Center for Automation Technologies and Systems (CATS)

Multiprobe Microassembly Control Issues

John Wason*, Bill Gressick*, John Wen*,
Jason Gorman+, Nick Dagalakis+

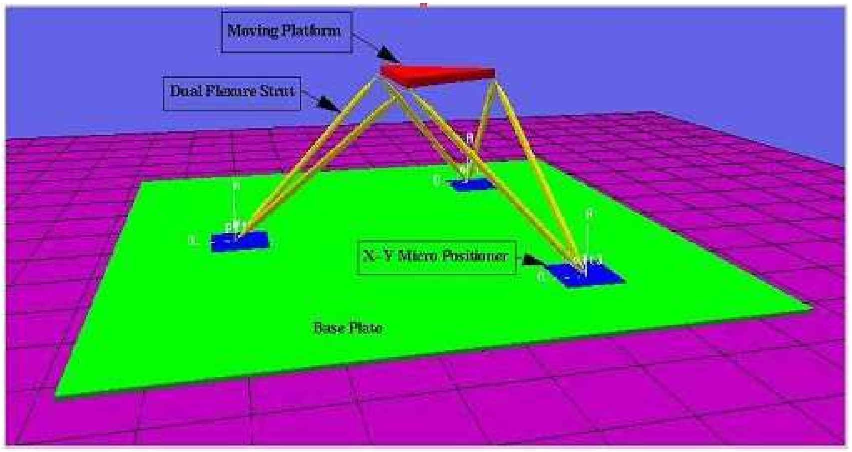
*Center for Automation Technology, RPI
+ Manufacturing Engineering Laboratory, NIST

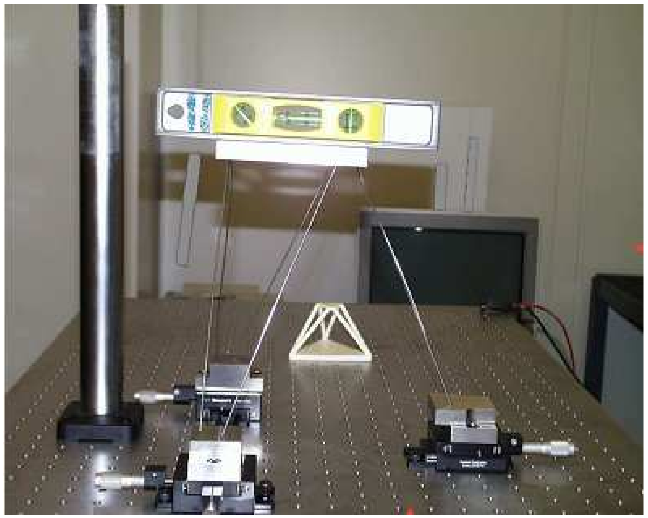
Rensselaer

Motivation

- Most MEMS devices monolithic
  - Mechanism effectively planar
- Current micro-assembly inflexible or fragile
  - Fragile micro-grippers
  - Specially shaped parts
- **Our goal: Develop and demonstrate a flexible micro-assembly station and tools for effective 3D manipulation and assembly of parts at sub-mm scale.**

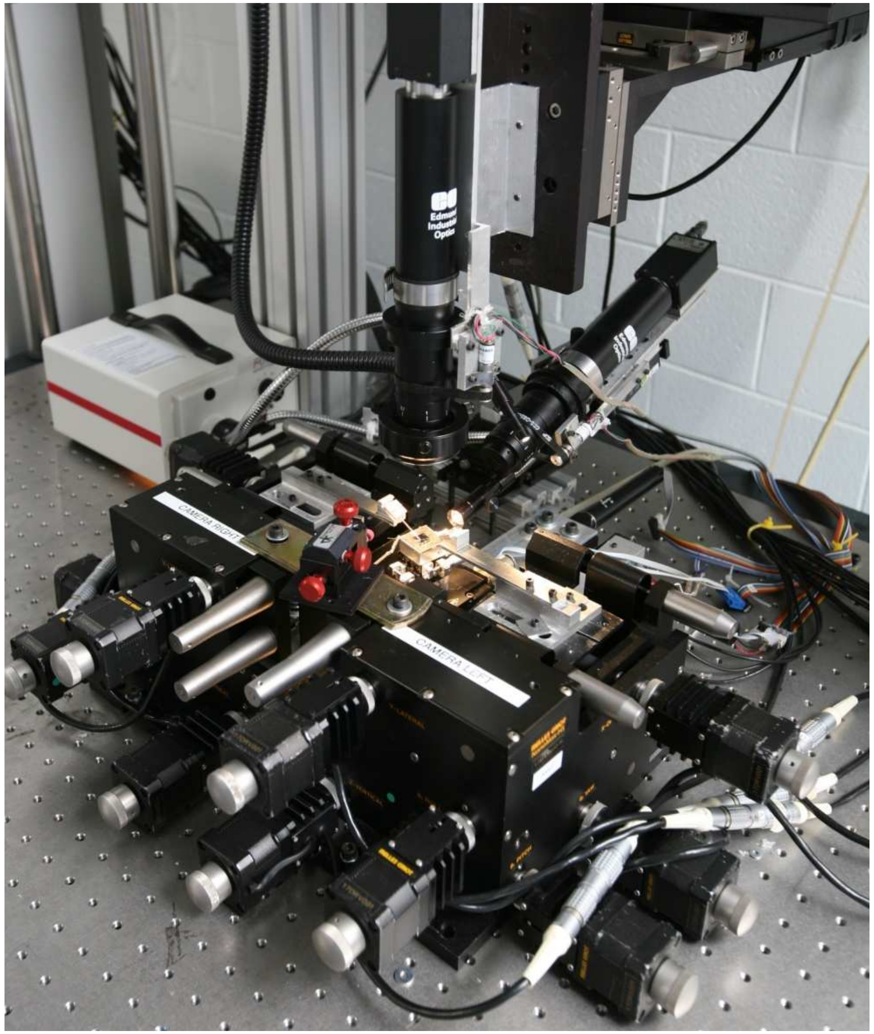
NIST Project





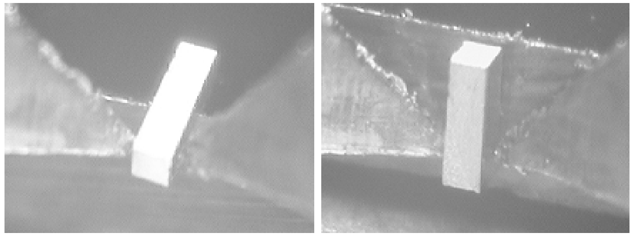
- Probe based microassembly
- Develop hardware/software
- Demonstrate 3D microassembly of parts provided by NIST.
- Techniques developed will be used to assemble advanced 6 DOF spatial MEMS device.

Micro Assembly Research at CATS

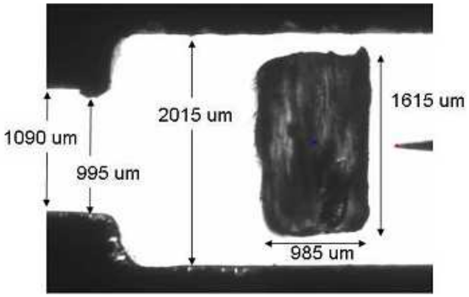


- Probe based manipulation
  - 2 active probes
  - 1 passive probe
- Development of hardware and software
- Sub-millimeter part and tolerances
- Projects
  - Micro-Insertion Task
  - Nanoprobe Bonding
  - Waveguide Fiber Alignment

Previous Work

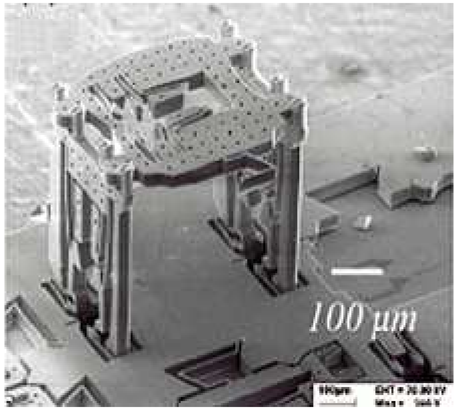


Shimada, Fearing 2000



Cappelleri, Kumar, Trinkle 2006

Ferreira 2004



Zyvex 2005

Gorman 2006

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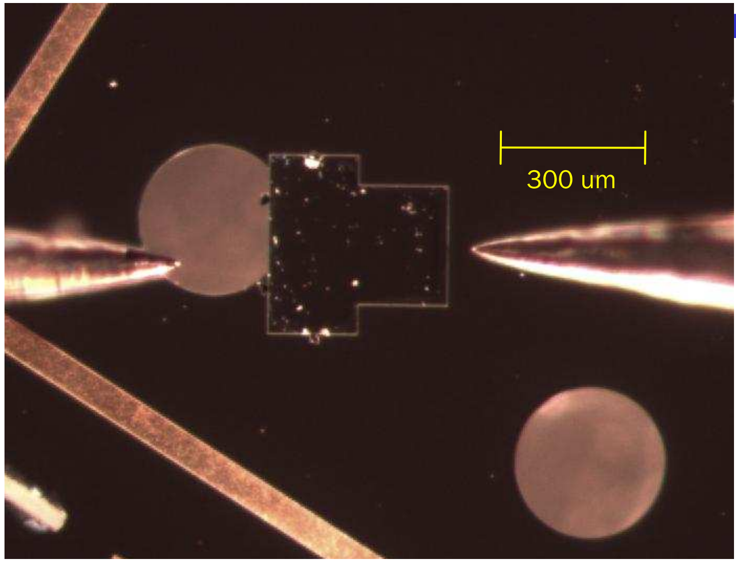
Previous Work

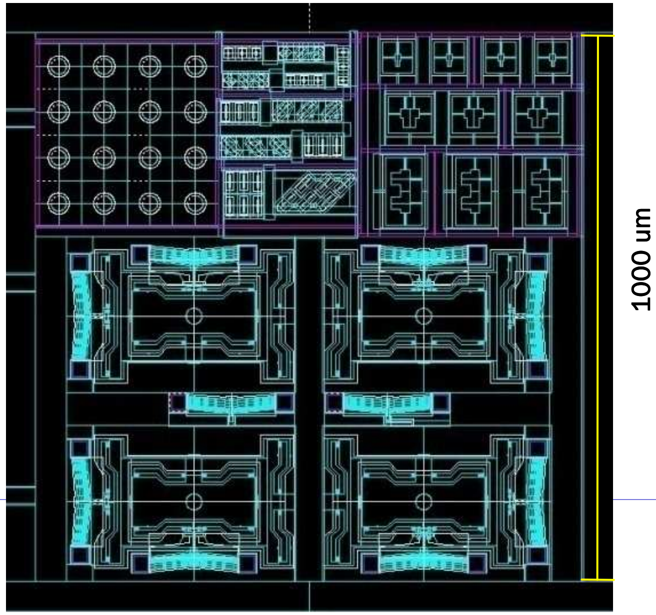
- Shimada, Fearing – Crude contact points, six degrees of freedom total system
- Zyvex – Requires special silicon parts, open loop
- Cappelleri, Kumar, Trinkle – fully open loop, susceptible to adhesion
- Ferreira – Meso scale parts, no out of plane rotation
- Gorman – Spherical particles, single probe

Microassembly Challenges

- Sensing
  - Microscope lenses effective to around 2-3μm
  - Force sensors extremely fragile
- Manipulation Strategy
  - Manipulator/part interactions not well understood
  - Adhesion instead of inertia/gravity/friction
  - Parameters vary greatly
  - Very sensitive to noise
  - Silicon is brittle
- Part Design *(future work)*

Initial Insertion Demonstration Project





- Goal: Insert single part into slot in a repeatable procedure
  - 300 μ m each side
  - "Peg" shaped to fit in slot
- Develop tools and procedures as foundation for full spatial mechanism assembly

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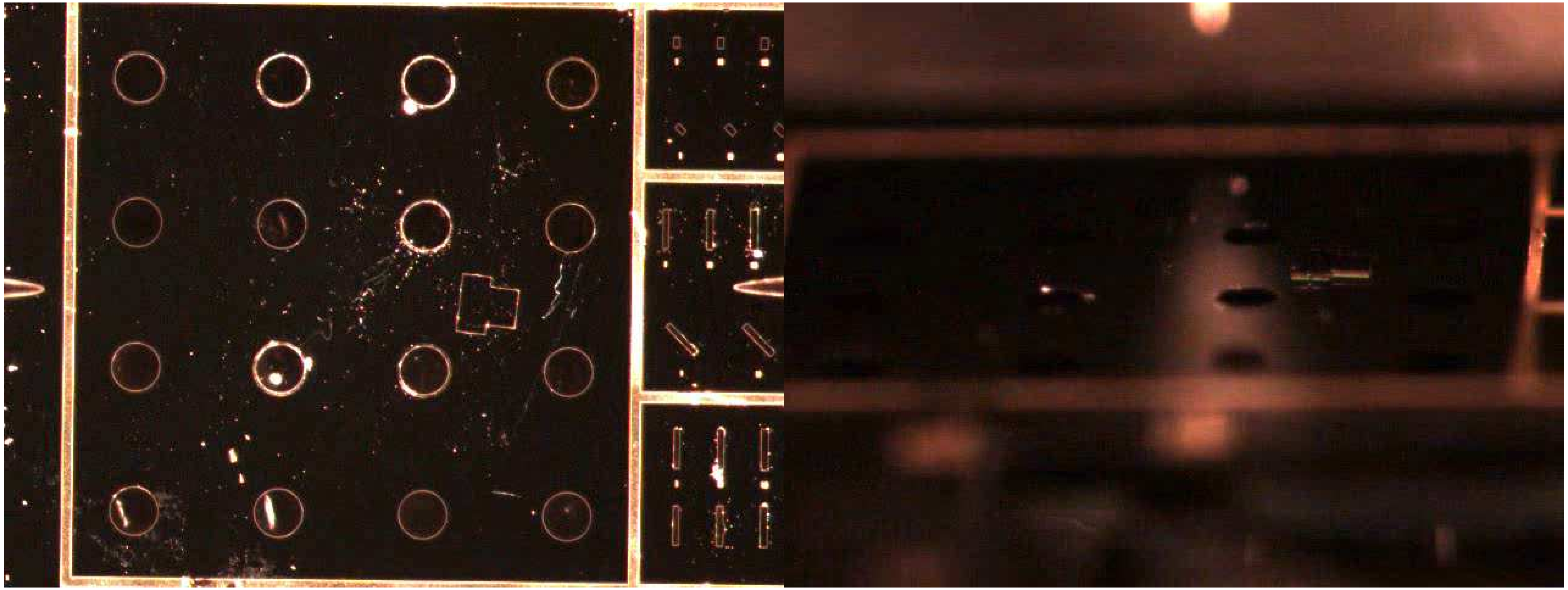
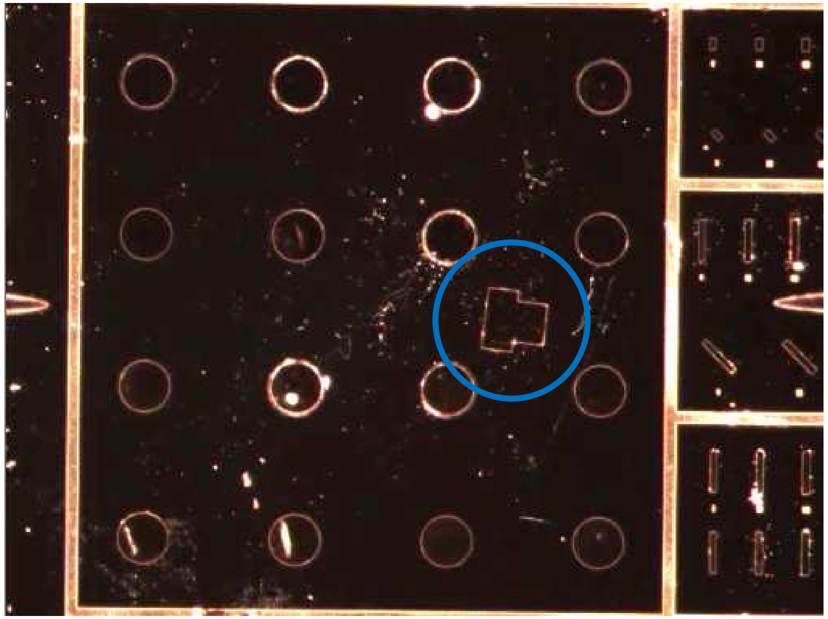
Automated Insertion Video



1. Calibrate System
2. Locate and Center Part
3. Grab Part
4. Flip Part with Third Probe
5. Insert Part

Part Centering

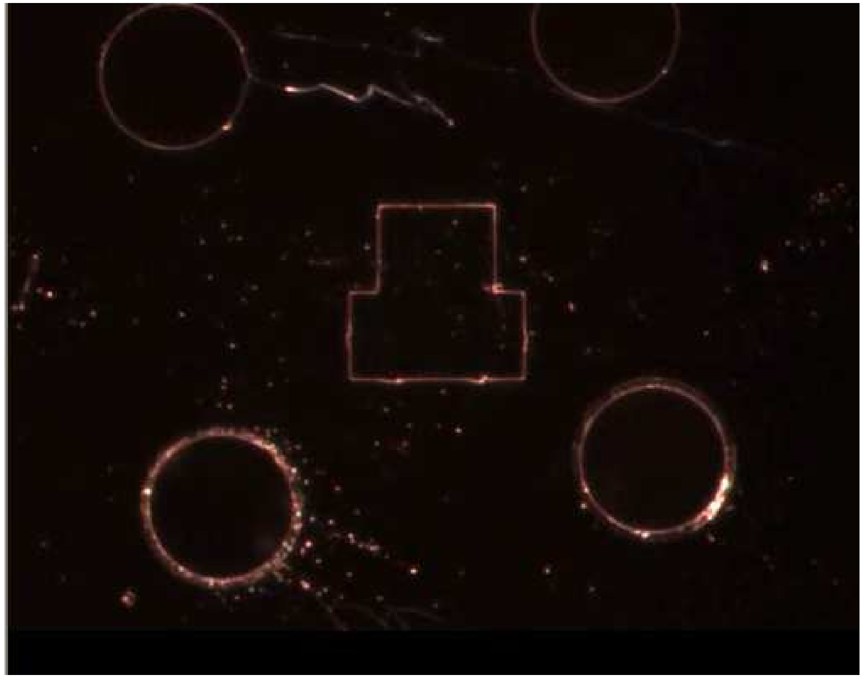


Locate Part

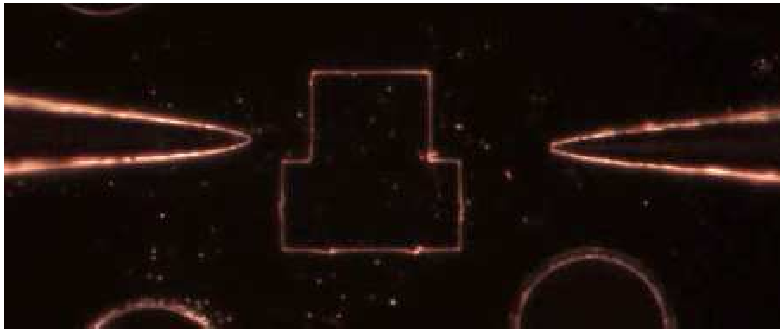
Template matching to find part in 1.5X image

Center Part

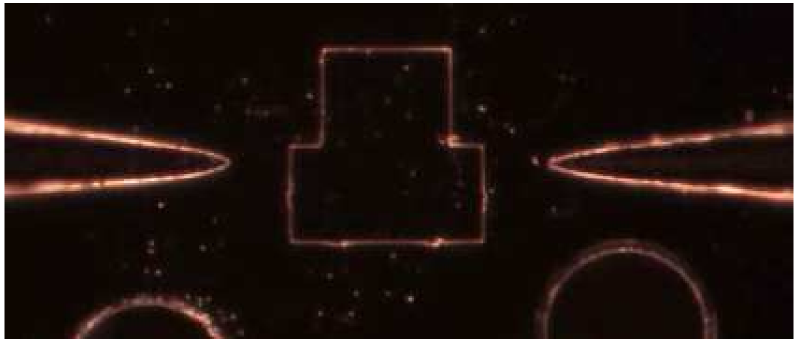
•Initial move inv. kin.
•Center part in 4X image with template Matching



Grasp Sequence



Initial kinematic Probe Position

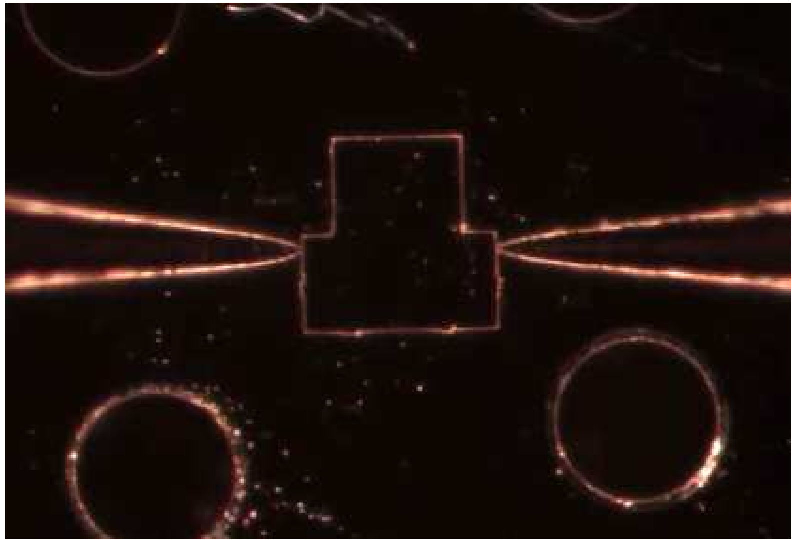


Refined with vision feedback

Initial probe height

Lowered probe height
(vision using reflection)

Grasp Sequence



- Grasp Formation
- Pressure controlled with visual force feedback

Part lifted off surface

Grasp formation strategy is very reliable

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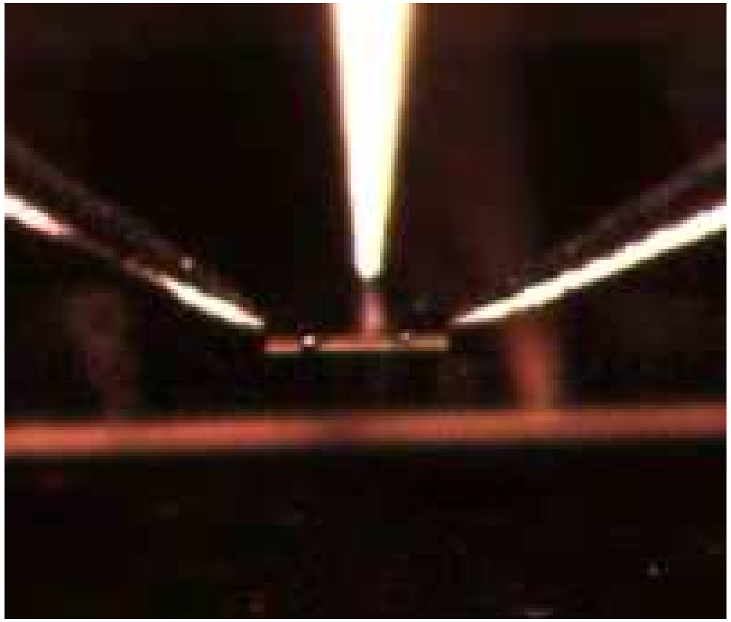
Third Probe Part Flip



Initial Orientation

Final Orientation

- *Third probe used to achieve out of plane rotation*
- *Highly repeatable due to adhesion forces*

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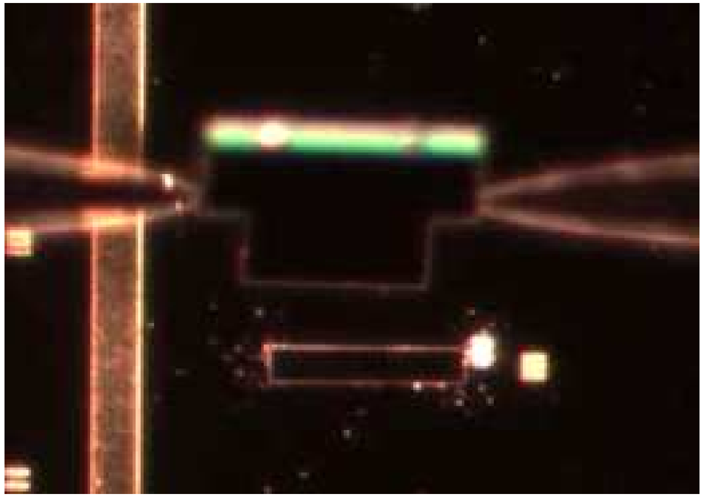
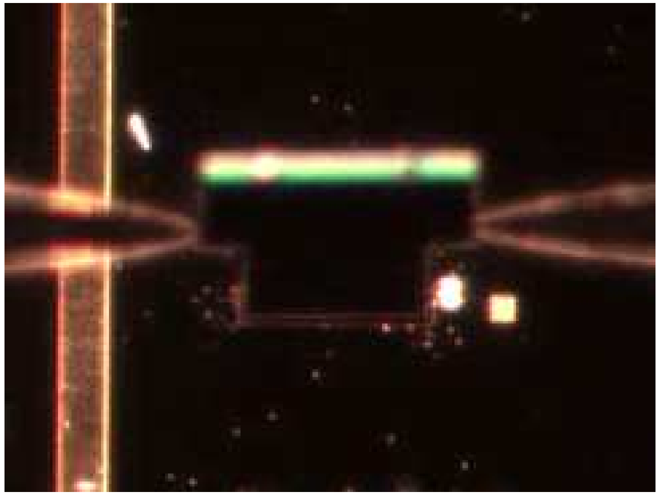
Part Insertion



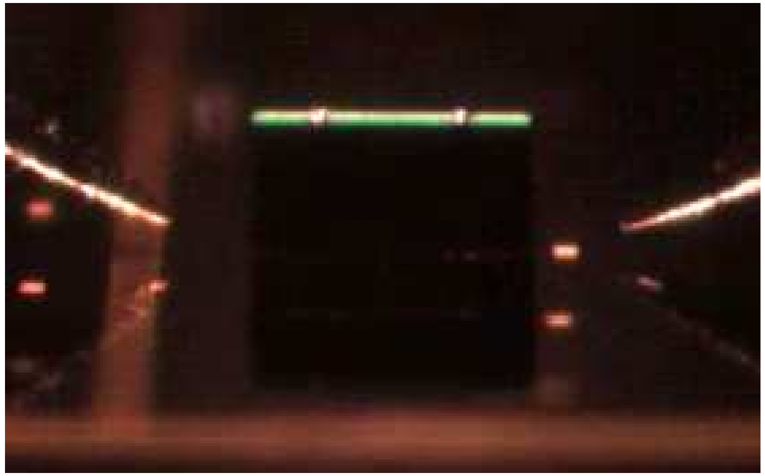
Initial kinematic alignment



Aligned for insertion with vision

Part Insertion/Release

Part Inserted

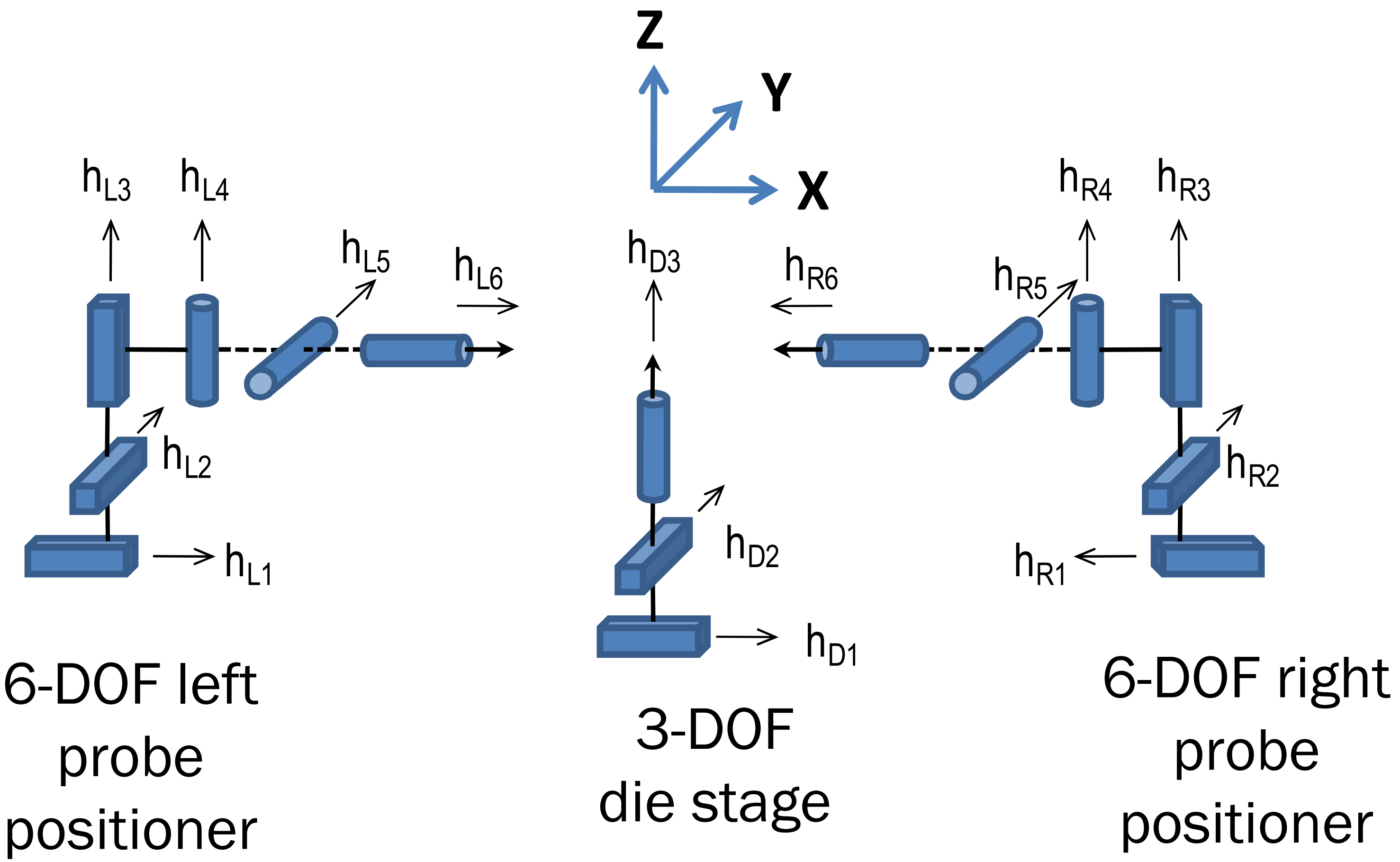


Part Released

Part is released with rapid movement in opposite directions to break adhesion

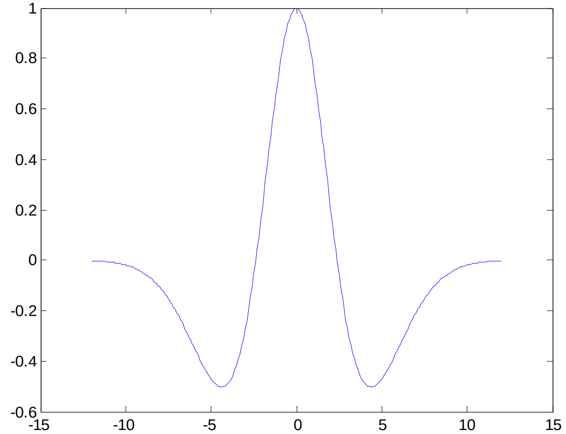
Grasp release is very reliable

System Kinematics

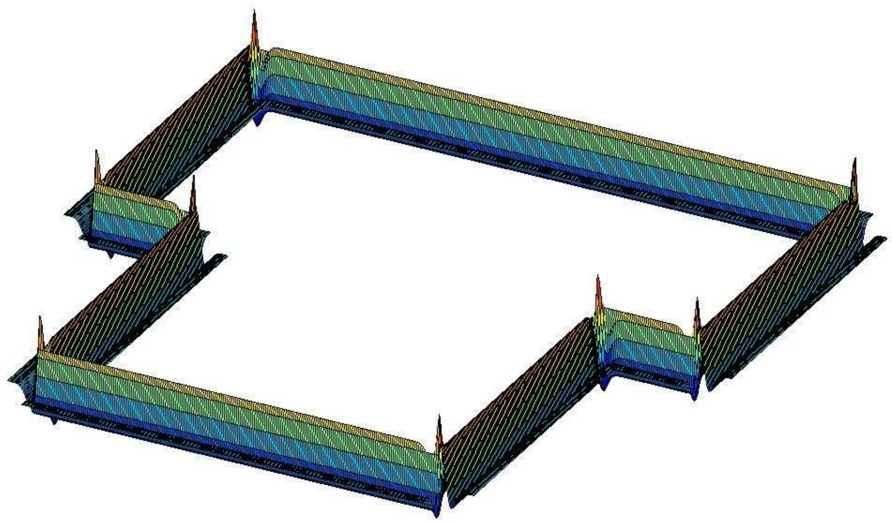


Kinematic parameters determined through vision calibration

Vision System



- Template Matching
- FFT convolution method
- Image resize used
- Laplacian-of-Gaussian method
- Stereo vision using two cameras
- Vision based probe force sensing



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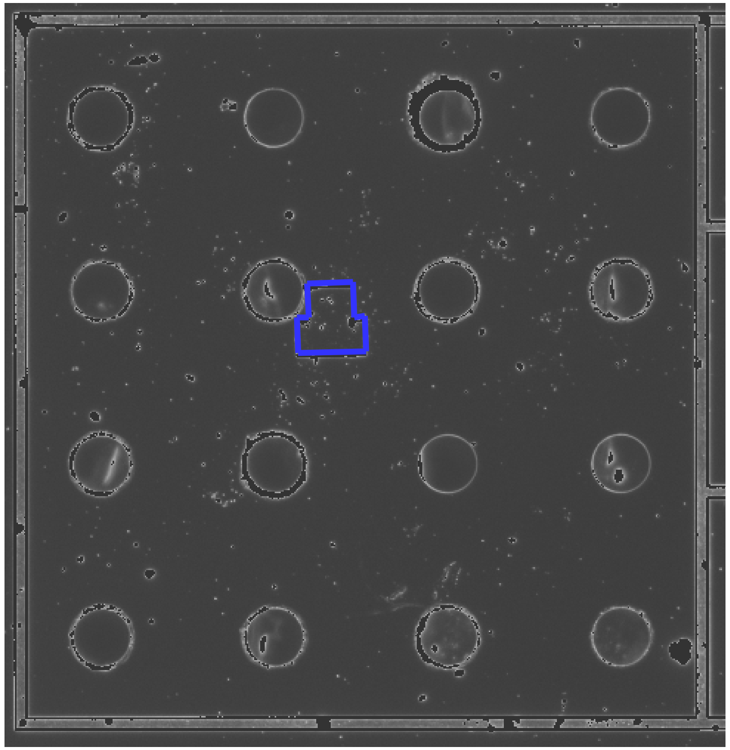
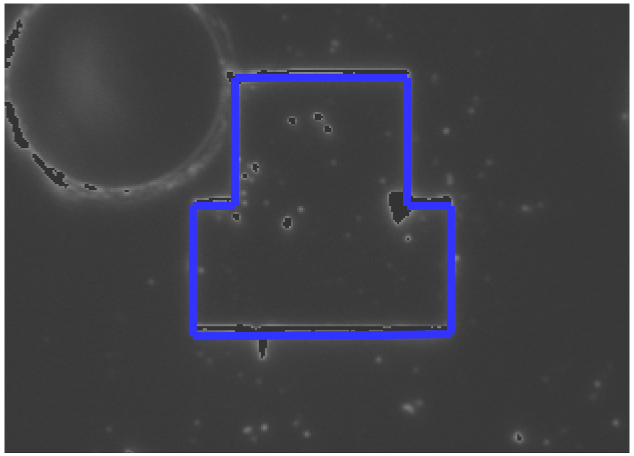
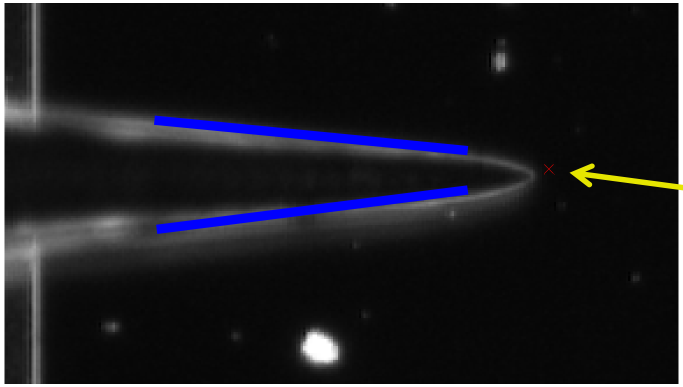
Part Location



- Template is used to find part
- Large searches use downsampling
- Optimization for final fit

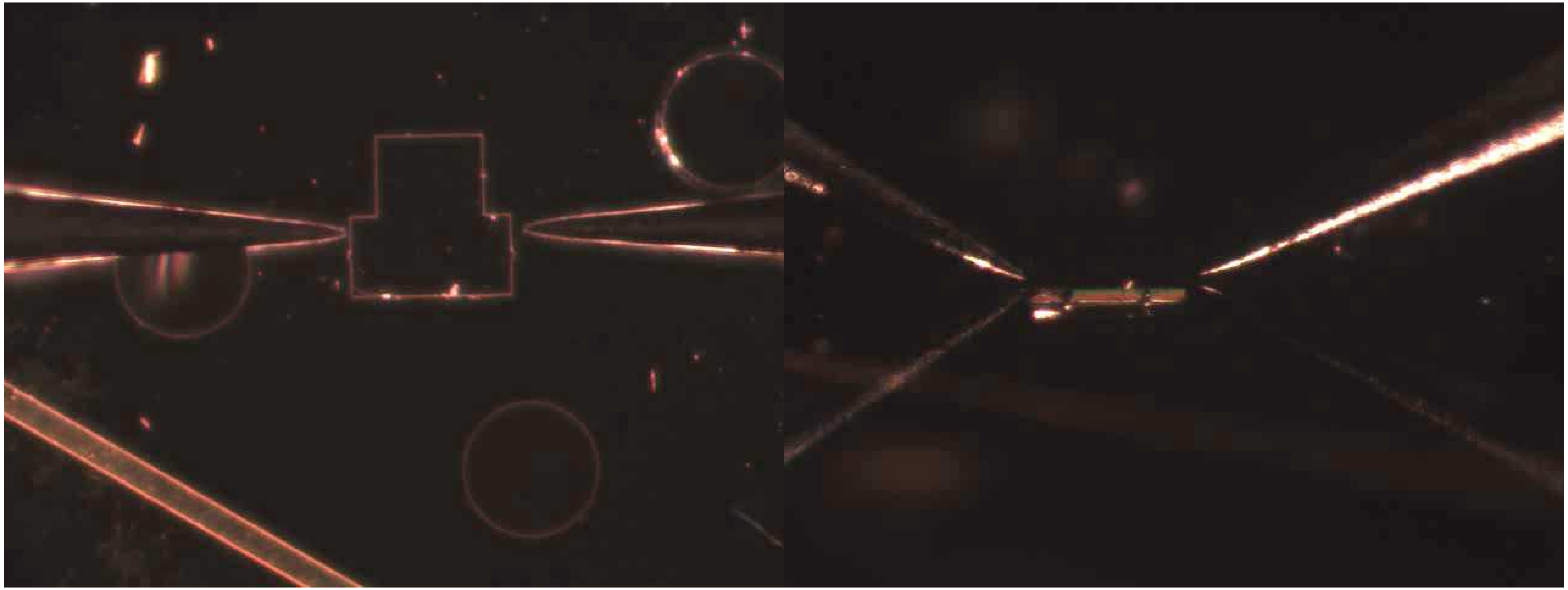


3D Probe Tip Locator



- Estimate used to crop top image
- Probe tip located in top image
- Epipole searched in side image for height
- 3D point determined from calibration

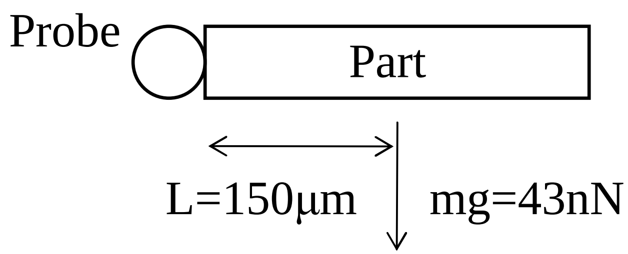
Grasping



- Grasp formed by pressing compliant probes against opposite edges
- Part will stick to single probe due to adhesion
- How does adhesion increase manipulability?

Adhesion

- Part weight 43 µg, or 43 nN
- Three forms of adhesion
  - van der Waals (2.8 µN)
  - Capillary Attraction (9.174 µN)
  - Coulomb Attraction (Negligible)
  - **Disclaimer: these are rough estimates**
- Flat spot develops on probe tip due to contact
  - Hertzian or JKR model
  - Causes extra 9.39 µN of van der Waals adhesion
  - **Can support a moment!!**



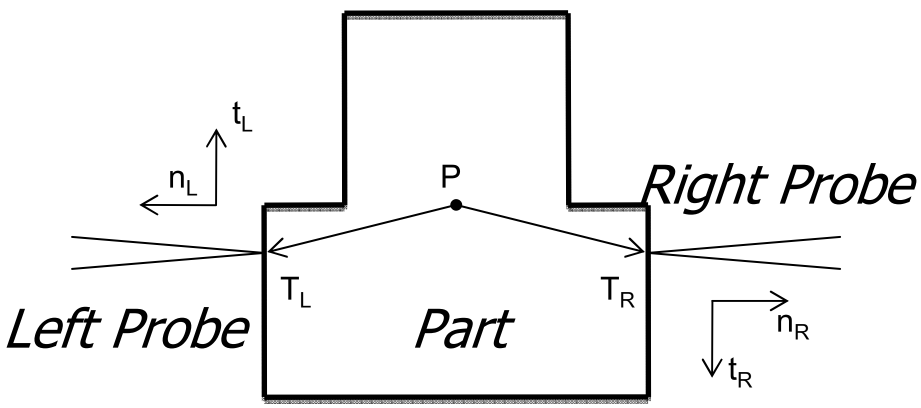
Single probe adhesion conditions

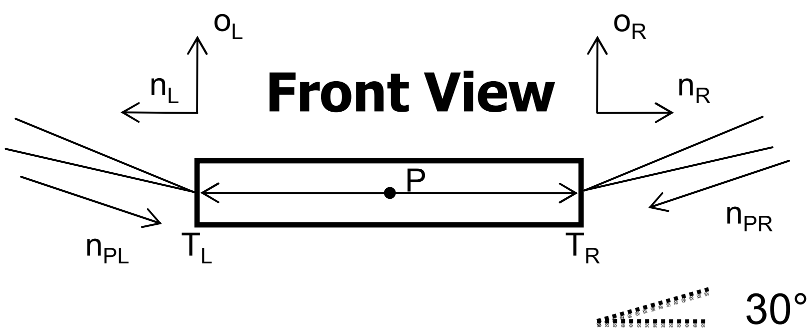
Probe-Part Contact Model

- Several standard contact models
  - Point contact, Hard Finger, Soft Finger
- Microassembly probe contact very different
  - Adhesion changes grasp analysis (becomes nonlinear)
  - Grasp behavior is *path dependant*
  - Flat spot generated by contact allows moment support
  - Probe can support 6 DOF wrench *(single probe scenario)*
- Different behavior requires new manipulation strategy
  - Stochastic rather than deterministic method
  - Must work over wide range of parameters
  - Typical feed-forward prediction not practical
- Experiments needed to quantify dexterous manipulation

Grasp Stability Conditions

Top View





Equilibrium Conditions

$$\sum F = 0 \quad \sum M = 0$$

$$\min \frac{1}{2} q_L^{\,T} \tilde{K}_L q_L + \frac{1}{2} q_R^{\,T} \tilde{K}_R q_R$$

where

Probe Setpoint

$$q_L = T_{PL} - T_L \quad q_R = T_{PR} - T_R$$

Probe Position

Compliant Probe Deflection

$$q_L \bullet n_{PL} = 0 \quad q_R \bullet n_{RL} = 0$$

$$F_L = \tilde{K}_L q_L + F_{L,Adh} \quad F_R = \tilde{K}_R q_R + F_{L,Adh}$$

$$F_L \bullet n_L > 0 \quad F_R \bullet n_r > 0$$

- System will configure to local energy minima
- Adhesion will change force balance
- Adhesion will change minima conditions
- Minima is path dependant!!

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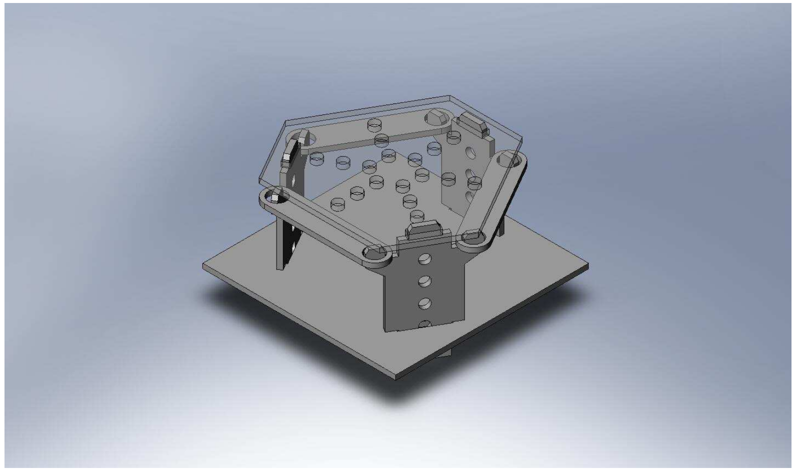
Conclusion

- Development of a flexible micro-assembly testbed
- Feasibility demonstration of macro scale tools for microassembly
  - Automated and operator-assisted assembly modes
  - Repeatable out-of-plane rotation
- Automate assembly process based on Vision Feedback
  - Fragile force sensor not necessary
- Automated grasp achieved with visual force sensing
- Initial definitions of grasp stability
- Vision still sensitive to appearance variations
- Future work focused on assembly of 3D micro-structures and improvement of the vision system

Future Work



- Repeatable gripping sequence
- Automated part tether release
- Vision system speed
- Assembly of smaller parts
- 3D microstructure assembly
  - Sub millimeter test structure
  - Parts provided by NIST/MEL