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SIMULATION OF ACTIVE MOVEMENT OF PEOPLE DURING EVACUATION FROM BUILDINGS

The following categories of movement are considered: comfortable, calm, active, with high activity. When the category of human movement becomes active with possible forceful actions, the task of modeling their active movement taking into account the natural deformations of human bodies arises. The anthropological characteristics of the person from the point of view of physical restrictions on mutual position of parts of a body at their active movement with force actions are analyzed. Taking into account the properties of physical limitations of the human body, a three-component mathematical model of horizontal projection of a person is proposed, which takes into account the conditions of gluing model components into a single complex object and restrictions on the angles of rotation of components. The model of the human body is represented by union of three ellipses: the main and two auxiliary. The main one can rotate continuously within the framework of maneuverability, and the auxiliary ones - within the angles arising from the anthropological properties of man. A meaningful formulation of the problem of modeling the active movement of people taking into account the natural deformations of bodies is proposed and the modeling algorithm is modified. Modification is to take into account the natural deformations of the human body by modeling the change in the spatial shape of the three-component model of the human body. Analytical expressions of the conditions of their non-intersection and placement in areas are obtained for the considered complex objects, which will allow to present the problem as a classical nonlinear programming problem and to use the existing optimization packages. The ability of the proposed algorithm to model the movement of people and the constraints of the problem, for which are obtained analytical expressions in the work, is shown by computer modeling. It should be noted that the restrictions considered in the paper on both the number of components of the object of movement and its shape are not fundamental. Models and algorithms allow you to make changes in both the number of components of the object and their spatial forms, which will only increase the complexity of the algorithms for solving the problem.

Keywords: human safety, evacuation, inhomogeneous flows, modeling, optimization, active movement with possible force actions, natural deformations of the human body

1. Introduction

The Constitution of Ukraine proclaims the highest social value of human security, life and health. Every citizen of Ukraine has a constitutional right to safe living, working and leisure conditions. These inalienable constitutional rights and freedoms of man and society as a whole are objects of national security of Ukraine.

It should be noted that in the last decade there has been a tendency to increase the number and scales of the consequences of emergencies (EM). Emergencies are accompanied not only by material but also human losses, so in emergencies it is very important to make a quick and correct decision to eliminate the consequences of the emergency and to save people.

Possible forms of protection of the population include the organization of the managed evacuation of people from places of development of emergency situations, in particular from buildings for the necessary time which is calculated on the basis of their design and planning decisions.

To this end, scientifically sound evacuation plans are being developed, the main components of which are human flow modeling programs. Therefore, an urgent problem is the imperfection of models and methods for modeling the movement of human flows during evacuation.

2. Analysis of recent research and publications

The problem of creating sound plans for the evacuation of people from buildings has set the task of developing models, methods and software packages for modeling the movement of human flows. Existing mathematical models of human movement are built mainly using the following two approaches: continuous and discrete (in time and space) [1]. The continuous approach [2] is based on the fact that human motion is described using differential equations. Human flow parameters are often modeled using flows of orders or hydroanalogy [3]. It should be noted that the movement of human flows has its own natural features: the transformation and distribution of parts of the flow, their merging and transition to neighboring sections of the road. For example, at transition of a site of smaller section the speed of a stream of the person decreases. The water flow rate in such cases increases. The disadvantages of this approach include the inability to model heterogeneous flows.

The discrete model, which reproduces the properties of human movement, has become a real improvement over existing continuous approaches. An example of a discrete model is a cellular model based on the idea of cellular automata (CA) [4]. In discrete approaches, space is divided into cells. As a rule, the share (person) occupies one cell. Movement is possible only on the cells at each time of movement (step), the directions of movement are limited [4, 5]. The disadvantage of the spacecraft model is the inability to take into account changes in the width of corridors, slots, tasks of different sizes and shapes of particles (people).

The combination of the advantages of both models (continuous and discrete) characterizes the field discrete-continuous model of evacuation SigMA.DC (Stochastic field Movement of Artificially People Intelligent discrete-continuous model – stochastic of field discrete-continuous model of human motion with elements of artificial intelligence). This model takes into account the dependence of human speed on density, age, emotional state. It is continuous in space in the chosen direction of movement, but it provides a finite number of directions where a person can move from the current position [6].

Classification of mathematical models is based on the representation of people: individual or global. In the first case, each person is "processed" by the calculation algorithm separately, individual human characteristics can be taken into account (weight, age, sex, speed, role in the evacuation process, etc.). In the case of a global representation, only the movement of a "mass" of people with certain homogeneous characteristics is considered.

Currently, the most common software product is CITIS: "Flowtek ID" for a simplified analytical and simulation-stochastic model and "Evatek" for an individual-flow model of human flow [7]. The results of calculations obtained by the model "Flowek ID" give an underestimated value of the time of the last person to pass different sections along the length of the evacuation route. The processes of reshaping and scattering of human flows, the description of which is not included in this model, also have a significant impact on time.

In the individual-flow of move Evatek model, the speed of a person's motion depends on the flow density, which is calculated for each person individually. To do this, a rectangle is built around a person, the large side of which is oriented in the direction of human movement. The constructed area is divided into separate sub-areas (it is impossible to move from one sub-area to another without leaving the area). This approach to motion modeling is explained by the impossibility of an analytical description of the process of movement of people, part of which is a description of the conditions of their intersection. The values obtained by the Evatek program during the last person's passage of different sections of the evacuation routes are near the lower limit of the allowable values, taking into account the stochasticity of the evacuation process [6]. But the results of the analysis of this direction of work carried out in [8] show that there is no model of individual current movement of people, adequate to the real flow. And for people of mixed composition in a wide range of public buildings of different classes of functional danger there are no models of flow simulation.

In [9], the problem of modeling the motion of inhomogeneous flows of people (ie mixed composition) is reduced to the problem of dense motion of people (represented by ellipses) with different densities. Different densities lead to their placement at each discrete point in time with different minimum allowable distances between them according to a number of additional technological limitations, among which we can distinguish movement at different speeds, given their maneuverability, comfort, etc. According to [6] during the movement we can distinguish the following categories of movement of people in the flow are: free, comfortable, active, with high activity. Model [9] can be used for comfortable and free movement of people.

When the category of motion changes and becomes an active category with possible force, the flow density increases [6]. Changes in density affect the nature of the movement of people in the flow, changing it from free, in which a person can choose the speed and direction of their movement, to compressed motion as a result of further increase in flow density, in which he feels the growing power of others.

Therefore, the unsolved part of the problem is the lack of models of active movement of people, taking into account the natural deformations of human bodies.

3. The purpose and objectives of the study

The purpose of this work is to develop a model of active movement of people, taking into account the force contacts during movement.

To achieve the goal of the work it is necessary to solve the following tasks:

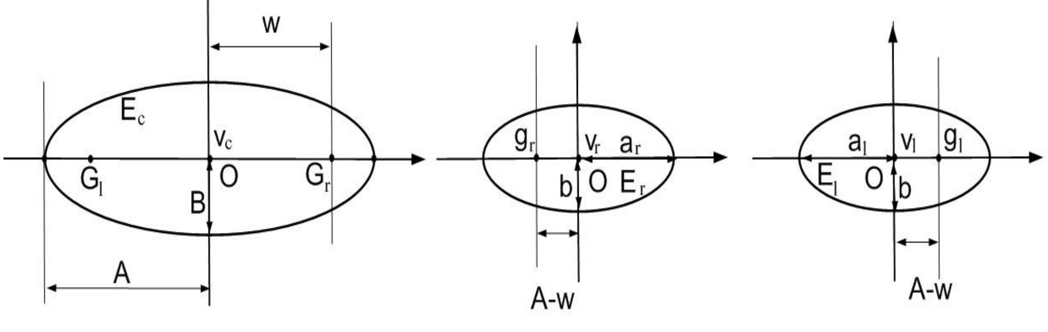
– to build a model of the human body taking into account its natural deformations;

– to develop a meaningful model and modify the algorithm for modeling the active movement of people taking into account their natural deformations.

4. Construction of a model of the human body taking into account its natural deformations

To build a model of the current movement of people in the flow, taking into account their maneuverability and natural deformations, it is necessary to analyze the anthropological characteristics of man and build a model of his body taking into account non-traumatic force.

Thus, to build a model of the human body, it is proposed to present its projection, taking into account [10], in the form of a non-rigid connection of three ellipses: E_c with the dimensions of the half-axes A and B, and E_l and E_r with the sizes a and b (see Fig. 1).



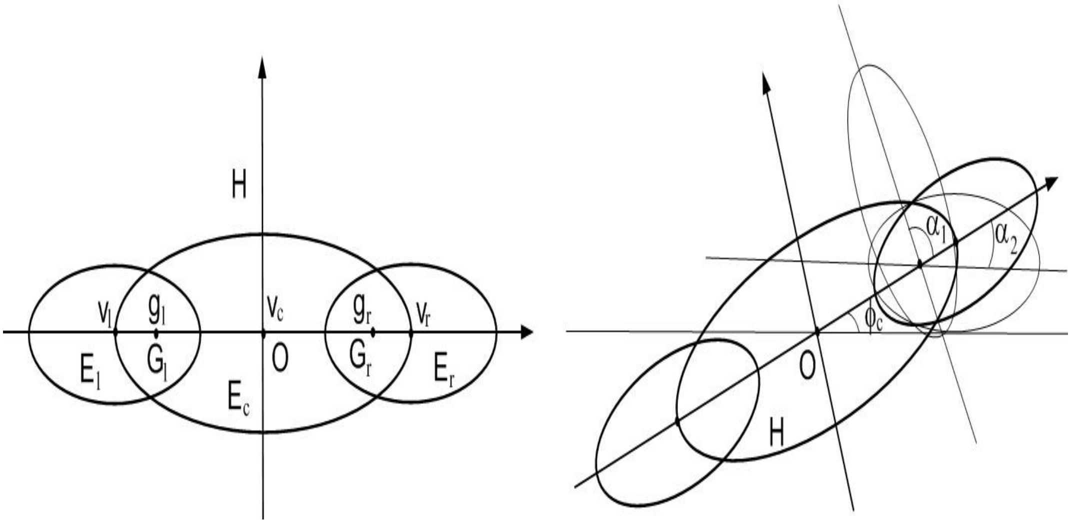
a) b) c)

Fig. 1. Three components of the human body model: (a) the trunk, (b) the right shoulder, (c) the left shoulder

Each object E is associated with placement parameters $v=(t,j)$, where $t=(x,y)$ is the object's E translation vector relative to the fixed coordinate system, and j is the angle of its rotation.

We denote by $E(v)$ an object $E=E(0)$ that ϕ is the angle of rotation and t is a vector of translation.

The pairs of points G_1, g_1 and G_r, g_r marked in the first figure, are used to "glue" the components of the model into a single object H (see Fig. 2 a).



a) б)

Fig. 2. Three-component model of the human body with constraints providing: (a) conditions for gluing the components of the model into a single object, (b) restriction on the mobility of the ellipse modeling the human shoulder

In addition to bonding conditions, the relative position of objects is subject to restrictions on the ratio of rotation angles arising from physical constraints on the relative position of parts of the human body (see Fig. 2), Thus, the angle of rotation j_r of an ellipse E_r cannot be greater than the angle $j_c+\alpha_1$ and less than $j_c-\alpha_2$, where j_c – the angle of rotation of the object E_c (see Fig. 2b).Accordingly, the angle of rotation j_l of an ellipse E_l cannot be greater than the angle $j_c+\alpha_2$ and less than $j_c-\alpha_1$.

Thus, it is proposed to use an object with the following constraints on the placement parameters as a model of human body projection:

$$g_l(v_l)=G_l(v_c), \quad (1)$$

$$g_r(v_r)=G_r(v_c), \quad (2)$$

$$j_c-\alpha_2 \le j_r \le j_c+\alpha_1, \quad (3)$$

$$j_c-\alpha_1 \le j_l \le j_c+\alpha_2. \quad (4)$$

It should be noted that in conditions of high density of placing people in the number of variable parameters of the model may be included values and with restrictions of the form

$$\alpha_0^{'} \le \alpha_l \le \alpha_1^{'}, \alpha_0^{'} \le \alpha_r \le \alpha_1^{'}, \quad (5)$$

allowing the model to account for the vertical rotation of the shoulder joint, which are also determined by physical limitations on the relative position of parts of the human body. It should be noted that all object sizes and constants in the simulation are generated for each object H at random with normal distribution.

Запишемо умову не перетинання двох об'єктів

We write the condition of non-intersection of two objects

$$H_i(v_{ci}, v_{li}, v_{ri}) = E_{ci}(v_{ci}) \bigcup E_{li}(v_{li}) \bigcup E_{ri}(v_{ri})$$

and

$$H_j(v_{cj}, v_{lj}, v_{rj}) = E_{cj}(v_{cj}) \bigcup E_{lj}(v_{lj}) \bigcup E_{rj}(v_{rj})$$

in the form of a function $\Phi'^{H_iH_j}(v_{ci}, v_{ri}, v_{li}, v_{cj}, v_{rj}, v_{lj}, T_{ij}) \geq 0$,

where a function $\Phi'^{H_iH_j}(v_{ci}, v_{ri}, v_{li}, v_{cj}, v_{rj}, v_{lj}, T_{ij})$ can be represented as in [10]:

$$\begin{aligned} &\Phi'^{H_iH_j}(v_{ci}, v_{ri}, v_{li}, v_{cj}, v_{rj}, v_{lj}, T_{ij}) = \min\{\Phi'^{E_{ci}E_{cj}}(v_{ci}, v_{cj}, T_{ij1}), \\ &\Phi'^{E_{ci}E_{lj}}(v_{ci}, v_{lj}, T_{ij2}), \Phi'^{E_{ci}E_{rj}}(v_{ci}, v_{rj}, T_{ij3}), \Phi'^{E_{li}E_{cj}}(v_{li}, v_{cj}, T_{ij4}), \\ &\Phi'^{E_{li}E_{lj}}(v_{li}, v_{lj}, T_{ij5}), \Phi'^{E_{li}E_{rj}}(v_{li}, v_{rj}, T_{ij6}), \Phi'^{E_{ri}E_{cj}}(v_{ri}, v_{cj}, T_{ij7}), \\ &\Phi'^{E_{ri}E_{lj}}(v_{ri}, v_{lj}, T_{ij8}), \Phi'^{E_{ri}E_{rj}}(v_{ri}, v_{rj}, T_{ij9}), \end{aligned} \tag{6}$$

where T_{ij} – vector of auxiliary variables.

As can be seen from (6), the conditions for describing the non-intersection of constructed objects are based on the description of the conditions for non-intersection of ellipses.

As follows from [9, 11], the conditions for the mutual non-intersection of ellipses are described by the inequality $\Phi'^{E_iE_j}(v_i, v_j, T_{ij}) \geq 0$, where the quasi-phi-function $\Phi'^{E_iE_j}(v_i, v_j, T_{ij})$ can be written as:

As follows from [9, 11], the condition of mutual intersection of ellipses are described by an inequality $\Phi'^{E_iE_j}(v_i, v_j, T_{ij}) \geq 0$, where the quasi-phi-function $\Phi'^{E_iE_j}(v_i, v_j, T_{ij})$ can be written as

$$\begin{aligned} &\Phi'^{E_iE_j}(v_i, v_j, T_{ij}) = (x_i - x_j)\cos T_{ij} + (y_j - y_i)\sin T_{ij} - R_i - \sqrt{b_i^2 + (a_i^2 - b_i^2)\cos^2(j_i - T_{ij})} \\ &- \sqrt{b_j^2 + (a_j^2 - b_j^2)\cos^2(j_j - T_{ij})}. \end{aligned} \tag{7}$$

5. Developing a meaningful model of modeling the active movement of people taking into account natural deformations of the body

Then the model of movement of people taking into account the natural deformations of the human body and maneuverability in their movement will take the following form.

Suppose there are N_k people in the evacuation area Ω_m with the location parameters $v_i = (x_i, y_i, j_i)$, $i = 1, 2, ..., N_k$, where (x_i, y_i) – the coordinates of the location of the beginning of the local coordinate system (current point), and j_i – the angle of rotation (maneuverability) of the *i*-th basic ellipse E_i , which is a three-component model of the i-th person. For each current point with coordinates $g_i(x_i, y_i)$, the velocity vector $\vec{v}_i = (x_i, y_i, j_i)$ is determined. Thus, the object is assigned the characteristics of speed (in meters per second), maneuverability (in radians), as well as set limits on the ratio of the angles of rotation of parts of the human body, depending on their deformations during movement.

Then the mathematical model of the subtask at each k-th iteration can be formulated in the form of finding the maximum displacement of people in the evacuation area, taking into account the conditions of their non-intersection, the conditions of their placement in the area, displacement, taking into account their maneuverability, and within the limits, which occur during natural deformations of the human body.

This article proposes an algorithm for moving people based on power contacts, which is presented in the sequence of next steps.

Algorithm.

Step 1. The evacuation area is presented in the form of a graph. Ribs - segments of corridors, vertices - intersections and points of "gluing" of segments.

Step 2. It is calculated distance from each point of the segment to the exit and the direction of the predominant movement.

Step 3. A grid with a sufficient number to determine the flow density is formed in the evacuation area.

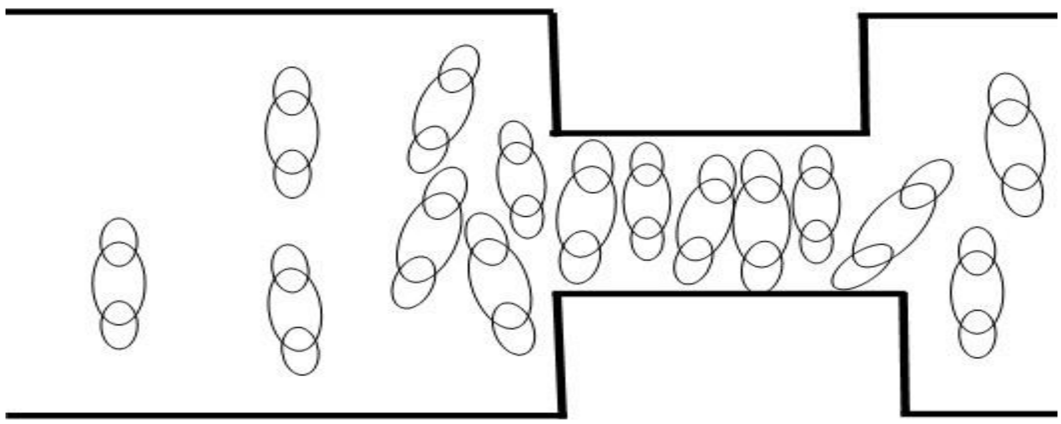
Step 4. People representing the three-component model are sorted to increase the distance to the exit.

Step 5. For each of the humans for coordinates the positions of the center and the angular of rotations are determined local density of flows and the preferred directions of movement.

Step 6. It is adjusted the speed according to the local density.

Step 7. Rational parameters are found in the area of admissible solutions, which is determined by the conditions of non-intersection of complex objects, the conditions of their placement in the segment and restrictions on the angles of rotation of each of the constituent objects. Rational parameters allow at the selected unit of time to make the maximum total movement of people.

Fig. 3 shows a fragment of modeling the movement of people, represented by a three-component model, at a random moment in time



→ - direction of movement

Fig. 3. The position of the people represented by the three-component model at a random moment of the time

The result obtained in Fig. 3 is the configuration of humans placement on the k-th iteration of optimization of active humans motion modeling, which demonstrates the validity of the proposed algorithm and is an experimental test of the task constraints for which analytical expressions are obtained.

6. Discussion of the results of modeling the active movement of people taking into account their natural deformations

When people move in the flow, the following categories of movements are distinguished: calm, comfortable, active, with high activity. As a rule, the category of movement determines the density of the flow of people. When the category of movement of people passes into the category of active movement with possible forceful actions, the problem of modeling their active movement with forceful contacts between them arises. This task is relevant in addressing the evacuation from buildings.

The anthropological characteristics of man are analyzed and the three-component model of man is offered (fig. 1–3). Formalized constraints (1–4), (5), which take into account the natural deformation of the human body. For the constructed model of the human body, the conditions of their mutual non-intersection and placement in the area are written in the form of analytical expressions (6), (7), which is the basis for constructing a model of the problem of modeling active human movement.

A computational experiment was performed [10], which consisted in determining the local density of people, which represented by a one-component models (ellipses) and a three-component models. It was shown that the local density of one-component objects corresponds to the experimental upper density estimates obtained in [6] for the free motion of human flows. The placement density for the three-component model is on average 21.4% higher. The latter estimate corresponds to experimental estimates of density (0.9-1.0 m2 / m2), which is observed in the movement of people with natural deformations of human bodies for active movement [6].

A contectful model of modeling the movement of inhomogeneous flows of people in the network, consisting of corridors on each floor of the house and stairS is build. Modified algorithm for modeling the movement of people in the flow. Modification is to take into account the natural deformations of the human body [6].

Computer modeling of the placement of objects represented by three-component and one-component models, which was carried out in [10], showed the effectiveness of the three-component model. The flow density is increased by an average of 21.4% and a density value of 9-10 people / m2 (0.9-1.0 m2 / m2 with an average area of horizontal human projection of 0.1 m2) is achieved, which meets the movement of people with natural deformation of their bodies. Thus, the three-component model of the human body allowed to model the movement of people taking into account their forceful actions, which corresponds to the densities of human placement, which are obtained from many numerous field experiments [6].

The article considers the restriction on both the number of components of the moving object and its shape (in the form of an ellipse, a set of ellipses), which meets the appropriate subject area. This restriction is not fundamental. Models and algorithms allow you to make changes in both the number of components of objects and their spatial forms, which will only increase the complexity of algorithms for solving the task.

The advantage of this approach is its flexibility. It is now possible to model the movement of people with non-standard physical parameters (for example, sumo wrestlers), people with loads, wheelchairs, etc. - just need to add to the model of inequality, which describing the conditions of non-intersection of new objects with ellipses and each other.

7. Conclusions

1. Analyzed anthropological characteristics of man and proposed a three-component model of man, which takes into account the conditions of bonding components of the model into a single complex object and the ratio of angles of rotation of model components arising from physical constraints on the relative position of body parts. The efficiency of the three-component model (it is increase flow density by an average of 21.4%) is shown in comparison with the one-component model and, as a result, the flow density of 9-10 people / m2 is obtained (0.9-1.0 m2 / m2 at the area of the horizontal projection of a person in 0.1 m2), which corresponds to the movement of people with force action within the natural deformation of their bodies. It should be noted that the convergence with experimental estimates can be increased by selecting parameters that determine the ratio of the size of the components of the model of the human body. The model can also serve as a top estimate in obtaining occupancy of areas such as temporary accommodation, mobile evacuation vehicles. Thus, computer modeling of the movement of people, which represented by the three-component model and analysis of literature sources allowed us to conclude that the results are consistent with experimental estimates.

2. The meaningful model and the algorithm of modeling of active movement of people taking into account natural deformations of bodies are offered. Modification is to take into account the natural deformations of the human body by building a three-component model of man. Analytical expressions of the conditions of their non-intersection and placement in areas are obtained for the considered complex objects, which will allow to present the problem as a classical nonlinear programming problem and to use the existing optimization packages. The ability of the proposed algorithm to model the movement of people and the constraints of the problem, for which analytical expressions are obtained, is shown by computer simulation.

It should be noted that restrictions on both the number of components of object of movement and its shape are not fundamental. Models and algorithms allow you to make changes in both the number of components of the object and their spatial forms, which will only increase the complexity of the algorithms for solving the task.

The proposed approach to modeling the movement of people increases the range of tasks to be solved today, and allows you to model the active movement of people with contact force. A further direction can also be considered the development of new approaches to modeling the movement of people with non-standard physical parameters (eg, sumo wrestlers), people with loads, wheelchairs, robots, etc.

References

1. Donald, Mott Mac. (2015). Evacuation modeling. Retrieved from http://www.mottmac.com (date of the application 10.03.2015).

2. Schadschneider, W., Klingsch, H., Kretz T., Rogsch C., Seyfried A. (2009). Evacuation Dynamics: Empirical Results, Modeling and applications: Encyclopedia of Complexity and System Science. Springer.

3. Tarantsev, A. A. (2002). Pro audney zavdannya modeluvent evacuation z vikoristannyam theory masovogo obslugovannya: Pozezna bezpeka, 23(3), 56–65.

4. Varas, A., Cornejo, M. D., Mainemer, D., Toledo, B., Rogan, J., Munoz, V. (2007). Cellular automata model for evacuation process with obstacles: Physica A, 382, 631–642.

5. Zhao, D. L., Yang, L. Z., Li, J. (2006). Exit dynamics of occupant evacuation in an emergency: Physica A, 363, 501–512.

6. Holshchevnikov, V. V., Samoshin, D. A. (2009). Evacuation and behavior of people on fires: a textbook. M: Academy of Ministry of Emergency Situations Ministry of Emergency Situations of Russia.

7. Karkin, I. N., Parfenenko, A. P. (2011). Floiwtech VD – computer-simulation method from evacuation calculation: International Scientific and Technical Conference Emergency Evacuation of People from Buildings. Warsaw, 111–118.

8. Kholshchevnikov, V. V., Parfenenko, A. P. (2015). Comparison of various models of the movement of human flows and the results of software and computer complexes: Fire and explosion safety, 24, 68–74.

9. Komyak, V., Komyak, V., Danilin, A. A. (2017). Study of ellipse packing in the high-dimensionality problems: Eastern-European Journal of Enterprise Technologies, 1 / 4 (85), 17–23.

10. Pankratov, A., Komyak, V., Kyazimov, K., Komyak, V., Naydysh, A., Danilin, A., Kosse, A., Virchenko, G., Martynov, V. (2020). Development of models for the rational choice and accommodation of people in mobile technical vehicles when evacuating from buildings: Eastern-European Journal of Enterprise Technologies, 4/4 (106), 29-36. DOI: 10.15587/1729-4061.2020.209256

11. Danilin, A. N., Komyak, V. V., Komyak, V. M, Pankratov, A. V. (2016). Upakovka ellipsov v pryamougol'nik minimal'nykh razmerov: USiM, 5–9.

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МОДЕЛЮВАННЯ АКТИВНОГО РУХУ ЛЮДЕЙ ПРИ ЕВАКУАЦІЇ З БУДІВЕЛЬ

Розглядаються такі категорії рухів: комфортні, спокійні, активні, з високою активністю. Коли категорія руху людей стає активною з можливими силовими діями, постає задача моделювання їх активного руху із урахуванням природних деформацій людських тіл. Проаналізовані антропологічні характеристики людини з точки зору фізичних обмежень на взаємне положення частин тіла при їх активному русі з силовими діями. Враховуючи властивості фізичних обмежень тіла людини, запропонована трикомпонентна математична модель горизонтальної проекції людини, яка враховує умови склеювання компонент моделі в єдиний складний об'єкт та обмеження на співвідношення кутів обертання компонент. Модель тіла людини представлено об'єднанням трьох еліпсів: основного і двох допоміжних. Основний може неперервно обертатись в рамках маневреності руху, а допоміжні – в рамках кутів, що витікають із антропологічних властивостей людини. Запропоновані змістовна постановка задачі моделювання активного руху людей з урахуванням природних деформацій тіл та модифіковано алгоритм моделювання. Модифікація полягає в урахуванні природних деформацій тіла людини шляхом моделювання зміни просторової форми трикомпонентної моделі тіла людини. Для розглянутих складних об'єктів отримані аналітичні вирази умов їх не перетинання та розміщення в областях, що дозволить в подальшому представити задачу, як класичну задачу нелінійного програмування та використати існуючи пакети оптимізації. Шляхом комп'ютерного моделювання показана діє спроможність запропонованого алгоритму моделювання руху людей та обмежень задачі, для яких отримано в роботі аналітичні вирази. Слід зазначити, що розглянуті в роботі обмеження як на кількість компонент об'єкту переміщення, так і на його форму не є принциповими. Моделі і алгоритм дозволяють внести зміни як в кількість компонент об'єкта, так і в їх просторові форми, що приведе тільки до підвищення трудомісткості алгоритмів розв'язання задачі.

Ключові слова: безпека людини, евакуація, неоднорідні потоки, моделювання, оптимізація, активний рух з можливими силовими діями, природні деформації людського тіла

Література

1. Donald Mott Mac. Evacuation modeling / Mott Mac Donald. URL:http://www.mottmac.com (date of the application 10.03.2015).
2. Schadschneider A. Klingsch W., Kluepfel H., Kretz T., Rogsch C., Seyfried A. Evacuation Dynamics: Empirical Results, Modeling and applications // Encyclopedia of Complexity and System Science. Springer. 2009.
3. Таранцев А. А. Об одной задаче моделирования эвакуации с использованием теории массового обслуживания // Пожаровзрывобезопасность. 2002. 23(3). 56–65.
4. Varas A., Cornejo M. D., Mainemer D., Toledo B., Rogan J., Munoz V. Cellular automata model for evacuation process with obstacles // Physica A. 382. 2007. 631–642.
5. Zhao D. L. Exit dynamics of occupant evacuation in an emergency / D.L. Zhao, L.Z.Yang, J.li. Physica A. 363. 2006. 501–512.
6. Холщевников В.В., Самошин Д.А. Эвакуация и поведение людей на пожарах: учебное пособие // М.: Академия ГПС МЧС России. 2009. 210.
7. Karkin I. N., Parfenenko A. P. Floiwtech VD – computer-simulation method from evacuation calculation // International Scientific and Technical Conference Emergency Evacuation of People from Buildings. Warsaw. 2011. 111–118.
8. Холщевников В. В., Парфененко А. П. Сопоставление различных моделей движения людских потоков и результатов программно-вычислительных комплексов // Пожаровзрывобезопасность. 24(5). 2015. 68–74.
9. Komyak V. M., Komyak V. V., Danilin A. N. A study of ellipse packing in the high-dimensionality problems // Eastern-European Journal of Enterprise Technologies 1/4(85). 2017. 17–23.
10. Pankratov A., Komyak V., Kyazimov K., Komyak V., Naydysh A., Danilin A., Kosse A., Virchenko G., Martynov V. Development of models for the rational choice and accommodation of people in mobile technical vehicles when evacuating from buildings // Eastern-European Journal of Enterprise Technologies. №4/4 (106). 2020. 29–36. DOI: 10.15587/1729-4061.2020.209256
11. Данилин А. Н., Комяк В. В., Комяк В. М., Панкратов А. В. Упаковка эллипсов в прямоугольни минимальных размеров // УСиМ. К. 5. 2016. 5–9.

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