Research of Space Teleoperation Based on FreeForm and Augmented Reality Technology

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Abstract

People, who want to complete various operations, usually have some risks and difficulties in the distant, sinister and complex environment. At present, the space teleoperation technology extends the field of human perception, expanding the scope of human behavior, keeping people away from danger to accomplish the same tasks. However, there always exists communication latency problems inside the teleoperation process. To solve this problem, people use Augmented Reality Technology (AR) to superimpose the entity information obtained from the Space Teleoperation System to the real world. Currently, the traditional AR could only enhance or extend human visual system, but fail in effectively simulating touch states. In order to overcome this disadvantage, this paper introduces a novel method that combines the FreeForm Haptic System with AR to improve the tactual simulation. In addition, PHANTOM’s mechanical arm possesses high degrees of freedom and maneuverability. This article also proposes FreeForm mechanical arm as a remote actuators for space teleoperation.

Keywords

FreeForm; AR; Touch; Space Teleoperation

Introduction

In the distant and difficult environment, there is a risk and uncertainty to complete various operation for people. Space Teleoperation Technology could allow operators to manipulate remote actuator away from danger to finish all kinds of actions in a secure environment. However, teleoperation demands timely information and accurate feedback. The delayed information or error feedback will lead to misjudgment and even huge losses. In order to solve this problem, people usually build virtual scene projections for teleoperation system. However, in the actual modeling process, virtual scene is hard to be predicted at zero error. With the deepening of research, people begin to build the virtual models and simulate the graphic models according to the information of real images in real environment, in order to augment realistic effect. This method to complete high accuracy forecast is AR. It makes use of computer graphics and visualization technology to place virtual information, such as graphic and graphic attributes, to the real world, enhancing person’s visual system, expanding visual vision, enriching feedback and assisting users' work. However, relying only on visual system to simulate and correct virtual environment has been unable to meet people’s requirements. This paper puts forward that combine the FreeForm Haptic System and AR to strengthen the tactile simulation in the virtual reality environment.

FreeForm Haptic System Overview

FreeForm Haptic System relies on Three-Dimensional Touch as the core technology. So it could let users build, move and modify 3D models through human “Touch”—one of the most important human senses. Virtual objects and scenes could be set up and simulated at zero error accordingly.

Touch/Force Feedback System Structure

In 1993, J.K. Salisbury and Thomas Massie from the MIT artificial intelligence institute invented the 3D interactive equipment with force feedback—PHANTOM (as shown in FIGURE1) and its supporting software development tools—GHOST. The force feedback device is designed for the users to feel the force effect, so as to interact with the virtual model directly. PHANTOM’s great invention and wide application marks the arrival of the computer haptic technology.

FIGURE 1. PHANTOM DESKTOP
Professor Srinivasa, one of man-machine haptic lab at the MIT, elaborated the Touch/ Force Feedback System from the aspects of human body structure in more detail. He put the Virtual Reality System into People’s Perception System and Machine’s Perception System. Among them, the people’s perception includes vision, hearing, touch, smell and the sense of taste; the perception of machine includes vision, hearing and touch. People’s Perception System refers that when people come into contact with the object, the feeling signal is transmitted to the brain through the skin and the motor neurons activate muscle to generate hands’ movement. And Machine’s Perception System refers that when users manipulate ‘Touch/Force hardware devices, the sensor will take the user’s position and movement feedback to the computer. Then the hardware device passes touch or force sense to the users. At last, this computer gathers real-time information, and generates stereo pictures, voice and video to realize virtuality and reality synchronized.

Therefore, the Touch/Force Feedback System is generally made up of the users, the touch/force hardware system and the computer.

FreeForm Haptic System Structure

This system includes the tactile hardware device—PHANTOM, software design platform—FreeForm Modeling Plus and OHAE software development kit.

PHANTOM, as a hardware interface, provides users with the mechanical arm based on arm interaction. This mechanical arm has six degrees of freedom. The operator controls the handle at the end of the mechanical arm to operate the virtual model.

What connected to the mechanical arm is a stylus. There is a contact point on this stylus. PHANTOM belongs to force feedback device with a single point, so it could simulates touch signal through stylus’s contact point. In addition, there are three small engines exerting pressure on this stylus. Then the mechanical arm transmits the generated force in real time to the operator. So the operator could feel the hardness, material composition and surface roughness of virtual objects. Moreover, the stylus could be designed into various shapes to simulate various types of objects.

It is worth mentioning that the PHANTOM could operate flexibly. Its mechanical arm is free to push and pull. Its pedestal could rotate at liberty. Mechanical arm’s indentation or stretch will zoom out or in 3D models. Turning pedestal right or left could adjust the models’ view as shown in FIGURE 2.

Software design platform—FreeForm Modeling Plus—provides designers with digital clay similar to real clay, the carving pen corresponding to mechanical arm and 3D design interface (as shown in FIGURE 3). Among them, the digital clay is composed of tens of thousands of triangular mesh. So designers could control carving pen to deform virtual clay to model.

OHAE (OpenHaptics Academic Edition) is the FreeForm Haptic System’s software development kit. C language interface function provided by OpenHaptics implements the command set associated with touch/force sensing rendering, such as HLAPI function library and HDAPI function library. Using OHAE, developers could develop FreeForm software design platform secondly, also could develop applications based on touch/force sensing feedback.
Research of Space Teleoperation Based on Augmented Reality Technology

Space teleoperation usually adopts AR to realize the supplement to the realistic environment. Traditional AR mainly relies on the technology of dynamic registration based on vision to process virtual scene in order to combine virtuality and reality.

AR is the development of traditional Virtual Reality Technology (VR). It uses visual technology and computer graphics to build virtual object models, and utilizes the sensor technology to superpose the non-geometry information of virtual objects, scenes and real objects or the information prompted by the system to the real environment. Eventually it will achieve seamless integration between virtual scenes and real scenes, so as to realize the effect of enhanced reality. Visibly, AR could complete the combination of virtuality and reality, real-time interaction. So applying it to the space teleoperation will improve the accuracy of teleoperation, thereby improve the operability and safety of teleoperation system.

Traditional AR system based on vision uses two real and virtual cameras to deal with coexisting virtual and teleoperation’s work scenes at the same time. To handle the virtual scene is to register the virtual information. Virtual scene registration technology is to “place” virtual objects’ images generated by computer graphics and visualization technology to the real environment without inconsistent feeling. With the development of AR, dynamic registration technology based on vision has become the most popular technology to deal with virtual scene. Dynamic virtual information processing based on vision, analyzes multiple images to determine the relative relationship of the cameras and real scene, and projects the virtual object onto the people’s view to combine virtuality and reality in order to augment reality.

Research Approach of Space Teleoperation on the Augmented Reality Environment Based on FreeForm

Combination of FreeForm and Dynamic Registration Technology Based on Vision

Use augmented reality based on FreeForm to improve the traditional dynamic registration technology based on vision.

Traditional AR system based on vision often adopts the dynamic registration technology and stereo display technology to augment reality. However, in all human perception, the tactile sensitivity is much higher than the visual sensitivity. Superposing the virtual objects or scenes to real scenes by Touch/Force Sense becomes easier and vivid. In the process of modeling and manipulating virtual objects to move, FreeForm mechanical arm is equivalent to the designer’s hand to interact with the virtual scenes freely according to the design thinking and operation requirements of human beings. When mechanical arm manipulates the virtual object based on FreeForm, designers could truly feel the force feedback carried by PHANTOM as the designer’s hand touching the object directly. Incorporating virtual scenes and real scenes by haptic sense could more accurately forecast the virtual scenes, so as to realize “enhancement” of the immersive and authenticity for virtual environment. In addition, there are several ways to realize users to interact with the virtual scene by FreeForm mechanical arm, such as touch, movement, deformation and grasping (as shown in FIGURE 4).etc. And it will produce different feedback intensities and directions according to the different interactions to give the tactile information to space teleoperation system directly. Tactile information generated by the FreeForm mechanical arm, and the visual display information generated by visual registration or stereo display technology, could further to determine the relationship of the virtual object and the observer with high efficiency and zero error, and actualize the virtual object or scene, so as to achieve the mix of virtuality and reality.

FIGURE 4. GRASP, DEFORM, MOVE VIRTUAL OBJECT

3D Touch Application Development

Putting existing third-party applications and new applications together by OpenHaptics Kit could develop applications based on 3D Touch.

Since OHAE development kit could make secondary development of FreeForm software platform, users could add different appearance attributes and behavior to the original models according to the
different requirements. Applications based on OpenHaptics are divided into three threads: graphics rendering thread, touch detection thread and touch/force sensing rendering thread. Firstly, the graphics rendering thread renders collected graphics, and provides rendering information for the second thread. Secondly, the touch detection thread determines the touch position between the PHANTOM and virtual objects, and provides the touch position collection for the third thread. Finally, the touch/force sensing rendering thread reads the physical position and behavior of the PHANTOM mechanical arm, transforming them to the mechanical arm’s posture in the virtual scene, calculating the feedback intensities and directions according to the physical location, behavior and surface properties of the virtual object, passing the calculated results to the PHANTOM mechanical arm, and then outputs them to users. In this way could we easily identify the relative position between the operator and the virtual object, and could the operator precisely control the virtual object to achieve the effect of augmented reality.

Conclusions
With the rapid development and popularization of computer haptic technology, FreeForm Haptic System will be widely used in aerospace, clinical medicine, film and television, animation design and other fields. FreeForm Haptic System could not only design, grasp, move and deform virtual objects freely and easily, but also could combine with AR to simulate and emulate the virtual scene on touch through the secondary development, so as to control space teleoperation in real time. AR based on the FreeForm proposed by this paper could simulate and correct the touch and vision of human senses at the same time to realize the combination of virtuality and reality at zero error.

ACKNOWLEDGMENT
This paper is guided by Professor Zhao Zhengxu. This author would like to express heartfelt appreciation to him for his right guidance and patient counseling. This paper also has obtained the help of Zhao Zhengxu’s CNV Laboratory. Thanks to all teachers and classmates in this term here.

In addition, thank the support of the National Natural Science Foundation of China under Grant No.60873208.

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