Grasping microscopic objects by an optical trapping system controlled by five finger tips

In-Yong Park, Sun-Uk Hwang, Je-Hoon Song and Yong-Gu Lee*
Nanoscale Simulations Laboratory
Department of Mechatronics, Gwangju Institute of Science and Technology (GIST)
1 Oryong-dong, Puk-gu, Gwangju, 500-712, South Korea

ABSTRACT

There are increased needs for manipulating microscopic objects. One of enabling technologies is an instrument called optical tweezers (OT) that uses a focused laser beam to trap and move microscopic objects. OT has been shown effective for directly manipulating spherical, cylindrical or axis-symmetrical shapes. For other forms of shapes that do not show any symmetry, there have been works on using micrometer sized balls as a handle to indirectly manipulate the objects. Direct manipulation is difficult because complex trapping potential needs to be calculated to stably trap non-symmetrical shapes. User interfaces for these “indirect” systems use a computer mouse to design a layout of balls for surrounding (holding) an object and a trajectory that describes how these balls as a whole moves. The contained object pushed by these surrounding balls then moves accordingly. In this study, we introduce an intuitive user interface system for manipulating these balls. Using virtual reality gloves, each finger tip position of an operator is used to position control these balls. This user interface system enables the operator to intuitively grasp, move and release irregular formed shapes.

Keywords: Optical tweezers, User interface, Virtual reality, Nanoassembly

1. INTRODUCTION

Since the introduction of optical tweezers (OT) by Arthur Ashkin1 in 1986, OT has been used as an effective tool for controlling the positions and orientations of micrometer to nanometer scale objects. The application fields of OT comprise of biology2, chemistry3, colloidal science4 and membrane technology5. And they are expanded rapidly to new fields. However, until now, most researches have focused on expanding application fields or analyzing the phenomena. In other words, researchers considered OT as a science not paying much attention to its role as a tool for “manufacturing.” Manufacturing in a sense that most reported works have not achieved enough sophistication and reliability such that OT can be used in an industry field rather than in a laboratory. To leap from a simple tool that only measures elastic properties of cellular membranes or moves microscopic objects to a more complex tool that can be used in manufacturing processes, we need to develop a method that can control the posture of microscopic objects accurately. This control also brings up the issue of intuitive user interface for the operator. We all know that trapped object will follow the movement of the laser focal point. Thus controlling the focal point position will control the movement of trapped objects. The focal point can be moved by tilting the laser reflection mirror or moving the sample stage. These direct maneuverings of instruments are difficult in the point of view of the user. Also, complex movements are extremely difficult to achieve. There are relatively few reported works about a user interface of OT. X. Xun at al.6 developed a user interface system that linked the movement of a digital pen to the focal point. This interface freed the operator from the burden of controlling the beam steering devices. And pay more attention to the task of moving the focal point. Although intuitive, this method requires direct trapping of the target object. And based on the geometry and the refractive index of the object, it may not be always feasible to trap the object. Our approach uses indirect spherical handles to “hold” any object and thus is immune to these kinds of problems.

In this report, we present a user interface system that uses a virtual glove. The movements of five trapped spheres are controlled by five finger tips of the operator. These trapped spheres act as a handle that can grab a secondary object. Each sphere is trapped by a scanning optical tweezers system that time shares the laser to simultaneously trap each sphere. In the point of view of the operator, he/she can concentrate on grabbing by five finger tips and the system

* Corresponding Author, lygu@gist.ac.kr
automatically traps each sphere to coincide its location with the location of corresponding finger tip. Thus the user can naturally grab a microscopic object, oblivious of the complexity of the optical tweezers.

2. EXPERIMENTAL SETUP

Figure 1 illustrates the schematic layout of our apparatus. For the efficiency in utilizing the laser power, the beam is designed to overfill the objective entrance aperture. Also, the laser is collimated when entering the objective entrance aperture. The laser manufactured by BWC has a wavelength of 1064 nm. And it is scanned by a piezo activated tilt mirror that operates in the order of 1Khz. Tilt mirror is controlled by a C-300 Series controller from nPoint. There is also a CCD camera for viewing the trapped sample in real time. And the controller and CCD are connected to a workstation that has a CyberGlove by Virtual Technologies, inc. attached. This is used as a user interface for the operator.

The numerical aperture of the objective lens from Edmund is 1.25 with 100 magnification factor. To protect the CCD from the laser, a dichoric mirror (DM) was used to reflect the laser beam and transmit the visible light. Polystyrene beads of 1.79um are used for trapping.

3. MULTIPLE BEAMS AND SCANNING

In the early development of OT, single optical trap has been used to trap single objects. However, because of the need for more complex traps, from dual optical traps to multiple optical traps have been developed. Multiple optical traps can be achieved by time sharing the laser focus on multiple locations. Galvano mirror, piezo activated mirror and acousto-optic modulator can be used to rapidly move the laser focus. On the other hand, multiple optical traps can also be obtained by holography. This is realized by spatial light modulators.

In this report, we use a piezo activated mirror to rapidly scan the laser focal point. And by time sharing the focal point locations, we are able to trap multiple objects. The scanning speed is carefully selected by several factors. Those are the size of the trapped spheres and the viscosity of the immersed medium. Furthermore, the scanning speed must be faster than the time scale of the Brownian motion of the target object.
3.1 Programming for the motion of tilt mirror

For controlling the angle of the tilt mirror, we need to be able to send a large amount of data to the controller. The device that we have allows two interfacing methods. They are USB and HSP (High Speed Parallel). USB interface that only allowed 500 angle commands per second was not suitable for our scanning demand. This is due to the limit in the data bandwidth of USB. Thus we chose to use HSP interface. HSP allows 40,000 angle commands per second. HSP interface is available on the controller port and a cable is connected from this port to the computer by DAQ PCI-6534 interface card\(^1\) from National Instrument. Thus our angle commands are sent to the controller by DAQ PCI-6534 and the controller sends appropriate voltages to the tilt mirror to change the angle of the tilt. It is common to use a graphical programming environment such as LabVIEW\(^14\) to control this kind of set up. However, because of the need to interface with the virtual glove that was supported on C++ programming environment, we chose to use Visual C++ .NET from Microsoft\(^15\). The developed program is capable of calculating the appropriate trajectory of the laser scan based on the positions of the operator’s five finger tips. There are two important considerations when calculating the trajectory. Those are dwell time that determines how long the beam spot must stay when it is positioned at the finger tip and the interpolating time that determines how fast it should move in between the finger tips. By varying these time variables we can make the scan continuous and smooth or discontinuous.

3.2 Integrating CyberGlove\(^\circledast\) and tilt mirror

The objective of this work is to control the angle of the tilt mirror by the movements of fingertips. This requires a tight integration between the tilt mirror and the CyberGlove\(^\circledast\). Figure 2 illustrates the schematic diagram of the system architecture.

In order to change the angle of the tilt mirror, the finger tips’ positions are monitored by the CyberGlove\(^\circledast\) and the required angles of the tilt mirror are sent to the controller by the HSP interface. This is done in real time. Laser that is reflected on the tilt mirror surface is focused and moves accordingly to the position of the finger tips. The operator can see the movement of five spheres through CCD and can control the spheres at his/her will.

![Diagram of system architecture and streaming data](image_url)

The coordinate values of the finger tips are three-dimensional and we abandon the height value that is orthogonal to the hand surface. Thus our system is two-dimensional. This is because our scanning space is planar. For three-dimensional scanning, we need additional device to change the focal point in the direction of the beam propagation. This is being investigated. The workspace of the fingertips is mapped to the workspace of the focal point so that finer finger tips movements can be used with maximal resolution. When doing a larger scale motion such as a hand motion, the motorized specimen stage moves accordingly. As we can see from Fig. 2, the system is a closed loop control system. And human operator works as a controller compensating errors. Tilt mirror rotates by the input angles and thus can use any device other than the CyberGlove\(^\circledast\), that can generate angle values.
4. RESULTS AND ANALYSIS

4.1 Creating multiple beam spots by scanning a single laser beam

Figure 3: The image of scanning laser without 5 trapped spheres while folding and spreading out fingers. Each number denotes, in sequence, the thumb, index, middle, ring and little fingers.

Figure 3 shows five bright spots that are position controlled by the GyberGlove®. Internally, there is a busy computing performed that calculates the angles of the tilt mirror to translate the focal points. Figure 3 only shows the beam spots without actually trapping the polystyrene spheres. From the state of fully spread hand in Fig. 3 (a), fingers are gradually moved close to each other until Fig. 3 (d). Then a reverse motion is performed until Fig. 3 (i). Due to the enormous scanning speed of the tilt mirror, it is almost impossible to visually monitor the exact locations and scanning trajectory of the laser focal point. Thus, before actually trapping the spheres, we need to examine the scanning by procedures similar to Fig. 3. The important factors are whether the strengths of the beam spots are uniform and whether the scanning trajectory is controlled correctly. If not, we need to examine the alignment of optomechanical components. Without the proper alignment, we can not successfully do simultaneous multiple traps. In Fig. 3, we can see that the spot movements are correct to the hand movement. Because of the fact that there is only one physical laser focal point at any given time, we need a long exposure time when imaging through CCD. For shorter exposure time, we may miss to see all five beam spots. Figure 3 was taken with suitably long exposure time.
4.2 Manipulating 5 trapped spheres

Figure 4: The image of 5 trapped spheres taken while folding and spreading out fingers. Each number denotes, in sequence, the thumb, index, middle, ring and little fingers.

The images in Fig. 4 were taken with five trapped spheres. As noted before, we verified the alignments of the optomechanical components by taking images of the beam spots before doing this procedure. In Fig. 4, we basically do the same process as in Fig. 3. Finger tips are moved close to each other and spread out. The thumb corresponding to sphere is located at the lower left side. Finger tips can still move by moving the wrist with other finger joints frozen. This is essential because while grasping a secondary object by five polystyrene spheres, there should be no relative motions between these spheres. Otherwise, grasped object can be released. Of course, for larger translational movement, we can move the specimen stage. However for precise finer movements, this feature is necessary. Figure 3 is much brighter than Fig. 4 due to the illuminations by the halogen lamp. Our method requires fine tuning of the dwell time and transient time. Dwell time denotes time spent on trapping one polystyrene sphere. Transient time is the time spent while traveling from one trapped location to the other. Because of the fluctuation of the position of the polystyrene spheres by the Brownian motion, dwell time must be longer than transient time for stable trapping. And to minimize any angular overshoot of the piezo tilt mirror, we limit the angular speed when changing from one dwelling location to the other. For setting the transient time, the rule of thumb was to spend one sixth of the time spent in dwelling. This needs further investigations.
5. CONCLUSION

As noted in the introduction, in order to use OT as a manipulator, we need an easy and accurate controlling method. Only by then, OT can be used beyond its current applications. In this respect, this study has introduced an intuitive interface that shields any user from the complexity of the OT instruments. Because the operator is part of the control loop, we need no prior process planning. Operator can adapt to any unexpected accidents that may arise during the work. Furthermore, because the operation is controlled by human hand, it is much easier and precise. Although there is some delay due to the mechanical angular movement of the tilt mirror and computations, there is little noticeable delay as far as the human operator is concerned. This delay can be reduced by optimizing the scanning speed and computing. We foresee that this work can be used to manipulate any objects, regardless of its index of refraction and geometry. Be it spheres, cylinders or any shape that depart from symmetry.

REFERENCES
15. Julian Templeman, VISUAL C++ .NET STEP BY STEP, Microsoft Press, 2003