Automated Micro and Nanoscale Assembly using Optical Tweezers

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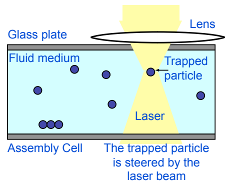
Sponsors: NSF, NIST, and Center for Nano Manufacturing and Metrology

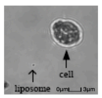
Advanced Manufacturing Laboratory AML

Motivation

- Automated 3D assembly of micro and nanoscale components is challenging
- Optical tweezers can be used to trap and move micro and nanoscale components
- Examples of devices that can be assembled using optical tweezers include wave guides, diodes, transistors etc.
- Optical tweezers are useful for studying characteristics of biological cells
- Currently assemblies are performed manually using optical tweezers
- Automation is essential for industrial viability




ZnO wires

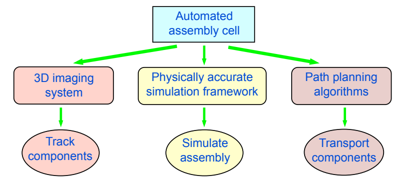


Cell and liposome

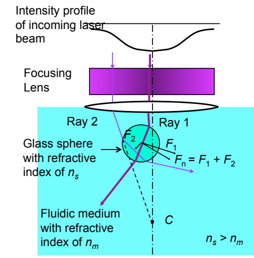
Examples of optical tweezers based assembly

Goals

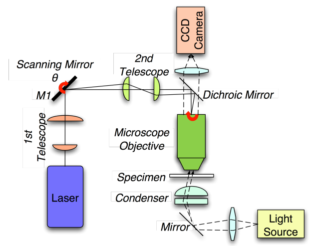
- Develop automated assembly cell based on optical tweezers
  - 3D imaging system for tracking locations of components in real-time
  - Physically accurate framework for simulating assembly operations
  - Automated path planning algorithms for transporting components to goal locations by avoiding collisions



Optical Trapping



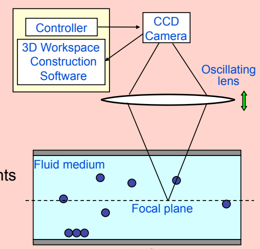
As a result of optical forces the glass sphere moves towards focal point C



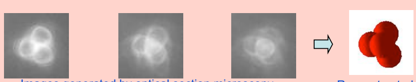
The optical tweezers instrument is built around a conventional optical microscope for convenience

3D Imaging Using Optical Section Microscopy

- Use images provided by optical section microscopy to estimate sizes and locations of components in workspace
- ***Challenges***
  - Noisy images
  - Images include optical effects in translucent materials
  - High degree of uncertainty in reconstructed shapes
  - scenes need to be updated at high rates
- ***Approach***
  - Retrieve geometric information of components from individual images
  - Combine information from adjacent focal plane images

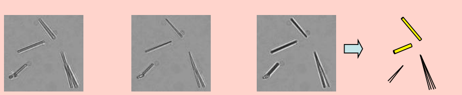


Estimating the 3D positions of micro-spheres


Images generated by optical section microscopy
Reconstructed 3D model

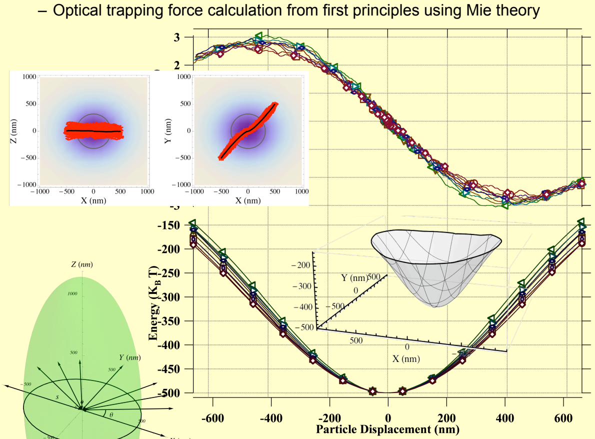
Estimating the lengths, center positions, in-plane orientation angles, and tilt angles of nanowires


Images generated by optical section microscopy
Reconstructed 3D model


Images generated by optical section microscopy
Reconstructed 3D model

Physically Accurate Simulations for Particle Motion and Trapping

- Develop a simulation framework to test control algorithms, estimate physical parameters, and perform statistical validation of assembly with optical tweezers
- ***Challenges***
  - Physically accurate simulations
  - Experimental validation to improve confidence in simulation results
- ***Approach***
  - Particle diffusion modeling using Brownian Dynamics on graphics hardware for significant speedup without compromising accuracy
  - Experimental optical force measurement techniques to measure trapping potential (such as step response below)
  - Optical trapping force calculation from first principles using Mie theory

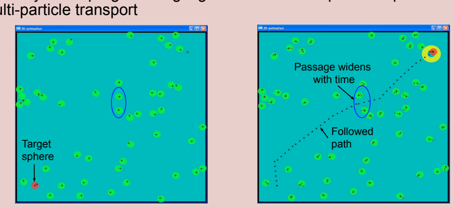


Optical trapping force estimation in two-dimensions from the response of a particle to a step input: allows the measurement of the trapping force without an assumption of the trap shape

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.

Automated Path Planning

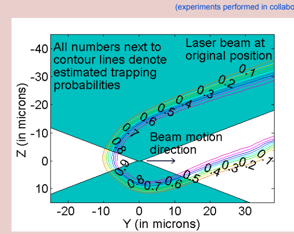
- Develop algorithms to automatically trap and transport particles
- ***Challenges***
  - Dynamic environment involving random Brownian motion of particles
  - Presence of uncertainties due to Brownian motion and sensor noise
  - Real-time computation within few milliseconds
- ***Approach***
  - Develop simplified trapping probability model by using Gaussian Radial Basis Functions
  - Develop single particle path planning algorithm using stochastic dynamic programming (Partially Observable Markov Decision Process)
  - Integrate dynamic programming algorithm in a decoupled and prioritized framework for multi-particle transport



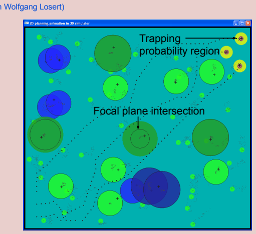
Transport of 2 µm glass sphere by avoiding collisions with other freely diffusing particles

Automated transport of 2 µm silica sphere in holographic tweezer set-up

(experiments performed in collaboration with Wolfgang Losert)



Trapping probability contours for 15 µm glass sphere



Simultaneous transport of three 2 µm silica spheres