Journal of Southeast University (English Edition) Vol.20 No.1 Mar. 2004 ISSN 1003—7985

Design of research platform on telerobot system based on virtual reality technology

Chen Junjie[1] Huang Weiyi[1] Song Aiguo[1] Xi Weiyang[1] Lin Chun[2]

([1] Department of Instrument Science and Technology, Southeast University, Nanjing 210096, China)

([2] Department of Automation, Nantong Institute of Technology, Nantong 226007, China)

Abstract: A new design strategy for a research platform of a telepresence telerobot system based on virtual reality technology is put forward. The design frame of the system is simply described, and its important core techniques are described. An octrees data structure is utilized to build kinematic and dynamic modeling of the virtual simulation environment, Delphi + OpenGL + 3DS MAX are adopted to carry through the virtual modeling and visible simulation exploitation of the slave-robot and its environment. Photo-correction is adopted to correct positioning deviation of the virtual geometric model and modeling errors. The cost of software and hardware equipment for the research platform realized is low. The master/slave robot (manipulator) system and all software in the system were designed and manufactured by our research group. The performance of the system has reached the level required for research. An indispensable experiment base is provided for the research of a telepresence telerobot system based on virtual reality technology.

Key words: tele-operation; virtual reality; research platform; 3-D simulation; design strategy

A teleoperation system with a telepresence effect, if used in a long-distance situation such as outer space activities or blue water exploration, will greatly improve people's efficiency in the progress of these fields. The problem remaining to be solved is the long communication time-delay between the slave-robot from far away and the local human-operator. It requires more than ten seconds. It's such a long time-delay that it impacts greatly on the running performance of the teleoperation system, which not only reduces the effect of telepresence, makes human operator hard to apperceive factually the circs of the environment from far away in real time, but also makes the system unsteady, especially in the process of force interaction between robot and environment. The most effective way to solve the communication time-delay problem in a telepresence telerobot system is to adopt virtual reality technology[1-3], which has been fully proved in both theoretical exploration and experimental research. Therefore, a telepresence telerobot system based on virtual reality technology is well worth researching. To effectively develop the research work, our research group has designed and manufactured a research platform for the system, taking into consideration the financial outlays and feasibility of research.

1 Platform Description

The research platform of the telepresence telerobot system based on virtual reality technology is shown in Fig. 1. It consists of a master-robot and a virtual simulation robot system at the master end and a slave-robot system at the slave end. The master-robot and virtual simulation robot system consists of a human operator, master-robot, sensor and controller for position and force information, processor for vision information, 3-D space display, communication tache, virtual environment generator, tool software and database; and the slave-robot system consists of a slave-robot, sensor and controller for position and force information, sensor and processor for vision information and software for checking and control*. There are two kinds of communication modes between the master end and the slave end: RS232 and Internet. To keep cost reasonable and research feasible, we adopted a commercial top grade PC at the master-robot, virtual simulation robot, and slave-robot systems, and the master-slave robot (that is manipulator when realized) system and all its software was designed and manufactured by our research group.

Received 2003-07-25.

Foundation items: The National High Technology Research and Development Program of China (863 Program) (No.2002AA742048), China Postdoctoral Science Foundation.

Biography: Chen Junjie (1958—), male, doctor, professor, chen.jj@seu.edu.cn.

* It should be pointed out that, at present, in a telerobot system, the apperception of the human operator to the real environment mainly comes from vision information feedback and position, force/touch information feedback. Therefore, the research platform established in this paper is merely one kind of structure of vision, position and force/touch information.

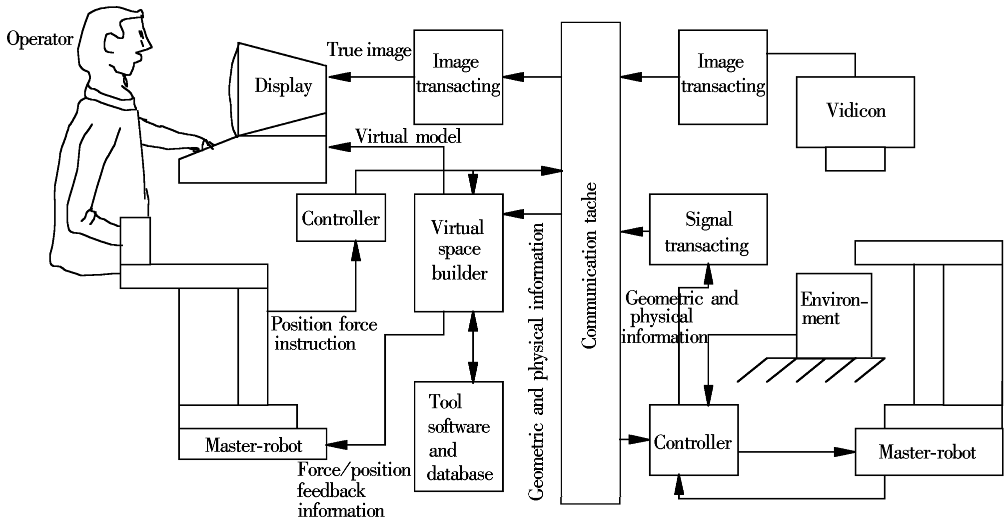

Fig.1 Structure frame of research platform of telepresence telerobot system based on virtual reality technology

The primary functions of the master-robot and the virtual simulation robot system are as follows:

① Communicate with slave-robot system, and send and receive data to/from slave-robot;

② Communicate with 3-D solid virtual simulation system, and exchange data between human-operator and virtual simulation system, and between virtual simulation system and master-slave robot;

③ Simulate communication time-delay in the system;

④ Realize all sorts of measurement and control functions (including the research for all sorts of control algorithms) among the human operator, master-robot and virtual simulation robot at the master end;

⑤ Receive and dispose vision information from the slave-robot, and generate a 3-D graph of the virtual simulation robot and virtual environment then correct its errors, and assume a friendly interactive interface between the human operator and computer;

⑥ Realize kinematic and dynamic modeling, visible simulation and error correction of the master-robot, virtual simulation robot and virtual environment in the system, and realize its large-scale calculation for real-time planning and collision detecting.

The primary functions of the slave-robot system are as follows:

① Communicate with master-robot and virtual simulation robot system, that is to send data to the master-robot and virtual simulation system and receive data from the system;

② Realize all sorts of measurement and control functions (including the research for all sorts of control algorithms) between robot and environment at the slave end;

③ Realize kinematic and dynamic modeling and its parameter identification of slave-robot and real environment in the system; receive, transact and send out vision information of slave-robot.

The central ideal of the system is to take a virtual simulation robot, replace the real robot, as the operating object of the human operator. Human operator and virtual simulation robot are both built at the master end. They can interact with each other in real time without time-delay. And the real robot at the slave end repeats the manipulation of a virtual simulation robot after communications time-delay. Whereas with a strategy like this, the virtual simulation robot is designed in an absolutely correspondence position as the real robot when choosing the structure of the whole system; therefore both the data interface and the operation interface go all the way, which not only enhances the currency of the software and hardware systems, but also reduces the quantity of modules, and reduces the corresponding difficulty in modules synchronously. The calculation result of kinematics and dynamics, and the result of planning and collision detecting can be used by the virtual simulation robot replacing the real robot. It is not necessary to programme these aspects respectively for two different objects. And all kinds of control algorithms can also be realized expediently in the virtual simulation platform and the real robot. It is convenient to the research for all sorts of control algorithm.

In the system, large-scale mathematical calculations, like modeling and visible simulation of kinematics and dynamics, real-time planning and collision detecting, require a mass of system resources, which impacts greatly on the 3-D graphing ability of the computer. To bring the 3-D graph system into good play, we import a distributed concept into the 3-D robot virtual simulation system. To fully ensure the quality of the 3-D graph, we replant large-scale mathematical calculation functions for virtual simulation of robot and environment respectively, modeling and visible simulation of kinematics and dynamics, real-time planning and collision detecting, to several top grade computers with great calculation ability. Since it comes down to the matter of interlinkage heterogeneously of computers with the whole system, we choose TCP/IP agreement as network low-layer agreement of the whole system.

2 Creation of a Virtual Simulation Robot and Virtual Simulation Environment at the Master End

The virtual simulation subsystem is the core of the system. It consists of a virtual simulation robot and graph simulation, kinematic simulation and dynamic simulation of the environment. To meet the need of real time and speediness when the human operator operates the master manipulator to make the virtual simulation robot run or interact with the virtual simulation environment, we adopt a simple boundary method to describe the virtual simulation robot. Because of the movement odds of the virtual simulation environment being less than those of the virtual simulation robot, and in order to show the 3-D graph effect of the virtual simulation environment and considering kinematic and dynamic modeling of the virtual simulation environment, we adopt octrees data structure to build the virtual simulation environment[4]. Octrees is one way of counting space occupancy of hiberarchy. It describes spacial entities of discretional shapes with unitive and simple form and structure by certain rules. The output can be hidden or shown easily, and the data structure is simple and consistent. Moreover, it is easy to realize gathering operations, minimal distance calculation and the calculation of physical quantities like volume, quality, weight, moment of inertia, dampness, rigidity and so on.

The method of intercalating material quality is adopted to transact the surface of objects. Material quality has attributes like color (shown as RGB), brightness, transparency, and roughness. When the object is selected, we can intercalate the material quality effect by means of a material quality editor. For example, plastic material has good transparency, rough surface, and bright color; and metal material has poor transparency, ashy or black color, some of them glisten on the surface. The method is commonly adopted when transacting small objects or simulating simple and single-material objects. The method has advantages like high transaction speed and small modeling workload.

The virtual modeling and visible simulation software Delphi is adopted as its programming environment, with OpenGL as its 3-D graph software library. The excellent graph function of 3DS MAX is used. Delphi is a visible high-speed application programming empoldering tool produced by the Borland Company. Using the Delphi program can win support of abundant third party components, and avoid wasting too much time and energy in writing program details. So it can greatly reduce our program workload. OpenGL, produced by SGI Company, is a graph library of the API form. At present, it has been used as the 3-D graph standard by several great companies such as Microsoft, SGI, IBM, DEC, SUN, and HP. OpenGL can work in SGI workstations, PC and MAC computers with the operating system of IRIX, Windows 9x, Windows NT, OS/2, and UNIX, which makes it possible to realize virtual modeling and empolder visible simulation software in ordinary computers. Furthermore, by OpenGL established model can be controlled at your convenience, and there is an excellent real-time interacting function. So it is a correct choice to adopt Delphi + OpenGL + 3DS MAX to carry through the virtual modeling and visible simulation exploitation of slave-robot and its environment.

The most important content in 3-D graph simulation program is organizing and saving model data. For the OpenGL graph interface has no form and structured Boolean operation function, it is impossible to draw complicated graphs, such as refined model or breathing landform scenes, using simply the function of OpenGL in 3-D graph simulation program. And there is another problem. If we adopt software like 3DS MAX or AutoCAD to modeling, how should we read the model data of these format and redraw in OpenGL? The 3ds files established by 3DS MAX or dxf files established by AutoCAD can be read with a special VCL device. We can also read the information of the model from these files according to their format, then save as an array or index for transferring. Whereas the structure of the obj 3-D graph data file of WaveFront is very simple. We use 3-D exploration or Milkshape 3-D to transform the 3ds file format established with 3DS MAX into obj format and read it, then redraw an integrated model by means of the counterchanges like translation, eddy, zoom and so on in the OpenGL graphics interface.

A virtual simulation graphs created with the method introduced above are shown in Fig. 2 and Fig.3.

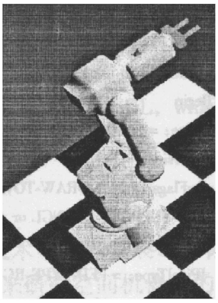

Fig.2 3-D model of reading obj format in OpenGL

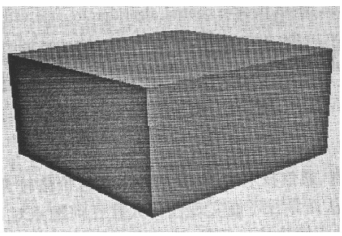

Fig.3 Magnetic disk model upbuilded in OpenGL

3 Calibration of Solid Vision and 3-D Simulation Model

One important character of the system is that the operation of control end in the system is finished on vision telepresence. Solid vision is realized by CCD vidicon equipped near the robot at the slave end, model creation computer at the master end, and communication tache. The solid vision has three main functions:

① To help the human operator gain vision telepresence about the work scene of the robot at the slave end.

② To use 3-D graph simulation and video frequency image superposition technology to calibrate the virtual simulation robot and virtual simulation environment models.

③ To use the geometric model, kinematic and dynamic model characters, the interdependent relationship for existence and influence, cooperative relation of their parameters, and to calibrate virtual simulation kinematic and dynamic parameters at the master end through correlative information sent back by the slave robot and the environment.

When a human operator manipulates a master-robot to control the virtual simulation robot and slave-robot, there are video frequency images of the slave-robot and real environment gained from CCD vidicon at the slave end, in addition to the 3-D geometry models of virtual simulation robot and virtual simulation environment established by computers. When a human operator manipulates the master-robot to run, the virtual simulation robot begins it at once (no time-delay), but the slave-robot begins after a time-delay. It is shown on the computer screen that, the geometric model of the virtual simulation robot runs to a certain position firstly, and it follows that the video frequency image of the slave-robot moves after the virtual simulation robot to the same position. For the geometric model orientation deviation and modeling error of movements of the virtual simulation robot and virtual simulation environment, geometric model positions of the virtual simulation robot and the virtual simulation environment cannot correspond the positions of the video frequency image of the slave-robot and the real environment after a time-delay. To correct the deviation and the error, we adopt photography-correction to superpose the geometric models of the virtual simulation robot and the virtual simulation environment onto the video frequency images of the slave-robot and the real environment. We gain signals of the real time simulation the graph (that is the geometric model) exported by graph system superposing onto the video frequency image by using a video frequency synchronization board. The video frequency synchronization board synchronizes the graphics system output and the coming vidicon output be, and offers the video frequency switch function at the same time, that is, the signals of synchronization board exporting to the video frequency monitor, come from vidicon or are produced by the graph system. The switch relies on the γ plane value of each pels, but in practice application, we have γ plane value as video frequency switch to make geometric model of simulation and video frequency image of vidicon superpose.

The photography-correction process is finished through the alternation between the human operator and the system. The human operator sets up the corresponding relation between objective model point and photography point with a mouse at first, then the system can figure out the photography-correction matrix. Both the geometry model and the video frequency image are shown on the computer screen. Human operator firstly confirms a few objective points that needed correction on the geometric model with the mouse, then finds out the corresponding image points on the video frequency image. In this way, the corresponding relation between the 3-D objective point and the 2-D image point is set up, as far as all the objective points and the corresponding image points are confirmed. The corresponding relation between the 3-D objective point and the 2-D image point is described with a photography-correction matrix, which adopts linearity least-square or non-linearity least-square to calculate the photography-correction matrix. In case that the photography-correction matrix is worked out, it can superpose the virtual geometry models onto the video frequency images of the slave-robot and real environment, and keep consistent, so that it can correct the virtual geometry models. The calibration effect is shown in Fig.4.

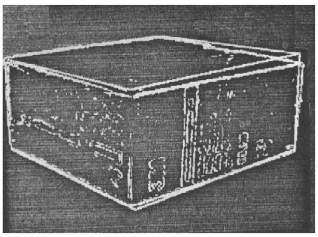

Fig.4 Furling of true image and 3-D model graph

4 Conclusion

This paper presents a new design strategy for a research platform of telepresence telerobot system based on virtual reality technology. The computers used in realized research platform are all commerial PC. Softwares of virtual simulation robot and virtual simulation environment can be created by computers at the master end. The master/slave robot (manipulator) system and all software in the system were designed and manufactured by our research group. The cost of software and hardware equipment of the research plat-form realized is low,but it is proved in practice use that the performance of the system has reached the needed level for research, and a rudiment of telepresence telerobot system based on virtual reality technology that can be used in practice has indeed come into being. Of course, we must do more research to perfect some aspects in the future, for example, the real-time capability of parameter identification in an unknown environment; the romance speed of the virtual environment, and the kindness and naturalness in the human-computer alternation, are all pivots that we should research and improve in the future.

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虚拟现实遥操作机器人系统研究平台的设计策略

陈俊杰[1] 黄惟一[1] 宋爱国[1] 奚维旸[1] 林 纯[2]

([1] 东南大学仪器科学与工程系, 南京 210096)
([2] 南通工学院自动化系, 南通 226007)

摘要: 提出了基于虚拟现实技术的临场感遥操作机器人系统研究平台的新的设计策略, 简述了其系统的设计框架, 详细描述了其中重要的核心技术.利用八叉树数据结构构筑虚拟仿真环境的运动学和动力学模型, 采用 Delphi + OpenGL + 3DS MAX 对从机器人及其环境进行可视化仿真.并采用摄像修正法修正虚拟几何模型定位偏差和建模误差.所实现的研究平台软硬件设备成本低, 主、从机器人(机械手)系统及系统中所有软件均由本课题组设计、研制, 系统性能达到了研究所需要的水平, 为虚拟现实临场感遥操作机器人系统的研究提供了不可缺少的实验床.

关键词: 遥操作; 虚拟现实; 研究平台; 3-D 仿真; 设计策略

中图分类号: TP242.2