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# Construction of a sense of force feedback and vision for micro-objects

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**Abstract.** The purpose of this research was to develop a combined sense system that uses both force feedback and visual feedback to determine the shape of the microscopic features of a microsample. It is thought that the efficiency of minute procedures would be improved if the operator were able to have a sense of force while using a manipulator. We used a cantilever to touch a minute object and obtain a reaction force from the degree of bending. We constructed a haptic device that gives a sense of that force to the operator, who can feel the force when a user touches the sample with a cantilever. In addition, when the haptic device is used in simulations, the user can feel a force as if he had touched the sample.

***Key words***: force feedback, haptic interface, simulation.

## 1. Introduction

Technologies that can accurately perform minute work are now being sought for both medical treatment and in the field of manufacturing semiconductors. Such minute work is improved by using micromanipulators, but their operation is difficult because the operator has no sense of force; he relies only on sight through a microscope. As a result, a person skilled in the use of this technology is needed for all minute work. It is thought that the efficiency of minute work would be improved if the operator were able to have a sense of force while using a manipulator.

This study describes the development of a more efficient system for minute operations. Our aim was to develop a system using not only the sense of sight through a microscope, but also a sense of force from the manipulator. For this fundamental research, a system was created to assess the reaction force when a minute sample was touched. A cantilever was used to touch the sample, and the reaction force was obtained from the degree to which the sample bent. In addition, we used a haptic device and amplified the force feedback from a minute sample of a virtual object.

## 2. System Structure

### 2-1. System Summary

The structure of the system is shown in Fig. 1a, and a schematic view is shown in Fig. 1b. This system consists of a microscope with an automatic x-y stage, a piezo stage, a feedback stage controller to control the x-y stage, a piezo stage controller, a haptic device for transmitting force feedback (Fig. 2), a cantilever (Fig. 3), and a PC via which the user can control and operate these components. The sample was fixed on the x-y stage by an injector (Fig. 4) and a holding pipette (Fig. 5). When the cantilever, which was fixed to the piezo stage, touched the sample, the operator could feel a force as if he had touched the sample using the haptic device. The resolution of the piezo stage is 1 nm. Table 1 gives the specifications of the injector, and Table 2 gives the specifications of the holding pipette.

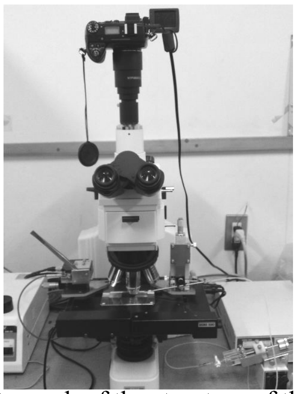

**Fig. 1a.** Photograph of the structure of the system.

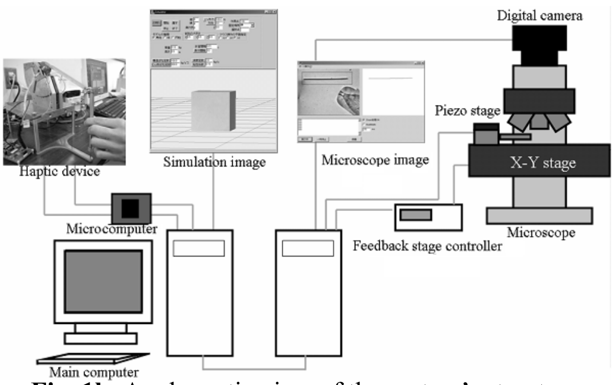


**Fig. 1b.** A schematic view of the system's structure.

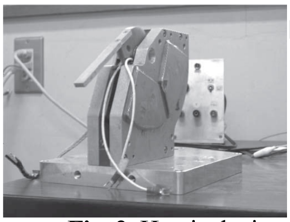

**Fig. 2.** Haptic device.

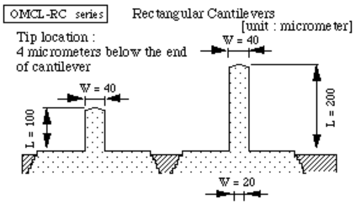


**Fig. 3.** Cantilever.

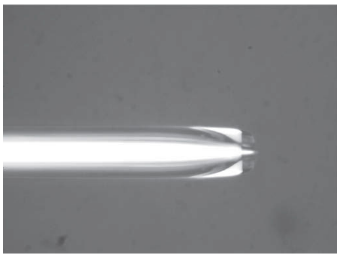

**Fig. 4.** Injector. **Fig. 5.** Tip of holding pipette.

**Table 1.** Specifics of the injector.

| | |
|---|---|
| Drive distance | 40 mm |
| Braking distance | 800 μ‖ |
| Size | 200×80×30 mm |
| Weight | 2 kg |

**Table 2.** Specifics of the holding pipette.

| | |
|---|---|
| Length | 60 mm |
| Inside diameter | 13 μm |

## 2-2. Haptic device

Figure 6 is a diagram of the haptic device. It consists primarily of a rotor, a laser, and a position-sensitive device (PSD). We installed a coil on the rotor with a polarity magnet, which generated electromagnetic induction by an electric current and a magnetic force. The angle of the rotor can be measured by the laser and the PSD. The rotor was able to follow any input waveform.

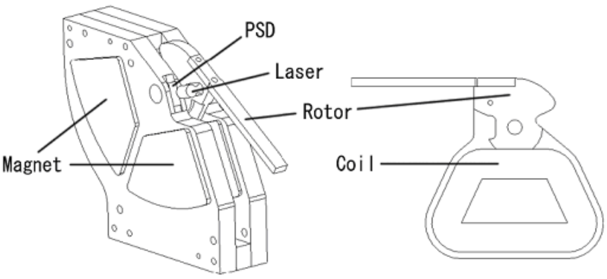


**Fig. 6.** Diagram of the haptic device.

It was necessary to control the actuator with a servomechanism on the actuator. Therefore, the system driving the actuator consisted of four actuators: a microcomputer, an inputting AD/DA port, an outputting microcomputer, and a PC outputting order value. The system controls the actuator during each part of the process. Figure 7 shows the structure of the haptic device.

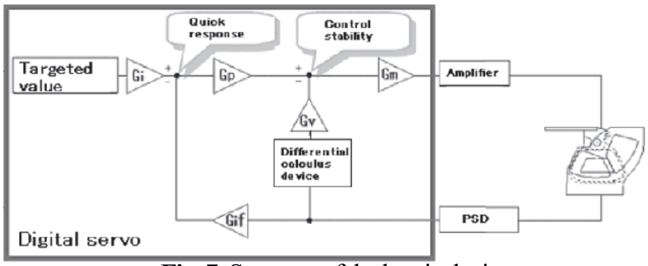


**Fig. 7.** Structure of the haptic device.

The actuator, which is structured by the PD control, is operated through a digital differential calculus device. A transfer function for the quadratic function system shown in Fig. 8 is provided for the actuator servo system. The role of each parameter of the control system is to adjust the total offset to a master in Gi/Gif, to regulate the item viscosity/resonance point in Gp/Gv, and to regulate the total gain in Gm. Table 3 is a list of the control parameters of the servomechanism system.

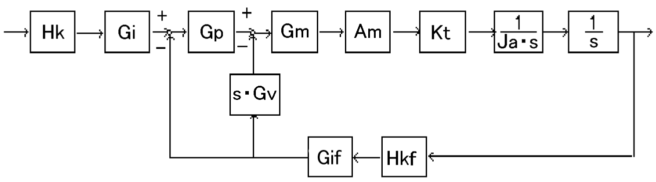


**Fig. 8.** Block diagram of the servomechanism system.

**Table 3** Control parameters of the servomechanism system

| Parameter | Reference | Unit |
|---|---|---|
| Gi | Controller Input Gain | 1.0 |
| Gif | Position Feedback Gain | 1.0 |
| Gp | Position Gain | 1.0 |
| Gv | Velocity Gain | 0.0015 |
| Gm | Manipulation Gain | 1.0 |
| Hk | Position Voltage Constant | 18.531 V/rad |
| Hkf | Position Voltage Feedback Constant | 18.531 V/rad |
| Am | Amplifier Constant | 1.0 A/V |
| Kt | Torque Constant | 2.768 Nm/A |
| Ja | Moment of Inertia | 0.0002147 kg $\cdot m^2$ |

## 3. Measuring the antipower

The reaction force is used to calculate the force that is applied by the minute object. In this experiment, we touched the minute object with the cantilever shown in Fig. 3, and the reaction force was obtained from the degree of bend of the cantilever. The layout of the experiment is shown in Figs. 7

and 8, and the environment of the experiment is shown in Figs. 9 and 10. As a result of this experiment, we obtained the reaction force applied by the minute object.

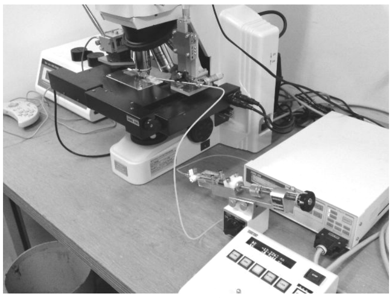

**Fig. 9.** Environment of the experiment.

**Fig. 10.** Environment of the experiment.

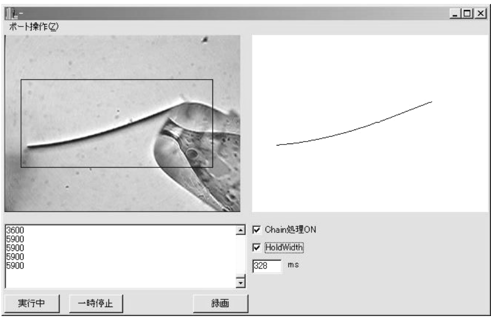


**Fig. 11.** Cantilever touching the tip of the holding pipette.

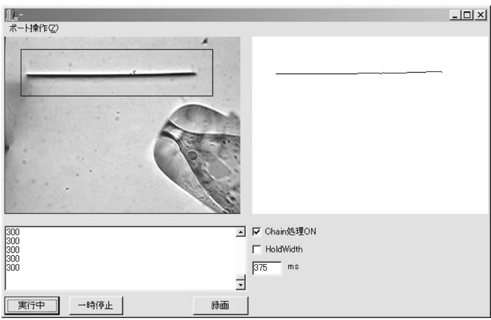


**Fig. 12.** The cantilever detection program.

Figure 11 shows the cantilever touching the tip of the holding pipette. The image processing speed of the cantilever was improved by the tracking process (Fig. 12). The bend of the cantilever is assumed to be linear-elastic so that Hooke's law may be applied. Then the restoring force F of the bend of the cantilever is given by

$$F = kx \qquad (1)$$

where x is the compression distance from the equilibrium position, and k is the spring constant.

## 4. Deforming the simulation of the sample

In this study, we aimed to build a working system using a microscope, a haptic device and a simulation. A fundamental element was the simulation of the deformation of a minute object. Figure 13 shows the graphical user interface (GUI) of the simulator. A graphic tool is created using OpenGL to draw the object and to choose the shape of the sample, for instance, a cube or sphere. A dynamic model of the sample consists of a spring-mass array of mass points in both the vertical and horizontal directions. An example of the arrangement of mass points is shown in Fig. 14. When a force was applied at a mass point, the simulation calculated the speed of all mass points that had been affected. The image is renewed after every ten calculations.

A spring is defined as having a size but no weight, and a mass point is defined as having a size, a weight and a rigid body. An arbitrary mass object can be placed on a spring on a bitmap (Fig. 15). In addition, a sample can be seen from various viewpoints, and the deformation of the sample, which is impossible to observe by microscope, can be checked. The shape of this object can be either a cube or a sphere, and any point may be selected as a fixed point or an operating point.

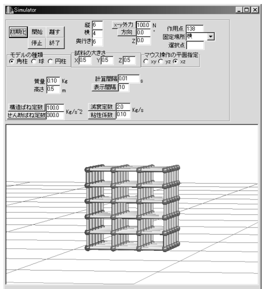

**Fig. 13.** Simulator.

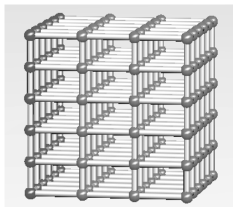

**Fig. 14.** Arrangement of mass points

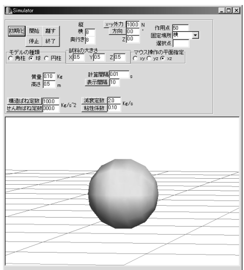

**Fig. 15.** Placing an arbitrary object on a bitmap.

The calculation method for the displacement of each mass point is based on Newton's equation of motion (Eq. 1) using the Euler method. A mass point is linked to an adjacent mass point at both ends of a spring. When the spring between the mass points is in the equilibrium position, the restoring force F is the sum of the elastic force of the construction spring and the shear spring, and the viscous force is given by

$$ma = \Sigma F \tag{2}$$

where $m$ is mass and $a$ is acceleration.

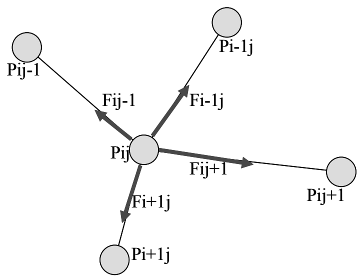


**Fig. 16.** Elasticity.

$\Sigma F$ is sum of the elastic force of the construction spring and shear spring, the viscous force and the damping force. To obtain the restoring force $F$, the restoring force was divided into $F_{damping}$, $F_{spring}$ and $F_{viscous}$. Equation 2 gives the following equations using the model shown in Fig. 16.

$$F_{spring} = \Sigma F_{ij} \tag{3}$$
$$F_{damping} = -C_d v_i \tag{4}$$
$$F_{viscous} = -C_v (v_i - v_j) \tag{5}$$
$$\Sigma F = F_{spring} + F_{damping} + F_{viscous} \tag{6}$$

where $C_d$ is the damping factor, $C_v$ is viscosity, and $v_i$ and $v_j$ are the velocities.

## 5. Conclusion

The present study evaluated whether the force feedback is amplified by touching a virtual object with a haptic device in a PC. We found that it is possible to amplify the reaction force, but were unable to create a large enough reaction force for a worker to feel its elasticity.

Future research should focus on building a system that allows a reaction force to be detected and shown more precisely. Such a system would make it possible to test smaller samples.

## 6. Acknowledgement

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