Virtual Environment System for Pirs Space Module Interior

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This paper presents original methods and approaches to implement virtual environment system for one of the International Space Station module. Such system may be used as a part of cosmonaut training complexes in order to orient trainees in the internal space of the module as well as to develop their skills of onboard equipment control. Proposed system structure consists of three general components: hardware part, software complex, and 3D scene with virtual model of considered space module. The last two components are own original products. Our solutions are based on using modern technologies of virtual reality (VR), including VR headset and Kinect device.

Keywords: *virtual reality, simulation, stereo visualization, training complex, real time.*

1. Introduction

One of dynamically developing direction within computer simulation is creation and adoption of new virtual environment systems and simulation-training complexes built on modern hardware and software bases. They are used to train qualified specialists for controlling complex equipment. Increasingly, a basis of such complexes and system is provided by technologies of virtual reality (VR, [1]).

Using VR technologies allows carrying out the most fully operator immersion in a three-dimensional virtual environment. Furthermore, several significant benefits are achieved compared to early used approaches without VR. First, there is no need to create a real model of an environment for each training complex and system. Implementation and service of such models often require substantial cash investments. Sometimes it's impossible at all. In VR solutions the environment is fully replaced by a virtual model displayed to the operator's eyes through virtual reality helmets and headsets. Graphic designer creates this model by means of 3D modelling system, for example Autodesk 3ds Max, Autodesk Maya and so on. It's much easier to support and update virtual models than real ones. Another advantage of using VR technologies in virtual environment systems and training complexes is to improve a quality for visual perception by the operator of virtual space, therefore bringing it more to a real prototype. It allows enhancing the effectiveness of qualified staff training by means of such systems.

VR implementation task is particularly relevant in the field of space training complexes and systems [2, 4, 5, 7]. This paper presents virtual environment system implementation methods and approaches for an interior of the International Space Station's (the ISS) one module. Pirs was chosen as such module. It is an important element of the Russian Orbital Segment, because it includes the docking unit for transportation spacecraft of the Soyuz and Progress type, as well as provides a spacewalk opportunity. Proposed solutions are based on using modern VR technologies and allow the operator to interact with virtual nvironment objects in real time. Developed system can be used to examine the interior details, to orient operators in the arrangement of important elements (devices, hatches, etc.), and also to train some skills needed on board the ISS. One of these tasks is learning to use a control panel placed inside the module.

2. Virtual environment system structure

Virtual environment system proposed by us moves the operator from real world to virtual interior of Pirs space module. The working principle of the system is as follows. The user puts on Oculus Rift headset and enters the workspace of Microsoft Kinect device. At the time of initialization, the system loads three-dimensional virtual scene with the interior and a virtual observer. The observer includes eyes (two virtual cameras) and models of hands. After loading the scene, virtual observer is bound with the operator. An image seen by virtual eyes is transmitted to the person's eyes with using VR headset. Thanks to several tracking systems (tracking of the operator's hands and torso is implemented based on the Kinect, head is tracked by the Rift headset), positions and orientations of the observer's elements in virtual environment are synchronized with positions and orientations of the corresponding parts of the operator's body in real space. The operator thus gets an opportunity to move and turn inside virtual interior, turn his head for viewing environment, and interact with interior elements by means of his hands. For example, buttons of virtual control panel inside space module are such elements. Clicking on them causes some actions (turning on or off the lighting, opening or closing the hatches etc.) defined by control scheme. This scheme is developed when creating virtual scene and saved with it.

To implement the system described above, we were developed original software complex. It consists of three subsystems, which are responsible for controlling virtual observer and other elements of virtual environment, computing the dynamics of objects, collision detection and response, and also virtual environment visualization with per-pixel calculation of realistic lighting. Each of these three subsystems provides real-time functionality and is original product, designed from the ground up without using third-party software components. To achieve our goal, we were also created own virtual scene with Pirs space module interior and model of virtual observer. The scene was made in Autodesk 3ds Max and converted to a format supported by our software complex. In addition, a control scheme for the virtual control panel was developed by means of our own scheme editor. Implementation of hardware part that is responsible for tracking of the operator's head, body and hands and necessary for rendered image transmission into his eyes is based on the Kinect and Oculus Rift devices.

Figure 1 illustrates general structure of our virtual environment system. Consider its components in more detail.

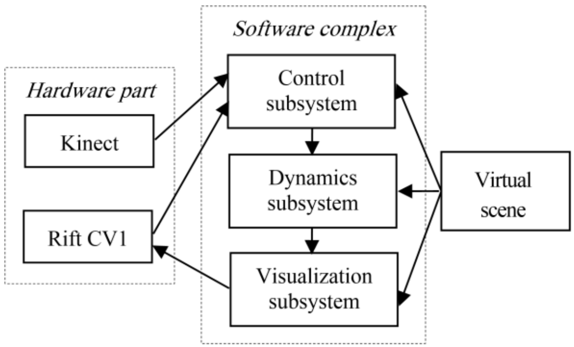

Fig. 1. Our virtual environment system structure

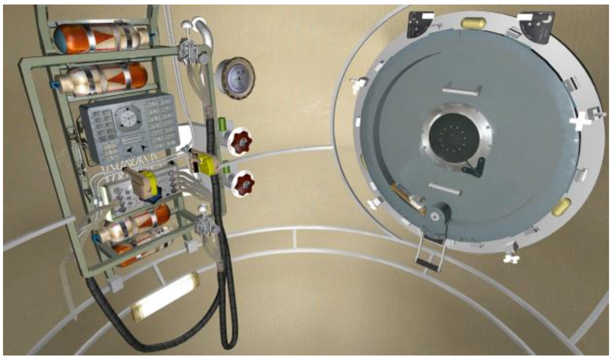

Fig. 2. 3D scene of Pirs module interior

Fig. 3. Virtual control panel

2.1. Virtual scene

Virtual scene created by us and loaded to our system is a detailed virtual model of the International Space Station's Pirs module interior (fig. 2). Except visible elements, it contains many bounding volumes (boxes, spheres, cylinders, etc.). They are used for collision detection and response when interactions of the operator with objects are occurred. Also a virtual control panel with possibility of pressing its buttons is placed into the scene (fig. 3). Control algorithm for the panel is set by means of special control scheme. Computing this scheme and synthesis of control signals are done in software complex.

To integrate the operator with virtual environment described above, a virtual observer is added to it. This observer consists of two virtual cameras (for the operator's left and right eyes) and hands. The tasks of current virtual environment system version are visual inspection of Pirs module interior by the operator and learning the basics of control with using the panel buttons. Therefore, all fingers of virtual hands except the index fingers are bent. The observer's movements and turns are provided by means of virtual motors (linear and rotational). Our software complex controls these motors in accordance with information arrived from the Kinect and Oculus Rift devices about the operator's position and motions in real world. To implement rotate and tilt of the operator's head, there are two rotational motors hierarchical linked with pair of cameras. Three linear motors are set in every virtual hand. It provides that their movements are parallel to vertical, transverse and sagittal body axes. In addition, another three linear motors and one rotational are linked with the observer as a whole. They are necessary to move the observer around the module and to rotate it about vertical body axis. All motors of the virtual observer are controlled by software complex with using own control scheme.

Fig. 4. Oculus Rift CV1 and Microsoft Kinect devices

2.2. Hardware part

Hardware part of our virtual environment system is based on Oculus Rift CV1 and Microsoft Kinect devices (fig. 4). The Rift headset provides transferring stereo images (synthesized by software complex) of virtual space surrounding the operator to his eyes. Stereo pair is displayed on LCD screen built into the device. Image separation for left and right eyes is performed by means of special optics, placed between the screen and the eyes. Distortions and chromatic aberrations produced by such optics are compensated with using preliminary correction of displayed images. This correction is done by the headset software.

Oculus Rift CV1 VR headset also includes tracking system based on a gyroscope, accelerometer and magnetometer. This system is used to compute position and orientation of the operator's head. Obtained data is sent to software complex that provides corresponding positions and orientations of virtual cameras for left and right eyes.

The Kinect device computes three-dimensional coordinates of user skeleton anchor points in real time based on information from internal RGB camera and IR sensor. In our work we use coordinates of wrists and torso points which sent to software complex for computing virtual hand positions, as well as position and orientation of virtual observer.

2.3. Software complex

Software part of developed virtual environment system consists of original control, dynamics and visualization subsystems. Control subsystem takes as its input a data about pressing buttons of the virtual control panel, as well as current positions and orientations of the operator's head and body. The last arrive from the Kinect device and Oculus Rift CV1 headset. Furthermore, control schemes for the observer and the panel are loaded from virtual scene. Based on arrived data, the subsystem computes the schemes and synthesizes control signals which are sent to dynamics subsystem.

Dynamics subsystem computes new positions and orientations of virtual cameras, hands and other objects of the scene, based on signals received from control subsystem. It also performs detection and response of collisions between virtual hands and the scene objects including buttons of the virtual control panel. Computed data is sent to visualization subsystem implemented by us with using the OpenGL graphics library, GLSL shader technology and CUDA. It performs distributed rendering of virtual environment by means of multi-core graphics processor (GPU). Visualization subsystem result is a stereo pair in the form of a single image separated into two equal parts. This image is sent to the Oculus Rift CV1. It also is duplicated on standard means for displaying (a monitor or a projector).

3. Implementation results

Developed methods and approaches were implemented in the form of virtual environment system prototype for Pirs space module interior. The complex consists of high performance computing unit based on Intel Core i7-8700K processor and NVIDIA RTX 2080 graphics card, Oculus Rift CV1 headset and its sensor, Microsoft Kinect v2.0 device, display. Software modules were realized with using object-oriented language C++,

Fig. 5. Immersing the operator in virtual interior of Pirs space module

the OpenGL 3D graphics library, shader language GLSL 4.3 and the CUDA parallel computing architecture. Stereo visualization of high polygonal virtual model of Pirs space module interior is performed in real time. The frame rate is about 300-400 FPS.

Figure 5 illustrates an example of applying developed complex to immerse the user in virtual environment. The operator feels that he is inside Pirs space module, sees its interior and virtual hands. User presses the control panel buttons by means of virtual index fingers, which movements is a copy of his wrists' movements.

4. Future work

Unfortunately, using the Kinect device doesn't provide full interaction of the operator's hands with virtual objects. In this work it was used as the initial stage of creating virtual environment for Pirs space module. A promising evolution direction for this and other similar systems is using specialized devices with sensors to track the operator's hands. Today, the most efficient solutions among them are Oculus Touch controllers and virtual reality gloves (fig. 6).

The Touch device looks like a joystick, but has a specially designed ergonomic shape. Its construction includes an accelerometer and IR sensor which allow computing the position and orientation of the operator's wrist with high accuracy. In addition, the controller tracks when the thumb and index fingers squeeze, as well as the palm state (squeezed or relaxed). Important feature of the Touch is haptic feedback which allows real hand to feel a contact with virtual environment objects. It is implemented by means of vibrating motor.

Optimal way to realize full interaction between hands and virtual objects is modern VR gloves [3]. Unlike the Touch they provide a control of all hand fingers and allow programing the feedback with more flexibility (there is a possibility of independent impact on individual hand areas). For example, the Manus VR Gloves [6] are one of such virtual reality devices. They provide nine degrees of freedom (9DOF) for each virtual hand. An orientation of real hand wrist is computed based on data received from a gyroscope, accelerometer and magnetometer. Finger movements are controlled by two sensors set on each of them.

Fig. 6. Manus VR gloves and Oculus Touch controller

An important problem in creating virtual environment systems for cosmonaut training is also a simulation of weightlessness conditions. Using a basin in the hydro lab or special suspension system can be considered as variant of its solution. However, both options have their advantages and disadvantages, requiring serious and depth study in future researches.

5. Conclusions

At this paper we propose methods and approaches for creating virtual environment system based on modern virtual reality technologies. Using stereo headset provides high level of immersing the operator in virtual environment. Proposed solution may be adapted for other models of the ISS modules.

As a next step, it is planned to improve our virtual environment system to implement realistic interaction of the operator's hands with space module interior objects. To solve this problem, it is expected to develop new methods and algorithms based on using VR gloves.

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