure 7 shows a listing snippet of the behavioral model of the integral membrane micro-accelerometer with Delta-Sigma analog-to-digital converter developed in VHDL – AMS.

SIMULATION RESULTS AND THEIR ANALYSIS

The developed model simulations results conducted with the use of hAMSter software are graphically displayed in fig. 8-9. From the results it can be seen that the digitized signal varies in the range from 0 to 1.25 V. Further on the digital signal can be moved to processing by a specialized microcontroller or microprocessor.

```
…
architecture behav OF sdm2 IS
   terminal a1o : electrical;           terminal a2o : electrical;  terminal inter1o : electrical;
   terminal inter2o : electrical;     signal Qo : bit;     signal Q : bit;     terminal DACo : electrical;
begin
  ADDER1: entity adder generic map (A => 5.0, B => -5.0)
        port map (input1 => vin, input2 => DACo, output => a1o);
  INTER1: ENTITY inter PORT MAP(input => a1o, output => inter1o);
 --adder2 : entity adder generic map (A => 5.0, B => -5.0)
 --         port map (input1 => inter1o, input2 => DACo, output => a2o);
 --inter2 : entity inter port map (input => a2o, output => inter2o);
  Q: entity quantizer generic map (threshod => 0.0)
    port map (clk => clk, input => inter1o, output => Qo);
  D_FLIP_FLOP: entity d_ff_srss port map (d => Qo, clk => clk, reset => '0', set => '0', q => Q);
  DAC: entity DAC generic map (max => 5.0, min => -5.0)
     port map (input => Qo, output => DACo);   output <= Qo;
end architecture behav;
-- Testbench of Sigma-Delta Modulator
library ieee, disciplines;
use disciplines.electromagnetic_system.all; use ieee.math_real.all; use ieee.std_logic_1164.all;
entity t_sdm2 is end entity t_sdm2
architecture bhv of t_sdm2 is
   terminal A : electrical;
   --quantity xin across iin through A to electrical_ground;
   signal op : bit;     signal clk : bit; --std_logic;        quantity v across A to electrical_ground;
begin
   CLK: entity clock(v1) generic map (5us) port map (clk);
  --  xin == 5.0*sin(math_2_pi*1.0e6*NOW);
   --UUT1: entity Vsine(v1) generic map (Va => 5.0, freq=> 1.0e6) port map (A, electrical_ground);
   ACCEL: entity mems_accelerometer(top_level) port map(A);
   M_SDM2: entity sdm2 port map(vin => A, clk => clk, output => op);
end architecture bhv;
```

Fig. 7. Fragment of the behavioral model of the integral membrane micro-accelerometer with Delta-Sigma analog-to-digital converter

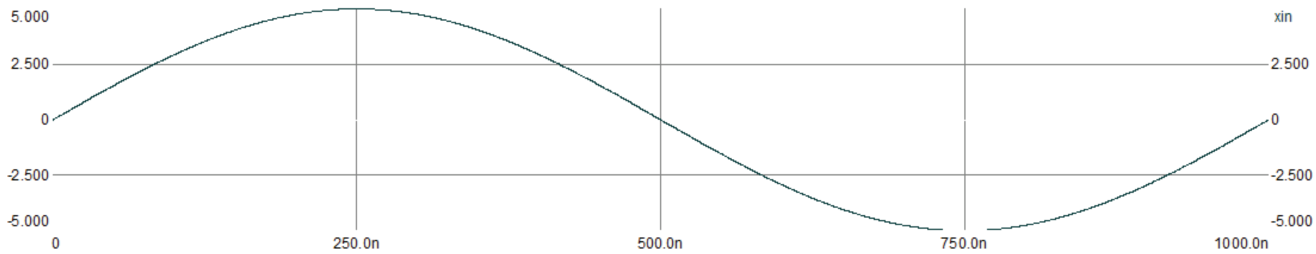

Fig. 8. The measured sensor analog signal (in case of sinusoidal change) resulted from the applied external acceleration aext

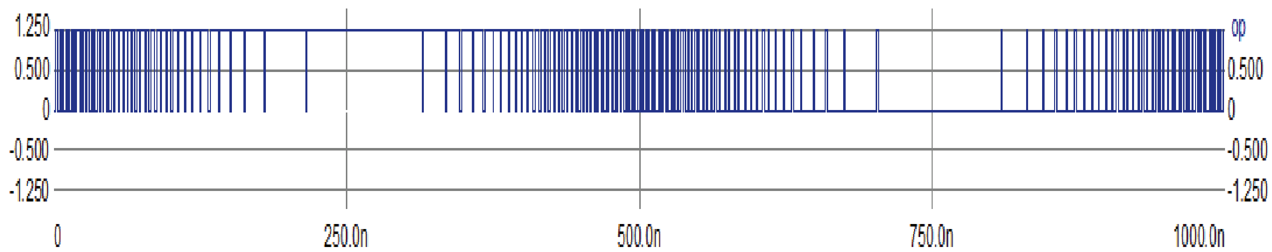

Fig. 9. The bits flow in the digitized sensor signal at the Delta-Sigma analog-to-digital converter output

CONCLUSIONS

The proposed VHDL-AMS membrane micro-accelerometer with Delta-Sigma analog-to-digital converter model allows simulating movement of the sensitive element working weigh from the applied acceleration, differential capacitor and original signal capacity change, signal digitizing with the help of Delta-Sigma ADC with defined micro-accelerometer structural parameters, and analyze an integrated device at the schemotechnical design level.

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REFERENCES

1. **Yazdi N., Ayazi F. and Najafi K. 1998**. Micromachined inertial sensors, Proc. IEEE, vol. 86, no. 8, 1640-1659.
2. **Maluf N. and Williams K. 2004.** An Introduction to Microelectromechanical Systems Engineering. Artech House Inc. 305 p.
3. **Teslyuk V., Pereyma M., Denysyuk P., Chimich I. 2006.** Computer-aided system for MEMS design “ProMIP”. Proc. of the 2nd Inter. Conf. of Young Scientists on Perspective Technologies and Methods in MEMS Design, MEMSTECH 2006, Lviv–Polyana, Ukraine, 49-52.
4. MEMS & Sensors for Mobile Phones and Tablets, 2014. Yole Developpment. 22.
5. **Akila Kannan. 2008.** Design and Modeling of a MEMS-Based Accelerometer with Pull In Analysis. Thesis, University of British Columbia, 149.
6. **Teslyuk V., Kushnir Y., Zaharyuk R. and Pereyma M. 2007.** A Computer Aided Analysis of a Capacitive Accelerometer Parameters. Proceeding of the 9th International Conference on The Experience of Designing and Application of CAD Systems in Microelectronics, CADSM’2007, Lviv – Polyana, Ukraine, 19-24 Feb. 548 – 550.
7. **Teslyuk V., Al Omari T., Alshavabkekh H., Denysyuk P. and Melnyk M. 2007**. Computer-Aided Design of MEMS at system level. Machine Dynamics Problems, Vol.31, 92 -104.
8. Standard VHDL Analog and Mixed-Signal Extensions. 2003. Packages for Multiple Energy Domain Support. 21.
9. **Ashenden P.J. 2004.** EDA CONSULTANT, ASHENDEN DESIGNS PTY. Elsevier Science, 84.
10. **Pavel V. and Richard Shi C.-J. 2005**. VHDL-AMS based modeling and simulation of mixed-technology Microsystems. 261.
11. Verilog-AMS Language Reference Manual Analog & Mixed-Signal Extentions to Verilog-HDL, Version 2.1. 2003. 279.
12. **Zaharyuk R., Teslyuk V., Farmaga I. and AlShawabkeh H.A.Y. 2008.** VHDL-AMS – Model for capacitive interdigital accelerometer. Proceeding of the 4th International Conference of Young Scientists on Perspective Technologies and Methods in MEMS Design, MEMSTECH, Lviv-Polyana, Ukraine. 134-137.
13. Virtuoso AMS Designer. Available online at <http://www.cadence.com/products/cic/ams_designer/pages/default.aspx>.
14. SystemVision. Available online at <http://www.mentor.com/-products/sm/system_integration_simulation_analysis/systemvision/>.
15. hAMSter Software for VHDL-AMS Simulations. Available online at <http://www.theoinf.tu-ilmenau.de/~twangl/VHDL-AMS_online_en/Home.html>.

16. SMASH Mixed-Signal Simulator. Available online at <http://www.dolphin.fr-/index.php/eda_solutions/products/smash/overview>.

17. **Napieralski A., Napieralska M., Szermer M. and Maj C.** 2012. The evolution of MEMS and modeling methodologies, COMPEL. The International Journal for computation and Mathematics in Electrical and Electronic Engineering. Vol.31, 1458 – 1469.

18. **Augustyniak I., Knapkiewicz P. and Dziuban J. 2012.** Modeling and tests of silicon-glass structure of dose high-energy radiation MEMS sensor. PRZEGLĄD ELEKTROTECHNICZNY. Vol.11b, 272-274.

19. **Fraden J**. **2010.** Handbook of Modern Sensors. Physics, Designs, and Applications (Fourth Edition). Springer Science+Business Media. 681.

20. **Kempe V.** 2011. Inertial MEMS Principles and Practice. Cambridge University Press. 492.

21. **Pelesko J. A. and Bernstein D. H. 2002.** Modeling MEMS and NEMS. Chapman & Hall/CRC. 384.

22. **Baker B. 2011.** How delta-sigma ADC work, Part 1. Texas Instruments Incorporated. Analog Applications Journal. 6.

23. **Baker B. 2011**. How delta-sigma ADC work, Part 2. Texas Instruments Incorporated. Analog Applications Journal. 5.

24. **Reiss J. D**. 2008. UNDERSTANDING SIGMA–DELTA MODULATION: The Solved and Unsolved Issues. – J Audio Eng. Soc., Vol. 56, No. 1/2. 16.

25. **Kozak M. and Kale I. 2003.** Oversampled Delta-Sigma Modulators: Analysis, Applications and Novel Topologies. Kluwer Academic Publishers, Dordrecht, The Netherlands.

26. **Zhao C. and Kazmierski T. 2007.** An efficient and accurate MEMS Accelerometer Model with sense finger dynamics for mixed-texnology control loops. IEEE Behavioral Modeling and Simulation Conference (BMAS), sep. 2007, San Jose, California, USA. 143 – 147.

27. **Bourdopoulos G. I., Pnevmatikakis A., Anastassopoulos V. and Deliyannis T. L. 2003**. Delta-Sigma Modulators: Modeling, Design and Applications. Imperial College Press, London, UK.

28. **Jespers P. A. G. 2001.** Integrated Converters: D to A and A to D Architectures, Analysis and Simulation. Oxford University Press, Oxford, UK.

29. **Schreier R. and Temes G. C. 2005.** Understanding Delta-Sigma Data Converters. John Wiley and Sons, Hoboken, NJ, USA.

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Simulation of the impact of work of heat pumps on the frost heaving of the base soil

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Abstract. The additional deformation of ground bases and foundations, which are located in the ground collectors of the heat pumps, has been identified. It is concluded that the values of these strains have the same order of their limit values which have been specified in the regulations.

Key words: heat Pumps, ground foundation, modeling, soil, foundation.

INTRODUCTION

The aim of the research. The research aims at identifying the value of additional deformations of the base by the frost heating of the soil under the working of heat pumps in the process of heating. In order to receive the desired results the theory of similarity has been used [1].

State of the problem. In this work the heat removal from the surface layer of soil with plastic pipes of large area, that are stacked parallel to the ground, usually in the form of several loops (Fig. 1) is considered. Thus, one loop along its length should not exceed 100 m, because otherwise high power of the pump will be required.

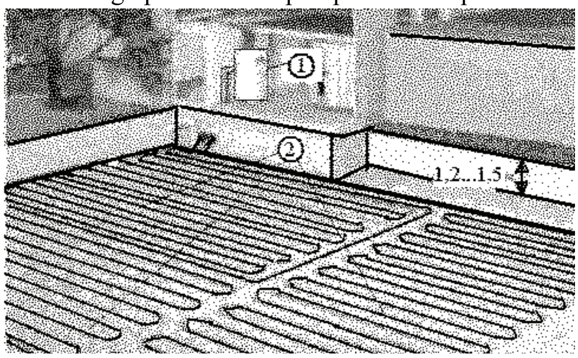

Fig. 1 Heating system of the building with the use of flat collector (scheme): 1 – heat pump; 2 – flat soil collector.

Individual circuits are connected to the dispenser, which should be at the highest point, to allow removal of air from the piping system.

According to the company "Junkers" temporary glaciation of the soil does not have any negative effects on the functioning of the heat collector and on the vegetative coating technological area. If possible, necessary to watch that in the area that is occupied by the soil collector, should not be plants with deep root system. It is also important that the pipes were placed in a sand bed to prevent possible damage by sharp stones. Before performing the backfilling the collector, necessarily recommended to pressurize the piping system. Best of all to keep the pipeline under the test pressure in the process of backfill. Then it is very easy to immediately see the likelihood of damage.

Performing the required displacement of soil is possible without major additional costs especially in new buildings.

The magnitude of the selection of thermal power from the soil depends on many factors, first of all – from the soil moisture. From experiments is known that especially good results were obtained when installing collector in humid loams. At the same time the least suitable for remove heat is dry sandy soils (Table 1).

Table 1. The specific capacities of selection off heat from soil from lot of types of rocks

Name of the soil	Specific capacity of selection off heat q, W/m^2
Dry sand	10
Wet sand	15,0 - 20,0
Dry loam	20,0 - 25,0
Wet loam	25,0 - 30,0
Loam saturated with water	35,0 - 40,0

Ground source heat pumps, in which heat exchange with the base is carried out using flat collectors, have in comparison with analogous heating systems the following advantages:

- low operating costs,
- high annual coefficients of efficiency of operation of the heat pump.

Rules of operation of heat pumps allow the cyclic glaciation - thawing them collectors [2]. Since in freezing pore fluid increases in volume by about 10 percents, and the toughness and modulus of deformation of ice have the same order with the same characteristics of building structures and significantly higher than in conventional soils, when designing basesand constructions, in which heat pump collectors are arranged, must take into account this phenomenon.

Table 2. The dependence of the technological area of surface base on the area of the heated building.

Living area [m^2]	The specific heating load [W/m^2]					
	30	40	50	60	70	80
	Required technological area of surface ground for arranging ground collector heat pump [m^2]					
100	90	120	150	180	210	240
125	113	150	188	225	263	300
150	135	180	225	270	315	360
175	158	210	263	315	368	420
200	180	240	300	360	420	480

In the construction practice currently specified phenomena take into account in such cases:

1. When determining the deformations of frost heaving (in Ukrainian conditions this kind of calculation is performed in the appointment of the depth of the foundation base).
2. In the cyclic freezing – thawing occurs deterioration of properties of the soil [3-5]. This phenomenon currently taken into account in the design of offshore structures by introducing further loads and impacts (in the calculation of stress - strain state) and the reduction coefficients (in determining the the mechanical properties) [6,7].
3. In the cyclic freezing - thawing occurs deterioration of the concrete. This phenomenon currently taken into account when designing by determining the amount of cycles of freezing - thawing of concrete, at which its strength decreases slightly (frost resistance) [8].
4. Concrete elements of building constructions, in which polymer collectors of heat pumps are located have a coefficient of thermal extensions on 1,…,2 decimal orders of magnitude smaller, than in the collectors for close values of deformation properties of concrete and polymer, owing to what when the temperature changes may occur additional thermal deformation in constructions.
5. Collectors of heat pumps may be lower than the level of groundwater, owing to what process of freezing - thawing in this case has a number of other conditions, than when tested in accordance with standard procedure.

During the operation of the heat pumps in the mode of heating, the cooling of the basis is happening whose temperature may take zero values or negative ones [9-11].As a consequence the frost heaving of the soil base takes place [12], which leads to additional moving of the foundation situated on it, for these reasons there are the changes of tensely-deformed condition of the system “the base-foundation-the structure over foundation”.

Since there are no indications connected with this problem in the valid documents [13], we have carried out some experiments to find out the effect of additional deformed foundations which is caused by the working of the soil heating pumps.

Materials and results of the study. In experimental studies we have considered the building on the solid base plate, located on the ground, in which the freeze-thaw of the soil takes place caused by the work of the ground heat pump (Fig. 2). The part of the base, where the freezing and thawing of vapor fluid takes place, was constructed using a water-ground filled flexible container with the walls irresistible to inner pressure (Fig. 3).

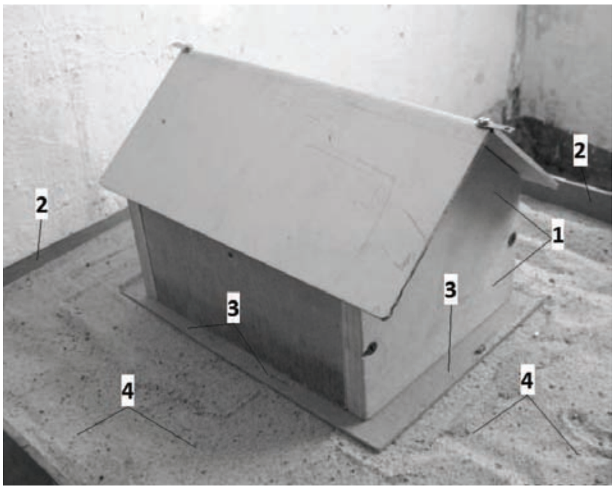

Fig. 2. Scheme of the test: 1 – building model; 2 – subsoil tray; 3 – slab foundation; 4 – ground foundation

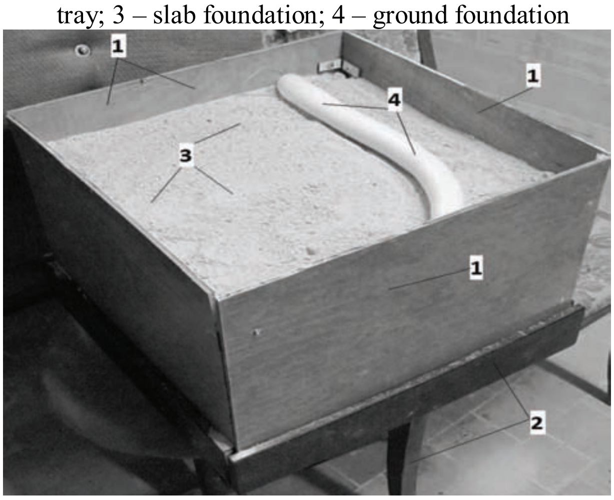

Fig. 3. Preparation of the substrate to the test: 1 – subsoil tray; 2 – bed; 3 – ground foundation; 4 – filled with soil and water rubber sheath

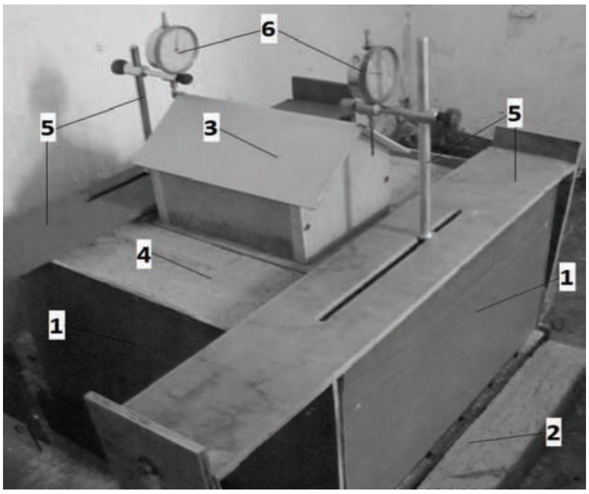

Fig. 4. Scheme of displacement measurement: 1 – subsoil tray; 2 – bed; 3 – ground foundation; 4 – ground foundation; 5 – the reference system; 6 – moving a dial indicator

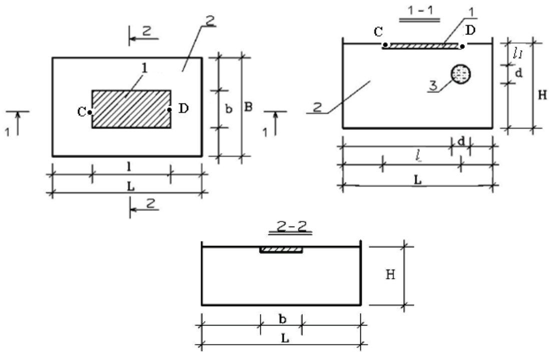

Fig. 5. Scheme of the "Clay tray – Base - a foundation." Note: In this scheme, there are no dimensions of the over structure.

Vertical movements of the building model were measured using a dial indicator movement, which is attached to a special system of the reference (Fig. 4).

The scheme of the soil tray located on grade building is shown in Fig. 5.

Tests were performed in the soil tray with plan dimensions of 40x40 cm and a height of 30 cm in the following sequence:

1. Firstly, the preparation was carried out to mark the base of the sand bedding soles which freezes and thaws due to the heat pump field (Fig. 3).
2. Further, the rubber sheath filled with the ground and water and the walls which are slightly resistible to the internal pressure was put on the base (Fig. 3).
3. After that, the base was built up to the marked level and the model of the structure made of waterproof plywood and polymer composite material was fitted (Fig.2).
4. To measure the vertical displacement of the building model the special reference system was used (Fig. 4).
5. Next, the model of the building was placed in a dry environment with air temperature t = -14 ° C. The Freezing of water in a rubber container led to frost heaving base and as a consequence - the vertical movement of the points "C" and «D» was placed on the building model. These movements were measured after 7 days after placing the experimental setup in a climatic chamber.
6. Thereafter, the temperature was raised to a value t = + 20 °; in this state structure was kept for 7 days and re-measured vertical displacements of the points "C" and "D"

Table 1 shows the properties of the sub grade and some characteristic dimensions [14-16] of the "base-foundation". In the process of the analysis, we used the elements of the theory of dimensions.

We considered dimensionless π-complex of the form:

$$\pi_1 = \frac{\sum_{i=1}^{n} \varepsilon_i k_i h_i}{W} = \frac{\varepsilon_l k_l d_{reg}}{W}; \pi_2 = \frac{dreg}{b}; \quad (1)$$

$$\pi_3 = \frac{l}{b}; \pi_4 = \frac{l_1}{b};$$

where: $\pi_1,...,\pi_4$ – dimensionless Pi – complexes; W due to the freezing (thawing) ground rise (subsidence) of the base; ε_i – relative deformation of i-th layer of soil due to freezing (thawing) soil; h_i – it's thickness; $k_i = 0.6,...,0.8$ – coefficient of working conditions; d_{reg} – the effective diameter of the field of frozen soil; l and b – respectively the length and width of the foundation sole; b – the distance from the base of the foundation to the foot of the basement to the top of the frozen region of the base.

Calculated using the presented data in table 3, Pi – complexes are shown in table 4.

Table 3. Calculating results

№	The names of the characteristics	Symbol	Units of measurement	Meaning
1	The modulus of the base deformation	E	MPa	
2	The degree of humidity of no water-base part	S_r	d. un.	0,02
3	The degree of humidity of water-base part	S_r	d. un.	0,99
4	The length of the foot of the basement	l	m	0,22
5	The width of the foot of the basement	b	m	0,18
6	Diameter of freezing (thawing) area	d_{reg}	m	0,03
7	The distance from the top of the field to the freezing foun-dation base	l_1	m	0,04
8	Lifting point "C" during freezing	$S_{3,A}$	$m \cdot 10^{-3}$	1,32
9	Lifting point "D" during freezing	$S_{3,B}$	$m \cdot 10^{-3}$	0,07
10	Draft terms of the foundation «C» in the process of thawing	$S_{O,A}$	$m \cdot 10^{-3}$	1,25
11	Draft terms of the foundation «D» in the process of thawing	$S_{O,B}$	$m \cdot 10^{-3}$	0,12

Table 4. Pi – complexes

№	Meaning of π-complexes	
1	π_1	0,90,…,34,32
2	π_2	0,17
3	π_3	1,22
4	π_4	0,22

Presented in table 4 data were used by us to determine the strain caused by freeze-thaw real soil bases.

For the foundation slab width of 7 meters with the formulas (1) and presented in table 4 data were calculated due to freezing - thawing soil foundation deformation of the base (Table 3). It was found that the recovery and deposition of base in this case varies in a range of 3, ..., 138 mm.

The following conclusions have been made:

1) the operation of the ground heat pumps leads to the cyclic freezing and thawing of the soil basements. This in turn leads to the rising (when the pore fluid freezes) and settling (when the pore fluid thaws) located on the basis of this foundation,
2) the rise or the subsidence of the slab foundation which is caused by the working of ground heat pump equals to 138 mm. These measurements have the same order with a maximum permissible deformations of the soil bases. [17- 20]. Thus, the deformation is caused by freezing or thawing of vapor base fluid in which the ground heat pump collectors are situated .It is important to take into account while projecting the foundation of the buildings and structures.

Table 5. The results of modeling

№	The names of the characteristics	Calculated formula	Unit of mea-surement	Meaning
1	The width of the foundation sole	-	m	7
2	The length of the foundation sole	$l = \pi_3 \cdot b$	m	8,54
3	Diameter of the frozen area	$d_{обл} = \pi_2 \cdot b$	m	1,19
4	The distance from the top of the frozen ground to the sole of foundation	$l_1 = \pi_4 \cdot b$	m	1,55
5	The rise (or subsidence) of the slab foundation	$W = \frac{\varepsilon_1 \cdot k_1 \cdot d_{обл}}{\pi_1}$	mm	4,…,138

CONCLUSIONS

In conclusion, we want to note that at the present time on the territory of Ukraine in the existing regulatory base are indicated the problem of accounting for the design effects of frost heaving caused by the heat pumps.

REFERENCES

1. **Sedov L. I. 1977** Methods of similarity and dimensionality in mechanics (8th edition). M.: Science, (in Russian).

2. **.** Geothermal heat pumps for heating and hot water expenditures. Book of the designer, Kyiv, Junkers, 2009**,** 103 (in Russian).

3. **Ratkova E. I. 2010** Changes in the state of forest soils in the transition periods: the freezing and thawing, Resources and Technology. – no 8, 123 –125 (in Russian).

4. **Ratkova E. I., Syunev V. S., Katarov V. K. 2013** Influence of the cycle "freezing - thawing" on the module of deformation and compressibility coefficient of loams, Scientific notes of Petrozavodsk State University. Series: Natural and Technical Sciences, no 4 (133), 75–78 (in Russian).

5. **Ratkova E. I., Syunev V. S., Katarov V. K. 2013** Impact cycles "freezing - thawing" on the deformation properties of soils of forest in Karelia // Resources and Technology. – no 10 (1), 74-89 (in Russian).

6. VSN 41-88 Designing of marine ice-resistant stationary platforms. Moscow – 1988, 56 (in Russian).

7. SP 58.13330.2012 Hydraulic structures. The main provisions. The updated edition SNiP 33-01-2003 M, 2012 (in Russian).

8. DSTU B V.2.7-47-96 (HOST 10060.0-95). Concrete. Methods for determination of frost stability. General requirements (in Russian).

9. Manual of the designing of engineering systems of residential and public buildings with heat pumps. Ministry of Regional Development and Construction of Ukraine. Kyiv.–2010, 82 (in Russian).

10. **Shapoval V. H., Morklyanyk B. V. 2009** Bases and foundations of heat pumps.– Lviv: Spolom, 64 (in Russian).

11. **Shapoval V. H. 2011** The temperature fields in the soil base of heat pumps: Monograph. – Dnipropetrovsk: Porogy, 2011, 123 (in Russian).

12. **V. B. Shvets, I. P Boyko, Y. L. Vynnykov, M. L. Zocenko, O.O. Petrakov, O. V. Solodyankin, V. H. Shapoval, O. M. Mashenko, S. V. Bida. 2014** The mechanics of soils. Bases and foundations: Manual– Dnipropetrovsk: Porogy, 231 (in Russian).

13. DBN V.2.1-10-89. Bases and foundations of buildings (in Russian).

14. **Novatskyy V. 1975** The theory of elasticity. – M.:Mir, 872 (in Russian).

15. **Shapoval V. H. 1996** Forecast of the sediment and foundations in dusty - clay basis under the influence of static and cyclic load. The thesis for the degree of Doctor of Technical Sciences. – Dnipropetrovsk, 350 (in Russian).

16. **Kartashov E. M. 1985** Analytical methods in the theory of thermal conductivity of solids. – M.:Vysshaya shkola, 480 (in Russian).

17. **Korn H., Korn T. 1974** Mathematical Handbook. – M.: Science, 840 (in Russian)/

18. **Dyhovychnyy U. A. 1975** and others Manual of a design engineer of residential and public buildings. – M.:Stroyizdat, 386 (in Russian).

19. **Abramovych H.N. 1976** Applied gas dynamics. – M.:Science, 888. (in Russian)

20. **Machinery. 1947** Encyclopedic Reference. Vol.1.– M., 456 (in Russian).

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