The task of increasing the number of training situations as one of the areas for improving the ergatic software and hardware systems "Aviation simulator"

V R Roganov¹, E A Asmolova¹, N S Esimova², R U Omirbekov², O Kuvshinova³ and G K Aidarbek¹

¹Penza State Technological University, 1a, Gagarina ave, Penza, 440039, Russia
²Humanitarian and Technical Institute "Akmeshit", 43, G.Muratbayeva ave, Kyzylorda, 120000, Kazakhstan
³Penza State University of Architecture and Construction, 28, Titova, Penza, 440039, Russia

E-mail: vladimir Roganov@mail.ru

Abstract. Currently, the ergatic software and hardware complex, called the "flight simulator", is used worldwide for professional training of crew members in piloting an aircraft in special flight conditions. Flight and integrated flight simulators include a visual environment simulator that synthesizes for a pilot a three-dimensional image of the external environment behind the simulator’s cabin, which allows pilots to be trained in visual landing on a runway model, while solving aeronautical problems. Simulators of the visual environment developed earlier could not synthesize recognizable areas of the area more than 400 × 400 km in size necessary for training in solving problems of self-driving. Therefore, simulators for the training of navigators were separately developed, teaching the determination of the location of the model of an aircraft in the model of the environment according to the models of radio engineering means of aircraft. Modern optical-technical-software systems for the synthesis of three-dimensional models of the external environment allow us to develop new and modernize existing flight and complex flight simulators by adding training to the crew of the aircraft in solving problems of aircraft navigation. The analysis carried out by the authors of this article showed that for this it is necessary to solve the problem of selecting objects that should become benchmarks and their placement according to the model of a large area. Solutions are proposed that allow us to solve the tasks and develop a model of a recognizable piece of the earth’s surface that is sufficient to solve the problems of piloting and self-driving training on an aircraft simulator.

1. Introduction

The modern development of hardware-software complexes of machine synthesis allows the real-time synthesis of terrain images on a monitor screen similar in quality to images on a television screen obtained with the use of video cameras. [1]. Certain euphoria from the results obtained often allows us to erroneously interpret the results as a solution to the problems of synthesis and modelling of a three-dimensional image [2]. Such an interpretation is usually based on the results obtained when viewing the "non-planar" image obtained by processing the lines on the monitor screen (figure 1) or when considering moving models of three-dimensional objects whose faces are illuminated taking into
account the rules of computer graphics (for example, when a cube model is moved on the screen, or a word written in "volume" font). 3D modelling systems are used in various sectors of the national economy: for training drivers of vehicles, while improving the conditions for operations using endoscopic racks and in other cases [3]. In the future, we will consider flight simulators (figure 2), allowing training pilots professional skills in piloting an aircraft and partially solving navigation problems on the ground [4].

![Image](example-non-planar-image.jpg)

**Figure 1.** Example of a “non-planar image”

### 2. Main part

To obtain a model of a three-dimensional external environment around the simulator cabin, at first, on a flat-screen, a video sequence is synthesized from 2D projections of the part of the 3D external environment model that fell into the surveillance camera (figure 3).

![Image](cabin-flight-simulator-wide-pupil.jpg)

**Figure 2 -** Cabin of the flight simulator with a display device with a "wide pupil" [5]

A 2D projection of a part of the 3D external environment is synthesized on a flat-screen by specialized software and hardware systems for machine synthesis [6]. For a long time, it was believed that it was enough to connect a display device for synthesizing 3D images to such a screen and such a system can be used as a “visual environment simulator” or as a complex that allows you to train a pilot of visual landing on a runway model [7].
The technology for obtaining 3D images is as follows. On a flat screen, a 2D projection of a part of a three-dimensional model of the external environment is synthesized with an interval of no more than 120 ms. Next, use one of two possible schemes with optical devices.

Conventionally, the first system is a system with stereo glasses. Usually, these are two screens, each of which is connected to its specialized software and hardware system for machine synthesis. One synthesizes an image for the left eye. One synthesizes an image for the right eye. The advantage of such a system is that a trained observer sees a 3D image in any case if the solid angles of the surveillance cameras coincide with the angles between the observer’s eye and the corresponding screen on which the corresponding image is synthesized. The disadvantage is that there is a time interval during which the visual apparatus of a particular person learns to see a 3D image of object models with quality that allows a person to visually determine the distance to the selected model. Usually, any person wearing stereo glasses immediately sees a sharp rather than a blurry image on the screens (among people there are exceptions when a person starting to view images through stereo glasses can lose orientation in space or get a severe headache after the session of such work). Moreover, not everyone can immediately visually determine the distance to the models in question, just as in real life they visually determine the distance to the selected objects. The results of experiments in which the authors of the article participated in conducting the research work “Research and optimization of manufacturing technologies for beam splitting plates and spherical mirrors, for single-channel and multi-channel glasses-free indicators of pseudo-volume images with a narrow pupil” (state contract No. 8009р/8265 of 04/30/2010) (1 and 2 stages) between Video3 LLC and the Federal State Budgetary Institution "Fund for the Promotion of the Development of Small Forms of Enterprises in the Scientific and Technical Field" showed that the training interval for a specific person’s visit to see a 3D model and visually determine the distance to it can last up to 5 months, with daily work with such a system for at least 20 minutes a day. In this case, all researchers immediately saw a clear image, but could not accurately determine the distance to visible models.

So, when teaching the human visual apparatus to see the 3D model when using systems with steroid glasses, negative effects may appear:

- headache;
- short-term loss of orientation in space during the first sessions of working with such systems, which was observed in two researchers (with a total number of researchers of 78 people).

Some researchers working with such systems had negative effects. They disappeared after long sessions of working with such systems, which is explained by the training of the human visual apparatus to see a 3D model. Most researchers have not observed negative effects when working with systems with stereo-glasses.

The second system used in the flight simulator is a frameless 3D image modelling system when a collimator is placed between the flat screen and the human eye (such a system affects the accommodation and convergence of the human visual apparatus). For observing 3D images, when using such systems, in addition to matching the corners of the visibility pyramid with the viewing...
angles of the 3D image modelling system used. To activate accommodation and convergence of the human visual apparatus, the observer must be mobile, or moving objects must be in the frame.

Both considered systems for modelling 3D images are referred to as three-dimensional systems for modelling three-dimensional images. The three-dimensional model is created in the human mind due to the targeted influence of special optics on the human visual apparatus of special images, which are 2D projections of three-dimensional external environment models on the plane of the screen (screens). We are all different, and this is confirmed by the results of our studies, but these features of human vision allow all people to see a 3D image model with sufficient quality to train an eye, but there may be an interval during which a person learns to see a 3D image. When used without spectacle systems, of all researchers, there was one of those who did not see the 3D image at the first moment of time.

In the 20th century, pseudo-volume systems were the main ones in the simulators of the visual environment of flight simulators. Their effectiveness is confirmed by the ability to train pilots in the complex process of visual landing on the runway model, including on the shortened model of the runway deck of the aircraft carrier. Previously, it was believed that the disadvantages without spectacle systems for modelling 3D images are:

- 3D viewing conditions only with a moving observer;
- the distance between the observer’s eye and the nearest visible three-dimensional model is more than 80 meters;
- the effect of observing a three-dimensional model is possible only in complete darkness, since the optical system absorbs a lot of light distance between the observer’s eye and the nearest visible three-dimensional model is more than 80 meters.

Glasses-free 3D model synthesis systems are categorized into two classes: “narrow-pupil” systems and “wide-pupil” systems. In a “narrow-pupil” system there is a limited space (figure 4), where the eyes of the observer should be, and only one pilot can comfortably observe the 3D model generated by it. In a “wide-pupil” system, the 3D model observation zone covers the area of a wide-body aircraft cabin (figure 2). In a “narrow-pupil” system, the observer’s head is placed within the observation area of the 3D image (figure 5). A single glasses-free indicator simulates for an observer a 3D model of the external space in the viewing angles of 40° horizontally and 30° vertically. To expand the visual angles, several such indicators are installed (figure 2, figure 5). To give an example, in figure 5 there are 3 indicators that add up to 120° horizontal and 30° vertical visual angles.

In all mentioned 3D image synthesis systems, a trained person can visually assess the distance to the observed objects. All considered systems are pseudo-volume. Unlike the true-volume systems (based on a rotating screen), these systems use a video sequence of 2D projections, and the human visual apparatus builds it up to a 3D model.

Figure 4. Scheme of a “narrow-pupil” pseudo-volume indicator based on a mirror collimator: 1 virtual image screen; 2 intermediate image screen, a TV screen where 2D projections of 3D objects are synthesized; 3 concave spherical mirror; 4 eye of the observer; 5 beam splitter plate.
The following effects were noticed during the analysis of pseudo-3D indicators of the OKU-type produced by NPP or RELLI, ELVIRA, SVETLANA A/15/M produced by Video3 LLC:

- There is a volume of space in which the observer’s eye or eyes see the three-dimensional image of the virtual space models, looking at two-dimensional changeable models which appear on the screen with the intermediate image;
- the image is bright enough to be seen by the observer in the natural light;
- the pseudo-3D image is a little “blurred”, but distinct enough, which does not affect the possibility of using such systems in aviation simulators, in endoscopy towers and in other cases when it is necessary to simulate 3D- images of objects;
- there is a “window wall zone” between the observer and the closest virtual space model, which, based on our experiments, is approximately 8 m, while, according to [1,3] it is at least 80 m.

The analysis of technical solutions proves that there exist good enough solutions to a problem of modelling the 3D-image of the environment model, which can be classified (figure 6). This is the result of the development of aviation simulators as training systems for creating professional piloting skills, when such systems had to synthesize the 3D-image of the runway model at the stage of learning the visual landing of the aircraft.
The pilot flying a real aircraft has to solve flight direction and navigation tasks. At present navigation tasks are solved to the maximum degree only during the flight above the airfield model. For this purpose, nearly all pilot-centred and complex aviation simulators create a recognizable 15×15 km land surface model with the model of the main runway of a particular airfield in the middle. The Canadian company CAE, which has been a world leader in creating aviation simulators, is now developing visual environment simulators which allow theoretical modelling of the 1500×1500 km flight area. In order to solve navigation tasks, we have to solve the problem of creating a model of a real area with the models of levelling objects. This model is called a visualization scene. In the past, the solution of this problem was limited by the insufficient memory capacity and efficiency of the software and hardware which were used for developing computer image generators. These limitations have been overcome. The following problems remain to be solved.

The first one is which requirements the visualization scene must meet. It must have the models of levelling objects $M_j^V$ which can be seen via the visual environment imitator of any type and, if necessary, the pilots must solve all the navigation tasks using them.

$$P_i^V = \sum_{j=1}^{N_j} I^V(M_j^V),$$

where $P_i^V$ is the place of the aircraft model in the environment model, determined by the pilot during the flight on the aviation simulator using the visual situation imitator.

$I^V(M_j^V)$ – information about the position of the aircraft model in the environment model obtained by the pilot when aiming the aircraft model by the visually observable $j$-th model $M_j^V$ through the cockpit window of the aviation simulator.

Figure 6. The classification of indicator systems simulating non-2D images (the systems used in building aviation simulators are in bold type).
\( N^v_t \) – the number of levelling objects, which at the time moment \( t \), are seen in the visual situation imitator.

The second one – the navigation tasks when flying a real aircraft can be solved not only while watching the levelling objects through the cockpit window, but also while watching the levelling objects through thermal scope \( M^q_j \) and radio locator \( M^r_j \).

\[
P^q_t = \sum_{j=1}^{N^q_t} I^q \left( M^q_j \right),
\]

(2)

where \( P^q_t \) is the position of the aircraft model in the environment model, determined by the pilot when using the aviation simulator based on the information from the thermal scope imitator,

\( I^q \left( M^q_j \right) \) is the information about the position of the aircraft model in the environment model, obtained by the pilot when aiming the aircraft model by the visually observable \( j \)-th model \( M^q_j \) on the screen of the thermal scope imitator;

\( N^q_t \) is the number of levelling objects, which at time moment \( t \), are seen through the thermal scope imitator.

\[
P^r_t = \sum_{j=1}^{N^r_t} I^r \left( M^r_j \right),
\]

(3)

where \( P^r_t \) is the position of the aircraft model in the environment model, determined by the pilot when using the aviation simulator based on the information from the radio locator imitator,

\( I^r \left( M^r_j \right) \) is the information about the position of the aircraft model in the environment model, obtained by the pilot when aiming the aircraft model by the visually observable \( j \)-th model \( M^r_j \) on the screen of the radio locator imitator;

\( N^r_t \) is the number of levelling objects, which at time moment \( t \), are seen through the radio locator imitator.

The third navigation task can be solved using the radio-technical facilities of air navigation (radio compass, radio station of short radar navigation, etc.)

\[
P^k_t = F_k \left( I_k \right),
\]

(4)

where \( P^k_t \) – is the position of the aircraft model in the environment model, determined by the pilot when using the aviation simulator based on the information \( F_k \left( I_k \right) \) from the \( k \)-th imitator of the radio locator.

When developing different aviation simulators of the environment model with the possibility of a pilot’s solving navigation tasks: the visual environment imitator, the thermal scope imitator and the radio locator imitator, three visualization scenes are developed. The visualization scene for the visual environment imitator. The visualization scene for the thermal scope imitator. The visualization scene for the radio locator imitator. Bearing in mind the facts that during a flight a pilot obtains up 90% of information through the visual analyser and that it is impossible to create a complete model – when developing visualization scenes we must remember that the number of models of levelling objects, placed in the corresponding scenes are a subset of real objects in the geographical area selected as the visualization scene prototype. In this case allowance must be made for the fact that the number of models of levelling objects in the whole visualization scene must be enough for solving navigation tasks:

\[
N^v_S = \frac{N^v}{S^v},
\]

(5)

\[
N^v_S \geq K^v_S,
\]

(6)
where \( N_s^v \) – the number of models of levelling objects of the visualization scene of the visual environment imitator per unit area;

\( N^v \) – the number of models of levelling objects in the visualization scene of the visual environment imitator;

\( K_s^v \) – the minimal number of models of levelling objects per unit area of the scene of the visual environment imitator allowing navigation tasks to be solved.

\[
N_s^v = \frac{N^v}{S^v}, \quad (7)
\]

\[
N_s^v \geq K_s^v, \quad (8)
\]

where \( N_s^q \) – the number of models of levelling objects of the visualization scene of the thermal scope imitator per unit area;

\( N^q \) – the number of models of levelling objects in the visualization scene of the thermal scope imitator;

\( K_s^q \) – the minimal number of models of levelling objects per unit area of the scene of the thermal scope imitator allowing navigation tasks to be solved.

\[
N_s^q = \frac{N^q}{S^q}, \quad (9)
\]

\[
N_s^q \geq K_s^q, \quad (10)
\]

where \( N_s^r \) – the number of models of levelling objects of the visualization scene of the radio locator imitator per unit area;

\( N^r \) – the number of models of levelling objects in the visualization scene of the radio locator imitator;

\( K_s^r \) – the minimal number of models of levelling objects per unit area of the scene of the radio locator imitator, allowing navigation tasks to be solved.

As it was shown above, the visual environment imitator gives the maximum amount of information to a pilot training on the aviation simulator: besides determining the location of the levelling point in the environment model and solving navigation tasks simultaneously, this imitator allows improving the skill of judging by eye. Therefore, when developing visualization scenes for the thermal scope imitator and for the radio locator imitator the visualization scene for the visual environment imitator is used as a basis, or

\[
N_s^v \supset N_s^q, \quad (11)
\]

\[
N_s^v \supset N_s^r. \quad (12)
\]

3. Conclusion

1. Optical-software-hardware systems of modern imitators of environment models synthesized for the aviation simulator allow solving the task of the synthesis of a recognizable area of land up to 1500×1500 km. Possible number of a number of models of levelling objects allowing are solved navigation tasks and determine visually the distance to the selected models of levelling objects.

2. In order to upgrade pilot-centred and aviation simulators by including training situations connected with solving navigation tasks it is necessary to develop visualization scenes for visual situation imitators, the thermal scope imitator and the radio locator imitator. In this case, all the models of levelling objects in the visualization scene for the thermal scope imitator are a subset of models of models objects of the visualization scene of the visual environment imitator. All the models of levelling objects in the visualization scene for the radio locator imitator are a subset of the models of levelling objects of the visualization scene for the visual environment imitator.
References

[1] Roganov V R, Miheev M Y, Roganova E V, Bolat A, Nurgozhin I and Fillipenko V 2017 Main provisions for formation of cognitive model of visually observable environment synthesized for aircraft simulator Advances in Eng. Research, Act. Issues of Mech. Eng. (AIME 2017) (Published by Atlantis Press) pp 671–676

[2] Design of optical systems 1983 ed R Shannon (Moscow: Mir) p 430

[3] Roganov V R, Miheev M Y, Roganova E V, Grintsova O and Lavendels J 2018 Modernisation of Endoscopic Equipment Using 3D Indicator in Applied Computer Systems pp 75–80

[4] Training systems 1981 ed Shukshunov V E (Moscow: Engineering) p 256

[5] https://yandex.ru/images/search?text=aviatsionn%20тренажёр%20картинки&stype=image&lr=49&source=wiz&pos=4&img_url=https%3A%2F%2Fpbs.twimg.com%2Fmedia%2FECF29lMWkAA9brR.jpg%3Alarge&rpt=simage (date of the application 02.04.2020).

[6] Roganov V R, Miheev M Y, Asmolova E A and Zhashkova T V 2016 Visual simulators for training simulators for vehicle drivers Proceeding of the soft Int. Symp. Reliability and Quality pp 326-328

[7] Modeling in the training of flight personnel of civil aviation 1992 (Results of science and technology. Ser. air transp. VINITI) 25 p 136