The Status Functions Application for Multispectral Data Images Processing in Virtual Reality Systems

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Abstract. **The analysis of problems of feedback channel design in virtual reality training systems is presented. These problems are combined into groups of technical implementation, software processing of data and mathematical models for assessing the state of a person studying in a virtual reality system. For the design of the technical implementation, possible technologies are considered. To create a non-invasive channel for assessing a person's condition, the possibility of using multispectral methods and image recognition technologies is highlighted. To develop the mathematical support, a brief analysis of the mathematical representation of the signals in the communication channel was made. The methods based on the canonical expansions of random functions are singled out. To process the signal, a method of status functions is used, based on the canonical expansions of random functions. An experiment was conducted to develop a feedback channel based on multispectral imaging techniques and status functions. In the experiment we used the study of the possibility of perceiving a 3D image of a volumetric display. The experiments demonstrated good prospects for the proposed technologies and mathematical methods. It was revealed that a short test demonstration of SIRDS-images or 3D-images before the beginning of the presentation of the main educational material promotes a holistic perception of pseudo-images.**

Keywords: status functions; multispectral images; data processing; virtual reality systems; 3D images; training, feedback channel; perception of three-dimensional images

I. Systems of Virtual Reality in Training

Currently the entire training system is being transformed [1]. One of the aspects of this transformation is the introduction of virtual reality training systems (VRTS) in the process of education. The experience shows that the application of the VRTS provides high educational motivation and the success of training. This is achieved through the activation of the brain, the realness of the objects and phenomena studied, the inclusion of all sensory organs. A new qualitative level can be realized by virtual reality methods in information processing, modeling and design of experiments, creation of complex machines and mechanisms, industrial objects and processes.

The main tasks of development of the VRTS is development of technical and mathematical software. It is also necessary to create methods for assessing the cognitive and psycho-emotional state of a person [2]. The set of problems arises when developing mathematical models of the state of the student, studying their psychological validity and the means of technical and programmatic implementation of systems for assessing learning outcomes [3]. At the same time, it is required to preserve the continuity of the key concepts of interaction between the learner and the teacher.

In order to assess of the levels of training, it is possible to use the following mathematical models: simple algebraic ones, taking into account the parameters of tasks, based on statistical methods, fuzzy sets theory, status functions [4].

The technical implementation of VRTS will most likely be based on applying a new concept of using the human-machine interface to create the effect of a three-dimensional environment in which the user interactively operates virtual objects, rather than images of these objects [5].

The complex problem of the technical implementation of VRTS is the creation of a communication channel for the interaction of a person with the technical system affecting it. We considered ways to design a feedback channel in an ergatic VRTS using mathematical models based on status functions.

A. *Technical opportunities of evaluating the change in the emotional state*

For the application of modern methods of assessing learning outcomes, it is necessary to evaluate the result of mastering knowledge, as well as the change in psychological state of a person. Human emotions are physiological mechanism of their interaction with the environment. Basic emotions have the simplest chemical and physical effects on the endocrine system of the body. If necessary, under certain circumstances they lead to a change in the type of behavior. Emotions act as key forces motivating behavior.

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Objective assessment of systemic changes in emotions and brain work is possible on the basis of methods for processing electro-encephalograms, vibraimages or multispectral images.

Electro-encephalographic methods allow to analyze subtle functional reconstructions of brain activity. This is their undeniable advantage. Data collection is carried out by a contact method. This imposes significant limitations.

Vibroimage is a functional analogue of electroencephalographic method. The frequency of processed signals does not exceed 10 Hz, and 0-30 Hz, respectively. For registration of the vibraimage, it is enough to use webcams. This allows us to expect broad possibilities for applying this method for assessing of the psychophysical state of a person and groups of people when several people are analyzed in the frame.

Non-invasive diagnosis with the use of multispectral technologies is based on photogrammetric methods of measuring of positioning of the human body in different spectral ranges. The novelty of proposed approach is the use of webcams with multispectral diapason and a special software algorithm, mathematics model of the status function. The information-measuring system receives images from web cameras, then binds objects or fragments to the coordinate system and automatically identifies them with the corresponding fragments from the database, and then performs diagnostics. The scale and orientation of original fragments can be arbitrary.

To identify fragments, a stereo identification algorithm is used. It allows to compare images of different geometries. The sequence of procedures based on photogrammetric and multispectral technologies allows solving the problem of recognition and selection of characteristic contour forms of the body. The implementation of the proposed procedure is designed to diagnose a typical motor pattern (smooth motion with constant motion), non-optimal dynamic stereotype (the appearance of additional compensatory syncopeies in the spine and limbs), atypical motor pattern (the appearance of additional movements and distortion of the trajectory and speed of motion) and some other.

The measurement of motor deviations can occur anywhere in the eyeshot of the multispectral measuring system (at home, on the street, in the classroom). In the output of the measuring system, a three-dimensional description of the shape and dynamics of the object in a given format are shaped. Output data can be transmitted over the network. Information can also be visualized as a virtual three-dimensional object with its own texture. Advantages of the method include low costs, high accuracy of measurements, ease of use, high degree of automation, efficiency (diagnostics is performed in real time).

B. Mathematical methods for describing the feedback channel of ergatic systems

The connection of input and output signals in the communication channel of the information measuring system can be realized by using a direct description, which is based on the use of differential or integral equations [6]. In this case, the description should use the consideration of the operator, which converts a multitude of input signals into output signals. Therefore models that use spaces in which coordinate functions are eigenfunctions of linear systems on infinite analyzed interval will be developed. This ensures the universality of the developed models.

It is advisable to use the mathematical model in the form of an operator for which bases of decompositions of input and output signals are given as harmonic functions [7]. It is assumed that the impact on the learner and assessment of his condition is presented in the form of a mixture of some signals. In this mixture, the learner state variables have a useful component $z(\boldsymbol{r},t)$ and additive noise $n(\boldsymbol{r},t)$. The model of the communication channel is represented in the form of some operator H'. The operator displays the useful component of the output signal as the received mixture, which depends on the properties of the transmission medium, as well as on the characteristics of the input and output devices (performing the matching). Then the mathematical model of the communication channel can be represented in the following form:

$$H'\big(x(\boldsymbol{r},t)\big) =< \Psi_r'(z'(\boldsymbol{r},t),\boldsymbol{r},t)| \frac{\partial z'(\boldsymbol{r},t)}{\partial t} = \Psi_r(x(\boldsymbol{r},t)z'(\boldsymbol{r},t),\boldsymbol{r},t) \tag{1}$$

where $z'(\boldsymbol{r},t)$ – learner state variables, Ψ_r, Ψ_r' – some nonlinear operators containing derivatives with respect to spatial coordinates, $\boldsymbol{r},t$ – spatial and temporal variables. Various changes in the output signal can act as state variables.

The operator H' is a system characteristic and reproduces the features of the signal observed in the output. The description of the feedback channel is reduced to the development of its system characteristics. Then the problem of numerical processing of a stationary random function [8] can be based on canonical representations of random functions. They are based on the representation of a random function in the form of a deterministic function of random variables [9].

The development of methods for using canonical expansions for mathematical processing of signals in feedback channels in VRTS was carried out in [2, 3]. These results should be used to solve the problem of assessing the state of a person trained in the VRTS for the formation of mathematical models of the state operator. Thus, when developing a mathematical model of a person's psycho-physical state, which is affected by a technical system for the purpose of training, status functions should be used [4].

As a result of the sequence of measurements of the interaction process between the trainee and VRTS and the representation of harmonic basic status functions from the form, mathematical models of human states can be determined. As a consequence, on the basis of these models, we obtain an analogue of the state vector of the system.

When the leaner interacts with VRTS, the new concept of using human-machine interface is realized for the creation of the effect of a three-dimensional environment in which the user copes interactively with virtual objects, not with images of these objects [5].

The problem of forming a mathematical model of the learner in the VRTS (1) can be solved by evaluating the perception of a three-dimensional image. There is a set of technical limitations in applying this approach.

C. Problems of the feedback channel interface

Firstly, the user can work only with complete prototype of real object or phenomenon. Inclusion of focus groups at the stage of device modeling has not shown effectiveness due to different personal ability to abstract and indicators of spatial thinking of users. Secondly, final users have significant individual differences, that lead to a great mismatch of the usability ratings of the device. In addition, the main methods of collecting estimates from users are questionnaire techniques and tests, the validity and reliability of which also require additional evidence.

According to statistics, approximately 40% of people, when viewing the SIRDS-picture, almost immediately perceive a three-dimensional image. About 50-60% perceive a three-dimensional image only through a special training, related to the selection of the optimal distance and focus of the view. Approximately 5-10% are not able to perceive an artificially formed volumetric image due to specific vision problems. Taking into account that modern multimedia educational technologies are oriented to the perspective of virtualization of educational material with the help of visualization of voluminous objects with new technical means [3], there is an urgent need to adapt (transform and switch) modern pedagogical methods and tools to a new qualitative level.

For the each of the following indicators, we will use an estimate based on the status functions [4]:

1. Characteristics of two-dimensional images

1.1. Screen resolution.

1.2. Color of the image (color rendering quality).

1.3. Frame rate.

2. Characteristics of the three-dimensional image.

2.1. Viewing angle.

2.2. Image size.

3. Monocular properties of volume perception (I1) - these are taken into account when creating content for the display:

3.1. Parallax movement.

3.2. Perspective.

3.3. Shadows.

3.4. Mutual overlap of objects (occlusion).

3.5. Rotating object.

3.6. Gradient texture.

3.7. Heterogeneity of form.

For each of the indicators, an evaluation is based on status functions [4]. For each assessment objective (display characteristics, sensor readings, image analysis by software) and subjective indicators are used. Analysis of status functions allows to draw conclusions on the perception of the image.

D. Experiment

When considering the volume pseudo-images (stereo images, 3D-images) without the use of special technical means (liquid crystal glasses, anaglyph glasses, etc.), it is required to perform two absolutely opposite actions:

a) to direct a relaxed glance through the image,

b) focus on the image, when each eye captures a clear and sharp image.

Studies were carried out at two independent levels:

I level – collective, classroom testing;

II level – "deep" individual testing.

In group testing, 87 people participated. The format of the messages of the textual-visual plan (lecture material) was selected depending on the target audience. The measurement of physiological activity of students was made depending on their physiological activity (movement of the head, limbs, thermographic data of the open skin) when passing the test material in the audience. The technology of such an experiment is described in detail in [2]. The difference was the way data is presented in 3D format. We used SIRDS-images, as well as 3D-images, formed on the basis of the patent [10].

List of used equipment:

Stereo camera based on digital camera ELP USB8MP02G-MF80, 8.0 Megapixel, shooting mode 2K-4K;

Digital camera GoPro 3+, shooting mode 2K-4 K;

Infrared laser flashlight with adjustable beam shape and backlight frequency;

TV camera Flir® Tau®2 with uncooled VOx microbolometer;

3D-display, designed on the basis of the patent of the Russian Federation No. 2526901;

Multimedia projector XGIMI H1;

Laptop: Sony Vaio SVD1321M9RB, Intel® Core ™ i5-4200U CPU @ 1.60GHz 2.29 GHz, 4 Gb RAM, Windows 10 Pro (64-bit OS, x64 processor); Tablet: iPad Air, RAM 64 Gb, iOS 11.0.3.

The results of the 1st level audit are shown in Fig. 1 and Fig. 2. The first figure shows the placement of students in the classroom.

Fig. 1. Content placement trainees. The upper rows in the audience are scanned with a visible decrease in resolution accuracy

Fig. 2. The average amplitude of activity movements with clearly visible periods of decline and increase in activity in the audience

Classical university audiences are the best in overview for group testing. the second figure shows a graph of the total average amplitude of active movements (movements of hands, head, face mimic, eye movements, etc.) of students. The time interval is 45 minutes. During this period, the theoretical content of the discipline is presented. The presentation of the material is carried out in the feedback mode (discussion and explanatory). On the chart, a fifteen-minute group climb of students' activity can be followed, followed by a "fatigue" decrease (8-10 minutes) and a new, more "effective" rise. In this case, the graph can be viewed as a conditional classroom "profile" of the learning group, which reflects the students' reaction to the instructional material presented by the teacher. Such visualization of the audit "profile", in real time, significantly expands the possibilities of the educational and educational process, makes it possible to effectively evaluate and correct educational and methodological material.

In individual testing, the "deep immersion" method was used in a virtual environment, which was formed using the status function method, 17 people were tested. The experiment was conducted twice (one week after the first testing), with the same composition of participants. In Fig. 3. are shows the system for conducting "deep" individual testing. In Fig. 4 are shows the example of the operation of the information-measuring system.

Fig. 3. General view of the information and measuring system of "deep" testing. Legend: 1 – digital camera; 2 – infrared searchlight; 3 – 3D-display; 4 – laptop with a test program

Fig. 4. An example of the work of an information-measuring system for "deep" testing: A1 – eye-fixing (pupils) in the search mode; A2 – eyes (pupils) in the perception mode; B1 – fixation of the eyes (pupils) in the search mode (inclination of the head); B2 – eyes (pupils) in the perception mode (inclination of the head)

II. Conclusions

The effectiveness of the learning process directly depends on the applied methods and means, as well as the ability to most accurately assess the assimilation of educational material. In this case, the possibilities of using new educational technologies on the basis of status functions are considered to form a feedback channel for training in specialized virtual reality systems.

The educational material using 3D technologies allows to effectively achieve the planned learning goals. Unfortunately, three-dimensional images, due to the physiological features of the perception of 3D images by humans based on 3D technologies, are not always perceived by students.

As shown by experiments, a short test demonstration of SIRDS-images or 3D-images of the target audience within 20-30 seconds. (the so-called "warm-up", "warm-up") before the beginning of the presentation of the main educational material, promotes the maximum inclusion of trainees in an active, holistic perception of volumetric images.

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