Human Directed Assembly of Heterogeneous MEMS Devices Using Precision Robotics

Track Two: Technologies and Business Practices for Enterprise Transformation
Session: Advanced Manufacturing Technologies

James F. (Red) Jones
Distinguished Member of the Technical Staff
Sandia National Laboratories

Co-Authors: Brian A. Kast, James M. Bailar, Nathan A. Weir & David M. Kozlowski

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Interest in Assembled Microsystems

Microsystems offer lower mass and smaller volume system components which can provide enhanced capabilities for existing and future systems.

- **Fuses** (Low mass could mean high shock survivability, longer throw, improved accuracy, etc.)
- **Sensors** (Integrate into legacy systems, lower power, expanded capability, more covert, etc.)

System is a group of parts interacting to achieve a common function and typically can include components for:

Power storage and/or transmission
Sensing, data storage, and/or data processing
Structure/packaging
Communication

Functional micro-Systems are comprised of a variety of parts fabricated using a variety of process and/or materials in order to meet required performance characteristics.

Typically, some assembly required….

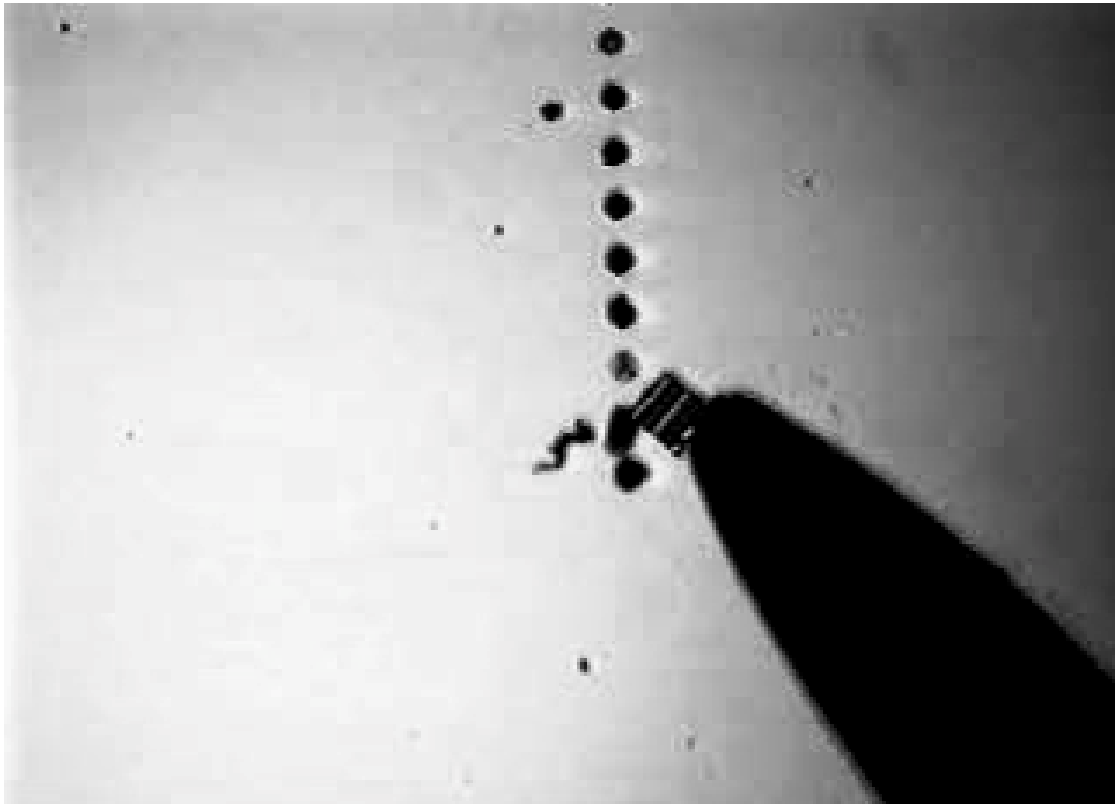
Allen-Bradley 42EF Photoswitch®
Courtesy of Allen-Bradley

Why Micro Assembly Is Difficult

Manual manipulation of 100μm OD gear*

*Courtesy of John Feddema, Sandia National Laboratories

Why Micro Assembly Is Difficult



Manual manipulation of 100μm OD gear*

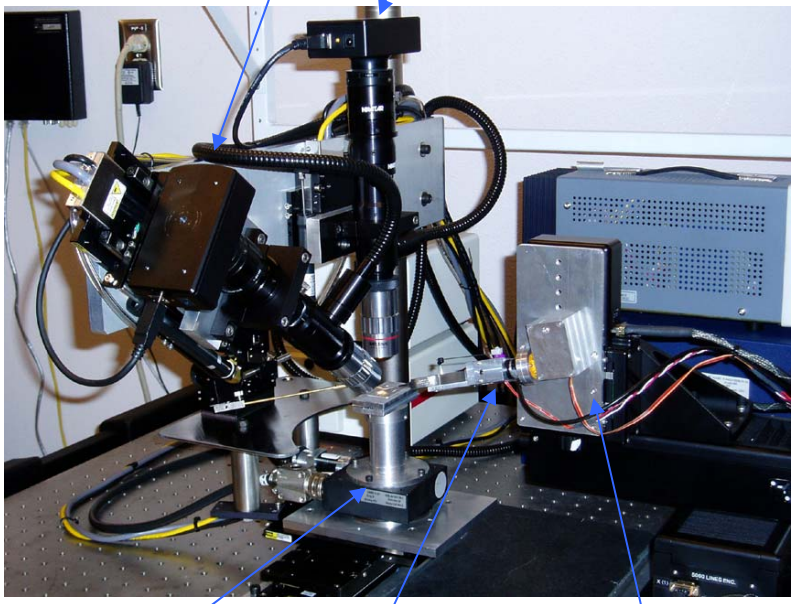
*Courtesy of John Feddema, Sandia National Laboratories

Robotic Micro Assembler

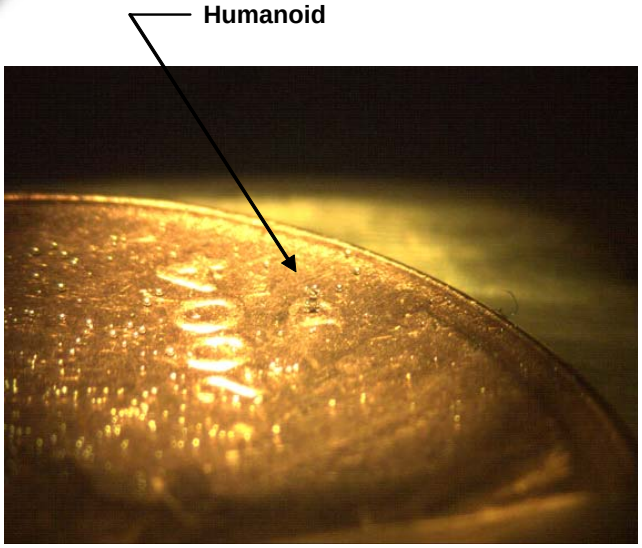
Operator Directed Robotics

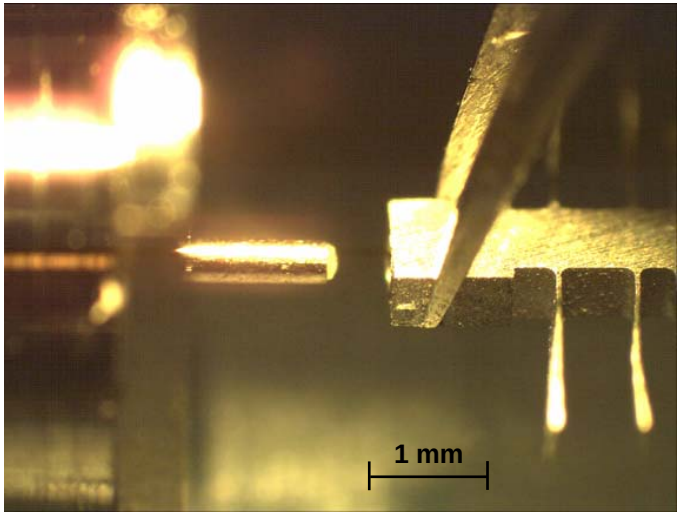
- **Rapid prototyping**
- **Assess viability of concepts**
- **Establish process for pilot production**

Operator Console with Phantom Haptic Interface

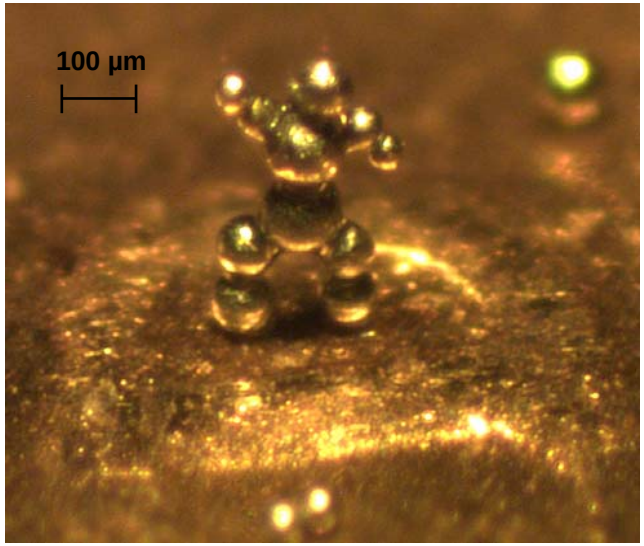


Assembled Structures



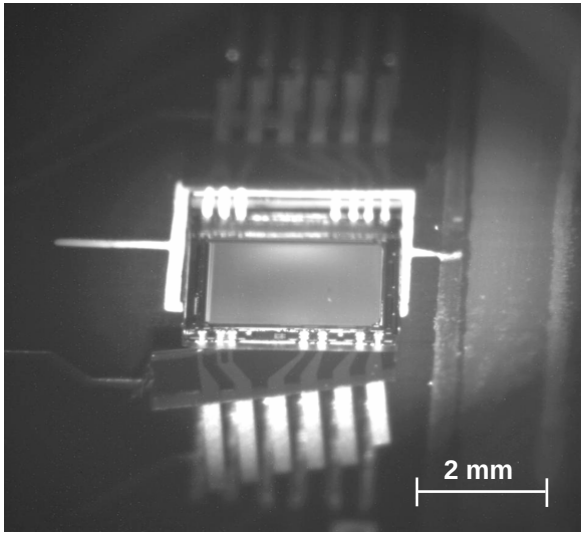


Meso-Machined RF Relay

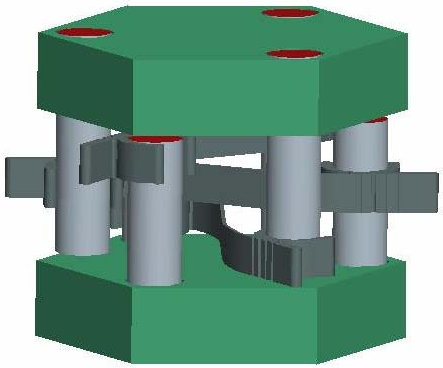


Penny Guy

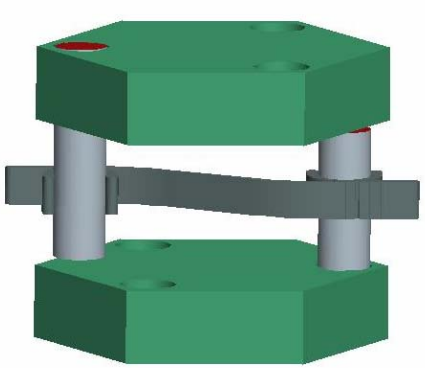
CCD Placement



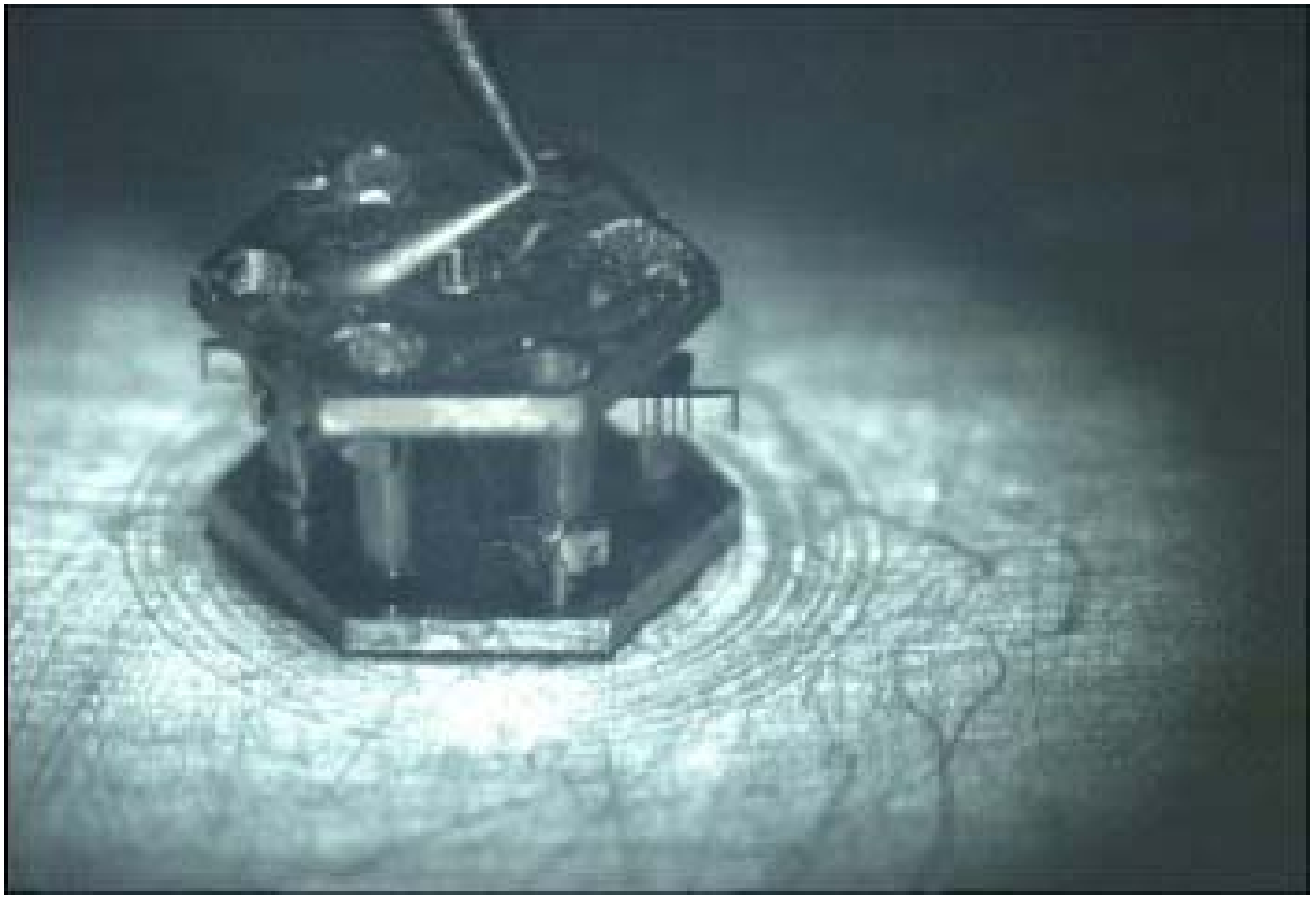
Assembled Mechanism - Pivot Bearing



CAD Model
(Fully Assembled)



CAD Model
(Single Flexure)



Video of Assembled Pivot Bearing

1 mm

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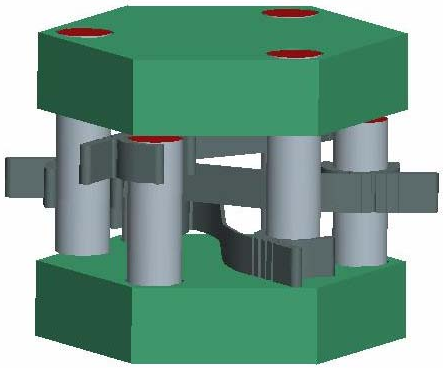

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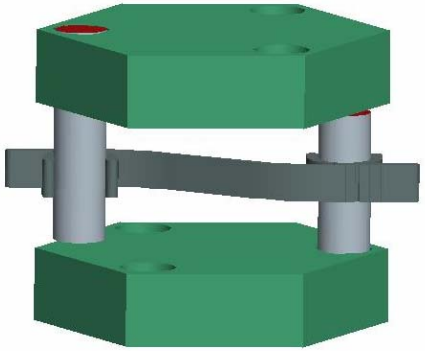

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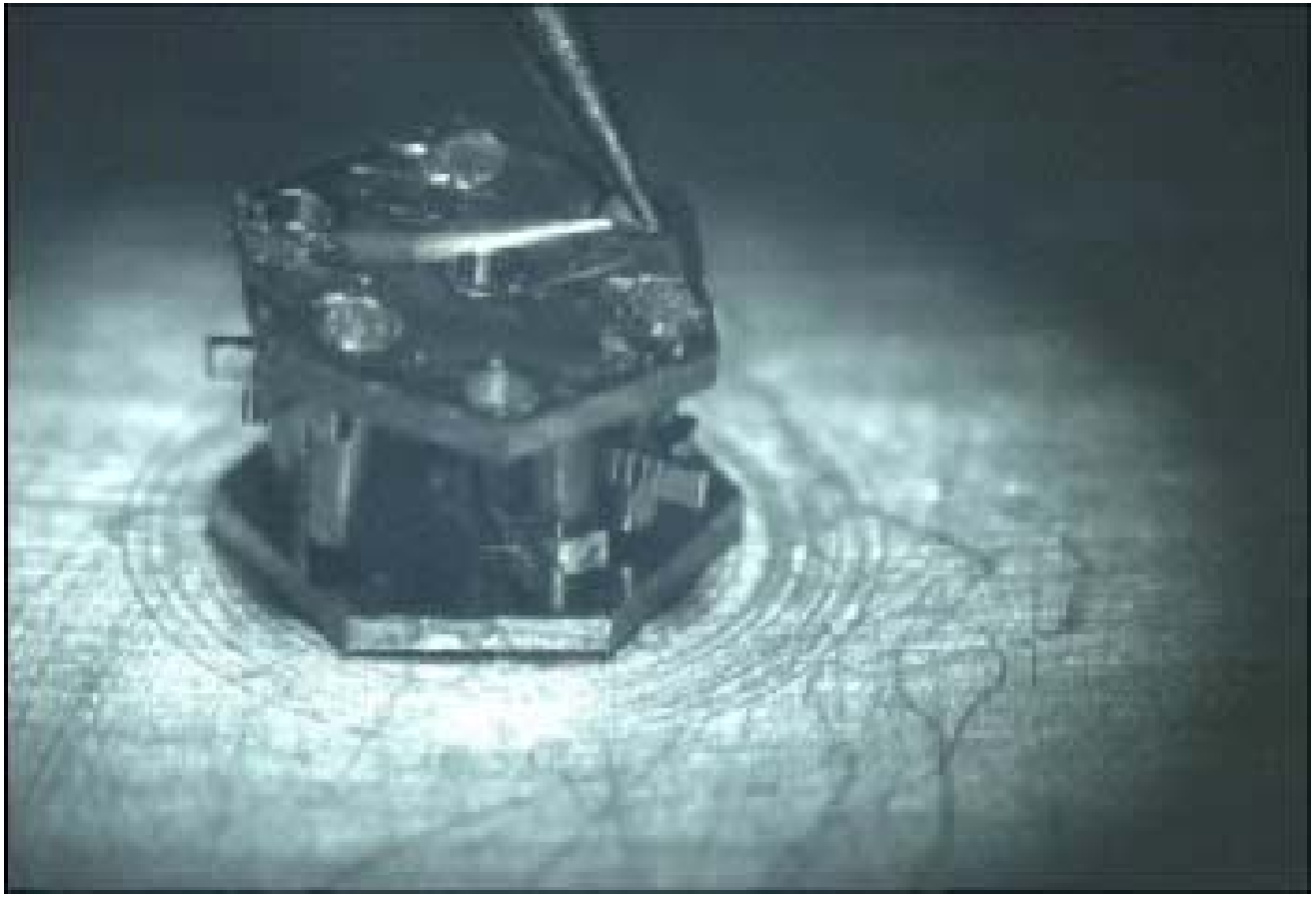

Video of Assembled Pivot Bearing

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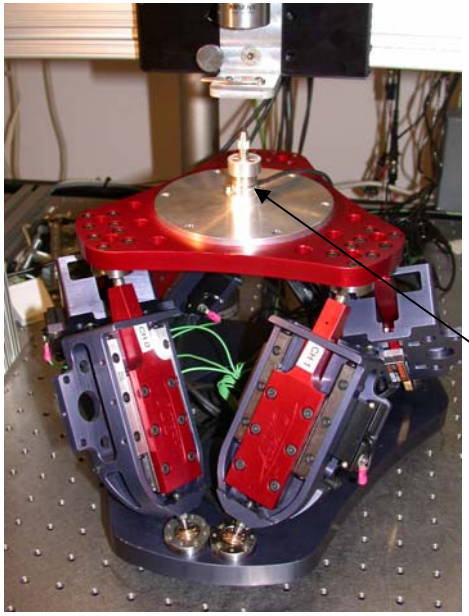
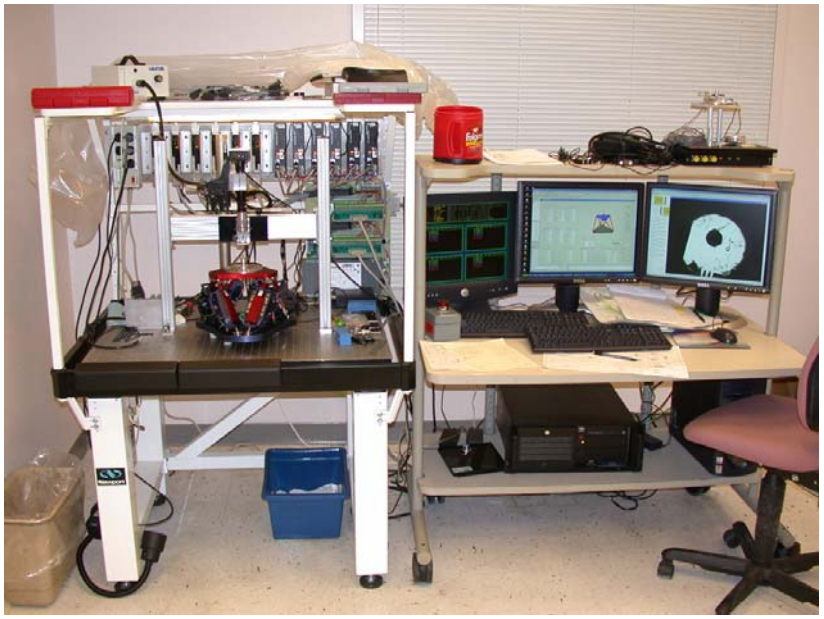
Force Control Test-Bed

- ALIO hexapod robot (10nm resolution on linear actuators)
- Supplied PID controller intended for photonic alignments
  - Low proportional/high integral gains
  - Poor path following and poor dynamic response
- Custom control system achieves necessary precision with high dynamic response
  - MATLAB®/Simulink® with Real Time Workshop®
  - xPC Target® real time target OS
  - Natural Admittance Control (NAC) algorithm

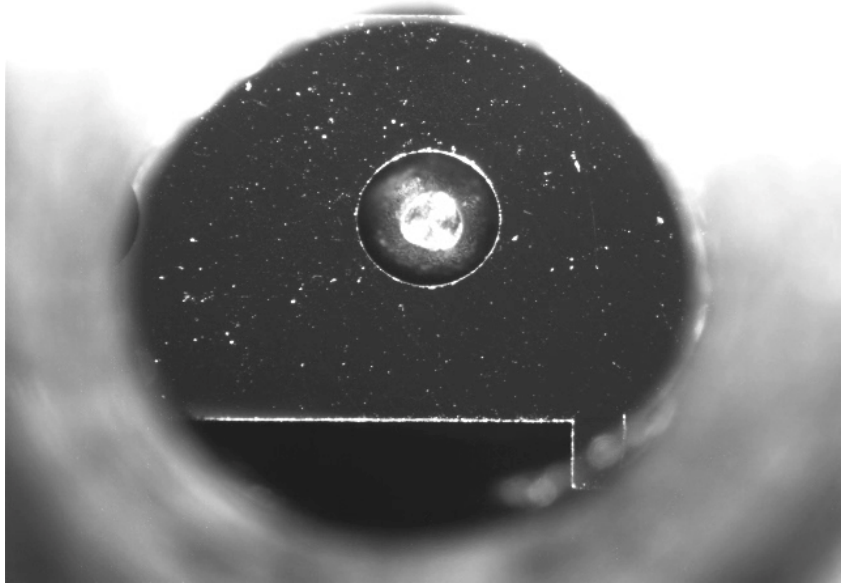


ALIO Hexipod



Hexipod robot with control system

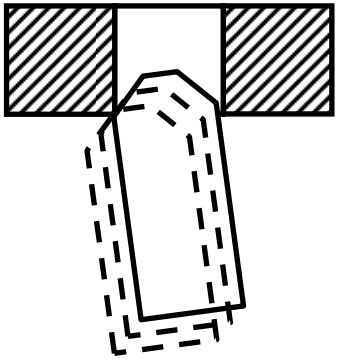
Force Controlled Assembly



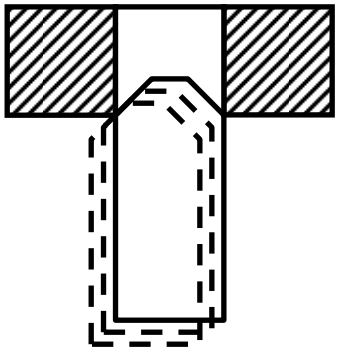
Video of Peg-in-Hole Assembly

500µm

- Peg-in-hole insertion under force control
  - 500µm nominal diameter
  - ~1µm clearance
- First attempt jams
  - Peg orientation not parallel to the hole axis
  - Peg center not aligned with hole center
- Insufficient force/moment data to infer a correction in orientation
- Probing part surface provides proper angular orientation
  - (not depicted in video)
- Second attempt does not jam
  - Peg axis parallel but not aligned with hole axis

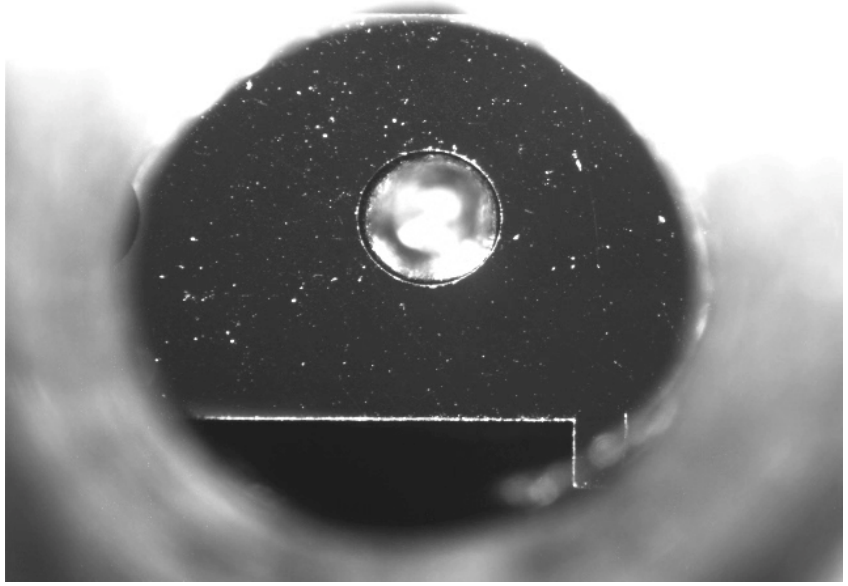


First attempt



Second attempt

Force Controlled Assembly



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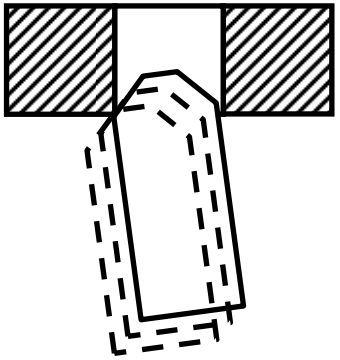

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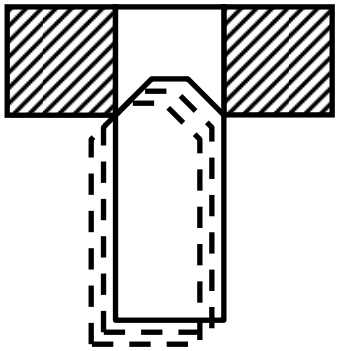

Second attempt

Status & the Future of the Technology

Demonstrated the capability to assemble devices where individual components range from a few millimeters to tens of microns.

What have we learned?

- **Human assembly of micro scale structures is not possible without "aids".**
- **Pick & place micro assembly is possible using precision robotics coupled with advanced sensors, controls, and processes.**

Applicability of robotic operator directed micro-assembly

- **Prototyping assembled micro-systems**
- **Low volume production typical to NNSA**
- **Develop and prove in process capabilities**

Next Step - Integrate sensors into the assembly process

- **Facilitates more efficient operator directed micro-assembly, especially for delicate parts/components.**
- **Help enable automated assembly of 3D heterogeneous micro-systems for moderate production throughput applications typical to national defense/security industry.**

Future Applications

Possibility exists to enable very small interesting devices

Near Term (ultra miniature)
- **Weapon fuse components**
- **Covert surveillance sensors**
- **Micro optical-electro-mechanical systems**

Mid Term (heterogeneous micro systems)
- **Munitions stability sensors**
- **Smart small munitions**

Long Term (integration of hybrid micro/nano systems)
- **Molecular transistors**
- **Nuclear batteries**

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