Automated Micro and Nanoscale Assembly using Optical Tweezers

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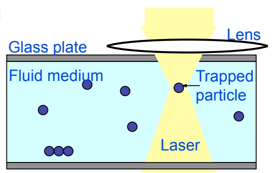
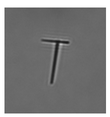
Motivation

- 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

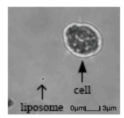


Assembly Cell

The trapped particle is steered by the laser beam



ZnO wires

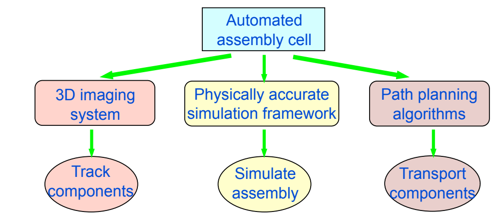


Cell and liposome

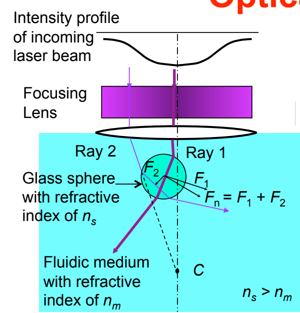
Examples of optical tweezers based assembly

Goals

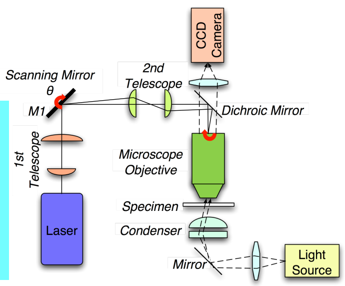
- Develop automated assembly cell based on optical tweezers
  - 3D imaging system for tracking locations of components in real-time
  - Physically accurate framework for simulating assembly operations
  - Automated path planning algorithms for transporting components to goal locations by avoiding collisions



Optical Trapping



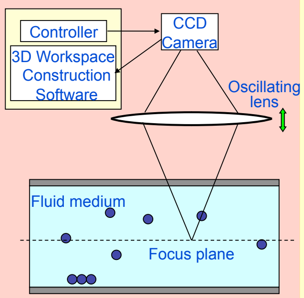
As a result of optical forces the glass sphere moves towards focal point *C*



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
  - 3D scenes need to be updated at high rates
- ***Approach***
  - Retrieve geometric information of components from individual images
  - Combine information from adjacent focus plane images



Assembly Cell

Estimating the 3D positions of micro-spheres

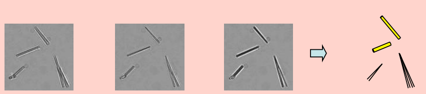
Images generated by optical section microscopy

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

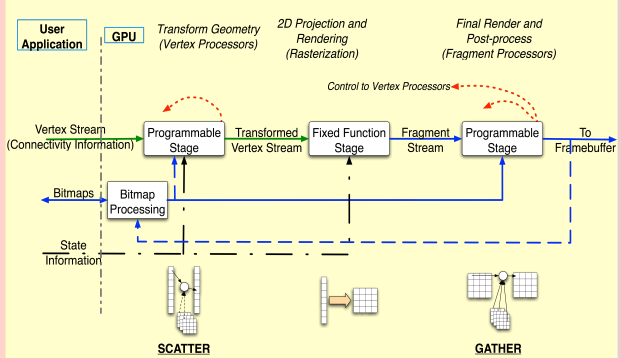


Images generated by optical section microscopy

Reconstructed 3D model

Physically Accurate Simulations for Assembly

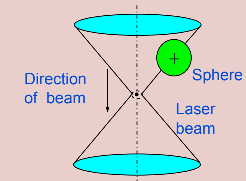
- Develop simulation framework to test control algorithms, estimate physical parameters, and perform statistical validation
- ***Challenges***
  - Simulations need to physically valid
  - Simulations need to be fast to support real time operation
- ***Approach***
  - Perform particle diffusion using Brownian Dynamics on graphics hardware for significant speedup without compromising accuracy
  - Compute optical trapping forces using Lorentz Mie theory and experimentally validate them
  - Model surface effects using molecular simulations



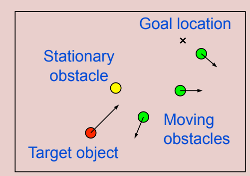
Mapping stochastic simulations to graphics hardware can achieve significant speedup

Automated Path Planning

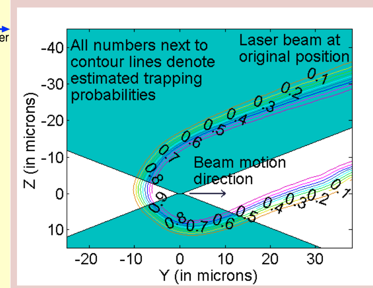
- Develop algorithms to automatically trap and transport particles
- ***Challenges***
  - Dynamic environment involving random Brownian motion of objects
  - Presence of uncertainties due to inaccuracies in sensor readings and Brownian motion
- ***Approach***
  - Develop simplified trapping probability model by using Gaussian Radial Basis Functions to represent simulation data compactly
  - Develop a path planning algorithm using stochastic dynamic programming (Partially Observable Markov Decision Process)



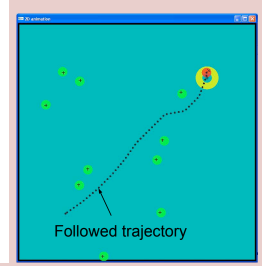
What is the probability of trapping the sphere?



What is the best algorithm to transport target object to goal location?



Trapping probability contours for 7.5 μm sphere



Path planning result