RESEARCH BRIEF

AUTOMATED MICRO AND NANOSCALE ASSEMBLY USING OPTICAL TWEEZERS

The potential

Optical tweezers can trap and move a variety of microscale and nanoscale components without physical contact and hence without damaging components due to stiction or deformation caused by contact forces. At the same time, optical tweezers provide a broad range of positioning and orienting capabilities to place components at the desired locations in the workspace.

By utilizing multiple trapping beams, multiple operations can be performed in parallel and the instrumentation can be based on inexpensive lasers and piezo-actuators. Thus the technique can scale to production in terms of both cost and efficiency, making optical tweezers a very promising technology for micro and nanoscale assembly.

The challenge

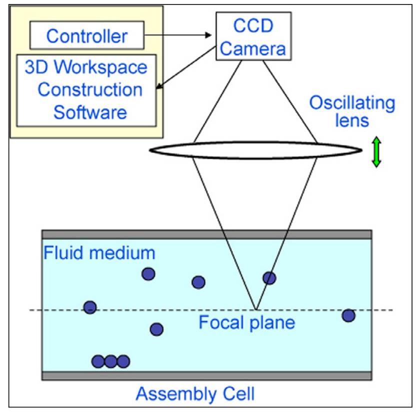
Currently, optical tweezers are mainly used in research laboratories. To use optical tweezers in production processes, the following challenges need to be addressed:

- The overall operation speed has to increase considerably to ensure that manufacturing can be performed in a cost-competitive manner.
- The overall operation yield has to increase considerably to ensure that a large number of assembly operations can be performed without encountering assembly errors.
- The reliance on highly trained expert human operators has to decrease considerably to ensure widespread use of this technology.

Addressing these challenges will make optical tweezers a viable technology for prototyping nanoscale electronic devices, manufacturing customized nano-structures for bio-medical application, and repair and rework of nano-structures produced using other processes such as self-assembly.

The research

S.K. Gupta and his team are developing automated assembly cells based on optical tweezers. This includes a 3D imaging system for tracking locations of components in real time, a physically accurate framework for simulating assembly operations, and automated path planning algorithms for transporting components to goal locations by avoiding collisions.

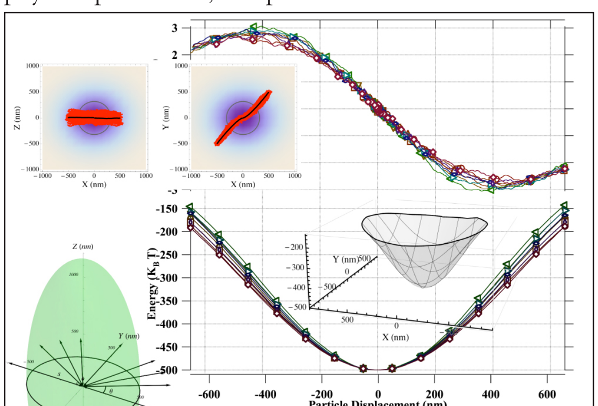


A schematic of section microscopy.

3D Imaging Using Optical Section Microscopy. Images provided by optical section microscopy are used to estimate sizes and locations of components in workspace. The challenges are noisy images, images that include optical effects in translucent materials, a high degree of uncertainty in reconstructed shapes, and scenes that need to be updated at high rates.

Gupta's team is retrieving geometric information of components from individual images and combining information from adjacent focal plane images.

Physically Accurate Simulations for Particle Motion and Trapping. The team is developing a simulation framework to test control algorithms, estimate physical parameters, and perform statistical validation of



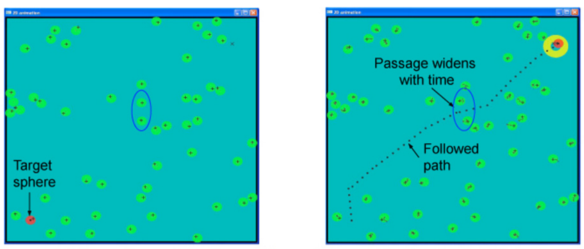
Optical trapping force estimation in two-dimensions from the response of a particle to a step input: allows the measurement of the trapping force without an assumption of the trap shape

Clockwise from the top left: i) the trajectory of a particle as it moves towards the center of the optical trap in the xy-plane, ii) the optical trapping force and trapping potential sampled at different angles in the xy-plane (inset shows a 3D-representation) and iii) an isosurface of the optical trapping potential model in 3D.

assembly with optical tweezers. The challenges include physically accurate simulations and experimental validation to improve confidence in simulation results.

Gupta's team employs particle diffusion modeling using Brownian Dynamics on graphics hardware for significant speedup without compromising accuracy. They are using experimental optical force measurement techniques to measure trapping potential and calculating optical trapping force from first principles using Mie theory.

Automated Path Planning. The researchers are developing algorithms to automatically trap and transport particles. The challenges include the dynamic environment involving random Brownian motion of particles, the presence of uncertainties due to Brownian motion and sensor noise, and a need for real-time computation within a few milliseconds.



An example of automated path planning: transport of a 2 micron glass sphere by avoiding collisions with other freely diffusing particles. At left is the sphere's initial position; at right, its final position.

The team is developing a simplified trapping probability model by using Gaussian Radial Basis Functions and developing a single particle path planning algorithm using stochastic dynamic programming (Partially Observable Markov Decision Process). They are also integrating a dynamic programming algorithm in a decoupled and prioritized framework for multi-particle transport.

Link

View a poster of this research at www.isr.umd.edu/SS2008/2009_posters/Gupta_optical_tweezers.pdf

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