Multiprobe Microassembly

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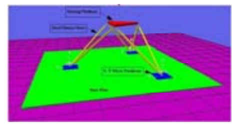
Introduction

- Micro-electromechanical System (MEMS) integrates actuator, sensor, and electronics on silicon substrate through microfabrication technology. It is widely used in sensors (e.g., acceleration and pressure sensors), actuators (micro-motor, scanning mirror), and optics (active alignment, deformable mirror).
- MEMS Technology using microfabrication is steadily evolving, but technology to manipulate and assemble parts on the micro scale is still relatively primitive.
  - Most MEMS devices are designed to not require assembly (monolithic)
  - Devices can be designed with breakable tethers to allow multiple parts to move once device production has been completed
- Avoiding assembly severely limits design flexibility
  - Mechanisms are effectively planar
  - Only one layer of moving parts is possible
- Current Micro Assembly techniques are not flexible or robust
  - Require exotic and extremely fragile micro-grippers
  - Use specially shaped parts with gripper handles – severely limits part geometry
- Our goal is to develop a flexible micro-assembly station and tools for effective manipulation and assembly of parts at micron scale.

Micro Assembly Research at CATS

- The CATS has built up a suite of hardware and software to enable highly accurate assembly of 3D MEMS devices.
- Micro Assembly involves working with parts which are sub-millimeter in size.
- Two projects have recently been undertaken
  - NIST Micro-Insertion Task
  - GE Fiber Alignment Task

NIST Project



- Investigate micro-insertion operations using probes rather than exotic grippers
  - Investigate effects of adhesion force when using fine-tip probes
  - Investigate vision feedback techniques
  - Investigate force-control techniques
- Determine hardware requirements for repeatable and adaptable microassembly.
- Demonstrate 3D microassembly of parts provided by NIST.
- Techniques developed will be used to assemble advanced 6 DOF spatial MEMS device.
- Assembled device will be used for nanotechnology development

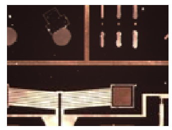
Micro Assembly Challenges

- Manipulator-part interactions are not well understood
  - Inertia and friction become insignificant compared to adhesion and fluidic forces at sub-millimeter scale
  - While models have been developed for these forces, parameters can vary so widely that they do not provide much predictive capability
- Silicon is extremely brittle
  - Forces on part must be kept high enough to ensure accurate manipulation but low enough to avoid damage
- Assembly process is extremely susceptible to noise
  - Vibrations that are negligible on the macro scale become significant
  - Small variations in surrounding air can cause part to be dropped
  - Electrical or humidity changes can cause drastic changes in adhesion behavior
- Sensing below a few microns is impractical
  - Microscope lenses can be used to practically sense down to around two or three microns
  - Force sensing has been used to help determine when contact with part has occurred, but due to the small forces involved the sensors are extremely fragile

Current NIST Insertion Project

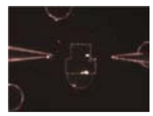
- Current project is a step toward full spatial assembly
- Goal is to insert single part into slot in a repeatable procedure
  - Part is 300 microns square
  - "Peg" shape to fit in slot
- Tools and procedures developed for single part assembly will be built upon for full spatial assembly

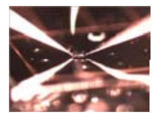
1. Locate Part



Part is initially placed on region on die and must be located
Point-and-click operator assisted operation

2. Move Close and Grab Part



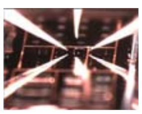


Die stage is positioned to center part
Vision used to lower probes to correct height
Probes moved into part to grab it

3. Rotate part to vertical position

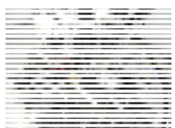
A third unactuated probe is used to rotate part out-of-plane
Pre-scripted operation

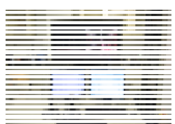
4. Insert Part



Part is moved close to insertion point
Bottom edge of part and position of the slot is detected using vision
Part is lowered into slot
Current tolerance is 6 um

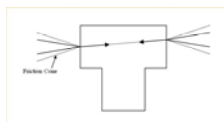
Micro Assembly System Overview

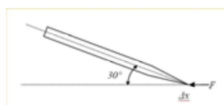




- The Micro Assembly system is a combination of hardware and software configured for telerobotic, operator assisted, and fully automated assembly tasks
- Several different components have been integrated to produce a highly synergistic system
  - Two – 9 DOF Melles-Griot nano-positioner stages for manipulation tools
    - Positional accuracy to 100 nm
    - Rotational accuracy to < 1 mdeg
  - Two – 1.2 megapixel C-mount microscope Firewire cameras
  - 3-DOF manual stage for unactuated third probe
  - 3-DOF actuated Die stage
  - Advanced Control Electronics based on custom and off-the-shelf components
  - MATLAB and VB based software interface

Grip Stability



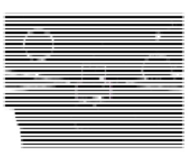


- Part is gripped by pushing two probes on opposite sides of part
  - Part is centered and aligned prior to grasp using die stage
  - Grip force is only applied in x-direction
  - Forms a Soft-Finger contact
- Because only two contacts are made, force must be equal and opposite
  - Line of contact must be within the friction cone of the probes
  - Leads to approximately 16 degrees of manipulability
- Probe deflection used to maintain contact
  - 5 micrometer deflection leads to a 1.45 mN force on part

Adhesion Forces

- Three adhesion forces considered
  - Van der Waals force
  - Electrostatic attraction
  - Capillary fluidic attraction
- Van der Walls force has been calculated at 1.7 x 10^{-30} N
  - Negligible force
- Electrostatic Attraction estimated at 100 nN
  - Sufficient to lift part of 77 nN
  - Equations used to estimate based on non-conductive polystyrene beads
    - Actual electrostatic attraction most likely much lower
- Fluidic and capillary forces are most likely the cause of adhesion for this assembly system
  - Humidity changes have been observed to cause drastic changes in manipulability
  - Fluidic forces extremely hard to estimate due to numerous factors that influence behavior

Future Work



- Improved vision system
  - Current vision system is limited
  - Uses thresholding and line tracing to locate features
  - Very susceptible to dust and other interference in images
  - State-of-the-art image processing techniques are being implemented
- 3D Micro Structure Assembly
  - Sub millimeter test structure has been designed
  - Assembly development dies are currently being fabricated by NIST

Conclusion

- Experiments in probe-based micro assembly have demonstrated the feasibility of using macro scale tools for micro assembly
  - Automated and operator-assisted assembly modes have been demonstrated
  - Repeatable out-of-plane rotation technique has been developed
- Vision feedback used to automate assembly process
  - No other form of feedback necessary
  - Improvements needed to increase robustness of image processing system
- Extensive hardware and software development has resulted in a highly effective and flexible micro-assembly testbed
- Future work is focused on the assembly of 3D micro-structures and improvement of the vision system

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