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Modernisation of Endoscopic Equipment Using 3D Indicators

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Abstract **– The development of new software to improve the operation of modernised and developed technological facilities in different sectors of the national economy requires a systematic approach. For example, the use of video recording systems obtained during operations with the use of endoscopic equipment allows monitoring the work of doctors. Minor change of the used software allows using additionally processed video fragments for creation of training complexes. The authors of the present article took part in the development of many educational software and hardware systems. The first such system was the "Contact" system, developed in the eighties of the last century at Riga Polytechnic Institute. Later on, car simulators, air plan simulators, walking excavator simulators and the optical-software-hardware training system "Three-Dimensional Medical Atlas" were developed. Analysis of various simulators and training systems showed that the computers used in them could not by themselves be a learning system. When creating a learning system, many factors must be considered so that the student does not receive false skills. The goal of the study is to analyse the training systems created for the professional training of medical personnel working with endoscopic equipment, in particular, with equipment equipped with 3D indicators.**

Keywords **– Cyberspace and human interaction, three-dimensional television, visual communication.**

I. Introduction

The development of personalised medicine strongly complicates the demands for the reflection of human organs during diagnosis and treatment with the use of endoscopic equipment. This sphere of research belongs to information system of 3D visualisation of complex medium, and it has begun to develop in aviation simulators [1]. That is why technology transfer is a usual means of development of the visualisation technology of complex medium for the purpose of personalised medicine [2]. The peculiarity of 3D indicators for aviation simulators is as follows [3]: they allow visually determining the distance to the final 3D models [4]. This allows them to be used in medical endoscopic equipment, when it is necessary to accurately determine the distance of a surgical instrument movement within a patient [5]. In this case, the doctor can only focus on the visual image of the instrument and the organs of the patient [6]. Earlier, with the use of endoscopic equipment, the doctor examined the image of the instrument and human organs on a flat 2D screen. This made possible to move the surgical instrument accurately along the X and Y axes. When moving along the Z axis, there were always problems. Partly, these problems are reduced using 3D indicators [7]. It was previously verified that the quality of modelling 3D images of object models was sufficient for professional training of an aircraft pilot's visual estimation. In other words, the visual orientation skills in space, obtained by a pilot training on an airplane simulator, corresponded to the skills obtained by a pilot controlling a real aircraft, including approaching landing with a visual definition of the distance to the ground [8]. Now the task is to apply the previously developed 3D indicator systems in medicine, for example, to improve the working conditions of doctors using endoscopic equipment. 3D indicator systems allow the doctor to identify more accurately diseases of human organs and move the instrument along [9] the Z axis. The most common 3D indicators and 3D complexes were investigated. The possibility to use 3D indicators and 3D indicator systems for modernisation of medical endoscopic equipment was considered to be successful. The best option for creating training software and hardware systems with visualisation of human organs is to include a database of video fragments obtained using real endoscopic equipment. In the future, these video fragments can be converted using application software packages [10]. Such a conversion is processing of video fragments in order to create stereo 3D films [11]. For this purpose, application packages that have already been successfully used in the film industry are usually used [12]. The illusion of viewing 3D images is obtained using stereo glasses and a special screen [13]. Such glasses allow each eye of a person to see images prepared only for this eye. In our case, two video sequences are formed [14]. One – for the left eye of a person, the second – for the right eye of a person. A video for the one eye of a person is obtained during the operation of the video camera. Video for the second eye is formed with the help of software packages. For the further use of video sequences for training doctors using stereo 3D indicators, the procedure for preparing the initial information looks like this. Special programs create additional video sequences for the second eye of a person. The first video sequences are created from the location of the video camera

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endoscopic equipment. This option is undoubtedly interesting when it comes to the production of entertainment programs and stereo movies. However, the system analysis showed that it was of little use for medical personnel working with endoscopic equipment [15]. The conclusions are based on results of experiments conducted with the "Contact" [16] training system and using the "Three-Dimensional Medical Atlas" training complex. The goal of creating such a complex was the training of doctors. The composition of the "Three-Dimensional Medical Atlas" includes special databases and software that allows repeatedly reproducing the actual operation [17]. All the necessary video fragments can be viewed in the 3D image [18]. As the initial information, video films obtained from the operation of real medical endoscopic equipment were used. The 3D images of individual organs were obtained using a 3D image without 3D glasses and 3D images of individual organs obtained using stereo 3D indicators [19]. During the tests, for supervision with the help of a glasses-free 3D indicator, original video fragments recorded by a single camera of endoscopic equipment were used. For viewing the use of a stereo 3D indicator, two video sequences were used. One video for the left eye was created using an endoscopic video camera. The second video sequence (for the right eye) was obtained after processing the original video sequence with the help of a software package produced by *SoftLab* (Novosibirsk) [20], [21].

A glasses-free 3D indicator also makes a 3D image. When viewing two types of 3D images, it was analysed how convenient it was to use a glasses-free 3D indicator or stereoscopic 3D indicators to conduct operations and create training complexes. The findings are similar to the conclusions made by the developers of aviation simulators, when developing visual imitators. Such simulators create for the observer a 3D image of the terrain with a quality sufficient for training the eye. When studying aviation simulators, it is said that such training systems are effective [22]. Let us consider the conclusions made concerning the modelling of 3D images.

II. General Regulations

To obtain the effect of visual observation of a three-dimensional object model, different methods are used. To obtain the effect of observing a three-dimensional object, a cube model or a model of a three-dimensional object with a clearly expressed difference in colour faces is moved along the flat screen. Sometimes it is enough to highlight the wire structure (Fig. 1). However, in these cases the person is sure that the considered three-dimensional model is at a distance, defined as the distance between his eye and the plane of the television screen. Later, we will consider this as an example of a "non-planar" image.

We introduce the definition of the term "a system that synthesizes a visually observable three-dimensional model". Further, we will assume that this term refers to system modelling of a three-dimensional model of the surrounding space in front of the observer with quality that allows a person to determine the distance to visible 3D models to the naked eye.

Upgrading endoscopic equipment, it is necessary to achieve an effect when the doctor is able to determine the distance to visible objects, including the *Z* coordinate. The experience gained during the development of 3D indicators for aviation simulators, when it was necessary to teach a pilot to visually determine the distance to the takeoff runway, showed that such a problem was solved using pseudo-volumetric 3D indicators, or pseudo-volumetric 3D systems.

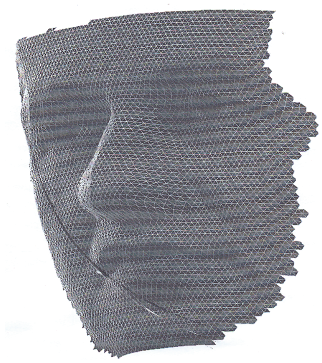

Fig. 1. Example of a "non-planar" image.

The term "pseudo-volume" indicates that pseudo-volume 3D indicators, or pseudo-volume 3D systems, affects certain components of a person's view, causing the pilot to assume that he sees a three-dimensional image. All people are different; the visual apparatus of each person has individual characteristics. Consequently, each person perceives a pseudo-volumetric image in different ways. The perception of a three-dimensional model obtained with the help of an optical-hardware complex affecting certain components of the visual apparatus of one person can differ from the perception of this model by another person. The experiments have proven it. However, there is common 3D perception for a person that allows creating 3D systems and being sure that if certain conditions are met, a person will see a 3D image with quality sufficient to perform professional duties. Thus, the 3D image obtained with the optical-hardware part of endoscopic equipment allows the doctor to move accurately the medical instrument inside the patient.

Two types of pseudo-volume systems are used in aviation simulators. Two-channel 3D modelling systems are best known (Fig. 2) when two video cameras form an image separately for the left eye and separately for the right eye. Then the image formed on a flat television screen for the right eye is fed to the right eye. An image formed on a flat television screen for the left eye is fed to the left eye.

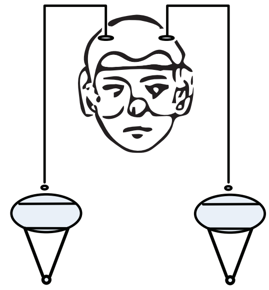

Fig. 2. One of the possible schemes of a 3D system with disparate screens.

The disparate component of the human visual analyser is dominant. However, the use of a 3D system with disparate glasses has a number of drawbacks. The main one is a period of time for training some people to see a three-dimensional image. The maximum recorded period of training was six months, with a person working with such systems at least 20 minutes daily, during a working week. A person whose visual apparatus has not learnt to see a three-dimensional image may experience discomfort, headache and dizziness. Experiments showed that a person considering a 3D image obtained by such methods gets tired quickly. The experiments were carried out using certified medical equipment assessing the person condition by the method of Dr. Foly. In particular, the Penza Diagnostic Centre refused endoscopic equipment equipped with such 3D indicators due to prolonged headache the doctors had after a session with such equipment.

This pseudo-volume method of 3D image formation, previously used in aviation simulators, is not the only one. More often, another method is used when, due to the collimator located between the screen of intermediate image formation and the eye of the observer (Fig. 3), two other components of human visual apparatus – accommodation and convergence – are affected.

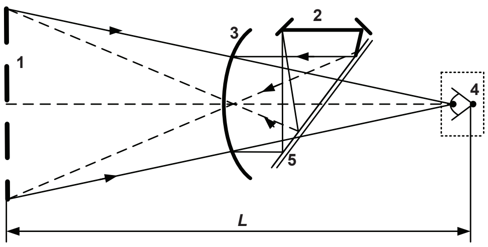

Fig. 3. Scheme of a narrow-angle 3D indicator based on a mirror collimator:
1 – the place where an imaginary image appears;
2 – the screen for formation of an intermediate image;
3 – the concave spherical mirror;
4 – the pupil of observation (where, when the eye is positioned, the observer sees a three-dimensional image);
5 – the beam splitter plate;
L – the minimum distance from the appearance of the nearest three-dimensional model.

Using this method, in order for a person to see a 3D image on a scale of 1 : 1, it is necessary that the viewing angle of the imaginary image occurrence be equal to the angles of the surveillance camera. An obligatory condition is the presence of a permanently visible mobile object, or a mobile observer. The condition of carrying out operations using endoscopic equipment always supposes the presence of a mobile image of the examined organs and a mobile video camera (which is equivalent to the presence of a mobile observer). Experiments have shown that the use of this method has the following advantages:

- all observers immediately see a three-dimensional image (the interval of training the human visual apparatus to see a three-dimensional image is minimal);
- while working with such equipment a person gets tired the same way as when watching usual TV.

On the basis of the obtained data, new endoscopic equipment was developed that includes: a video camera, a conventional television screen and two 3D indicators.

It should be taken into account that for comfortable observation of 3D image, the observer's head should be located in the pupil of observation. The experiments showed that to create comfortable conditions for physicians to observe 3D images, it is necessary to use two 3D indicators. One 3D indicator is located on the right and serves doctors located to the right of the patient. The second 3D indicator is located on the left and serves doctors located to the left of the patient.

For the analysis of 3D modelling systems, a concept of a quality criterion Q_{3D} is introduced, which allows choosing the 3D modelling system that best provides the solution to the problem. In general, this criterion can be written in the form of a functional:

$$Q_{3D} = F_1(H; I_{3D}),$$

where

H – features of the visual apparatus of a human observer;
I_{3D} – quality of the visually observable model.

Often, this criterion is sufficient to assess the possibility of using 3D image simulation system to solve the problems. When it is necessary not only to evaluate the already existing 3D image modelling systems, but also to outline ways to improve them and analyse the features of the hardware-software complexes the following functional is used:

$$I_{3D} = F_2(Q_{SCR}; Q_{SYS}),$$

where

Q_{SCR} – is the quality of reproduction of the visually observable model on a special indicator (or on the indicator system), taking into account the visual apparatus of the human observer;
Q_{SYS} – the quality of modelling the image of a visually observable model with the help of hardware, which is displayed on a special indicator (or on the indicator system).

In turn, to evaluate the special indicator used, the following functional is used:

$$Q_{SCR} = F_3(R_{SCR}; L_{SCR}; T_{SCR}; U_{SCR}; Q_{SYS}),$$

where

R_{SCR} – is the resolution of the screen used;
L_{SCR} – features of the reproduction of colour shades on the screen used;
T_{SCR} – the time of the next frame change on the used screen;
U_{SCR} – allowable viewing angles of the simulated image;
Q_{SYS} – the characteristics of optical systems used to produce a three-dimensional image.

Thus, it is assumed that the problem of modelling a "visually observable three-dimensional model" is divided into two tasks. The first task is to provide the possibility of entering maximum information about the object of observation. The second task is to transfer the received information, display the formation of intermediate image and transform two-dimensional projections into a model perceived by the person as three-dimensional. 3D indicators were developed to solve specific problems of aircraft simulator. The technological chain is in all cases the following. First, a central two-dimensional projection of part of the space that has got into the camera is synthesised on the screen. Then this image from the screen with the help of optics is delivered to the human visual apparatus. In aviation simulator construction on the screen the virtual space image is synthesised using real-time computer graphics methods. As initial information, polygons and lights, described mathematically, are used so that a qualitative image of a two-dimensional projection is obtained. As a result, the observer sees a clear image, calculated in advance for the solid angles of a given surveillance camera. When using a real endoscopic rack, a real camera is used, which gives certain distortions of the two-dimensional projection of the observed real object. These distortions first appear on the screen, where the central two-dimensional projection of this object is displayed, and then appear in the formation of the final 3D model of these objects. To minimise distortions, it is necessary to solve the synthesis problem on the screen of the central two-dimensional projection of the object and select the characteristics of optical converters that will deliver the image from the screen to the human visual apparatus. The goal of optimisation of two criteria is to create the most realistic 3D model that can be used to solve the tasks. Now, there are good solutions, which are separate for the first and the second task. In the complex, these two problems are not considered. The reason is the overwhelming use of 3D indicators in aviation simulators, where little attention is paid to the price of such complex. The studies conducted in Penza showed that for medical institutions it would make sense to turn to modernisation of glasses-free 3D indicators of endoscopic equipment. Successful results were obtained using glasses-free 3D indicators with the following characteristics:

min R_{SCR} = (800 × 600) pixels;
L_{SCR} – standard for new TV screens;
T_{SCR} – 50 Hz;
U_{SCR} – 40° horizontal and 30° vertically;
Q_{SYS} – a standard video camera for endoscopic equipment with a solid angle of 40° in a horizontal plane and 30° in a vertical plane, and a defect-free 3D indicator based on a mirror collimator (Fig. 3).

As experiments have shown, new equipment improves the conditions of diagnosing human diseases and does not fatigue doctors so much.

III. Results

As a result of consolidation of theoretical and practical knowledge in the construction of 3D visualisation of complex medium, a method of quantitative assessing of separate 3D indicators units for endoscopic equipment has been proposed in the present study.

Transfer of information technology of cognitive visualisation of special complex objects from aviation simulator production to personalised medicine is topical and perspective.

The proposed structure of endoscopic stand with two glasses-free 3D indicators for doctors situated to the left and to the right from the patient has become important in practice.

Startup was launched and technological sample of endoscopic stand was developed with support from State Contract No. 5917p/8265.

IV. Discussion

Studies of training systems involved employees of Riga Polytechnic Institute, Penza State Technological University, Penza State University of Architecture and Construction, LLC "Video3". In each case, studies were carried out using both specific software and hardware training systems, as well as individual devices and application software packages. The findings obtained during the experiments are successfully used in the development of new training complexes. This is confirmed when investigating the possibility of using 3D indicators in medical endoscopic equipment and equipment for training physicians. In accordance with State Contract No. 5917p/8265 dated 31 March 2008, prototypes of optical-software-hardware training complexes were created and a comparative analysis of two types of 3D indicator systems was carried out. The results will be used in the future for developing new software and hardware training systems.

PenzSTU and "Video3" LLC have successfully completed the study of new endoscopic equipment. The new complex has one video camera, one conventional television 2D screen and two glasses-free 3D indicators, or one indicator with stereo glasses. The article has been written after the analysis of the results of the experimental operation of new complexes. Two video films have also been recorded. One video has been created taking into account that it will be viewed on a 3D indicator and, therefore, it does not have a stereos picture. The second video has been created taking into account the viewing on the stereo indicator. Then, the 3D images have been compared. When viewing two 3D video images, the analysis has been carried out and the tasks solved – what needs to be changed to make the work of the new complex more successful. As a result, it has been determined when to use a specific type of 3D indicator and special software.

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