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IMPROVING THE INTEGRATION OF THREE-DIMENSIONAL MODELS IN AUGMENTED REALITY TECHNOLOGY

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Abstract—*This study proposes an approach aimed at improving the visualization of three-dimensional objects by means of augmented reality technology using as a platform of widely available mobile devices. The study analyzed the literature to determine the current state and available technologies. The proposed techniques include: the use of a set of different light sources with subsequent calculation and visualization of lighting surfaces of the object at the stage of preparation of the three-dimensional model, changing the parameters of objects by using pre-compiled textures, preparation and storage of models, control of three-dimensional objects. The proposed ways to improve the display of three-dimensional models and improve data structures for their storage, will significantly reduce the load on software and hardware, as well as improve the display quality of models.*

Index Terms—Augmented reality; improved display; change of parameters; saving of models.

I. INTRODUCTION

Augmented reality (AR) – the design of any digital information (images, videos, text, graphics, etc.) on top of the screen of any device. As a result, the real world is supplemented by artificial elements and new information. It can be implemented with the help of applications for ordinary smartphones and tablets, augmented reality glasses, stationary screens, projection devices and other technologies.

To understand what augmented reality technology is, let's look at a few examples and AR products.

Examples of AR includes.

1) The Ikea augmented reality app allows customers to choose the right product that is perfect for their rooms. They can view the room through the camera on their smartphone. By swiping and clicking on Ikea products, they will immediately be able to see if any item of furniture in their apartment matches.

2) Gap has recently launched an augmented reality locker room in which consumers can try on different items without wandering around the shops, carrying tons of things.

3) Bayern Monaco has launched an augmented reality program that allows users to take selfies with their idols without going to Munich and trying to catch superstars.

4) The Land Rover augmented reality app allows drivers to see the car's engine through the transparent hood.

Augmented reality was to some extent achieved by a filmmaker named Morton Heilig in 1957. He invented the sensor, which delivered visual sounds, sounds, vibrations and smells to the viewer. Of course, this was not a computer control, but it was the first example of an attempt to add additional data to the experience.

Relatively recently, there have been many other breakthroughs in augmented reality. The most notable of which are.

1) Bruce Thomas developed the open mobile AR game called ARQuake in 2000.

2) ARToolkit (design tool) became available in Adobe Flash in 2009.

3) Google announced the open beta version of Google Glass in 2013.

There are programs available for AR research in almost all industries, including.

- Archeology, art, architecture.
- Commerce, office.
- Construction, industrial design.
- Education, translation.
- Emergency management, disaster recovery, medical and search and rescue operations.
- Games, sports, entertainment, tourism.
- Military.
- Navigation.

Consider a few specific examples. Fiat Chrysler Automobiles (FCA) used the OPS Solutions projection AR system in its work. Now, at each stage of the assembly process, workers receive visual information about their next step.

In 2015, the machine-building enterprise AGCO (USA) equipped the sites with large displays, which displayed a three-dimensional composition of products and a complete set of documentation necessary for fast and high-quality assembly of products (tractors and other agricultural machinery).

In 2017, the company switched to using Google Glass glasses, which accelerated quality control by 20%.

PVAITV and MibiPV portable virtual visualizers, designed specifically for engineers and IT professionals, allow you to scan equipment and detect faults that need to be fixed. The program indicates the location of a damaged connector or damaged cord.

When assembling wind turbines at a Florida plant, General Electric workers communicate with experts through augmented reality glasses, show the assembled equipment in sight, and get answers to questions from experts on how to design turbines with the same glasses. The analysis shows a 34% increase in productivity compared to the use of advanced technology assembly equipment.

In addition to the increasingly active use in industry, augmented reality is used in computer games, marketing (in particular, in street marketing, when the big screen with AR is displayed in a crowded place), in fashion, social networks, medicine and surgery, tourism, in the press, museum affairs and the list of examples of the use of AR is constantly replenished.

II. Physical Basics of AR. Characteristic Features

Augmented reality is achieved through a variety of technological innovations; they can be realized independently or together with each other to create augmented reality. These include.

1) Common equipment components – processor, display, sensors and input devices. The smartphone usually contains a processor, display, accelerometers, GPS, camera, microphone, etc. and contains all the equipment needed for an AR device.

2) Displays – although the monitor is perfectly capable of displaying AR data, there are other systems such as optical projection systems, glasses, contact lenses, EyeTap (a device that changes the rays of light captured from the environment and replace them on a computer generated, spatial augmented reality (SAR), which uses conventional projection techniques as a replacement for any type of display) and pocket displays.

3) Sensors and input devices include – GPS, gyroscopes, accelerometers, compasses, RFID, wireless sensors, touch recognition, speech recognition, eye tracking and peripherals.

4) Software – most developments for AR will be to develop further software to use the hardware capabilities. There is already an advanced reality markup language (ARML) that is used to standardize XML grammar for virtual reality. There are several software development kits (SDKs) that also offer simple environments for AR development.

Based on the above, we can say that the work of augmented reality and the quality of display models depend on the hardware and software (Figs 1 and 2).

The following aspects depend on the hardware part:

- accuracy of object recognition;
- accordingly, the accuracy of installation of objects;
- speed of determining key points;
- speed of marker determination;
- respectively, the speed of installation of the model;
- accuracy of determining geographical data;
- quality of model interaction;
- quality and speed of post-processing (if present);
- almost all the load on the interaction with the object falls on the hardware.

The following aspects depend on the software part:

- accuracy of marker determination;
- accuracy of determining key points;
- correct scaling of the object;
- model quality;
- adjustment of model parameters;
- the implementation of any behavior of the object is entirely on the software part.

Also very important is a natural factor – lighting. From can be improved, both hardware and software. But, rightly so, it is very costly and inefficient. Therefore, this parameter is important but independent.

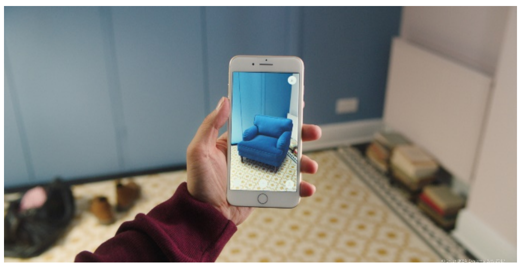

Fig. 1. An example of the use of augmented reality for the interior

Fig. 2. Example of augmented reality with geolocation

Some explanations are made to the criteria listed above. Regarding the hardware, the basis for these criteria are:

- camera resolution;
- CPU power;
- accuracy of GPS;
- display resolution;
- consistency of display and camera resolution;
- correct operation of the touch pad.

In relation to the software part it is:

- binarization algorithms;
- algorithms for determining the threshold;
- algorithms for determining the contours of objects;
- algorithms for adjusting the size of the object;
- storage of models;
- adjustment of various realism parameters;
- event processing programming.

III. Review of Scientific Papers

Consider a number of works that are devoted to the study of augmented reality related to this topic.

The first is the work of scientists Jim Scheibmeir and Yashwant K. Malaiya [1]. This paper discusses some tools for developing augmented reality and offers testing algorithms that will help identify defects and, as a result, improve the visualization of objects. Augmented reality applications merge virtual models and the physical world. These applications are becoming more popular in many verticals, and several SDKs are available to assist in creation. This research suggests creating test cases that focus on characteristics of perspective, presence, interaction, immersion, persistence, and performance.

Thanks to this work, it was found that:

1. Automation and machine learning of image detection features also need to be leveraged to assist in the detection of potential defects in the AR applications.
2. The revised quality model and the ML enabled automation framework seek to expand current capabilities and methods to enhance defect detection in AR applications.

Possible improvements are

1) A significant part of the development tools did not participate in testing.

2) Testing methods are not complete.

3) However further development of testing methodologies and tooling is needed.

4) The novel features of an AR user interface is not adequately addressed by traditional testing methods, or of the ISO 25010 model.

The second is the work of scientists X. Wang, A. Kotranza, J. Quarles, B. Lok, B.D. Allen [2]. Were proposed a pipeline to rapidly incorporate real objects into a ME (MERGED). First the user scans the object from multiple angles and then removes any noise or support material using a GUI. Next the user merges the multiple scans and fills any holes. Then, the user affixes color markers to the real object and the model. Finally, the user can visualize and interact with the object in the ME.

Scientific significance is

1) For most objects, a user can capture the shape of an object and track it inside the ME in 2 hours.

2) This work significantly increases the realism of the model, as it creates it on the basis of a real object and provides an opportunity to interact with it.

3) This system is particularly applicable to engineering design.

4) The MERGED system is a prototype, leaving room for much improvement.

Possible improvements are

1) Improving the colored marker tracking for handling multiple objects.

2) Increasing the tracked volume and number of cameras.

3) Perform in evaluating actual designs.

Another well-known study in this direction is the work of authors D. E. Breen, E. Rose and R. T. Whitaker [3]. Several techniques for interactive occlusion detection and collision detection between static real objects and dynamic virtual objects in unrealized reality were presented. Computer vision algorithms are used to acquire data that model aspects of the real world. Either geometric models may be registered to real objects, or a depth map of the real scene may be extracted with computer vision algorithms. The computer vision-derived data are mapped into algorithms that exploit the power of graphics workstations, in order to interactively produce new effects in augmented reality. By combining live video from a calibrated camera with real-time renderings of the real-world data from graphics hardware, dynamic virtual objects occlude and are occluded by static real objects. As a virtual object is interactively manipulated collisions with real objects are detected, and the motion of the virtual object is constrained. Simulated gravity may then be produced by automatically moving the virtual object in the direction of a gravity vector until it encounters a collision with areal object.

Scientific significance is

1) Developed a general set of techniques that addresses the problem of occlusion and collision detection in augmented reality.

2) The techniques described here markedly improve the “reality” of augmented reality.

3) In an interior design application, generating depth maps may be the most straightforward way to acquire a model of the environment.

Possible improvements are

1) Conducting such studies on relatively small details.

2) Dealing with complex scenes or unknown objects is another shortcoming of the model-based approach.

3) Using models with parameters.

Since this occlusion and collision techniques rely on specific hardware capabilities, the performance and functionality of the available graphics hardware must also be considered.

IV. Problem Statement

The second section described the process of realization of augmented reality, the criteria for the quality of display of objects, which depend on both hardware and software. The purpose of this work is primarily to improve one of the program criteria, namely the adjustment of model parameters.

Let's start with quality. Since the model is formed using computer graphics, it is very drawn and clear. In some cases, this can be a disadvantage, for example, when the user camera is not of the highest quality, and the model should be as follows. Otherwise, it stands out.

Another problem is lighting. This is especially noticeable in the morning or evening, when all objects have clear shadows and the model does not, and the model is illuminated equally from all sides. This significantly impairs the integration of the object into the real world.

As a result of the lighting problem, an even more important problem is the shadow itself. When real objects have clear shadows, and a virtual object does not have it at all.

For maximum effect, with the help of software and hardware, for each situation in real time should be calculated lighting, according to it should be calculated shadow and all this should be adjusted according to the picture quality. But in practice, it is very expensive and will not be widely used, due to the significant delay in calculations and staffing changes to the object. Therefore, this paper proposes an approach in which, with the help of a preliminary rendering, we have versions of the model with different shades of different quality. Experiments have shown that literally a couple of options are enough to make a universal set of models.

This approach makes it possible to significantly increase the realism, while not loading the system and with instant results. This work, in order to optimize, also offers a data structure in which the object will be stored and the possibility of manipulating the object in space is considered.

Issues for improvement:

- realistic display of objects;
- the ability to change the parameters of objects during visualization;
- format and structure of storage of objects;
- manipulation of objects in space.

V. Improving the Integration of Three-dimensional Models in Augmented Reality Technology

A. Research methods and tools

An analytical review of methods and tools for developing augmented reality was conducted. To implement augmented reality technology requires two main software components: tracking and visualization. At present, researchers and specialists have developed a large theoretical and algorithmic basis for their implementation, both in the form of various individual components and in the form of integrated programs and sets of development tools. Some components include libraries and computer vision frameworks, 3D graphics engines, and other solutions. Tracking is a complex process involving tracking the observer's position relative to the environment. Marker-based optical tracking was chosen for use in the study as the most functional of the options that can be used for mass implementation [4]. With this type of tracking, the frames of the video stream coming from the camera are analyzed for the presence of a special image – a marker. If the token is recognized, a transformation matrix is calculated, which allows you to determine the position of the camera and then correctly integrate the virtual object into the real environment. A set of Qualcomm Vuforia development tools was used as the tracking engine. This tool has been specially designed for mobile devices. Many existing solutions can be used to implement part of the augmented reality technology associated with three-dimensional visualization. During the search and analysis, the development environment Unity was chosen [5]. It has a graphics engine optimized for mobile devices.

B. Methods for ensuring realism in the visualization of three-dimensional objects

First of all, the issues of realistic visualization of objects were considered. The synthesized computer image can correspond to the original under visual observation only at the psychophysical level. The maximum approximation to the original can be provided if the mathematical model of the scene and the processing program accurately convey the lighting conditions, the geometric shape of objects, their relative position, size and position of shadows and other features of the real scene. The selected Unity development environment supports all 4 standard light sources: diffused, directional, point and cone. The combination of these sources can be used to create a lighting scheme of the object.

However, the resources of mass mobile devices do not allow the use of more than two point or cone light sources. Also, this model does not take into account the light reflected from other objects in the environment: the so-called global lighting. Although the latter significantly increases the realism of the visualization. In this case, when visualizing augmented reality, the surrounding objects on the virtual stage are completely absent. As a result, it seems logical to use static (pre-calculated) lighting in addition to dynamic (real-time lighting) to increase the realism (Fig. 3).

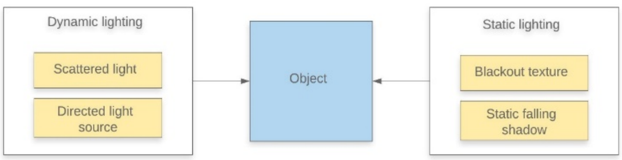

Fig. 3. Combination of static and dynamic lighting

An approach is proposed in which the calculation and visualization of the illumination of the surfaces of the object is carried out in advance at the stage of preparation of the three-dimensional model and further visualization in real time does not require additional resources. With this approach, at the stage of developing a three-dimensional model of the object, lighting of any complexity can be applied to it using an unlimited number of light sources.

Of great importance is the possibility of preliminary calculation of shadows formed as a result of indirect lighting. The calculation can be performed using various methods of global lighting, such as Ambient Occlusion. The shading of the object calculated in this way can be visualized in an atlas texture. A distinctive feature of the applied approach is that a separate independent shading texture of the object is created, which is further mixed with the main one. Thus, when creating multiple color solutions of the object does not require appropriate training for each texture.

Another of the proposed methods is the display of a static incident shadow cast on a flat surface on which virtual objects are located (Fig. 4).

As well as the shading texture, the falling shadow is calculated in advance in high quality and stored as a texture. Next, the texture is applied to the plane below the object. In order to optimize the shader material of the plane does not use information about light sources. The falling translucent shadow makes a significant contribution to the realism of embedding a virtual object in a real environment. A distinctive feature of the presented approach is the possibility of successful application in real-time problems.

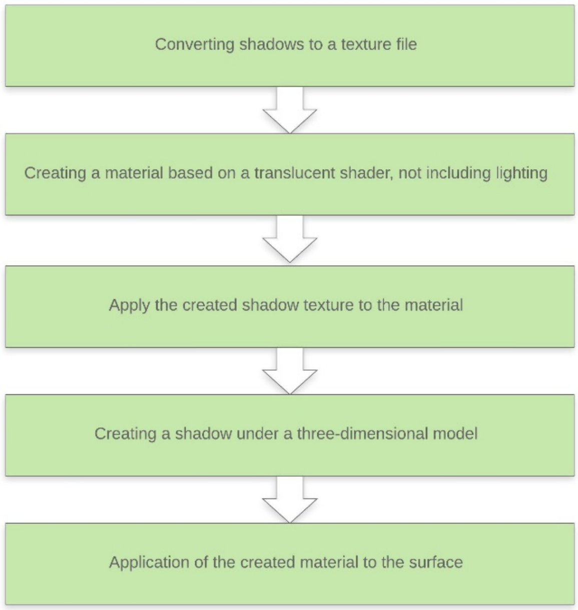

Fig. 4. Algorithm for creating a static shadow

C. Techniques for changing the parameters of the object in real time

The basic principles of changing the parameters of the object in the visualization of augmented reality on the example of changing materials were proposed. These include changing real-time settings and a simplified user interface available to the layman. For example, changing the materials of individual polygonal grids of the model can be simplified to the user's choice of one of the available solutions, given sets of materials, according to an algorithm in which each model element in the loop is replaced by the corresponding model elements from the available set.

When the user selects one of the color solutions from the list, the appropriate materials are applied to parts of the model. By analogy with materials, different parameters of the object can change. For example, the lamp is on or off, is in a special mode; the sofa is unfolded, or folding. The algorithm remains basically the same.

D. Preparation and storage of models

The implementation of the proposed methods to ensure the realism and change of materials requires the development of a certain process of preliminary preparation of models (Fig. 5), as well as a special structure of storage of objects (Fig. 6).

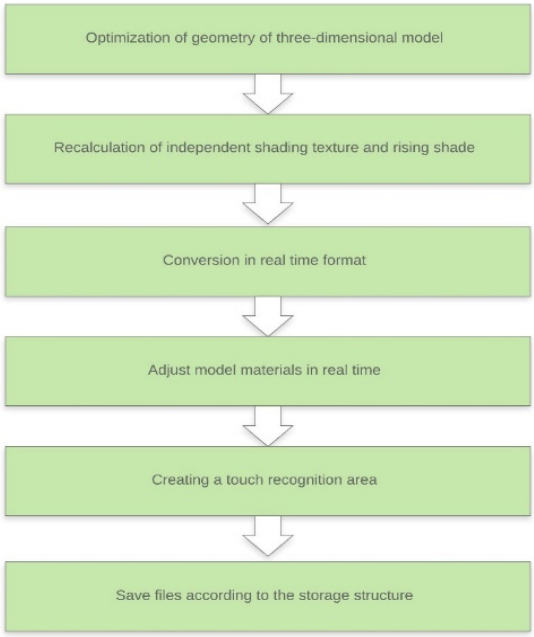

Fig. 5. Algorithm for preparing a three-dimensional model

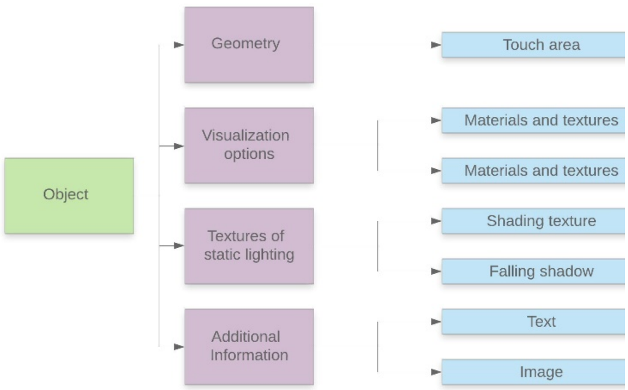

Fig. 6. Storage structure of the model

E. Moving three-dimensional models

In order to improve user interaction, a mechanism for manipulating three-dimensional objects using gesture input methods was proposed. As noted in previous studies, the task of moving objects can often be simplified to two-dimensional. And, thus, in this case, the movement is carried out within the plane, along the X and Z axes, and the rotation – around its Y axis. In this case, the Y coordinate remains unchanged, and the X and Z coordinates change according to the expression:

$$\begin{bmatrix} Z_1 \\ X_1 \end{bmatrix} = \begin{bmatrix} \cos\cos\varphi & -\sin\sin\varphi \\ \sin\sin\varphi & \cos\cos\varphi \end{bmatrix} \cdot \begin{bmatrix} Z_0 \\ X_0 \end{bmatrix},$$

where φ is the angle of rotation of the object around the Y axis.

The touch screens of mass mobile devices are mostly equipped with the function of recognizing several touches simultaneously. Thus, it is possible to assign one gesture (simple touching and moving one finger) to move the object (translation of coordinates), and the other (touching two fingers at the same time) – to rotate.

An algorithm that processes input from a touch screen has been proposed. If a touch screen is detected, a check is made to see if it has entered the virtual object area. To do this, use the method of waking rays. The virtual beam is awakened from the point of contact by the user of the touch screen located on the plane of the screen found by the Unity virtual camera. In the case of intersection of the object with a beam, a positive result is returned. If there are several virtual objects on the stage, it is necessary to determine which of them interact.

When more than one touch is detected on one object, the rotation mode is recognized. The angle to which you want to rotate the object is determined by measuring the angle of rotation of the line drawn through the two points of contact, compared with the previous frame. If more than two touches are detected on the object, only the first two are processed (Fig. 7).

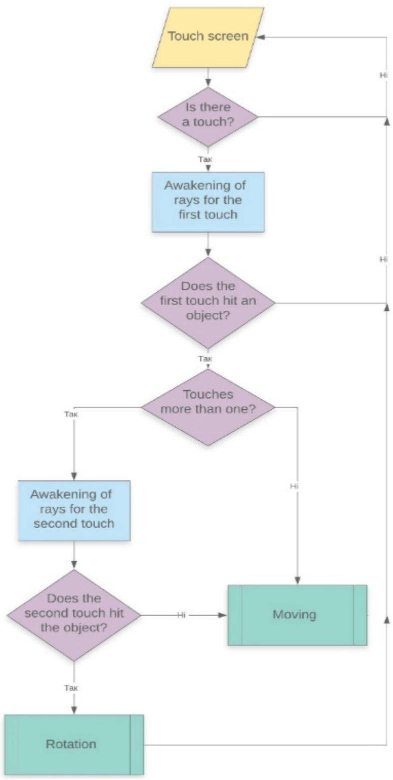

Fig. 7. Method of manipulating objects

F. Modeling results

As described above, the way to improve the visual perception of augmented reality objects without creating a significant load on software and hardware is pre-modeling.

With this simulation you can create different shades of the same object, different degrees of illumination, different shadows. It is also worth modeling several versions for cameras with degraded quality of work, so that the object does not differ much from the real environment. Just a few versions for each case give an almost universal set of versions of the model, which can be instantly integrated into the real environment, and does not load the system at all. In addition, this approach is convenient, so we do not need to store the model completely. We have a basic model, and all its versions are implemented using textures that are superimposed on top. They are not heavy, so they are easy to store.

Consider the process of forming such a model:

1) First we download the original object.

2) In the virtual scene, various methods of global lighting are calculated, such as Ambient Occlusion, shown in Fig. 8.

3) As a result of the calculation, we obtain an atlas map for all parts of the model, shown in Fig. 9.

4) The calculated map is universal and can be applied to different color versions of the model.

5) By artificially degrading the quality, several versions for medium quality cameras are formed.

6) As a result of combining the basic model, the shadow map of the model, different color solutions and versions of the quality of the model, we get a universal set, which significantly improves the quality of visualization and can be applied as shown in Fig. 10.

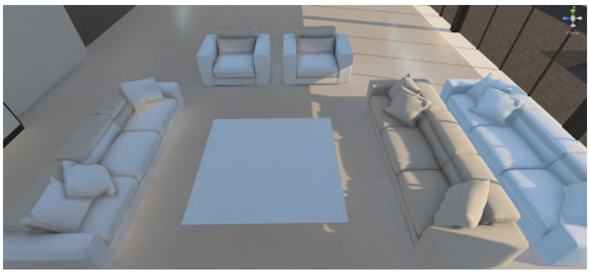

Fig. 8. Example of lighting modeling

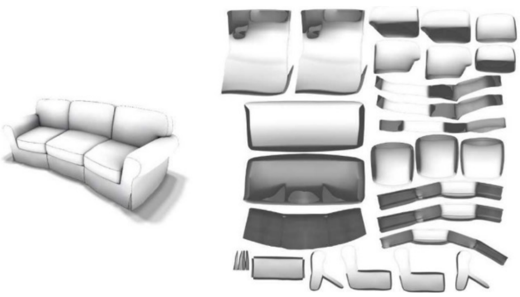

Fig. 9. Independent atlas map for all parts of the model

Fig. 10. An example of the application of a universal set of the model

VI. CONCLUSIONS

This work is devoted to the issues of visualization and information processing, in particular the improvement of visualization of three-dimensional objects by means of augmented reality technology.

The main results of the work performed are:

1) The current state in the field of augmented reality research is analyzed, the shortcomings of modern augmented reality systems are identified and methods for their solution are proposed.

2) Search and analysis of development tools for the possibility of use for research purposes.

3) Developed methods to ensure the realistic display of three-dimensional objects by means of augmented reality.

4) The basic principles and algorithm of change of parameters of objects of the augmented reality at visualization in real time are offered.

5) Techniques for preparation and optimization of three-dimensional models for realistic visualization on mobile devices are proposed.

6) The mechanism of manipulation of three-dimensional objects is offered.

It should be noted that the proposed techniques and algorithms are universal and compatible with new, potentially more advanced technological solutions. Also, the results of the study are not limited to use on hand-held devices, but have the potential to be used on specialized devices, such as augmented reality glasses, which have significant prospects in the future. The proposed techniques can be applied directly in the design of software products for use in real business processes of trade, design, as well as in a number of other areas.

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О. С. Безпалько. Покращення інтеграції тривимірних моделей в технології доповненої реальності

В роботі проведено дослідження, метою якого було вдосконалення візуалізації тривимірних об'єктів засобами технології доповненої реальності. Дане дослідження пропонує підхід, метою якого було вдосконалення візуалізації тривимірних об'єктів засобами технології доповненої реальності з використанням в якості платформи масово доступних мобільних пристроїв. У ході дослідження проаналізована література з метою з’ясування сучасного стану та доступних технологій. Запропоновані методики включають в себе: застосування сукупності різних джерел освітлення з подальшим розрахунком та візуалізацією освітлення поверхонь об’єкта на етапі підготовки тривимірної моделі, зміну параметрів об’єктів шляхом використання попередньо скомпільованих наборів текстур, підготовка та зберігання моделей, можливість керування тривимірними об’єктами. Запропоновані шляхи покращення відображення тривимірних моделей та вдосконалення структур даних, для їхнього зберігання, дадуть можливість значно зменшити навантаження на програмне та апаратне забезпечення, а також покращить якість відображення моделей.

Ключові слова: доповнена реальність; покращення відображення; зміна параметрів; збереження моделей.

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Напрям наукової діяльності: інформаційні системи; нейронні мережі; доповнена реальність.

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А. С. Безпалько. Улучшения интеграции трехмерной модели в технологии дополненной реальности

В работе проведено исследование, целью которого было совершенствование визуализации трехмерных объектов средствами технологии дополненной реальности. Целью исследования было совершенствование визуализации трехмерных объектов средствами технологии дополненной реальности с использованием в качестве платформы массово доступных мобильных устройств. В ходе исследования проанализирована литература с целью выяснения современного состояния и доступных технологий. Предложенные методики включают в себя: применение совокупности различных источников освещения с последующим расчетом и визуализацией освещения поверхностей объекта на этапе подготовки трехмерной модели, изменение параметров объектов путем использования предварительно скомпилированных наборов текстур, подготовка и хранение моделей, возможность управления трехмерными объектами. Предложены пути улучшения качества трехмерных моделей и совершенствование структур данных, для их хранения, дадут возможность значительно уменьшить нагрузку на программное и аппаратное обеспечение, а также улучшит качество изображения моделей.

Ключевые слова: дополненная реальность; улучшения качества; изменение параметров; сохранение моделей.

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