MODELING OF MICROMANIPULATION ROBOT
IN VIRTUAL ENVIRONMENT

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Abstract
Micromanipulation has been recognized to be very difficult due to the inefficiency of traditional micromanipulation methods. The paper presents a general framework for micromanipulation robot based on virtual reality technology. The significance of introducing virtual reality into micromanipulation is analyzed, and the current research in this field is reviewed. Based on this, we propose a micromanipulation system that integrates virtual environment with vision feedback and force feedback. The system realizes vision close-loop control and force close-loop control to enhance the performance of micromanipulation device. A graphics modeling method is proposed for a microassembly task. Hardware and software implementation is described and discussion about the research is presented.

KEYWORDS: micromanipulation, virtual reality, vision feedback, force feedback, microassembly

1. Introduction
A micromanipulation robot is widely used such as to operate genes and to inspect integration circuits by using a stereoscopic microscopic. Micromanipulation systems with high precision and high intelligence to fulfill tasks independently are urgently demanded [1]. Micromanipulation refers to manipulation with the micro objects in the magnitude of micrometer [2][3]. Such precise works create heavy burdens as follows: firstly, the vision information provided by the microscope and the CCD camera is 2 dimensional and unclear and the vision information is limited, which cannot be observed from the other angle or other viewpoint, so the operator is easy to get visual fatigue; secondly, since the characteristic of micromanipulation is high precision and small working place, any operating error can lead to the failure of the entire manipulation process. It is necessary to perform the micromanipulation with the aid of visual, tactile and force feedback by introducing virtual reality technology. The projects in this field focused in Japan, Europe and America. One of its main research contents is to realize 3D visualization and another content is to realize force and haptics feedback.

A μ-robot system with micro precision was realized with the aid of virtual reality interface and microscope visualized system by A. Sulzmann in the Swiss Federal Institute of Technology Lausanne[4]. Fumihito Arai built a bio-micromanipulation platform using 3D visualizing method with calibration between virtual space and real space [5]. Tokyo University, Waseda University and Suzuki Motor Corporation cooperated and developed a virtual surgery system with force feedback to handle organs as elastic models [6].

A project was developed at Helsinki University of Technology in Finland to create a model of micro world and tools using virtual reality technology. Quan Zhou studied the micro-scaled effect such as van de waals forces, electrostatic forces etc in detail [7].

In the remainder of this paper is organized as follows: The general framework will be presented in Section 2. Section 3 discusses the hardware and software implementation and we conclude this paper in section 4.
2. System Framework

The framework of the micromanipulation system we proposed is described in Fig. 1. It centers on the virtual environment. The user can directly control the virtual environment through the human-machine interface by program or by the master hand. The position information including translation and rotation command is delivered from master hand to virtual environment; via communication line it is delivered to the micromanipulation robot controller.

The operator can use a software switch to decide whether to work online or not. When the switch is on the OFF status, the virtual environment is a complete offline simulation environment. During this process, the virtual environment will check if there is any collision between objects and generate a virtual force to the master hand. This status can be used for previous simulation before the actual micromanipulation or as training system for the inexperienced operator. When the switch is on the ON status, the system is an online micromanipulation system. The user can operate the actual slave micromanipulation robot through the master hand, and the working environment will overlay the virtual environment real-time. Because of the mechanical error and some other unpredictable reason of the system, the position of manipulation robot and the virtual environment cannot be exactly synchronized. The virtual environment is revised by the actual working condition monitored by the vision system to get the actual pose and position.

The micro image processor can provide position (translation and rotation) information to calibrate the virtual environment.

3. Hardware and Software Implementation

3.1 Hardware Implementation

The micromanipulation robot in this system is a 6 DOF robot, shown in Fig. 2. It is made up of macro motion parts and micro motion parts. The macro motion parts have six motion parts driven by high precision step motors. The left one provides 2 DOF and the right one provides 4 DOF. The accuracy of translation part is 1 \( \mu m \), and the accuracy of rotation part is 0.01°. On the end of the left micromanipulator, a 3 DOF piezoactuated nano-positioner is installed, in which repeatability of each DOF is less than 30nm.

Image processing and visual serving control calculations are performed with a vision system consisting of a SMZ-3A optical microscope, 2 CCD Camera and a PCI-XR multi path video capture card with the resolution of 768 × 576.

Since the micromanipulator has 3 DOF, the master hand applied in the system at least has 3 DOF. Here we applied decoupling pantograph structure to design the master hand. The working space of the master terminal is 200 × 200 × 150 mm³, which is adequate for the operator in the macro world. Fig. 3 shows the photo of the master hand. With the master hand, force feedback can be achieved.
when the peg-in-hole microassembly task is taken whether in virtual environment or in really micromanipulation.

Megellan Spacemouse can provide 6DoF (3 translate and 3 rotate) to the operator when manipulating the virtual environment or real environment. With the button of the Spacemouse, we can control the motion of virtual and real environment respectively.

3.2 Software Implementation

Due to large working range and high positioning precision of micromanipulation robot, only one static model of the robot is inadequate. Therefore, during the graphic modeling of the micromanipulation robot, two dynamic models were built. Macro motion part refers to the entire micromanipulation robot modeled with the same geometry size; the other one is micro motion part referring to the micro peg and micro hole modeled with a given scale amplification with higher resolution. When the micro peg is approaching the micro hole from a far distance, macro motion model is used to monitor the process. After the distance between these two objects is under micrometer level, the virtual environment will automatically switch to display the micro model.

The virtual environment for micromanipulation robot is carried out using the commercial WorldToolKit(WTK) graphics library and Visual C++. WTK can import geometry modeling from other geometry tools such as 3DMAX, UG, AutoCAD, PRO/E. WTK provide tool to use textures to increase the complexity and realism of your virtual environment, allowing you to avoid performance degradation[8]. PRO/E is selected as geometry modeling tool. Detailed developing processing is described in Fig. 4. The virtual macro part is displayed in Fig. 5(a) and micro part of micromanipulation robot is showed in Fig. 5(b) based on a microassembly task.

3.3 Discussion

The modeling of micromanipulation based on virtual environment, is in fact the application of virtual reality into micromanipulation field. The main problem and some key techniques list as following:

- **Computer model of micromanipulation.** The main contents include geometry model, physical model and kinematics simulation. Since common sense does not always work in the micro world, virtual reality methods are especially suitable for microassembly planning. In microassembly adhesion and contact forces will be necessary.

- **Haptics and force interaction technique.** It is necessary to get force information in micromanipulation. Much emphasis is laid on haptics display and force feedback research. Haptics is still a difficult challenge in the VR research. The force model of micromanipulation is difficult to build up due to its nonlinearity.

- **Calibration of virtual environment.** The virtual environment depends on the precision of computer model, so it must calibrate with the position of the real feedback visual information to make preview and path planning possible. It is a main content to calibrate visual sensor.
information and virtual model[9].

- **Collision detection.** Rapid and precise collision detection is prerequisite to immerse into virtual environment with realistic force interaction. The main contents include constraint detection, collision detection and collision reaction.
- **Task planning under the virtual environment.** In search of an optimized method to realize rapid and correct microassembly task. In our research it is divided into gross planning of macro part and fine planning of micro part.

4. Conclusions

In our research, we set up a visual virtual manipulation platform for the micro world to supervise the manipulation process and virtual environment corresponding to the actual micromanipulation system to preview or simulate motion plan before the actual manipulation. Experiment show that it can greatly enhance the success rate of manipulation and reduce the possibility of the breaking of manipulated object and manipulating tool.

There are two kinds of close-loop control system in the framework. The vision close-loop control system calibrates the virtual model with vision feedback information. The other one is force close-loop control system. The operator can monitor the microassembly through the master hand with force feedback together with vision feedback.

The implementation proves a micromanipulation system based on virtual environment will be a valuable tool to enhance the performance of micromanipulation device and reduce the gap between the macro world and the micro world.

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