Study of virtual reality and haptic feedback for a 3D micromanipulation system

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Abstract

In this study, we focus on the use of augmented reality/virtual reality (AR/VR) and haptic feedback in an affordable and highly flexible micromanipulation system for a haptic device that supports microscopic manipulation of the interface between the work space and the operator. Further, the manipulation system considered in this research is used for assembling detailed parts in three dimensions under a microscope. The application of AR usually requires sensing of the work space with more than one microscope or sensor, but this system uses the background finite-difference method with background models for the monocular microscopic images of the work space. The VR support creates a 3D VR space with images captured by the monocular microscope. Instead of using the microscope, the operator manipulates the system by looking at the large screen of a PC monitor in order to perform the work carried out in the 3D VR space in a real work space. We use the haptic device for manipulations in the VR space. On the basis of the force generated along with the feedback, the operator can carry out positioning by using the pick and place method and the tactile sense gained by operating the haptic device.

Keywords*:* Micromanipulation, VR, AR, Haptic feedback

1. Introduction

In recent years, the miniaturization of parts has increased along with the demand for assembling these detailed parts [1]. However, the working method for the assembly of a micro part is not sufficient. If the worker who assembles a micro part while an operator uses a microscope is not a skilled worker, the part assembly will require a considerable amount of time and high accuracy may not be obtained. This could be attributed to the fact that the narrow workspace of micromanipulation has poor visibility and limited operability. In this research, we have developed a system independent of an operator's skill by using visual support [2] and haptic support [3]. In the case of visual support, a virtual reality space that reproduces the work environment using an image of the work area of the actual environment acquired from the microscope is created, and the operation within the virtual reality is reflected. In the case of haptic support, the object in the virtual reality space can provide a sense of touch and enable an intuitive operation [4]. Moreover, in this research, haptic support improves the handling accuracy by the use of a haptic device that restrains a motion and not just a simple haptic sensation such as the tactile sensation of an object.

2. Micromanipulation System

In this research, we have designed and built a microscopic operations supporting system that can assemble a 100-μm micro part under a microscope, as shown in Fig. 1. This system consists of a personal computer, a microscope for observing the micro parts and the work space, a CMOS camera, an XYZ positioning table for moving the end effector of the micromanipulation tool, and an X positioning table for moving a microscope. The XYZ positioning table is equipped with a handling tool at the tip [Fig. 2]. This handling tool uses a liquid bridge force [5]. The position of the handling tool is joined to a joystick using PHANToM Omni.

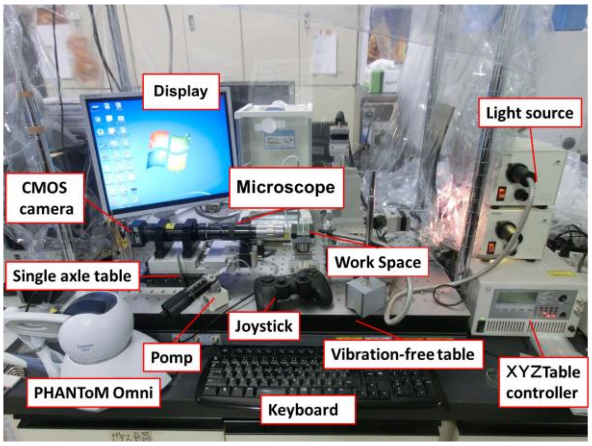

Fig. 1. Micromanipulation system

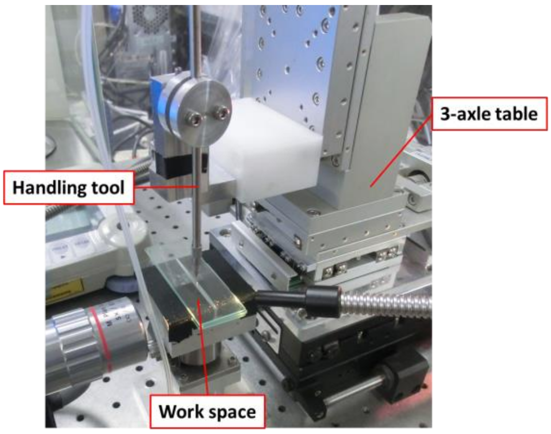

Fig. 2. Handling tool

3. Visual Support System for Micromanipulation System

This system provides visual support using AR/VR and haptic support using a haptic device. Fig. 3 shows the internal processing of a support system for the micromanipulations. The operator manipulates the PHANToM Omni of the haptic device, a joy stick, and a keyboard for the micromanipulation assembly by looking at the computer display that projects the microscopic image. In this system, image processing, AR processing, VR processing, haptic feedback processing, and move stage control are carried out inside a computer. In the case of translation table control, a command is sent to the XYZ positioning table in order to move the handling tool. The image of the work space is sent to the computer using a microscope and a camera, and thus, the image processing is carried out. Then, information required for an extended actual feeling and virtual reality is processed and rendered on the display.

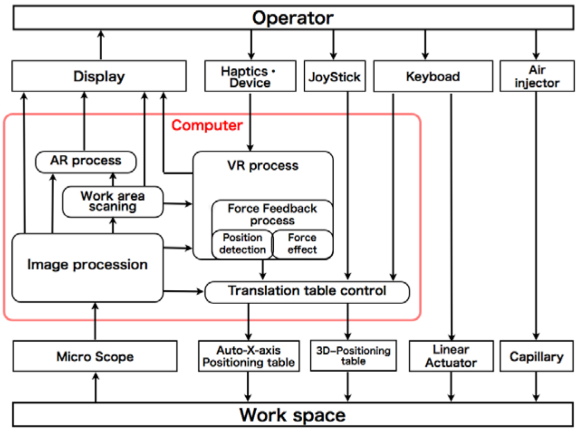

Fig. 3 Internal processing of a support system

3.1 Position Detection of a Microscopic Object

In this system, the location of a microscopic object required for augmented reality and virtual reality is computed by the recognition information about the shape of the microscopic features of a single eye, and the position information on a 1-axis stage (Fig. 4). The microscopic image has less light than a normal image, and hence, it is difficult to precisely recognize an object in this image. Therefore, image processing (background differencing technique, thresholding, labeling, and smoothing) is performed, and the recognition accuracy of a subject is increased. The method of detecting the position of an operational object involves moving the stage of the microscope from the side of working clearance, acquiring the image in each position, and performing the above-mentioned image processing on these images. First, the camera is moved to the place at which the object is not reflected, and an image for the background differencing technique is obtained. Next, the microscope is moved 2.5 μm, an image is taken, and image processing is performed in this image. Further, the position information on the operational object in this scene is obtained by performing the Hough transform of a circle. This procedure acquires 100 images and performs image processing in the work space at a depth of 2.5 mm; the position information in the depth direction of the operational object is determined from the position information on the moving stage after the object recognition.

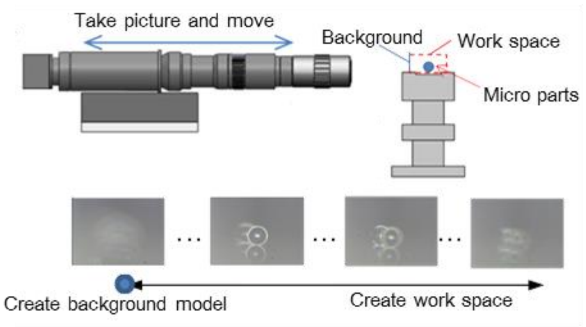

Fig. 4. Recognition of work space

3.2 Support System using AR/VR [6]

This system creates a virtual reality space on the basis of the position information acquired by image recognition. The virtual reality space is created using OpenGL [7]. This virtual reality space is a reappearance model of a work space and is created on the basis of the position and form information of the object under the microscope as obtained by image processing. The operator can do the required work by estimating the depth of this virtual reality space as he would in an actual environment. Moreover, in the 3D virtual reality space, under an actual microscope, the movement of and the changes in the observation point are easy to determine, and the operator can see the work space from arbitrary positions. Instead of using the microscope, the operator manipulates the object by looking at the PC screen, and the work performed in the 3D virtual reality space is performed in a real work space.

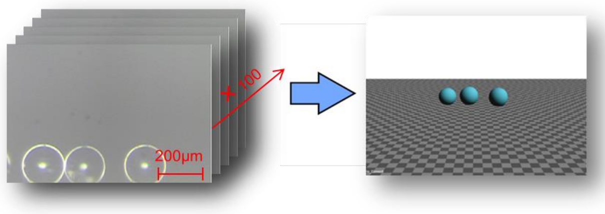

Fig. 5. Creation of VR space

4. Support System using Haptic Device

In this system, the operations support function of the haptic feedback using the PHANToM Omni is also implemented.

The intuitive work of an operator is determined by generating a tactile sensation of the object in the virtual space. In this system, the PHANToM Omni of the haptic device is used for the operation in the virtual reality space.

PHANToM Omni has a 6-axis position input and an interface in which a 3-axis haptic feedback is possible.

4.1 Haptic Feedback in VR Space

In this system, the haptic feedback is provided to the CG of the work space made from OpenGL (Fig. 6(1)). The creation of the haptic feedback model uses the OpenHaptics Toolkit (Fig. 6(2)). In the virtual reality space, the tip of the stylus handle of PHANToM Omni is synchronized with the handling tool of the actual environment and is expressed with a cursor (a blue triangular pyramid). The cursor, an operational object, and the floor generate a tactile sensation. However, the 3D model and the haptic model are separate and are arranged in piles. (Fig. 6) Therefore, an operator receives haptic feedback support and can perform work by using a tactile sensation of the object.

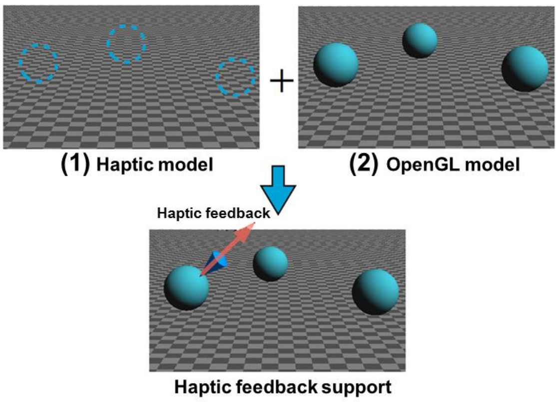

Fig. 6 Creation of Haptic model

4.2 Haptic support that Restrains Motion

This support is the support that restrains the motion of the operator's hand and reduces excessive vibrations of the hand. Further, this system reproduces work in a virtual reality space on the basis of the actual environment; however, the high flexibility of the manipulation interface may obstruct work. The most remarkable obstacle is the influence of unintended vibrations of the operator's hand. These vibrations affect the device directly and are also reflected in the actual environment, thus decreasing the accuracy of work. In such a case, generally, the system introduces a high-pass filter and controls the vibrations. Further, a virtual frictional force is exerted on the surrounding work area of the operational object in this research. This force is the frictional force committed to the movement of the cursor and decreases the vibrations. Although smooth operativity is sacrificed by introducing this support, the accuracy of handling improves and the efficiency of work increases.

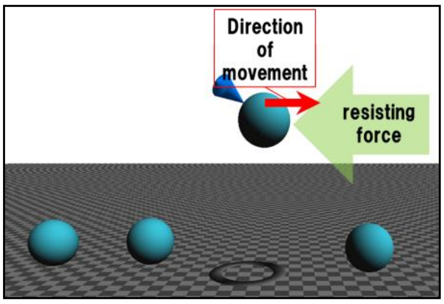

Fig. 7 Support system using restricted haptic feedback

5.Experimental Evaluation of Proposed System

5.1 Basic experiment

This experiment evaluates the vibration alleviation by haptic support.

In this experiment, an experimenter makes PHANToM Omni stand still for 15 seconds at the reference point and records the position information on the XYZ axis of PHANToM Omni, thus estimating the variation in the position of each axis on the handling tool (Fig. 9).

Based on a certain experimenter's measurement data, the position data of the handling tool are plotted on a 3D graph (Figs. 10 and 11).

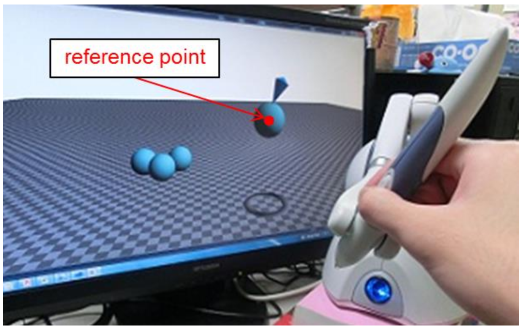

Fig. 9 Experimental image

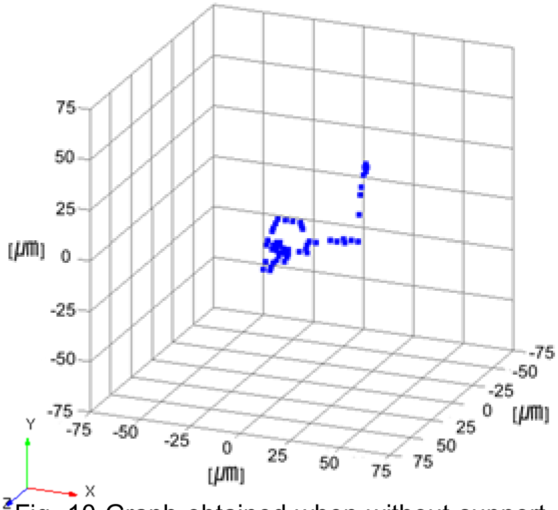

Fig. 10 Graph obtained when without support

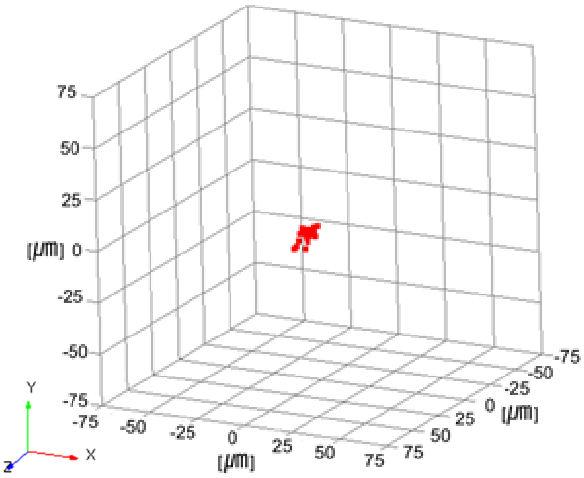

Fig. 11 Graph obtained when with support

According to Figs. 9 and 10, the variation in the device position decreases by introducing haptic support that restrains a motion. This support in which the variation in the device position decreases by the generation of the inner force is effective in mitigating the vibrations.

5.2 Experimental Evaluation of Support System

This experiment compares the time to end a set task performed with and without a support. This task involves the creation of a 3D triangle with four 200-μm glass beads (Fig. 12). This task requires the accuracy of handling that arranges the last glass bead correctly on the foundation of three balls. In order to measure the exact working efficiency, the experiment starting point is the time at which the four objects are arranged in a horizontal line, and the ending point is the time at which the handling tool is separated from the last glass bead. The device used for operation is PHANToM Omni, and when in the case when a support is used, the device uses restricted haptic feedback. We compare the experimental results obtained when a support was used and when it was not used, and compute the increase in the working efficiency. The result of the experiment is presented in Table 1.

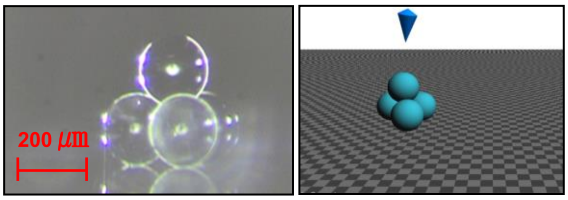

Fig. 12 Creation of 3D triangle

Table 1 Experimental support system

Operator	Without Support[sec]	With Support [sec]
A	749	294
B	716	355
C	1589	394
D	225	165
Average	819	302

From the experimental result, we note that the working hours have been shortened by approximately 63% by introducing this work supporting system. The reasons for the improvement in the working efficiency of this task are the introduction of the haptic support that restrains a motion, the decrease in the vibrations that interfere with the work, and the increase in the handling accuracy. Moreover, by introducing the vision support using VR, we can estimate the depth of the working clearance, which could not be estimated under a microscope; the micro assembly also becomes easy. Therefore, the support proposed by this research is effective. However, the problem of this system is that it is difficult to distinguish the sensation of the inner force when the tactile sensation support of objects is used simultaneously and the inner force sensation support is restricted.

6. Conclusion

In this research, we proposed AR/VR and haptic feedback support, and obtained the following results:

(1) The VR space using virtual reality was created, and the visibility of the microscope improved.

(2) Intuitive handling was made possible by using haptic feedback.

(3) The task accuracy was improved by using a haptic support that restrained the motion.

(4) The working time of micromanipulation decreased by 63% when the proposed supporting system was used.

In our future work, we intend to improve the performance of the handling manipulation tool.

Acknowledgment

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