Virtual Body Immersion into Real World

F.M. Kulakov
Saint-Petersburg Institute for Informatics and Automation of RAS
Saint-Petersburg, Russia
e-mail: kul@mail.iias.spb.su

G.V. Alferov
Saint-Petersburg State University
Saint-Petersburg, Russia
e-mail: alferov@apmath.spbu.ru

Abstract[1]

A problem of immersion of an arbitrary computer-synthesized virtual body into a real environment at considerable distance from observer is considered. The problem under discussion refers to so-called Augmented Reality which is a rapidly developing trend within Virtual Reality. A virtual body in this case is an augmentation to the reality. The problem has "visual" and "tactile-force" aspects. Advanced approaches to realization of these aspects of immersion are proposed.

1. Introduction

One of actual tasks relating to problems of the virtual reality is a task of 3D image immersion of an arbitrary computer-synthesized virtual body into an 3D image of real environment providing simulation of tactile and force interaction of man's arms with this body. The considered task has "visual" and tactile-force aspects. The visual aspect falls into versions depending on choice of means for viewing real environment: a video camera or optical system. When environment is located at the long distance from observer the first version is the only possible one as the second version is feasible when it is near to observer.

The visual effect of immersion (first version) implies that observer is able to see:

1. stereo pair of real objects images within environment (working zone) obtained by double video cameras;
2. stereo image of virtual object (body) as if it were real and present amid real objects of environment created by computer synthesis;
3. stereo pair of images of man's hands obtained with video cameras as if they were acting with real objects of the environment, and also as if they were acting with virtual object.

The tactile-force effect implies that man is able to perceive virtual body as if the interacted with real body having specific size, form, mass, weight, texture and resistance to friction.

The problem to be considered belongs to the category of so-called "Augmented Reality" (Azuma, 1997; Azuma, Bishop, 1994; Azuma, 1999), what is a fast developing branch of "virtual reality". A virtual object in this case is augmented to reality giving the name to it. Many companies and science teams work to solve the abovementioned tasks. A row of successful solutions already finds a broad application in various training devices, medicine, design work, industry and also for robot telecontrol when virtual body is a robot (Becjzy, 1995). But continuation of these efforts still remains actual for the search of better solutions that could have augmented realism of man's immersion into the virtual world, made systems of virtual reality cheaper, expanded application sphere for these systems.

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2. Approach to Realization of Visual Effect

Basic conditions for satisfaction of "visual" effect of virtual body immersion in case when man views it with video cameras are following:

1. Human's eyes should be transferred to the distant environment (working zone) using a double video cameras in the zone for transmitting zone picture to the helmet mounted displays.
2. Computer generated virtual body should be "placed" into working zone together with "virtual hand" of man.
3. "Holographic effect" should be realized, i.e. possibility of viewing working zone and virtual object in zone from different points and direction following in real time human's head position.

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object and his virtual hands should not be seen and replaced by overlaying parts of virtual object and hands and vice versa.

To realize visual effect of immersion an adequate soft/hardware complex is proposed.

Basic functional units of this complex, whose structure is shown in Figure 1, are:

1. A double mobile video cameras mounted on a special robot-like device) for obtaining of stereo image of remote real environment.
2. Position control system of robot-like device.
3. Head tracking system (HTS) containing a sensor for obtaining primary data on head's position/orientation and a sensor data processing system to calculate head's position/orientation coordinates.
4. System of two video cameras mounted on operator's head for generation of stereo images of operator's arms and hands.
5. System for tracking positions and orientations of all elements making geometrical models of arms and hands.
6. Two-helmet-mounted displays for representation of computer stereo images.
7. Graphic station for Augmented Reality generation.
8. Special device for realization of tactile-force effect of immersion.

The basic functions of the graphic station specialized software packet realized in corresponding subprogram are the following.

1. Generation of geometric (topographic) models of virtual body, objects of working zone, hands, arms; specifically, these bodies may be approximated by multihedrons (which apexes are 3D points, every facet being triangle;
2. Linear and angular transposition of the body geometrical models;
3. Generation of image for the geometrical model of scene including the objects of the working zone, the arms, hands, the virtual body;
4. Realization of the "screening effect", i.e. elimination of invisible fragments of body images screened by body models nearer to the observer for his prescribed position;
5. Localization of 2D-area belonging to unscreened (visible) fragments of the geometrical model images of the working zone, the arms, hands, the virtual body (Figure2);
6. Substitution with precise registration of the localized areas belonging to the visible fragments of the geometrical models images by the suitable areas, belonging to these fragments of the real objects obtained by video cameras.

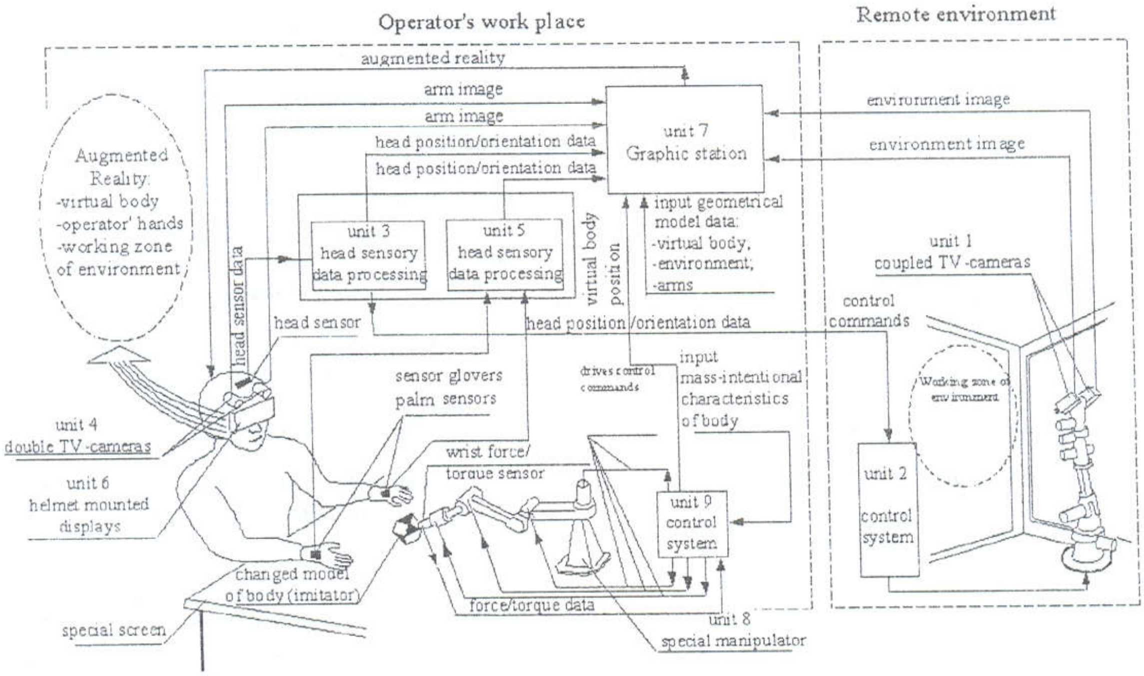

Figure 1. Block-Diagram of System for Virtual Body Immersion unto an Environment

To provide functioning of this software packet the following data are to be used:

1. initial data for geometrical models generation;
2. current data concerning coordinates:

- head position/orientation;
- position/orientation of all element making the hand and arm geometrical models and the other mobile objects of environment.

First, current data it is necessary to change angle and scale of the models images following head position/orientation for providing pseudo-holographic effect. Second, it is necessary to generate the images of mobile objects. These data are generated by system tracking head position/orientation a so-called head tracking system (HTS) (unit at Figure1) and by systems tracking position/orientation of all elements of corresponding arm, hand geometrical models. HTS can be realized based on one of many principles: electromagnetic inertial, optical TV, etc. In our case it would be important to improve characteristic of HTS, namely HMB giving operator a room for movement. Same time, the system should not be very expensive. The most attractive choice would be a system combining inertial and optic-TV principles.

A good possibility to improve reality of visual perception is provided by substitution of computer generated seen fragments of geometrical models images of working zone, arms, hands by their real images, obtained with video cameras. This act, namely, provides the effect of the virtual body immersion in real environment. It is evident that the position/orientation of double mobile TV-cameras for stereo image generation must be identical to the head position/orientation. Special control system is used for this aim (unit 2 at Figure1). This system controls robot-like device analogous to devices for active anthropomorphic vision (Aceacia, 1995) (unit 1 at Figure1).

The given approach to realization of the visual aspect of immersion of virtual body into real environment requires solving a number of problems. The most principle and hard are two ones. The first - is a problem of precise registration of visible unscreened fragments of the real environment and hands images obtained by video camera with the same of the geometrical models computer generated images and to keep this registration in real time of process of change of position by observer and movement of virtual body. A complexity of the registration problem is produced by high resolution of eye retina that makes 0,5 angular minute. For the best video systems one pixel at helmet-mounted displays will be 2,5 angular minutes. So, even one pixel of non-registration will be caught by eye reducing sense of reality.

The second problem is continuity of perception. Studies have shown that data processing for obtaining a picture of scene needs huge number of calculations what seriously complicates sampling with a rate necessary for continuity of perception. The problem becomes more poignant with dynamic character of scene, operator's hands and virtual object movement. Moreover, the angle image and scale will change due to possible movement of observer.

For successful solution of the problem of providing continuity of perception a reasonable compromise is required between detalization and realistic representation of virtual object and time required for processing one frame.

3. Approach to Realization of Force Effect

At present, there are several devices to implement tactile-force effect of immersion that is interaction mans hands with virtual body: *Cyber Force*, *Cyber Grasp*, and *Cyber Glove* produced by the *Virtual Technologies Co.* We suggest some alternative device which can be used in case of the first version of immersion that is as if a working zone and human hands and arms are observed by video-cameras. Apparently application of this device will help to reproduce the interaction more realistically than above-mentioned devices. The observer will have the sense that he deals with a real body having a prescribed shape, size, mass, weight, and resistance to friction. This device is analogous to devices decrypted in (Bogomolov, Kulakov, 1999). It is a specially designed manipulator with controlled drives and six degrees of freedom. Instead of a gripper, the manipulator has an imitator of virtual body (Figure 1, unit 8) having the same shape as real ones but made of a light material. The manipulator has a wrist force-torque sensor to measure six projections of the resultant vector applied to the imitator by hands. The manipulator must operate in the following two modes. In the first mode, the manipulator must be positioned in so that the virtual body imitator is in the same position as the virtual body or moves in the desired manner. This mode provides the operator with the ability to move his hands freely in space in order to grasp or push the body imitator. The second mode is used when the distance between the virtual body and the hands becomes zero. Obviously, the distance between the imitator and the hands at that moment is also zero. This mode imitates the tactile force interaction which would take place if the operator's hand pushed or grasped and moved a real body with a prescribed shape, size, mass, weight, and friction coefficient.

It is important that the operator does not see the manipulator and body imitator in any of these modes. He should only see that he grasps a real body of the given texture, color and shape; he should sense the body's weight, mass and friction resistance. Unfortunately the manipulator can get into field of viewing of the video-cameras used for hands viewing. However, it can always be recognized in the scene image owing to its specifics, e.g. black color. When the video image of the scene is converted into a computer image, the black color can be replaced by the same color as that of the special screen to remove the background below the operator's hands

The realization of this kind of interaction requires using control signals for the manipulator drives which would generate the imitator movement in the same time law as that of a real body of the same mass, weight, friction, and the same forces applied to it.

Solution of this problem is realized by numerical integration of differential equations for the motion of a body having mass, inertial matrix under action of force and torque generated by man's hands. These force and torque are measured by above-mentioned force/torque sensor.

Mass, inertial matrix are prescribed for the concrete virtual body. Therefore these equations are defined in full. Numerical integration of these equations results in calculation and ultimately joint coordinates of special manipulator as time function.

It should be noted that the described devices for the imitation of tactile-force interaction can perform the same operations as the well-known devices *Cyber Force*, *Cyber Grasp*, and *Cyber Glove* produced by the *Virtual Technologies Co*.

In contrast to these, however, the technology we suggest is much less costly because it does not require the application of a *Cyber Grasp* and a *Cyber Glove* to imitate the interaction. Besides, our devices provide a more realistic imitation of the operator's hands interaction with the body. This is due to the fact that the tactile interaction and the perception of the body shape and size are absolutely exact, since the i mitator size and shape reproduce these parameters of the virtual body and are sensed by the operator's own hands, rather than by a *Cyber Glove* and a *Cyber Grasp* which do not provide an exact sensing of the body shape and size. In addition, the use of a force-torque sensor to measure the resultant force and torque applied by the operator to the virtual body imitator and the use of movement imitator with prescribed mass-inertia characteristics allow fully complete reproduction of sensations that a man would have if he interacted with any real body, including a body in weightlessness. The Cyber Force system is uncapable to provide such a full reproduction.

The suggested technology is a little less versatile than the Cyber Force technology because of the necessity to replace imitators, depending on the type of virtual body, but in practice this is not a serious disadvantage. The number of body variants for an particular task is limited, and the cost of an imitator made from, say, foam plastic is quite low.

4. Complex Prototype

At present, a prototype of the complex for realization of virtual body immersion is developed whose structure was defined in sections 2 (Figure 1).

The prototype structure does not include yet functional unit 5 - a system for tracking spatial position and orientation of all elements in geometrical models of man-operator's arms, unit 4 - a system of two double video cameras mounted on operator's head for taking stereo images of arms and hands.

Figure 2 presents the prototype of testing complex created at present.

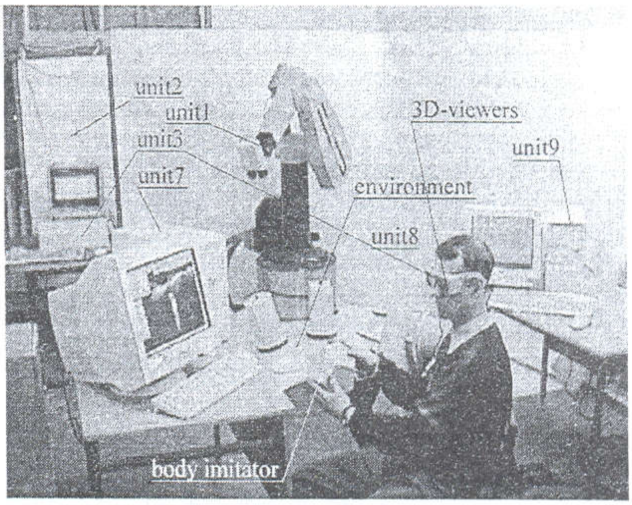

Figure 2. The Prototype of the Complex for Realization of Virtual Body Immersion

Software of the prototype, as its hardware, is not complete. Standart procedures of graphic libraries Open GL and written in Delphi procedures were used to develop of the graphic station software required for realization of Augmented Reality. The procedures generate 3D geometrical models of environment and virtual bodies. They form also images of these models. In our case surface of modules of International Orbital Station "Alpha" (IOS) is taken as an environment and anthropomorphic manipulator of a "Pelican" type with seven degrees of freedom including gripper is used as virtual object.

Figure 3 shows 3D images of the IOS and virtual manipulator.

5. Experimental Testing

The goal of experimental testing is a verification of operability of the developed and built prototype of the complex, in particular, testing of ability to provide a continuity of visual sensing of dynamic scene image and testing of reality of tactile-force interaction of hands arms with virtual body, more precisely, with its imitator.

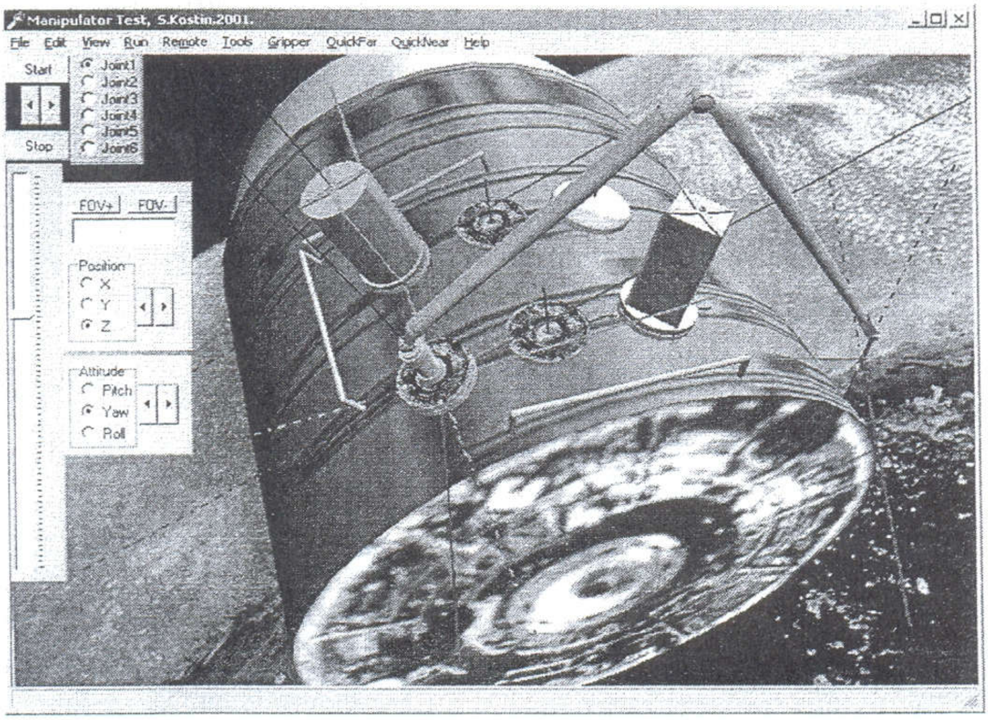

Figure 3. IOS Assembly Site and the Virtual-Manipulator Geometrical Model

For verification of the first mentioned ability the Orbital Complex geometrical model image and the anthropomorphic robot model image were employed.

Figure 4 shows wire representations of these geometrical model images as maximal complexity of the representation, evaluated by number of lines, is 4200÷4500.

It was carried out several experiments. They were presented influence of an image complexity on frame calculation time. The complexity of images was seen changed first - owing input in image surface between wires. Second – owing input in image background, third – owing texture and background together.

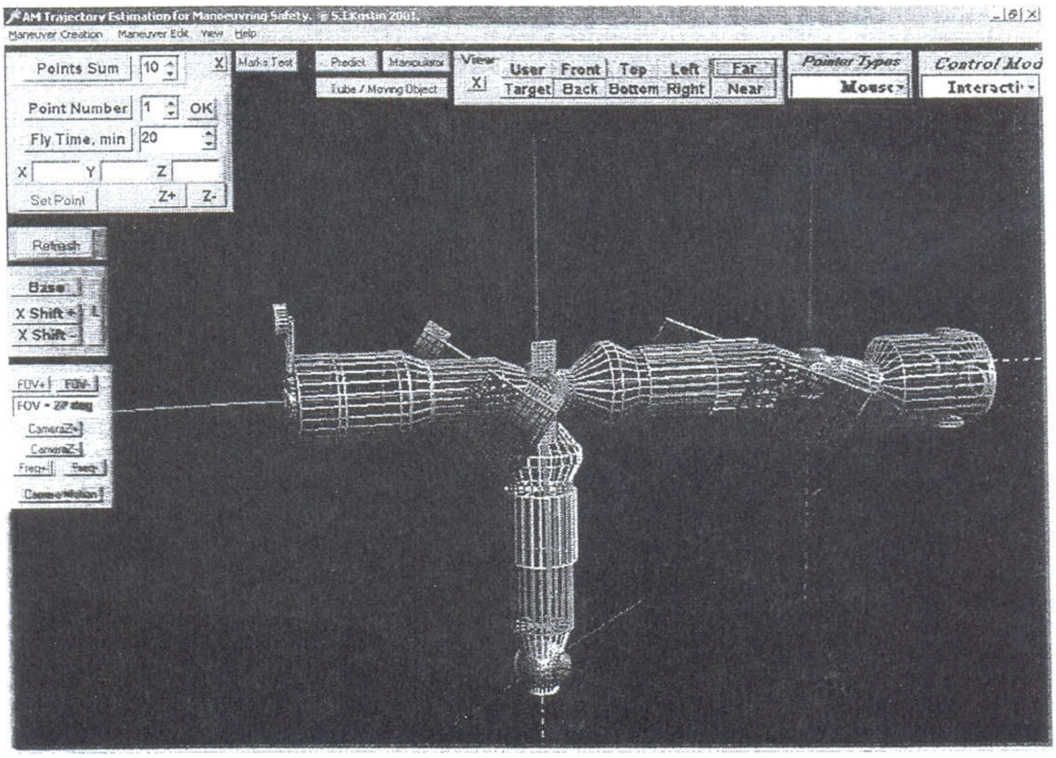

Figure 4. Wire Representations of Geometrical Model Images of IOC

Result of experimental testing was the following:

- in case of wire representation of geometrical models without background using the single frame calculation time is 12 msec (frame frequency is about 100 Hz);
- in case of representation of geometrical models with surface between wires without background and texture the frame frequency 60 Hz;
- in case of texture using – 50 Hz;
- in case background – 35 Hz.

Graphical station for generation computer synthesized images of geometrical models was employed: two processors Pentium III 800 MHz, videoadapter ASUS 7100. So, with the employed types of environment, virtual body and equipment of testing complex the frame frequency does not exceed 25 Hz. It is enough for providing continuity of visual sensing by variation of angle and scale of image caused by spatial movement of operator's head and the manipulator.

To verify the second of the mentioned abilities, that is a reality of the tactile-force interaction with the imitator of virtual body, dodecahedron and cubic were used as imitators. They should be moved under action of applied forces. The latter were applied by man's hands. Interaction with bodies of different masses was studied. The inertia matrices were chosen so that they correspond to cubic or dodecahedron made out of aluminum. An interaction under conditions when weight equals zero that is zero g, and also g is equal not zero is tested. Influence of friction and imitator stiffness is tested.

The experimental results showed that simulation of interaction of hands with bodies is enough realistic. Therefore, man perceived the process of interaction as a continuous one and sensed that he interact with real body.

6. Conclusion

Results of the initial stage of research in frame of virtual body immersion into real environment are the following:

1. Approach to development of technology for creation of Virtual objects in Real World with providing visual and tactile/force effects was proposed.
2. Structure and specification of soft/hardware complex for realization and testing of the proposed Technology was developed.
3. Prototype of a part of this complex was designed and made; it includes soft/hardware providing the proposed advanced method for realization of tactile/force interaction of man arms with virtual object and also soft/hardware to test reality of visual effect perception of the virtual objects into Real World.
4. Experimental testing has verified a possibility of a continuity of visual sensing of dynamic scene images and reality of tactile-force interaction og human hands with virtual body.

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