Enabling Haptic Assembly of Micrometer Structures

3D micromanipulation with optically encoded ANP101 positioners

Andreas Schmid and Mandayam A. Srinivasan
University College of London, UK

Stefan Thalhammer
Helmholtz Zentrum, Munich, Germany

Introduction

How can human touch be extended to enable manual exploration and manipulation of micro- and even nanostructures? This is one of the key questions driving our research. Mandayam A. Srinivasan of Massachusetts Institute of Technology, USA and University College of London (UCL), UK, with support from the Technical University of Munich's Institute for Advanced Study, Germany, has developed a micromanipulation system with a haptic interface to enable manual exploration, manipulation, and assembly of microstructures.

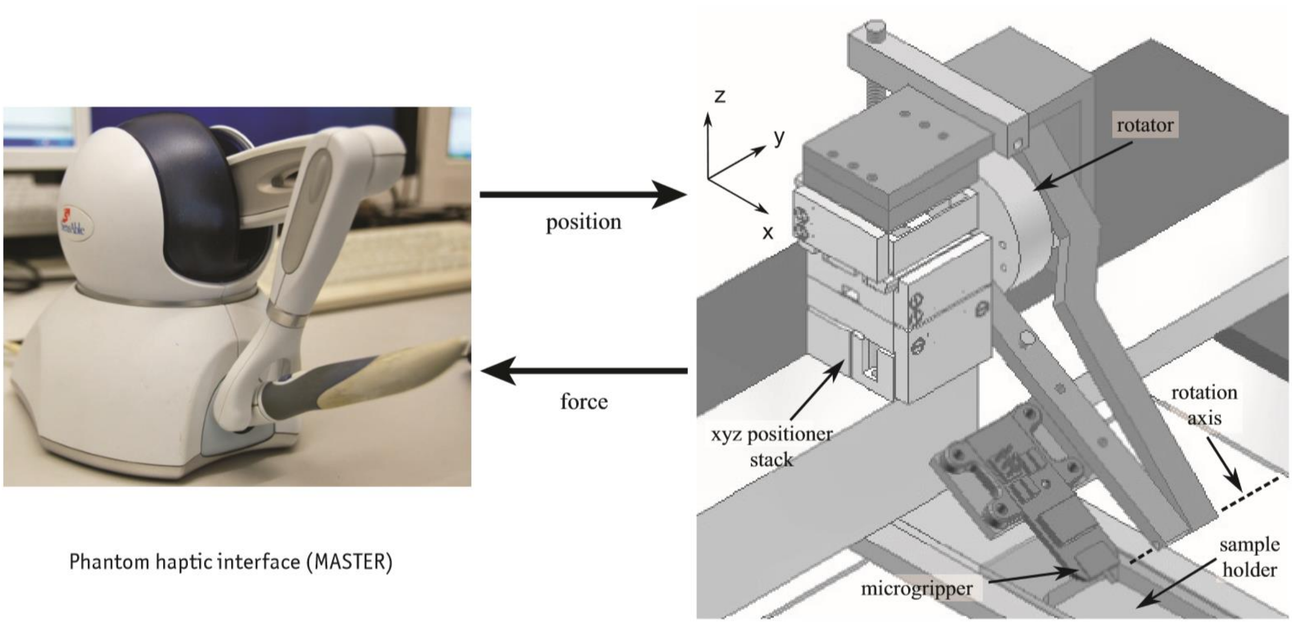
In collaboration with Andreas Schmid of UCL, Stefan Thalhammer of the Helmholtz Zentrum, Munich, and R. Yechangunja of Yantric, Inc., USA, he has demonstrated manual grasping and moving micrometer-sized objects with direct haptic feedback of the gripping force in real-time. With this technology, one can manually place objects of 10 to 100 µm in three dimensions with nanometer precision [1,2].

Setup

The Master-Slave micromanipulation system consists of a haptic interface (Master) – taking human position commands and displaying interaction forces – and the robotic micromanipulator (Slave). The devices are connected through a controller PC. A stereomicroscope at the slave end enables visualization of the micro-objects.

Slave system:
For the micromanipulator, a force-sensing micro-gripper with a 100 µm opening is mounted on top of a customized xyz-positioning stack. The three-axis positioner stack consist of two attocube ANPx101/NUM/Cust and one ANPz101/NUM/Cust. Additionally, an ANR101/NUM/Cust rotator can adjust the tilt angle. Using attocube's piezo motion controller, the positioners are run in closed-loop mode with the control command continuously updated by the master commands. The internal position control *via* optoelectronic encoder (NUM) used here is available upon special request.

Master system:
The required 3D-position is read by the Phantom haptic interface (in the centimeter range), scaled down and sent to the controller (micro/nanometer range). On the slave side, the force measured by the micro-gripper in the micro-Newton range is scaled up to the Newton range and exerted on the operator's fingers through the haptic interface.



Phantom haptic interface (MASTER)

Micro-manipulator (SLAVE)

Figure 1: Haptic interface (left) and positioner arrangement for the micromanipulator (right).

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Results

In order to validate the tracking behavior and the force measurement capabilities of the manipulator, the setup was used to approach a glass slide from above. Performing an operator controlled, oscillating movement in y-direction (Figures 2a and 2b) the gripper was carefully moved downwards (Figure 2c) while the measured force of the gripper sensor (Figure 2d) was scaled up and presented to the operator. This force was caused mainly by friction of the tip touching the glass surface. With decreasing height, the force increases, which can be observed in Figure 2e.

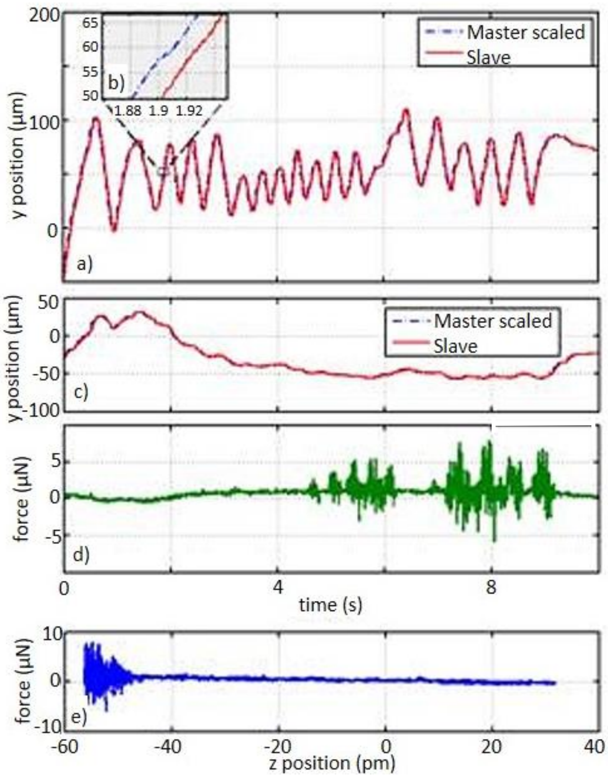

Figure 2: Tracking behavior and force measurement during surface approach. a) and b) show the y-position of the oscillating gripper (slave) compared to the scaled master position with a zoomed view on position trajectory. c) shows the z-position of the gripper and the master. d) shows the measured force over time, while e) shows the measured force over z-position.

The 3D manipulation capabilities are demonstrated by stacking four 45 µm diameter polystyrol beads into a two-layered pyramid. The resulting structure is shown in Figure 3. Each bead was lifted up from the ground, moved to a target position, precisely put down and released. The human operator commanded the opening of the gripper through the Phantom device while the measured force was scaled up and displayed to the user on the device. This gives the operator a direct “feeling” for the bead.

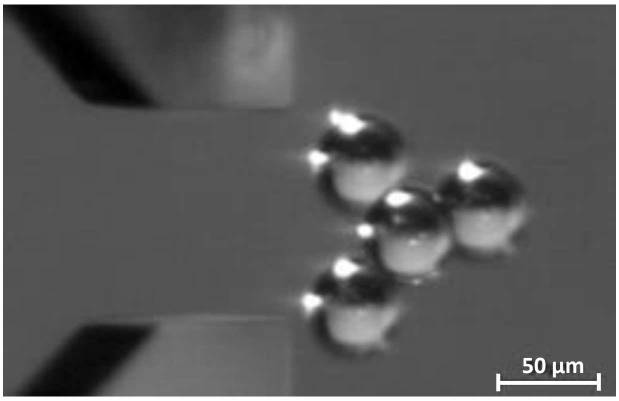

Figure 3: Microscope image of a pyramid of four 45 µm beads as a result of 3D assembly done using the micro-gripper whose tips are also visible in the image.

Conclusion

The major purpose of the presented teleoperation setup was to build a tool for human experimenters, which provides them with direct and intuitive capabilities to explore and assemble microstructures. The applied gripping force on the object can be controlled through a haptic feedback loop. This does not only prevent fragile objects from damage but actively helps reducing adhesion during contact manipulation.

Our human-in-the-loop system gives scientists a versatile tool for micro-assembly and characterization at hand.

References

[1] A. Schmid, R. Yechangunja, S. Thalhammer, and M. A. Srinivasan, Proceedings of the IEEE Haptics Symposium, 517-522 (2012).

[2] Potemski, F. M. D. Pellegrino, and D. M. Basko, Phys. Rev. Lett. 108, 017602 (2012).