

# Computer Simulation of Video Surveillance Complexes in Virtual Environment Systems

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## **Abstract**

The paper describes methods and approaches for imitation of controlled video surveillance complexes in three-dimensional virtual environment systems. Proposed solutions include principles of creating virtual models of observation and image display devices in 3D modeling system Autodesk 3ds Max, methods for operation simulation of a real camera and screen, as well as surveillance system control by means of three-dimensional virtual control panel. To ensure that the hands of real operator immersed in virtual environment can interact with elements of such control panel, a pair of Oculus Touch controllers is used. Operation logic of the control panel is implemented by means of functional scheme technology. Visualization of virtual environment and images displayed on screens of simulated video surveillance systems is performed in real-time by using modern multicore graphics processors. Software modules were created based on developed methods and approaches. Approbation of them was carried out in virtual environment system VirSim and showed adequacy and effectiveness of proposed solutions for simulation of video surveillance complexes in virtual environment systems and training complexes.

**Keywords:** visualization, virtual environment, three-dimensional model, camera, screen, control scheme, virtual object, material.

## **1. Introduction**

Virtual environment systems have become widespread in many areas of human activity from computer games industry to the tasks of training qualified specialists [1-4]. In these systems, a person is immersed in virtual environment by means of VR headset, where virtual models replace the surrounding real objects. In modern life, an important role is played by such objects as the means of recording and displaying video signal on events occurring in some place, which are combined into video surveillance complexes. For example, they are present in cars to control blind spots by the driver, in unmanned aerial vehicles for manual control of flight trajectory and territory survey, in spacecraft to ensure the processes of docking with the International Space Station and landing on planetary surfaces. Therefore, the development of effective methods and approaches for simulation of video surveillance complexes in virtual environment systems is an important and actual task.

Active research is being carried out in the field of creation and development of technologies for virtual modeling of video surveillance systems and their elements. The main directions of such a research are implementation of virtual observation devices taking into account parameters of their real prototypes, and processing images from virtual cameras based on computer vision technologies. For example, articles [5-7] describe methods and approaches to modeling video cameras in virtual environment in the part of rendering images, which are obtained by means of virtual devices, with imitation of real device characteristics. The authors of paper [8] consider the task of implementing a network of virtual cameras with automatic control in three-dimensional scenes, which provides the ability to track moving objects

within field of view of these cameras. Despite good elaboration level of many important aspects in the area under consideration, insufficient attention is paid to the task of complex modeling of video surveillance systems in virtual environment, which includes implementation of virtual devices for observation and displaying, as well as their control by an operator immersed in virtual space.

This paper proposes methods and approaches for video surveillance complex simulation in virtual environment systems, including creation of basic element models of such complexes in modeling system of 3D virtual scenes. The novelty of developed solutions is implementation of new texture map type needed to create models of display devices in virtual environment. Such textures make it possible to use any virtual object or its part as a screen that shows images from one of the scene's virtual cameras. In addition, original approach is used to control elements of video surveillance system models, based on functional schemes and three-dimensional virtual control panels.

## 2. Creating basic elements of video surveillance system in 3D scene

To ensure the possibility of designing video surveillance complexes in three-dimensional virtual environment, this paper proposes a technology based on integration of own software module (plugin) into the Autodesk 3ds Max modeling system. This module allows implementing the most important elements of such complexes, namely virtual models of observation devices and display devices with their characteristic physical and optical properties. The plugin creation is carried out by means of built-in scripting language for 3ds Max.

Virtual model of observation device (video camera) in three-dimensional scene includes geometric model and virtual camera object. Geometric model is a set of textured triangle polygons that creates a visual representation of the device. It usually copies some real prototype and can be implemented using standard tools of 3ds Max. Virtual camera is used for rendering scene images seen by simulated device, and is hierarchically linked with geometric model, being its child node. Standard camera object in 3ds Max has a limited number of parameters and does not cover the necessary set of physical and optical properties required to simulate real device. Developed plugin adds new object "Physical camera" to the modeling system. Along with the basic properties, this virtual camera allows to set such parameters as physical size of device's matrix, the focal length of a lens, diaphragm, and servo autofocus. Rollout of settings for the Physical camera object is illustrated on the left side of Figure 1.

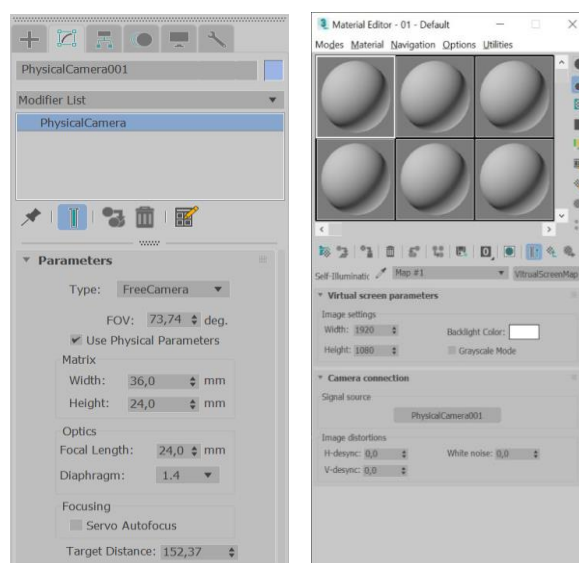


Fig. 1. Rollouts of settings for new virtual camera with physical parameters (left) and new "Virtual screen" texture map (right) in 3ds Max.

Visual representation of display device model (screen, monitor, etc.) is also based on polygonal geometry with using materials and textures. To superimpose images of the scene obtained by virtual camera on the required area of such model, this paper proposes new type of texture map which we called "*Virtual screen*". The right side of Figure 1 shows settings rollout for such texture, which includes two blocks, namely parameters of simulated screen and parameters of connection to observation device. The first block allows selecting resolution of displayed images in pixels, adjusting backlight intensity for R, G, B color channels of virtual screen's pixels, and setting display mode to grayscale or full color. The main parameter of the second block is *Signal source*, which defines one of the scene's virtual cameras as the image source for considered texture map. In fact, it establishes a link between observation and display devices. In addition, it is possible to simulate signal distortions that may occur in electronic systems of real devices and in information transfer channels between them. This is provided by using special coefficients of synchronization failure (horizontal and vertical desync) and the amount of so-called white noise. Proposed approach to the implementation of display device models based on the Virtual screen texture makes it possible for them to use an image output area with an arbitrary geometric shape.

### 3. Rendering images for virtual screen

One of the main tasks solved in the proposed approach to simulation of video surveillance systems is implementation of new texture map type "Virtual screen" in the visualization system of three-dimensional scenes, taking into account the parameters of virtual camera linked to this map. To solve it, every time before rendering the main frame, it is necessary to perform a pre-processing stage, which consists in synthesizing an image for each texture of the Virtual screen type used in the scene. Figure 2 shows a diagram of such process.

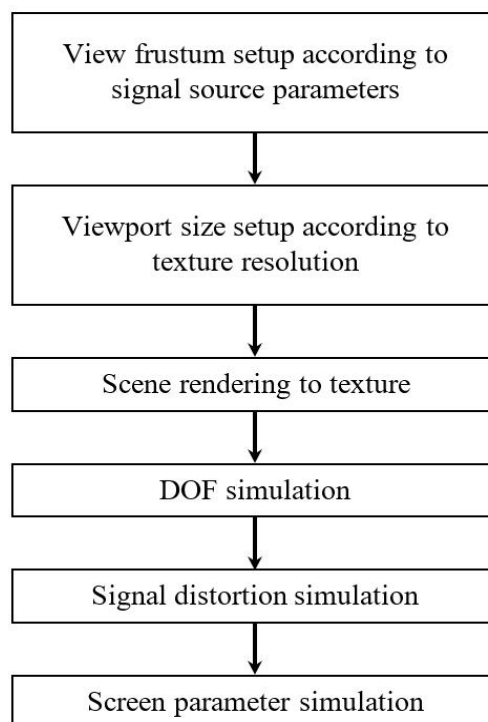


Fig. 2. Image synthesis diagram for the Virtual screen texture.

At first, we determine the view frustum based on the focal length and matrix size of virtual camera of the Physical camera type, which is linked to considered texture. Width and height values (in pixels) that are specified in parameters of the texture are set as viewport size. Next, graphics processor (GPU) performs 3D scene rendering, during which visualization system writes result color and depth of each pixel not to the frame buffer and z-buffer,

but to intermediate textures using off-screen buffer technology (FBO). These textures are passed to an input of special shader for depth of field simulation (DOF) on GPU. To implement the DOF effect, the shader uses special algorithm [9] of blurring the incoming color texture by means of Gaussian filter in accordance with current parameters of virtual camera (focal length, diaphragm and focus distance). Resulting image is also saved in intermediate texture used at the stage of signal distortion simulation.

Distortion simulation shader is only executed if desync coefficients or white noise value for considered Virtual screen texture are non-zero. White noise imitation is performed by means of grayscale noise map whose texture coordinates are computed using pseudo-random numbers. Synchronization failure is simulated by rendering a quad strip (a chain of connected quads) that consists of identical horizontal quads covering the entire area of output image buffer. Input texture with undistorted image is mapped on this quad strip. Texture coordinates of each pair of the strip vertices lying on the same horizontal line are shifted to the left or right by an offset value depended on pseudo-random number and horizontal desync coefficient. In addition, texture coordinates for all vertices of the strip are simultaneously shifted up or down by the same offset value depended on pseudo-random number and vertical desync coefficient. The stage result of signal distortion simulation is also an intermediate texture.

At the final stage, we perform GPU-accelerated simulation of such settings of the Virtual screen texture as grayscale mode and screen backlight color. In this work, two above-mentioned settings are considered mutually exclusive. Therefore, RGB color correction is implemented only for full color mode according to the following formula:

$$C_{\text{corr}} = (k_R C_{\text{src},R}, k_G C_{\text{src},G}, k_B C_{\text{src},B}), \quad (1)$$

where  $C_{\text{src}}$ ,  $C_{\text{corr}}$  – source and corrected pixel colors of image for virtual screen,  $k$  – screen backlight color specified in Backlight Color field of the Virtual screen map's parameters.

Mapping synthesized textures to objects during the main rendering of virtual scene is performed similarly to self-illumination textures. Fragment shader adds to intensity  $I$ , computed for each processed object fragment, a color  $C_{\text{vsrc}}$  of the corresponding pixel from the texture map:

$$I_{\text{res}} = I + C_{\text{vsrc}}. \quad (2)$$

## 4. Control of video surveillance system

In addition to implementing models of video surveillance complexes in virtual environment, this paper considers the task of such model control by hands of an operator immersed in virtual space. Proposed solution is based on two key elements: virtual observer and 3D virtual control panel.

Virtual observer is a combination of two virtual cameras and models of human hands. The cameras are the operator's eyes in virtual environment. Images of three-dimensional scene rendered with them are displayed in real eyes of a person using Oculus Rift VR headset. Positions and orientations of the cameras are computed based on position and orientation of the operator's head, which come from sensors of the headset. To implement an impact of the observer on scene objects, realistic virtual models of hands were created (Figure 3), which are controlled by a pair of Oculus Touch controllers. The models copy movements of the operator's hands and provide the possibility of bending and unbending virtual fingers. Apart from polygonal geometry, virtual hands include invisible volumes (boxes, spheres, cylinders, etc.) bounding it. Impacts on objects of the scene is modeled by detection and response of collisions between bounding volumes of hand models and bounding volumes of these objects.



Fig. 3. An example of 3D virtual models of hands and control panel.

3D virtual control panel (Figure 3) consists of polygonal model, bounding volumes, models of element actuation sensors, as well as functional scheme. The scheme has inputs, logic elements, function blocks, communication lines and outputs. The inputs are connected to the sensors, and the outputs are connected to controlled scene objects. When fingers of virtual hand impact on elements of the control panel (for example, pressing buttons), the sensors generate non-zero signals at the corresponding inputs of the scheme. Before rendering each frame, control signals at the outputs of the scheme are computed in accordance with signals at its inputs. Formed signals provide the ability to control parameters of virtual observation devices (focal length, diaphragm, focus mode, view direction, etc.) and virtual display devices (signal source, screen backlight color, etc.).

## 5. Results

Methods and approaches for simulation of video surveillance complexes proposed in this paper were implemented in our virtual environment system VirSim [10] developed at the SRISA RAS. Plugin for the Autodesk 3ds Max modeling system was also created, which allows using virtual cameras with physical parameters, and textures of the Virtual screen type when creating three-dimensional scenes.

Testing of developed solutions was carried out using a scene of the virtual polygon, which includes about six hundred thousand textured triangles. For this, virtual models of observation devices (three copies), display device, and control panel were placed in the scene (Figure 4). CCTV camera is used as observation device prototype. Its model consists of polygonal geometry, virtual camera object of the Physical camera type, and two joints with electric motors (Figure 5). The latter provide the ability to change the yaw and pitch angles of the device in order to select needed direction  $\mathbf{V}$  of camera view. Table 1 presents parameters of simulated observation devices.



Fig. 4. Model of video surveillance complex in the scene of virtual polygon, including three cameras, display and control panel.

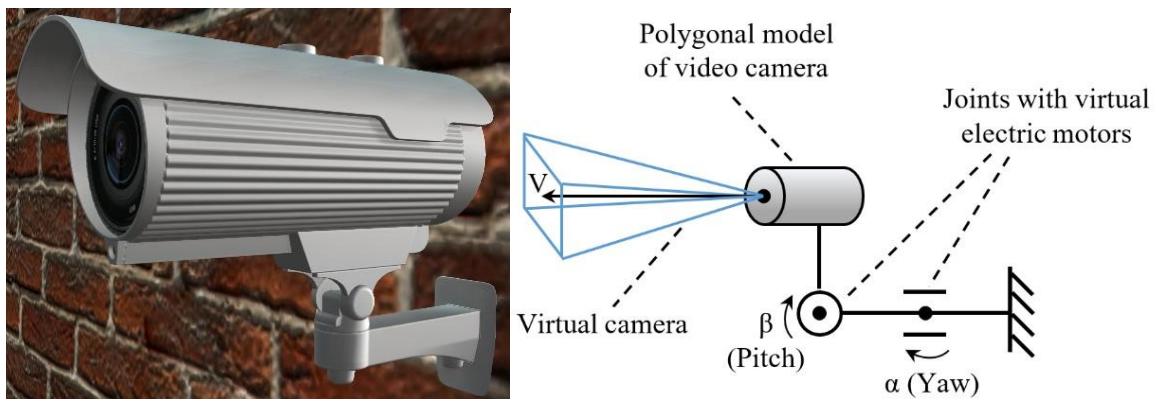


Fig. 5. 3D virtual model and structure scheme of virtual observation device.

Virtual display device is a model of ordinary monitor. Its screen plane is textured using a map of the Virtual screen type, initially linked (in modeling system) with the first observation device. Signal source selection, as well as changing of other texture parameters, can be performed directly during the operation of virtual environment system.

Table 1. Parameters of virtual observation devices.

Device number	Matrix size	Focal length	Diaphragm	Yaw angle	Pitch angle
1			1/5.6		
2	36 x 24 mm	20-200 mm	1/8	-70° ... 70°	-45° ... 45°
3			1/2.8		

Developed three-dimensional virtual control panel for video surveillance complex contains 11 buttons. Three of them allow selecting one of the available virtual observation devices as the signal source. The remaining buttons control selected device and perform the following functions: increase and decrease the yaw and pitch angles, increase and decrease the focal length of a lens, perform autofocus, turn on or off servo autofocus mode. To implement the operation of this control panel, functional scheme illustrated in Figure 6 was created. *Button coder* block included in the scheme computes and stores the code (from 0 to 2) of last

pressed signal source button. This code is transmitted to control inputs of demultiplexers, which switch signals of control panel buttons to elements associated with selected observation device. The task of *Camera control* blocks is to recompute values of the focal length and orientation angles of the device when corresponding buttons on the control panel are pressed. Computing voltages supplied to electric motors *ENGINE\_YAW* and *ENGINE\_PITCH* (placed in the joints of observation device models) is carried out using PD controllers.

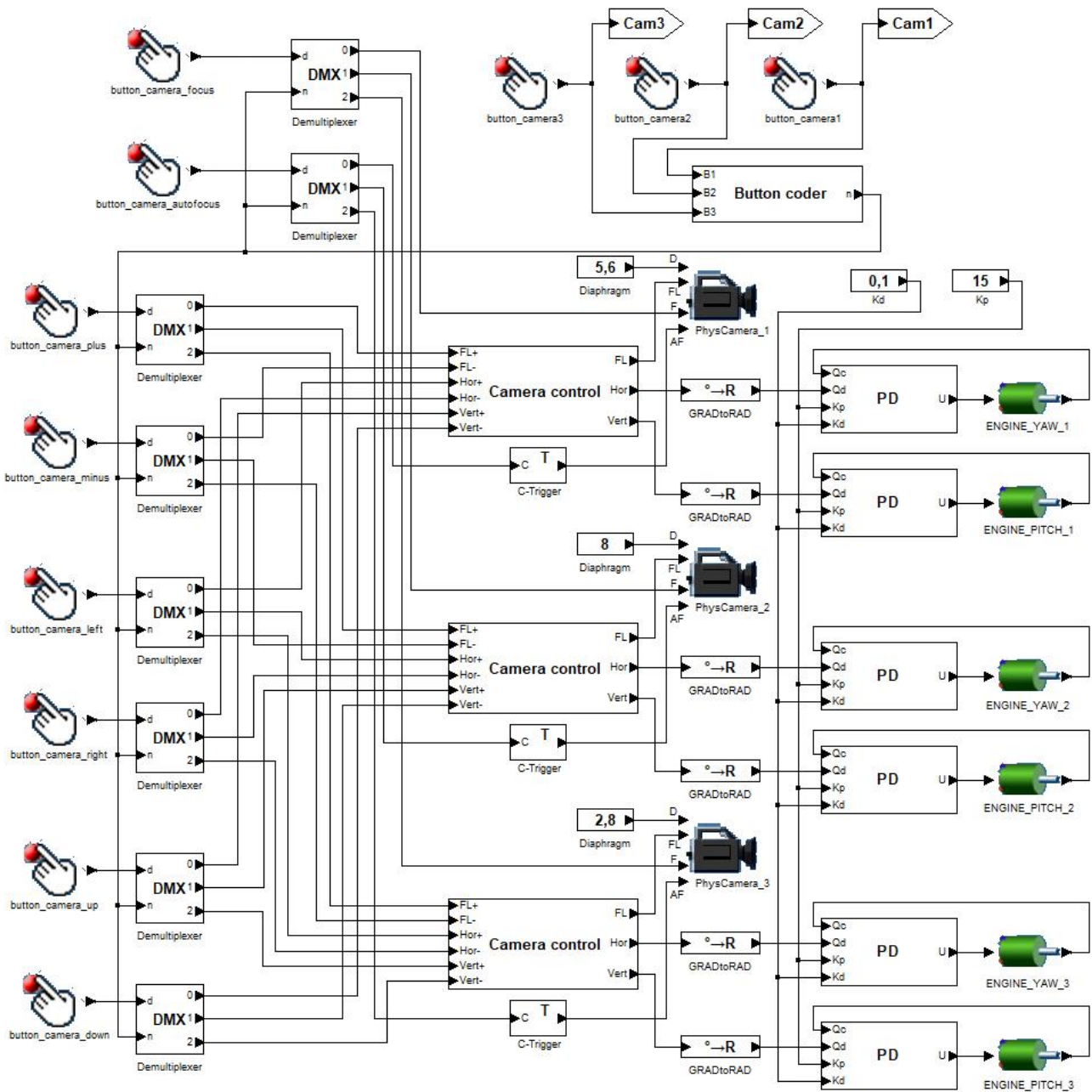


Fig. 6. Functional scheme for control of video surveillance complex.

Figure 7 shows how the operator, immersed in the scene of virtual polygon using Oculus Rift headset, presses buttons of the control panel by means of virtual hand models. Virtual hands copy the operator's real hand motion due to Oculus Touch controllers.



Fig. 7. Virtual surveillance complex control using Oculus Touch.

Approbation results of proposed methods and approaches in the VirSim software complex showed that they make it possible to effectively implement virtual models of video surveillance complexes in virtual environment systems, training complexes and other applications.

## 6. Conclusions

This paper presents original methods for implementing models of video surveillance complexes in a virtual environment. The advantage of proposed solutions is an integrated approach to simulation of such complexes, including their creation in a three-dimensional scene, synthesis of video streams from observation device models and visualization on display device models, as well as control of system elements using virtual reality technologies. Results obtained in the paper can be used in software development for training complexes and virtual environment systems.

## 7. Acknowledgements

The publication is made within the state task of Federal State Institution “Scientific Research Institute for System Analysis of the Russian Academy of Sciences” on “Carrying out basic scientific researches (47 GP)” on topic No. FNEF-2022-0012 “Virtual environment systems: technologies, methods and algorithms of mathematical modeling and visualization. 0580-2022-0012”.



## References

1. Garcia A.D., Schlueter J., Paddock E. Training astronauts using hardware-in-the-loop simulations and virtual reality // AIAA SciTech Forum, Orlando, FL, 2020.
2. Bruguera M.B., Ilk V., Ruber S., Ewald R. Use of virtual reality for astronaut training in future space missions – spacecraft piloting for the Lunar Orbital Platform – Gateway (LOP-G) // 70th International Astronautics Congress, Washington D.C., 2019.
3. VR trenazher. Virtualnaia realnost v obuchenii. Neftianaia promyshlennost [VR simulator. Virtual reality in learning. Oil industry]. <https://www.youtube.com/watch?v=keXlfMKyxsI>. Accessed 25 April 2022. [in Russian]
4. VR-trenazher. Deistviia pri pozhare [VR Fire Safety Training]. <https://www.youtube.com/watch?v=cm9vFeB18X8>. Accessed 25 April 2022. [in Russian]
5. Bisagno N., Conci N. Virtual camera modeling for multi-view simulation of surveillance scenes // 26th European Signal Processing Conference (EUSIPCO), 2018, pp. 2170-2174.
6. Kučič M., Zemčík P. Simulation of Camera Features // Proceedings of the 16th Central European Seminar on Computer Graphics, 2012, pp. 117-123.
7. Barsky B.A., Horn D.R., Klein S.A., Pang J.A., Yu M. Camera models and optical systems used in computer graphics: part I, object-based techniques // Proceedings of the 2003 international conference on Computational science and its applications, 2003, pp. 246-255.
8. Qureshi F.Z., Terzopoulos D. Surveillance in virtual reality: System design and multi-camera control // Conference on Computer Vision and Pattern Recognition, 2007, pp. 1-8.
9. Maltsev A.V., Torgashev M.A. Raspredelennoe modelirovanie glubiny rezkosti pri vizualizatsii trekhmernykh stsen na GPU [Distributed simulation of DOF when rendering virtual scenes on GPU] // Trudy NIISI RAN, Vol. 9, No. 5, 2019, pp. 100-104 [in Russian].
10. Mihaylyuk M.V., Maltsev A.V., Timokhin P.Ju., Strashnov E.V., Krjuchkov B.I., Usov V.M. Sistema virtual'nogo okruzenija VirSim dlja imitacionno-trenazhernykh kompleksov podgotovki kosmonavtov [The VirSim virtual environment system for the simulation complexes of cosmonaut training] // Pilotiruemye polety v kosmos, Vol. 4, No. 37, 2020, pp. 72-95 [in Russian].