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Three dimensional visualization of models and physical characteristics of oil and gas reservoir for virtual reality systems

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The paper describes three-dimensional visualization of grid models of oil and gas reservoir for virtual reality systems. It was implemented in a C ++ programming language, for visualization of the model using the OpenGL library and in the virtual environment of the OpenVR library, which needs use of the SteamVR utility. Created module of visualization requires connection of special equipment for operations with the virtual environment, such as headset with its own display, base stations and controllers. As input data for drawing of model geometrical data and physical characteristics of oil field in .GRDECL format provided by Shchlumberger Eclipse are offered. Files of this format store data describing three-dimensional models consisting of $N_x \times N_y \times N_z$ of cells on Ox, Oy and Oz, which represent the distorted parallelepipeds. The advantage of using virtual reality in visualization is that for the observer visual perceptions considerably improves, and immersion in a virtual environment is accompanied by the effect of presence. In the VR display the quality of drawing of an object significantly differs from what can be watched on a flat screen monitor.

Key words: computer graphics, computer animation, machine graphics, virtual reality, OpenGL, OpenVR, shader, visualization, grid model visualization.

Трехмерная визуализация модели и физических характеристик нефтегазового пласта для систем виртуальной реальности

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В работе описаны основные действия для трехмерной визуализаций сеточных моделей нефтяных и газовых месторождений для систем виртуальной реальности. Работа была реализована на языке программирования C ++, для визуализации модели была использована библиотека OpenGL и для визуализации модели в виртуальной среде использовалась библиотека OpenVR в дополнении с программой SteamVR. Созданный модуль визуализации требует подключения специальных оборудований для работы с виртуальной средой, таких как шлем виртуальной реальности, базовые станции и контроллеры. В качестве входных данных для прорисовки модели предложены геометрические данные и физические характеристики модели в формате .GRDECL. Данный формат создан фирмой Shchlumberge

Eclipse и используется для описания моделирования нефтяного месторождения. Файлы такого формата хранят данные описывающие трехмерные модели, состоящие из $N_x \times N_y \times N_z$ ячеек по Ox, Oy и Oz, которые представляют собой искаженные параллелепипеды. Преимущество применения виртуальной реальности при визуализации состоит в том, что для наблюдателя визуальное восприятия значительно улучшается, также погружение в виртуальную среду сопровождается эффектом присутствия. В виртуальных очках качество прорисовки объекта существенно отличается от того, что можно наблюдать на плоском экране монитора.

Ключевые слова: компьютерная графика, компьютерная анимация, машинная графика, виртуальная реальность, OpenGL, OpenVR, шейдер, визуализация, визуализация сеточной модели.

Виртуалды шындық жүйелеріне арналған мұнай және газ қабатының моделін және физикалық сипаттамаларын үш өлшемді визуализациялау

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Мақалада виртуалды шындық жүйесінде мұнай және газ қабаты моделінің торлы үлгілерін үш өлшемді визуализациялаудың негізгі әрекеттері сипатталады. Жұмыс C ++ бағдарламалау тілінде іске асырылды, модельді бейнелеу үшін OpenGL кітапханасы және виртуалды ортада модельді визуализациялау үшін OpenVR кітапханасы және қосымша SteamVR бағдарламасы пайдаланылды. құрылған визуализация модулі виртуалды ортада жұмыс істеу үшін виртуалды шындық көзәйнегі, базалық станциялар және контроллерлер секілді арнайы жабдықтарды қосуды талап етеді. Модельді визуализациялау үшін қолданылатын деректер ретінде .GRDECL форматындағы геометриялық деректер және модельдің физикалық сипаттамалары ұсынылады. Schlumberge Eclipse фирмасымен құрылған .GRDECL форматы мұнай кен орнының моделін сипаттау үшін қолданылады. Бұл форматтағы файлдар Ox, Oy және Oz бойында $N_x \times N_y \times N_z$ ұяшықтарынан тұратын үш өлшемді модельді сипаттайтын деректерді сақтайды. Виртуалды шындықты пайдаланудың артықшылығы – бақылаушының көрнекті қабылдауы айтарлықтай жақсарады және бақылаушы өзге виртуалды ортада қатысу әсеріне ие болады. Виртуалды шындық көзәйнегінде объектіні сызу сапасы тегіс экранды монитордағы бейнелеуден айтарлықтай ерекшеленеді.

Түйін сөздер: компьютерлік графика, компьютерлік анимация, машиналық графика, виртуалды шындық, OpenGL, OpenVR, шейдер, визуализация, торлы модельдің визуализациясы.

1 Introduction

Visualization is an integral part of science, which represents evident display of big arrays of numerical and other information, which is an obviously possible thanks to computer graphics. Currently, the computer graphics has a wide application, both in scientific activities and in everyday life. In scientific activities the computer graphics helps to build the virtual three-dimensional objects for the analysis of simulation results, presentation of work, etc. And also this branch found the application in a pattern of computer games, for creating animated films and special effects for movies.

There visualization in a format of the virtual reality, which demonstrates projects in head mounted display (HMD) or in special rooms of virtual reality, is described. Today the virtual reality founds the application in many spheres. For example, in science the virtual reality allows to plunge into the environment and in details to research different models. In architecture the virtual environment considerably reduces expenses by replacing construction of expensive products with an illustration of the virtual model, which also allows to research a product and even to test different technical characteristics. The virtual environment, created for trainings and preliminary training in spheres of education: piloting, driving or for military tests, considerably reduces risk of different injuries and unnecessary expenses. Also, virtual reality has found the application in medicine.

Virtual reality objects are as close as possible to similar objects in the real world. They have a texture, material, behavior, close to reality, in case of collision with other objects and it can be noted in case of interaction with an object, since in a virtual environment there is the possibility of installing physics.

The paper describes a three-dimensional visualization of oil and gas reservoir model, which is performed using OpenGL [1,2] library and with the known data in a format .GRDECL in virtual reality system using OpenVR [3] library. For this purpose it is necessary to study the geometrical basic data provided in a format .GRDECL and to create the tool to read the following data: the volume, model coordinates, activity of the cells, physical characteristics of model. Then it is necessary to consider the main possibilities of OpenGL library, of shading programming language (GLSL) and to define spheres of their application and draw a three-dimensional model within the developed program with computation on GPU. In conclusion it is necessary to connect HMD, base stations, controllers and to make drawing of oil and gas reservoir model with effect of presence.

2 Literature review

Nowadays there is a research laboratory "The Collaboration Centre which works on solving problems of modeling and visualization [4, 5]. For this purpose the laboratory uses tools to support applications for the virtual and augmented reality, which work at different platforms. These tools include rooms and the head systems of virtual reality, sensor desktops, different systems of tracking, etc. The research laboratory "The Collaboration Centre"works in different directions; scientific programming, visualization, virtual reality consulting, display and smart space consulting, etc.

“TechViz” company also works in the field of virtual reality [6]. The company is engaged in different decisions for 3D – visualization, where the latest technologies are used. Also they are engaged in development of technologies in the field of computer architecture, cluster computing, etc.

The article [7] "A Collaborative Virtual Reality Oil & Gas Workflow"describes the research in oil and gas branch, in particular marine engineering. This research considers the visualization of marine engineering projects with use of the virtual reality technology. Also the specialized web interface was created for users, where they could work jointly with other users, imitating workflow in virtual reality environment. As a result of the research, the authors proposed their own version of the problem solution.

VR is used in many different science fields to improve human interaction with computations [8, 9, 10, 11].

3 Materials and methods

3.1 Input data for three-dimensional visualization of the oil and gas reservoir model and physical characteristics

There is a simulator called ECLIPSE, which is used to create hydrodynamic oil and gas field's models [12]. Source data of ECLIPSE is a plain text file, so they can be read out and used for designated purpose by means of library intended for files. ECLIPSE has two formats of a grid – .GRDECL and .EGRID, where the grid geometry is given in binary format. Format .GRDECL, created by Schlumberge Eclipse, describes modeling of the three-dimensional oil and gas reservoir consisting of $N_x \times N_y \times N_z$ of cells. The advantage of this format is to minimize the volume of the used random access memory.

To draw a grid model the main files with geometrical data, which store arrays called COORD, ZCORN, ACTNUM and an array that stores data about physical characteristics of model - NTG are used.

- The COORD file provides the array of X, Y, Z coordinates of directing vectors for cell's edges. The array of the size $(N_x + 1) \times (N_y + 1) \times 6$ contains $(N_x + 1) \times (N_y + 1)$ of vertical or oblique needles, which in turn have 2 points $(X1, Y1, Z1, X2, Y2, Z2)$. On needles, which are directing vectors, are located the vertices of cells.

- The ZCORN file provides the array Z coordinates of cell's vertices. An array of size $2N_x \times 2N_y \times 2N_z$ contains values of coordinates on an Oz axis of eight peaks of cells.

- The ACTNUM file provides the array that determines the activity of cells. The array of the $N_x \times N_y \times N_z$ size contains values 0 and 1, respectively mean inactivity and activity of cells.

- The fourth file, named according to the title of the physical parameter, provides the array, which defines color of each cell. The array of the $N_x \times N_y \times N_z$ size contains data, which are transformed to values on an interval [0, 1].

The used input data for testing of the developed program were obtained from real fields, such as the model of East Moldabek section of the Kenbay field from JSC KazMunaiGas Exploration Production [13], open data of the project "SAIGUP". Also the test model "Sample" and MATLAB Reservoir Simulation Toolbox Models: Project Data Geological Storage of CO2: Mathematical Modelling and Risk Analysis (MatMoRA) [14] and project data of "Sensitivity Analysis of the Impact of Geological Uncertainties on Production"[15] were used.

3.2 Three-dimensional visualization of model and physical characteristics of oil and gas reservoir by means of OpenGL library and the OpenGL Shading Language

The used OpenGL library [16] is the low level, hardware-independent program interface, which makes visualization [17]. In other words, it is possible to define an object by specifying the corresponding coordinates of all vertices, set color, interact with an object (rotate, reduce, increase, move), determine the location of an object or position of the observer in three-dimensional space. This interface has many sets of functions for defining operations and commands necessary for visualization of three-dimensional objects.

At the time of an application window creation the basic frame buffer is created, that is area of graphic memory. OpenGL was designed as a state machine to update the contents of the frame buffer. In fact, OpenGL is the finite state machine having different statuses. In OpenGL states can be modified by controlling buffers, various options, and then to draw on a certain context.

Using only OpenGL library leads to the fact that all work on a draw of frames is performed by the central processor. Therefore the graphic accelerator was used for implementation of the program, which gives an opportunity to write programs for computation the pixel‘s color on the screen. To use a graphics accelerator, a program called a shader is used. Applying shaders, it is possible to use most effectively all computing power of the modern graphic chips. Shaders are programmed in the C programming language similar GLSL [18] language, which is a high-level programming language.

Each shader must perform its mandatory work, that is, write some data and transfer them further on the graphic pipeline. It is a small program consisting of vertex, fragment and many other shaders and running on the GPU. There are several types of a shader:

- Vertex shader - performs transformation associated with vertex data, such as multiplying vertices and normals by a projection and modeling matrix [19], setting vertex colors, etc. The compulsory work for a vertex shader is to record the vertex position in the built-in variable gl_Position.

- Geometrical shader - a shader that can handle not only one vertex, but also a whole primitive. It can either drop the primitives, or create new ones, that is, the geometry shader is able to generate primitives.

- Fragment shader - processes each received fragment at the previous stages of the graphic pipeline. Processing can include such stages as: obtaining data from a texture, rendering light, mixing miscalculation. Mandatory operation for a fragmentary shader is to record fragment color in the built-in gl_FragColor variable.

All objects in OpenGL are presented in the form of a set of graphic primitives: in the form of points, lines and triangles. With use of these geometrical primitives and the subsequent mathematical processing of basic data, as a result, it is possible to construct difficult screen objects. Therefore for visualization of required model, it is necessary to create the instrument to identify the coordinates of all vertices of triangles.

3.3 Virtual Reality System

Virtual reality (VR) represents the three-dimensional environment generated by means of the computer, where the user can fully or partially immerse into this environment and interact with it. The probable virtual reality supports the user’s sense of the reality of what is happening. VR providing interaction with the environment is called interactive. Also there is computer-generated VR and VR, available to a study, giving an opportunity to research the big detailed world.

Today there are several types of the VR. One of them has effect of complete dipping in probable simulation of the world with a high level of detailing. It uses a high-performance computer capable of recognizing user actions and responding to them in real time.

In addition special equipment connected to the computer is used, which create, output the image and provide an immersive effect in the process of the environment research. During operation HMD, base stations and controllers of the HTC VIVE model were used (fig. 1). For interaction with the virtual reality was used the program interface OpenVR [20]. It was developed for support of SteamVR technology and virtual reality equipment, where SteamVR is the environment for performing virtual reality [21].

Figure 1: Headset - HMD, base station and controller of HTC VIVE

The used HMD consists of two small screens located opposite to each eye to which images for the left and right eye are displayed; the system monitoring orientation of the device in space; the blinders preventing hit of external light. Screens show the stereoscopic images which are slightly offset from each other, providing realistic three-dimensional perception. HMD also contain the built-in accelerometers and position sensors. The most important thing in the system of this type – the accuracy of tracking operation, when tracing turns of the head for correct output of the corresponding image to displays.

There are special devices for interaction with the virtual environment - controllers. They contain the built-in position and motion sensors and also buttons and scrolling wheels, as at a computer mouse. With OpenVR library it is possible to connect controllers for interaction with objects in the virtual space. For convenient use of controllers by developers was entered an object controller, which creates even more realistic effect of presence by drawing the identical controller in the environment. In case of connection of these devices on the screen and HMD it is possible to observe how this object moves to identically real movements of controllers.

The realized program as a result gives three-dimensional model of oil and gas reservoir in virtual reality system (fig. 2 - 3). A cube ($3 \times 3 \times 3$) was chosen as the initial test model.

After visualization, it is possible to add various transformation functions for three-dimensional objects. In graphic programming these functions of interaction are used quite often. They allow examining in detail the drawn object from all sides by moving, increasing or rotating. The idea of this method consists that all transformations are presented in the form of matrixes, where they are multiplied among themselves and then coordinates of vertices are multiplied by a final result. In the program these conversions are carried out in parts of the visualization with use of projection matrixes for the left and right eye, tracking of the position of HMD and controllers. To interact with drawn model it is necessary to use the following formula, where current position of HMD, controllers and a projection of the left

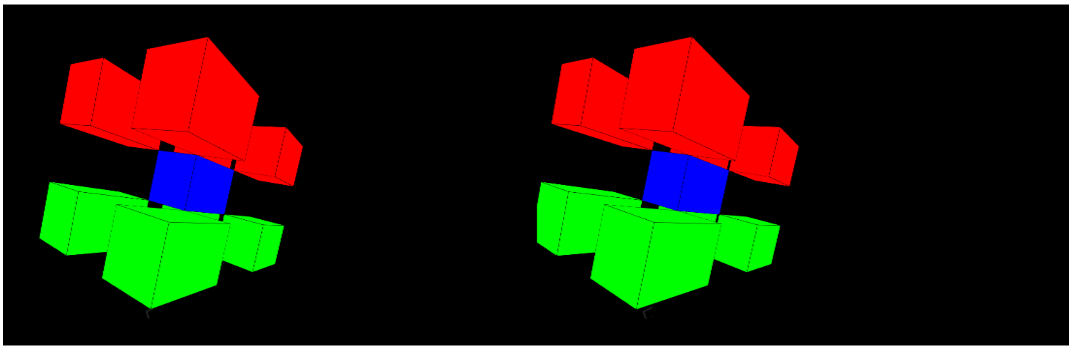

Figure 2: The constructed cube ($3 \times 3 \times 3$) in the virtual reality system. Projection of the image from the virtual reality glasses on the display. The display shows two frame buffers for the left and right eyes with different angular displacement of the image

Figure 3: The constructed cube ($3 \times 3 \times 3$) in the virtual reality system. Example of display of model in the head mounted display

and right eye can be received by means of special functions in OpenVR library.

$$M = Projection \times View \times Model \tag{1}$$

M – transformation matrix; $Projection = GetProjectionMatrix(nEye, nearClip, farClip)$ – projection matrix for specified eye; $View = HMDPosition^{-1}$ – inverse HMD position matrix; $Model = Model_{new}$ – matrix transformer, which is solved using the formula (5). Formula (5) is calculated using a well-known mathematical expression. To obtain a new transformed matrix, the transformer matrix T and the current matrix are used (2, 3).

$$Model_{new} = T \times Model_{old} \tag{2}$$

$$ControllerPosition_{new} = T \times ControllerPosition_{old} \tag{3}$$

$ControllerPosition_{old}$ – current controller position matrix; $ControllerPosition_{new}$ – new controller position matrix. Next, to find an unknown matrix $Model_{new}$, using equation (4), we derive formula (5).

$$T = ControllerPosition_{new} \times ControllerPosition_{old}^{-1} \tag{4}$$

$$Model_{new} = ControllerPosition_{new} \times ControllerPosition_{old}^{-1} \times Model_{old} \tag{5}$$

It is known that for transformation (rotation, displacement, scaling) it is necessary to multiply the resulting matrix by the starting point, where it is changed to the vector (x, y, z, w), adding the new parameter w. If $w = 0$, then this direction, if $w = 1$, then this vector is a position in space (fig. 4).

$$X_{new} = MX_{old} \tag{6}$$

X_{old} – current position vector of the model; X_{new} – new position vector of the model.

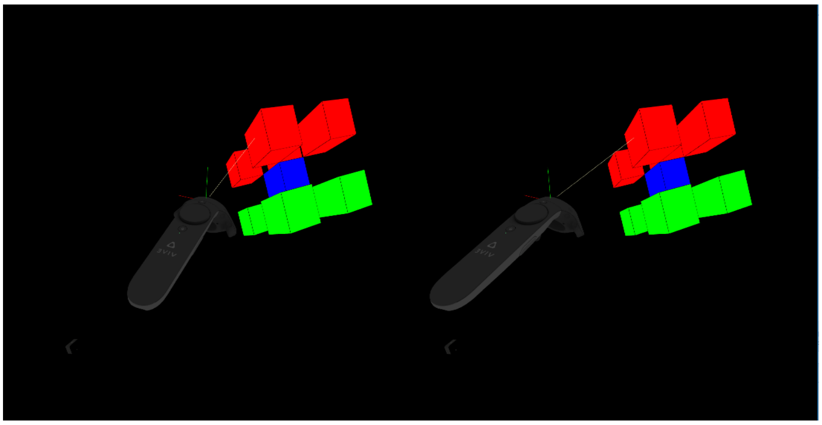

Figure 4: Connection of controllers

4 Results and discussion

For testing of the realized program different reservoir models were used. Figures 5 – 13 provided visualization of models with use of OpenGL in virtual reality system:

- Model of East Moldabek section of the field Kenbay with JSC "KazMunaiGas Exploration Production" (fig. 5 and 6), cell's quantity of complete model –$36 \times 77 \times 33$ [13].
- MATLAB Reservoir Simulation Toolbox. [17] Data of the "Geological Storage of CO2: Mathematical Modelling and Risk Analysis"(MatMoRA) project, cell's quantity of complete model – $100 \times 100 \times 11$ (fig. 7 and 8) and cell's quantity of second complete model – $100 \times 100 \times 21$ (fig. 9) [22].
- Test model of layer – Johansen, cell's quantity of complete model – $149 \times 189 \times 16$ (fig. 10)
- MATLAB Reservoir Simulation Toolbox. Data of the project "Sensitivity Analysis of the Impact of Geological Uncertainties on Production"(fig. 11), cell's quantity of complete model – $40 \times 120 \times 20$ [15].
- Sample models, cell's quantity of complete model – $33 \times 33 \times 11$ (fig. 12) and $67 \times 49 \times 10$ (fig. 11).

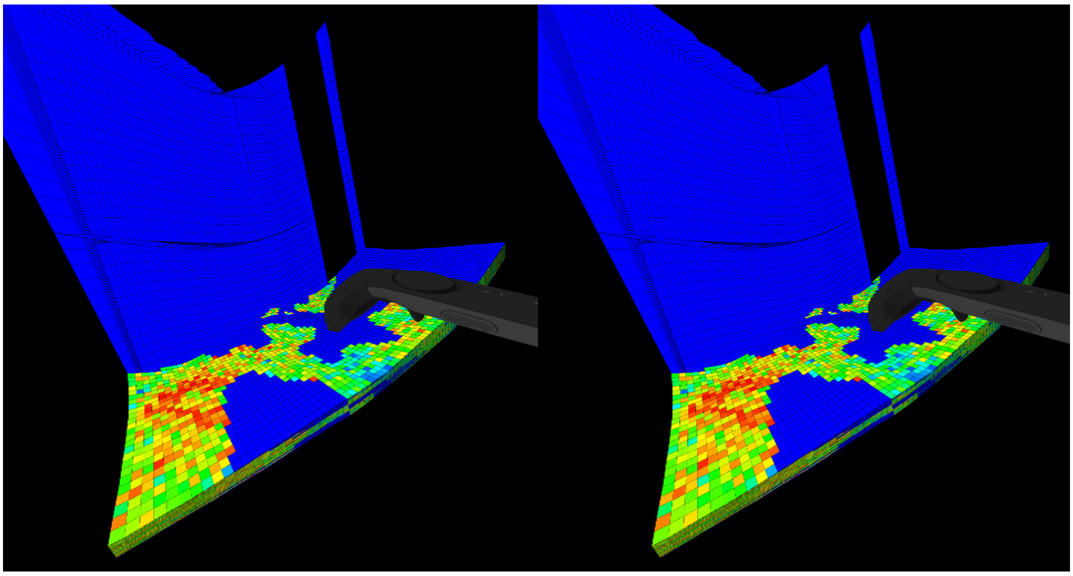

Figure 5: Test model of the field Kenbay, visualized in the virtual reality system

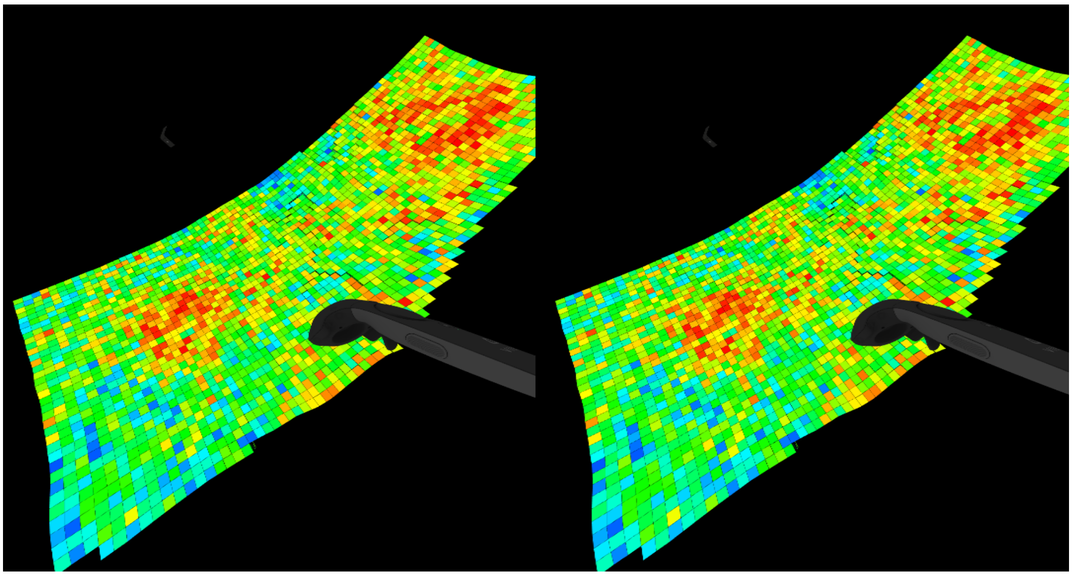

Figure 6: The edited model of the field Kenbay, visualized in the virtual reality system

In these figures, it is possible to watch an image projection from HMD to the monitor screen, where two frame buffers for the left and right eye with an angular displacement of the image are displayed. The figures also show a controller which carries out the control of test models of an oil and gas reservoir.

The developed program uses the graphic accelerator that helps to create more difficult objects, to add different matrixes for interactivity of application, to superimpose operation on GPU, at the same time reducing loading of CPU. However the developed program spends a certain amount of time for reading of large volume of data, with later processing of the

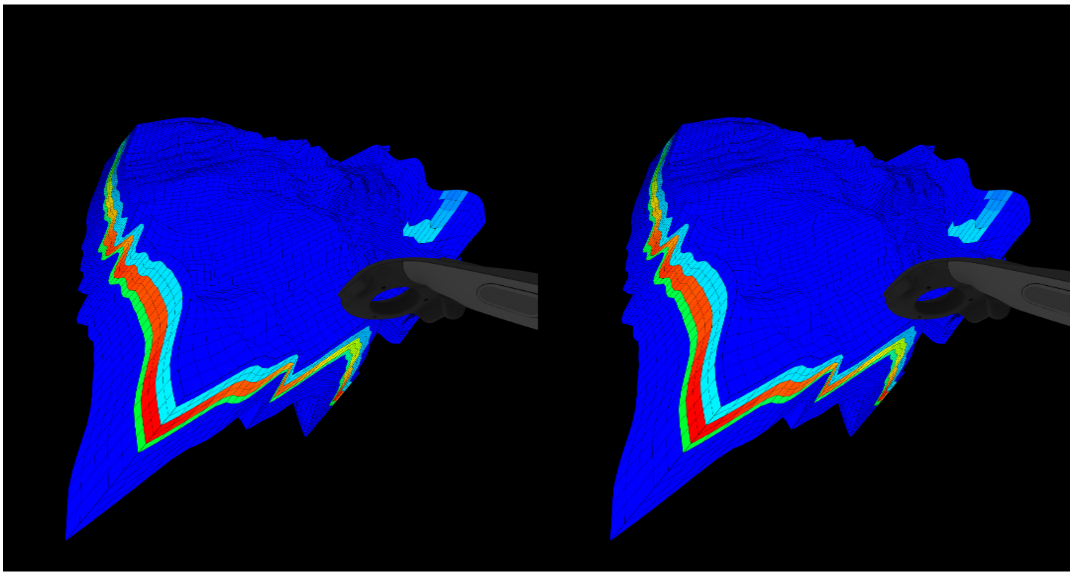

Figure 7: Test model of layer from MATLAB Reservoir Simulation Toolbox, visualized in the virtual reality system

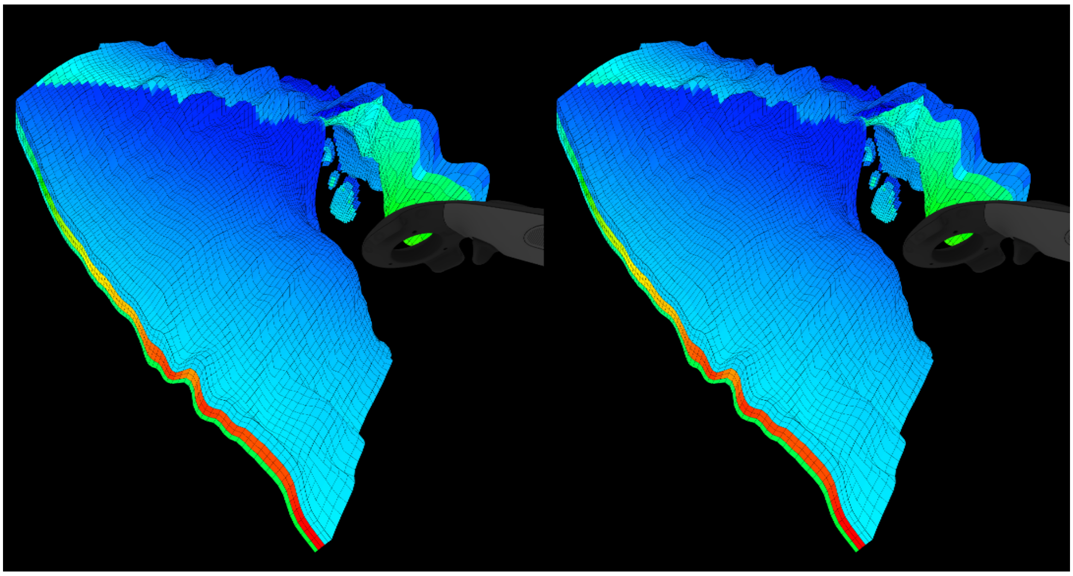

Figure 8: Test model of layer from MATLAB Reservoir Simulation Toolbox, visualized in the virtual reality system

acquired information for loading in the buffer, which means that this part of work is performed by the central processor.

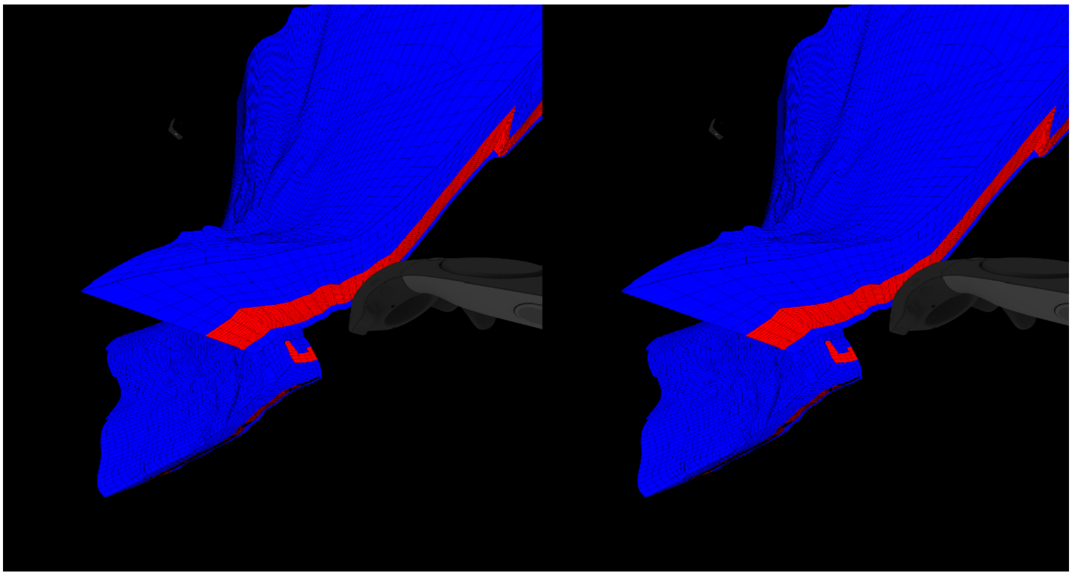

Figure 9: Test model of layer from MATLAB Reservoir Simulation Toolbox, visualized in the virtual reality system

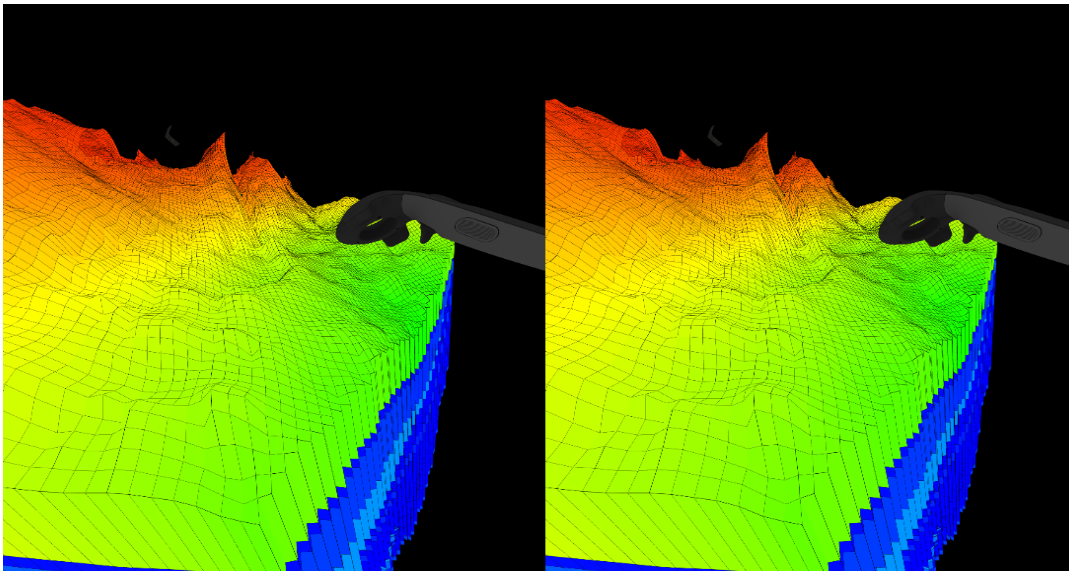

Figure 10: Test model of layer Johansen, visualized in the virtual reality system

5 Conclusion

The paper describes the main actions for developing an application, which represents three-dimensional grid model of oil and gas reservoir on VR headset, with necessary use of the appropriate equipment. The advantage of using virtual reality consists in improving of visual acceptability and dipping in the virtual environment with effect of presence. In VR headset display the quality of drawing of an object significantly differs from what can be watched on

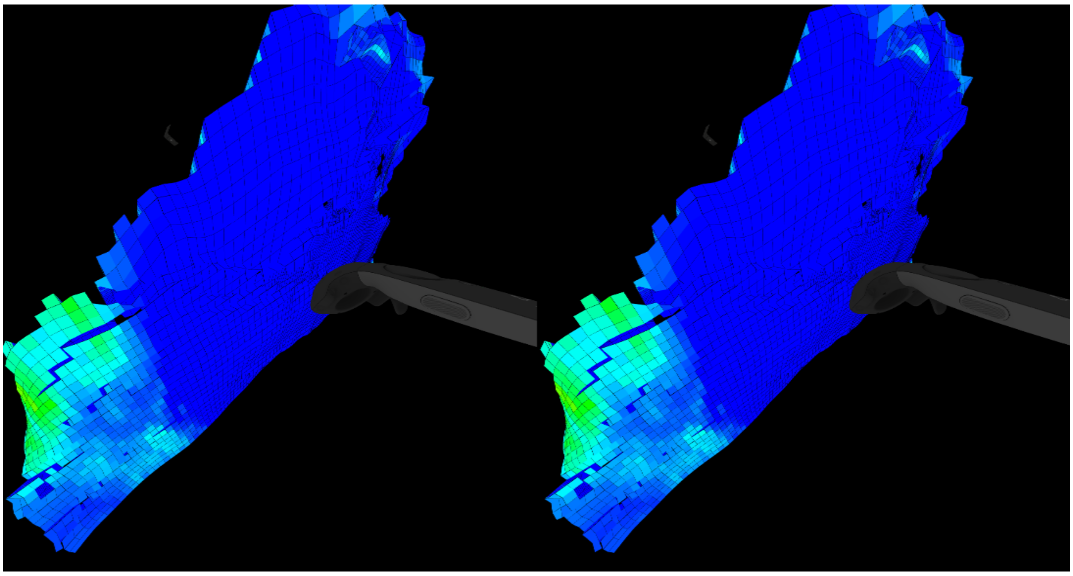

Figure 11: Test model of layer from MATLAB Reservoir Simulation Toolbox, visualized in the virtual reality system

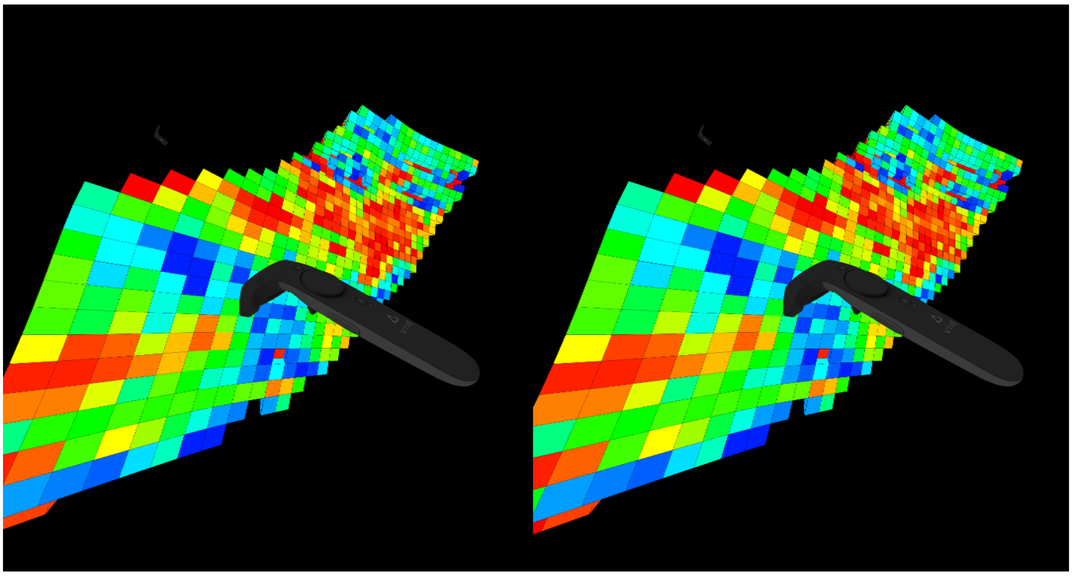

Figure 12: Test model of layer – Sample, visualized in the virtual reality system

the plane screen of the monitor. Also it is worth noting that in headset display it is easier to notice different errors, small details, which are difficult for noting out in a 2D format. This work also gives an opportunity to interact with the drawn model by means of controllers in real time that many times improves perception of the events. With use of OpenGL library there is also a possibility of interaction with model by means of a computer mouse. However the virtual reality and interactivity of operation by means of controllers has big advantage over primitive visualization with control of a mouse, since realistic images are created in the

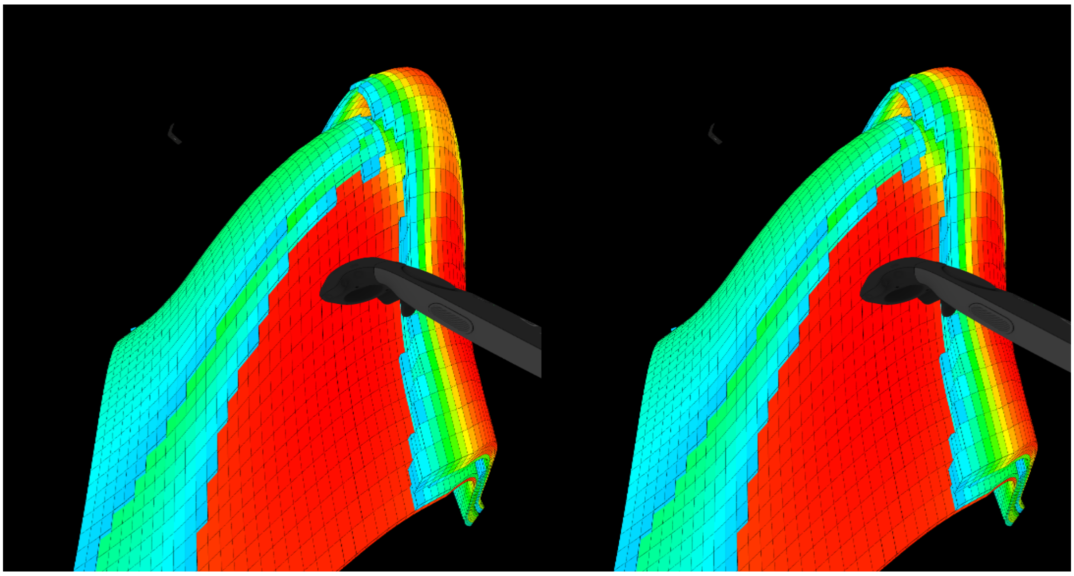

Figure 13: Test model of layer – Sample, visualized in the virtual reality system

virtual environment. They imitate physical presence for the user that leads to the effect of full presence.

6 Future work

In the future, it is planned to use the Vulkan standard, which was created to reduce the load on the central processor. It is also planned to add the user interface (UI), visualization in augmented reality system (AR) and in mixed reality system (MR).

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