Structural and mathematical models of software and hardware platform of the training complex

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Abstract. The article discusses the problem of formalizing the structure of software and hardware platform training complex based on a controlled treadmill. The general structure of the platform components is formulated. A mathematical model is developed for an omnidirectional platform in notation of set theory. The criteria for optimizing the software and hardware platform were selected: economic costs, compliance with structural characteristics, energy efficiency; quality indicators. Structural and mathematical models and criteria will allow the design and optimization of the hardware and software platform for the training complex.

1. Introduction
The quality of work in emergency situations and uncertainty is directly related to the level of staff training. Preparing staff for work in such conditions requires a high reaction rate in the modern technological world. The speed of decision making affects the success of the activity as a whole. The level of training requires the systematic development of algorithms for action in emergency situations and in situations of uncertainty, complicated by poor visibility and lack of oxygen, panic and stress.

Training complexes are considered as an effective tool for staff training. Comprehensive training requires not only a visual presentation (on the monitor, in a virtual reality helmet or otherwise), but also the creation of the necessary level of physical activity. Integration of specialized software and hardware platforms into training complexes allows achieving the expected results. Most platforms are based on treadmills. Their use allows the user to feel the necessary load during preparation. Otherwise, the use of the simulator will not allow you to develop a muscular reaction to events in the training scenario [1, 2].

Software and hardware platforms allow you to integrate a person into virtual reality, ensure his movement in any direction, implement interaction with virtual objects through modern controllers, and the integration of many sensors will allow you to track his condition in real time for subsequent analysis and diagnostics.

Existing platforms have several disadvantages. Dynamic platforms (fig. 1) are the most suitable device class for organizing the training process [3]. However, their functioning requires a control system based on mathematical and software. The task is complicated by the fact that the control system is required to provide adaptive regulation of the speed and direction of movement of the platform, according to the actions of the user.
A universal mathematical model does not exist. Existing models do not allow to pose and solve the problem of optimizing the software and hardware platform for the training complex. This is due to the lack of special criteria adapted directly to this class of systems. Therefore, the urgent task is to formalize the structure of such systems. The approaches used in its solution are applied in the field of developing information systems, designing industrial equipment, training complexes [4].

In the framework of this work, the problem of formalizing a software and hardware platform in the form of structural and mathematical models is considered. The apparatus of set theory was used to solve it. The platform optimization criteria are formulated on the basis of the model; in the future they will be taken into account when designing and setting the system optimization problem.

2. The structural model of software and hardware platform

The general structure of the hardware-software platform of the training complex is formulated on the basis of system analysis methods. The main components of the structure are: an omnidirectional platform that conveys user movement in VR; integrated control panel, including: interfaces for interacting with VR, viewing databases, managing the platform; A wireless device based on a wireless access point.

We carry out the decomposition of this structure. Fig. 2 shows a detailed structure of a software and hardware platform with an indication of all functional modules, components, and relationships between them.

The presented structural model formalizes the main components of the software and hardware platform and is used in the development of a mathematical model and the practical implementation of system components.

3. The mathematical model of the omnidirectional platform

The structure of the omnidirectional platform is implemented on the basis of the presented structural model.

The mathematical model of the omnidirectional platform \( OMNI \) is presented in the notation of set theory:

\[
OMNI = \{ OMNI_{LP}, OMNI_{MP}, OMNI_{TD}, OMNI_{SW+HP}, OMNI_{WR} \},
\]

where

- \( OMNI_{LP} \) - set describing user parameters of the omnidirectional platform;
- \( OMNI_{MP} \) - set describing the mechanical parameters of the omnidirectional platform;
$OMNI_{TD}$ - set describing the parameters of typical devices of the omnidirectional platform;  
$OMNI_{SW+HW}$ - set describing the hardware and software settings of the omnidirectional platform;  
$OMNI_{WR}$ - set describing the work room parameters of the omnidirectional platform.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{structure_diagram.png}
\caption{Decomposition of the structure of the software and hardware platform.}
\end{figure}

For ease of presentation, we denote the location of the coordinate axes and planes of the omnidirectional platform: $\alpha X$ - omnidirectional platform width axis; $\alpha Y$ - omnidirectional platform length axis; $\alpha Z$ - omnidirectional platform height axis; $XoY$ - horizontal plane of an omnidirectional platform.

Omnidirectional platform user options are presented of a set:

$$OMNI_{LP} = \{LP_x, LP_y, LP_z, LP_{\text{weight}}\},$$  

(2)
\[ LP_d = LP_L \cdot LP_W , \]  

where 
\( LP_d \) - the area occupied by the user; 
\( LP_L \) - projection of user height on axis \( oZ \); 
\( LP_{sd} \) - maximum length of a single displacement, is a function of the projection of the user's height \( LP_H \); 
\( LP_{weight} \) - user weight; 
\( LP_L \) - projection of user length on axis \( oY \); 
\( LP_W \) - projection of user width on axis \( oX \). 

A single displacement of user calculated using the formula:
\[ LP_{sd} \approx \alpha \cdot LP_H + \beta , \]  

where 
\( \alpha \) - coefficient allowing to calculate the maximum step length depending on the user's height \( LP_H \); 
\( \beta \) - calculated constant.

The omnidirectional platform allows the user to move in any direction along the plane \( XoY \), so the optimal working area is calculated based on the conditions:
\[ LP_{sd}^{max} \in [\pi \cdot (LP_{sd})^2 ; \pi \cdot (LP_{sd}^{max})^2 ] , \]  

where 
\( LP_{sd}^{max} \) - optimal user workspace; 
\( LP_{sd} \) - the maximum displacement defined by substituting \( LP_H^{max} \) (maximum user height) in formula (4). The work area is calculated based on the real and maximum calculated values of the unit movements of the user \( LP_{sd} \), \( LP_{sd}^{max} \), respectively.

The mechanical parameters of the omnidirectional platform are presented in the form of a set:
\[ OMNI_{MP} = \{MP_{weight}^{max} , MP_{dimensions}^{max} \} , \]  

where 
\( MP_{weight}^{max} \) - maximum omnidirectional platform weight; 
\( MP_{dimensions}^{max} \) - maximum dimensions of an omnidirectional platform.

The calculation of these parameters is carried out according to the following formulas:
\[ MP_{weight}^{max} = \{LP_{weight}^{max} , f_{weight}(OMNI_{TD}) , f_{weight}(OMNI_{CD}) \} , \]  

where 
\( f_{weight}(OMNI_{TD}) \) - component weight function \( OMNI_{TD} \); 
\( f_{weight}(OMNI_{CD}) \) - component weight function \( OMNI_{CD} \).
\[ MP_{dimensions}^{max} = \{OMNI_L , OMNI_W , OMNI_H \} \]  

where 
\( OMNI_L \) - projection of the length of the omnidirectional platform on the axis \( oY \); 
\( OMNI_W \) - projection of the width of the omnidirectional platform on the axis \( oX \);
OMNI_H - the projection of the height of the omnidirectional platform on the axis, calculated on the basis of the inequality:

\[ OMNI_H \geq LP_{H}^{\max} + OMNI_{H}^{F_A}, \]  

where

OMNI_{H}^{F_A} - fixed area projection OMNI_{H}^{F_A} omnidirectional platform axis oZ .

Due to the possibility of free movement on a plane XoY, movement is carried out in any direction relative to the zero point:

\[ LP_{ZP} = (X_{ZP}, Y_{ZP}, Z_{ZP}), \]  

where

X_{ZP} - coordinate of the middle width of the workspace of the omnidirectional platform;
Y_{ZP} - coordinate of the mid-length of the workspace of the omnidirectional platform;
Z_{ZP} \in [0; LP_y] - workspace coordinate belonging to the projection of the user's height on the axis oZ .

Projections of the platform on the axis are calculated based on the inequality:

\[
\begin{align*}
OMNI_L \geq 2 \cdot (L_{SD}^{max} + OMNI_{F_A}), \\
OMNI_W \geq 2 \cdot (L_{SD}^{max} + OMNI_{F_A}).
\end{align*}
\]

Parameters of typical omnidirectional platform devices are presented in the form of a set:

\[ OMNI_{TD} = \{DSD, ICP, WL, CAM, EE\}, \]  

where

DSD - data synchronization device settings;
ICP - integrated control panel parameters;
WL - wireless connection parameters (supported communication standard, number of simultaneously connected communication devices, maximum number of devices connected to an access point, range of supported networks, maximum area of interaction with an omnidirectional platform, security of connecting to a device, etc.);
CAM - parameters of positioning cameras;
EE - actuator parameters (servomotor and servomotor driver parameters).

Let us consider in detail the parameters of positioning cameras:

\[ CAM_i = \{CAM_{IS}, CAM_{ES}, CAM_{POS}\}, \]  

where

i - positioning camera number, i = 1, 2, ..., k ;
k - number of positioning cameras;
CAM_{IS} - internal parameters of the positioning camera common to all cameras (video resolution, maximum frame rate, camera angle coefficient, focusing distance, distortion, supply voltage);
CAM_{ES} - external parameters of the positioning camera (distance from the camera to the working section of the omnidirectional platform; angle of inclination of the camera relative to the working plane; illumination of the working section; camera visibility; viewing radius);
CAM_{POS} - camera coordinates in the form of a union of projections on the axis oX , oY , oZ of an omnidirectional platform.

Omni-directional platform software and hardware parameters are presented as a set:
where

\[ \begin{align*}
DSDSW & \text{- data sync device software;} \\
PlSW & \text{- omnidirectional platform control software;} \\
PlHW & \text{- omnidirectional platform control hardware;} \\
IDSW & \text{- instructor device software;} \\
ODSW & \text{- operator device parameters;} \\
TPD & \text{- third-party hardware and software.}
\end{align*} \]

The parameters of the workspace of an omnidirectional platform are presented as a set:

\[ \begin{align*}
OMNI_{WR} = \{WR_v, WR_{Temperature}, WR_{Humidity}, WR_{Illumination}, WR_{Pressure}\},
\end{align*} \]

where

\[ \begin{align*}
WR_v & \text{- volume of the working room;} \\
WR_{Temperature} & \text{- working room temperature;} \\
WR_{Humidity} & \text{- working room humidity;} \\
WR_{Illumination} & \text{- minimum degree of illumination of the working room;} \\
WR_{Pressure} & \text{- atmosphere pressure.}
\end{align*} \]

A set of optimization criteria will allow you to estimate the quality of an omnidirectional platform. The main directions of optimization:

- economic costs;
- structural criterion;
- energy efficiency;
- quality indicators.

The criterion of economic costs for the implementation of the software and hardware platform will be formulated as follows:

\[ \begin{align*}
OR_E = E_{HW} + E_{SW} \rightarrow \min,
\end{align*} \]

where

\[ \begin{align*}
E_{HW} & \text{- platform hardware costs;} \\
E_{SW} & \text{- platform software costs.}
\end{align*} \]

Costs \( E_{HW} \) are calculated taking into account the cost of all components of the software and hardware platform (structural elements, power elements, consumables, etc.). The calculation also includes the cost of cameras and equipment for their placement, equipment for VR, controllers, etc.

Costs \( E_{SW} \) include the costs of developing software for all components (VR, training subsystems, subsystems for managing simulators of physical activity and user movement, licensing).

An important point in optimizing platform parameters is to ensure that the design parameters of the platform meet the specified requirements. We express a constructive criterion in the form of a generalization of criteria [5]:

\[ \begin{align*}
OR_C = \begin{cases} 
OMNI_L + 2 \cdot OMNI^{SI} \rightarrow \min, \\
OMNI_H + 2 \cdot OMNI^{SI} \rightarrow \min, \\
OMNI_H \rightarrow \min, \\
MP_{\text{max}} \rightarrow \min.
\end{cases}
\end{align*} \]
OMNI$^{34}$ - omnidirectional platform safe service area.

The structural criterion is reduced to minimizing the overall dimensions of the platform while fulfilling restrictions on the dimensions of the working surface.

The energy efficiency criterion allows you to lead to less energy consumption in the process of its operation. It is focused on the best efficiency indicators by reducing power losses $\eta$, as well as lowering the total power of the track $P$ (when meeting the requirements for its operational characteristics):

$$ OR_e = \begin{cases} \eta \rightarrow \min, \\ P \rightarrow \min. \end{cases} $$  \hspace{1cm} (18)

Platform quality estimation can be carried out in several directions.

In terms of the effectiveness of the learning process. The set of estimation is a quality indicator $R_{pk}$ of staff training using the platform and the time $R_t$ required to develop the necessary competencies while reducing the economic costs $R_{ET}$ of organizing the training process:

$$ OR_k = \begin{cases} R_{ET} \rightarrow \min, \\ R_{pk} \rightarrow \max, \\ R_t \rightarrow \min. \end{cases} $$  \hspace{1cm} (19)

The calculation of these indicators can be carried out expertly by the ratios presented in [6].

In terms of product software quality. Calculation according to GOST R ISO / IEC 25010-2015 is an indicator of the quality of the software and hardware platform. The quality indicator criterion can be expressed as follows:

$$ OR_k = \sum_{i=1}^{N} (V_i \cdot Q_i) \rightarrow \max, $$  \hspace{1cm} (20)

where

$V_i$ - weight coefficient of the i-th metric;

$Q_i$ - estimation of the hardware and software platform by the i-th metric.

From the point of view of the user. Estimation the level of user satisfaction when interacting with a software and hardware platform is an indicator of the quality of the platform [7]. In a formalized form, this estimation has the form:

$$ OR_k = \frac{\sum_{i=1}^{N} (q_i)}{N} \rightarrow \max, $$  \hspace{1cm} (21)

where

$q_i$ - estimation delivered by the i-th user, which can be obtained through a survey.

Thus, many criteria for evaluating the software and hardware platform within the framework of the developed mathematical model were formulated according to economic, constructive, energy-consuming and high-quality indicators. This allows optimization and comparative analysis of platform components.

4. Conclusion

In this paper, we consider the issue of formalizing the structure of a software and hardware platform based on an omnidirectional controlled treadmill for a training complex. An analysis of the sources showed that a comprehensive approach to the study of the structure and relationships between the components of the platform is needed to ensure the best performance indicators.
In the work, a structural model of the platform is formulated, within the framework of which the main elements and the relationships between them are considered. On its basis, a mathematical model is developed, which is presented in the notation of set theory. It is distinguished by taking into account the parameters of the omnidirectional platform, the characteristics of the room, the software and hardware components used, as well as the parameters of the platform user. For the model, the criteria of economic costs, structural compliance, energy efficiency and quality indicators are formulated. Their application will allow you to choose the best combination of platform components and the values of its parameters.

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