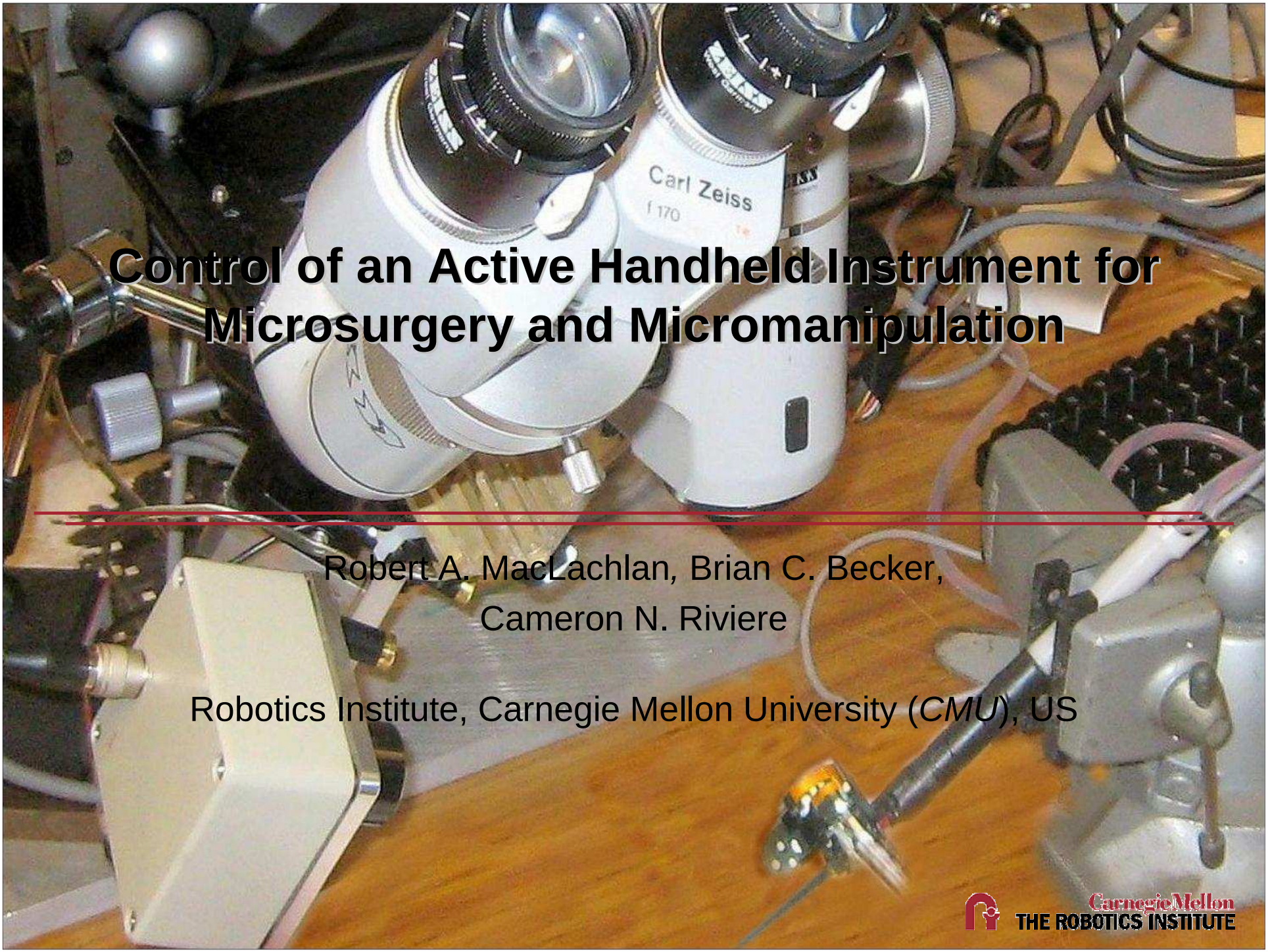

Control of an Active Handheld Instrument for Microsurgery and Micromanipulation

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THE ROBOTICS INSTITUTE

Motivation

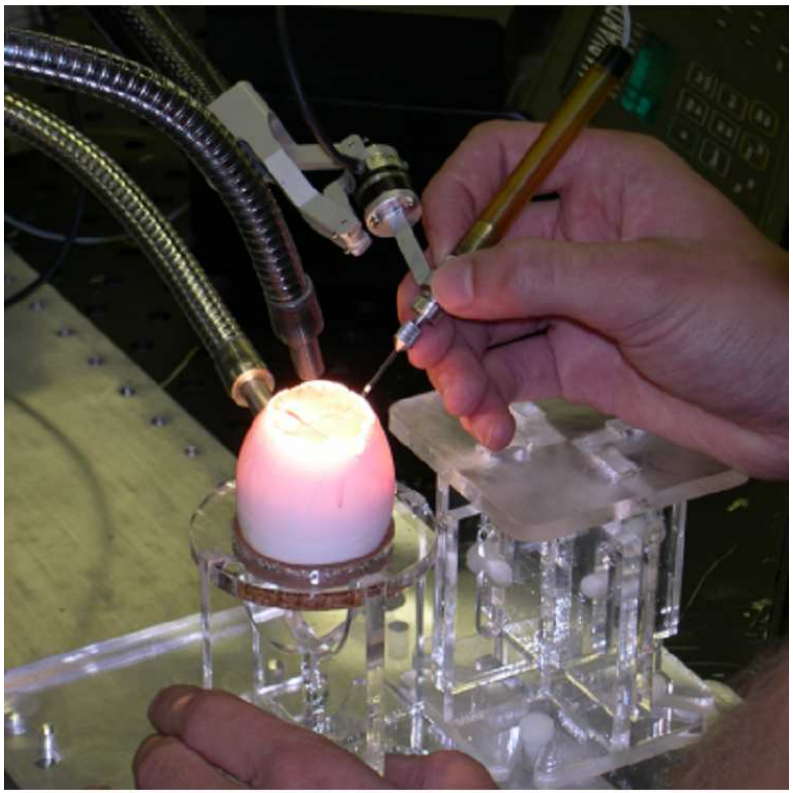
- Increase accuracy in micro-manipulator/surgery tasks
  - Work with micrometer precision
- Compensate for hand tremor
  - Remove involuntary movement or “shake”
- Modify motion of the instrument
  - Use virtual fixtures
- Inexpensive, easy-to-use
  - Minimize learning curve

Human Hair

Micromanipulator Designs

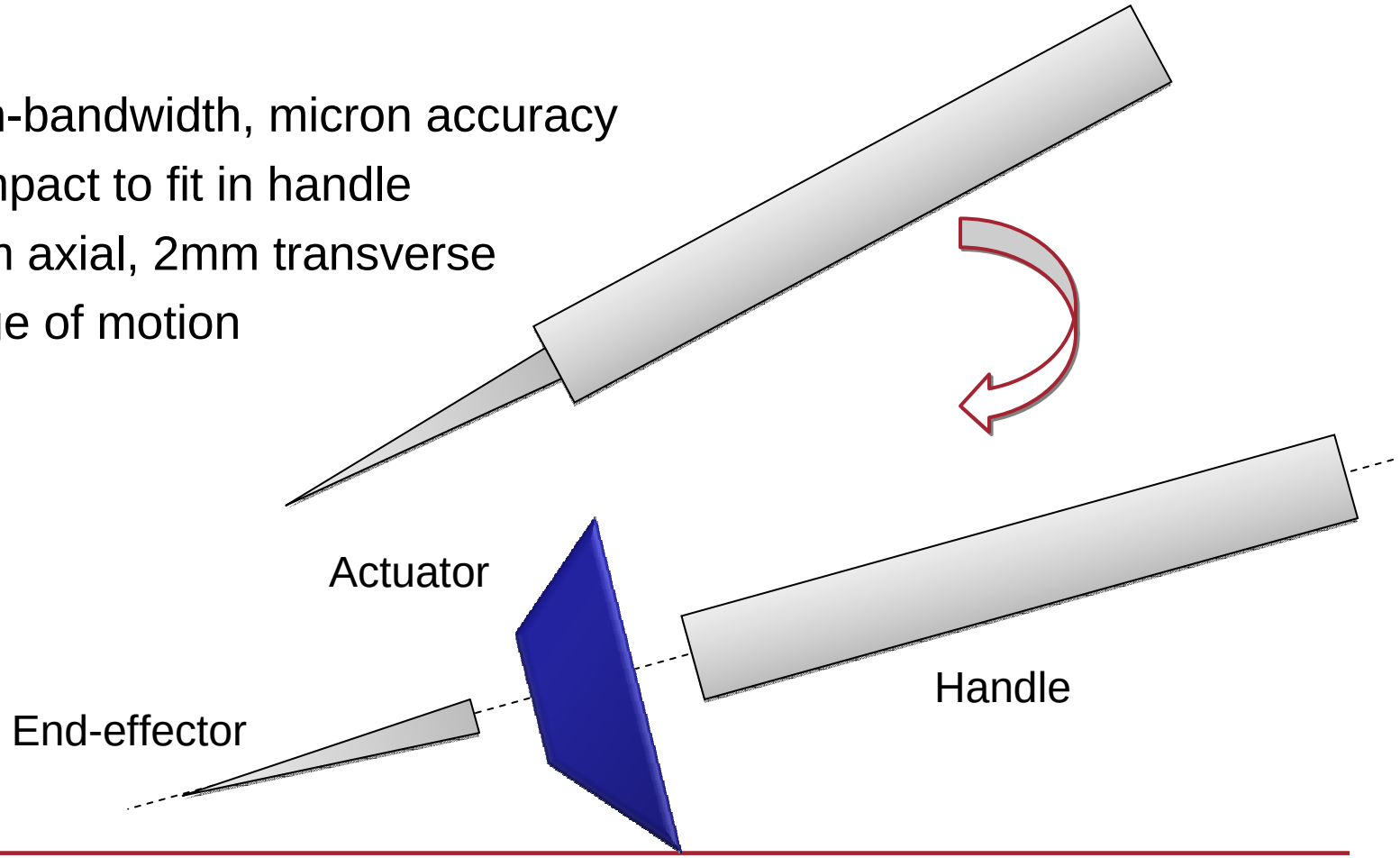
- Tele-operated Actuation
  - DaVinci from Intuitive Surgical

- Cooperative Actuation
  - SteadyHand from JHU [Taylor 99].



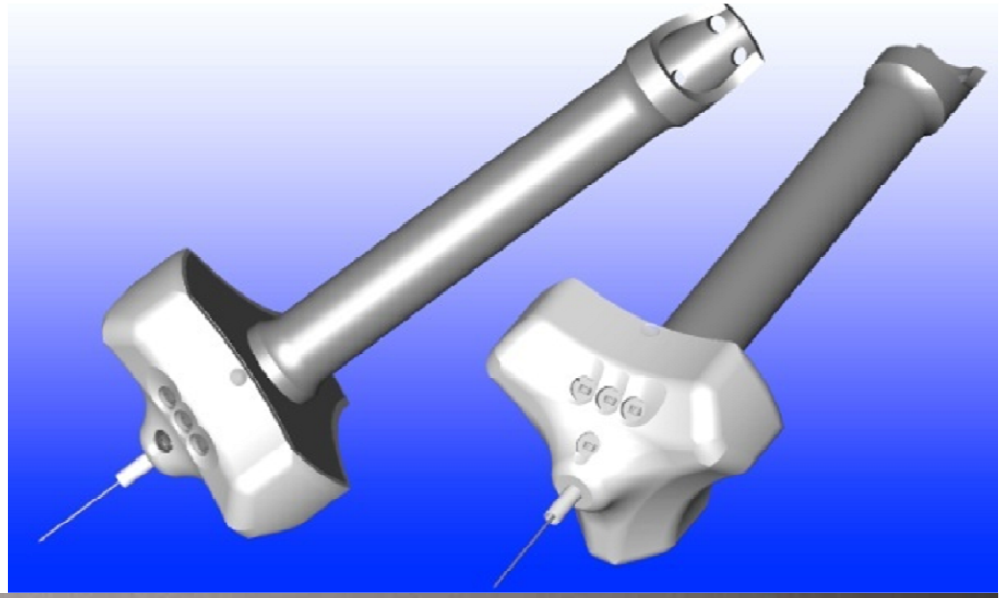
Micromanipulator Designs

- Handheld Actuation
  - Actuators between hand and end-effector of the instrument
- Goals
  - High-bandwidth, micron accuracy
  - Compact to fit in handle
  - 1mm axial, 2mm transverse range of motion

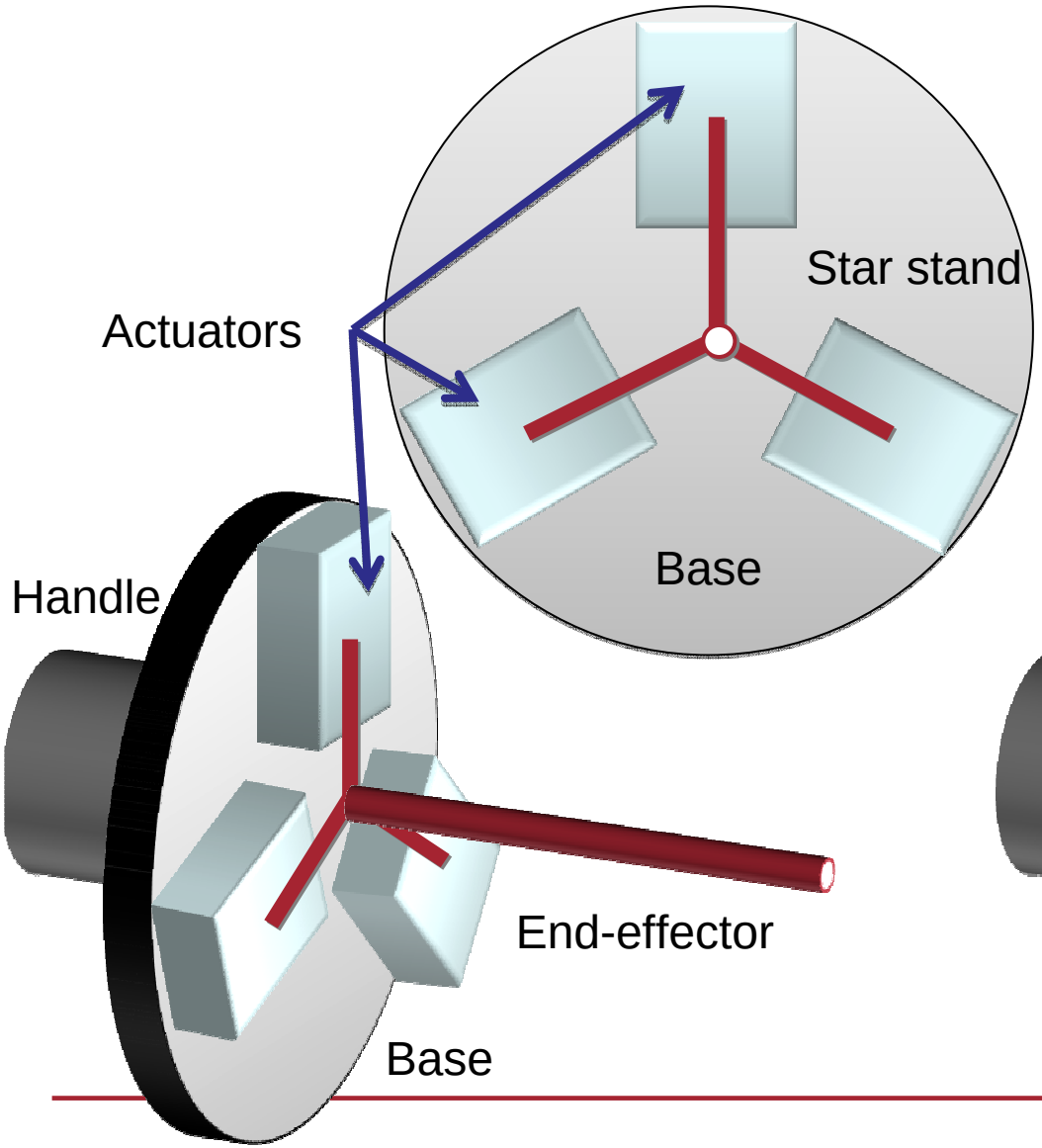


Micron Micromanipulator

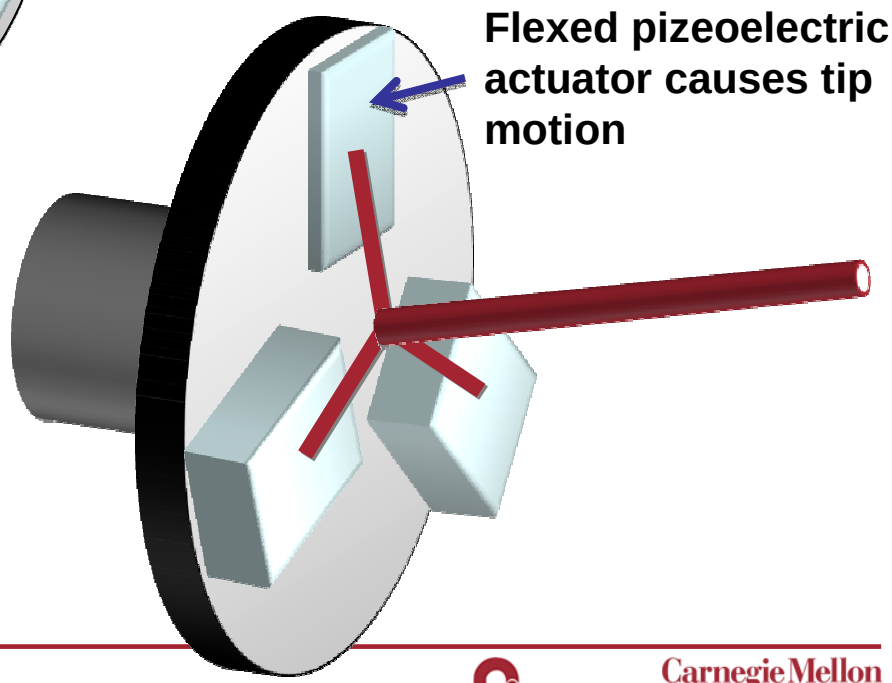
- 3 DOF micromanipulator
  - Actuators between handle and end-effector
  - XYZ 3D space actuation
  - Fully handheld
  - Compensate for tremor
  - Hollow center



Micron Actuation

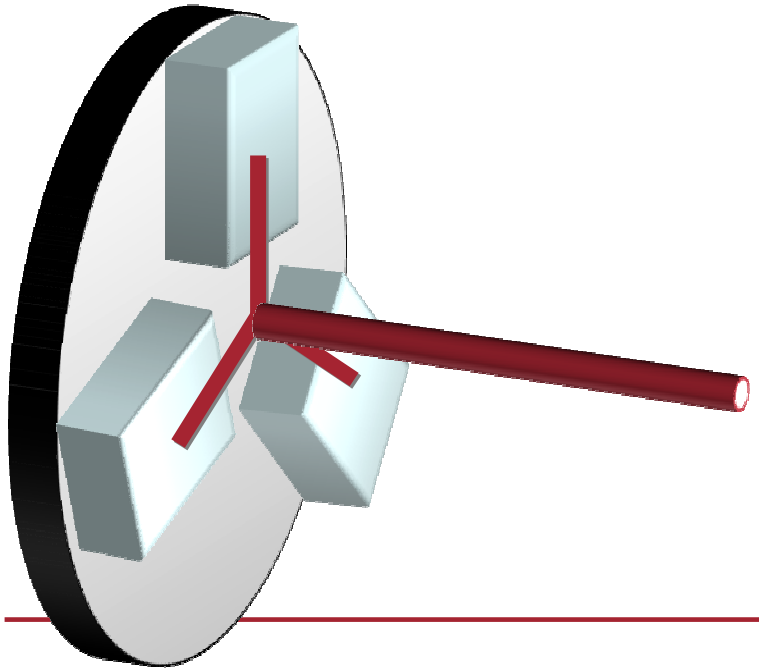


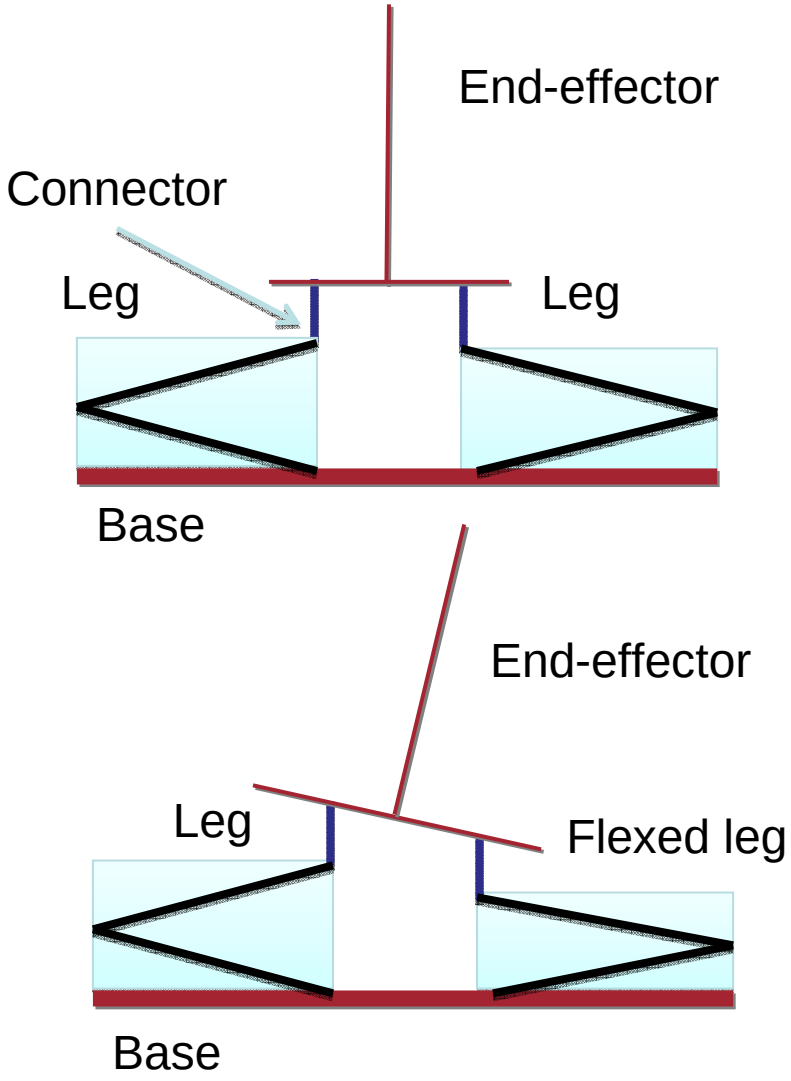
- Three Thunder® bender piezoelectric “legs”
- Laminated metal, not ceramic, for large range of motion
- Stiff – exert Newtons of force



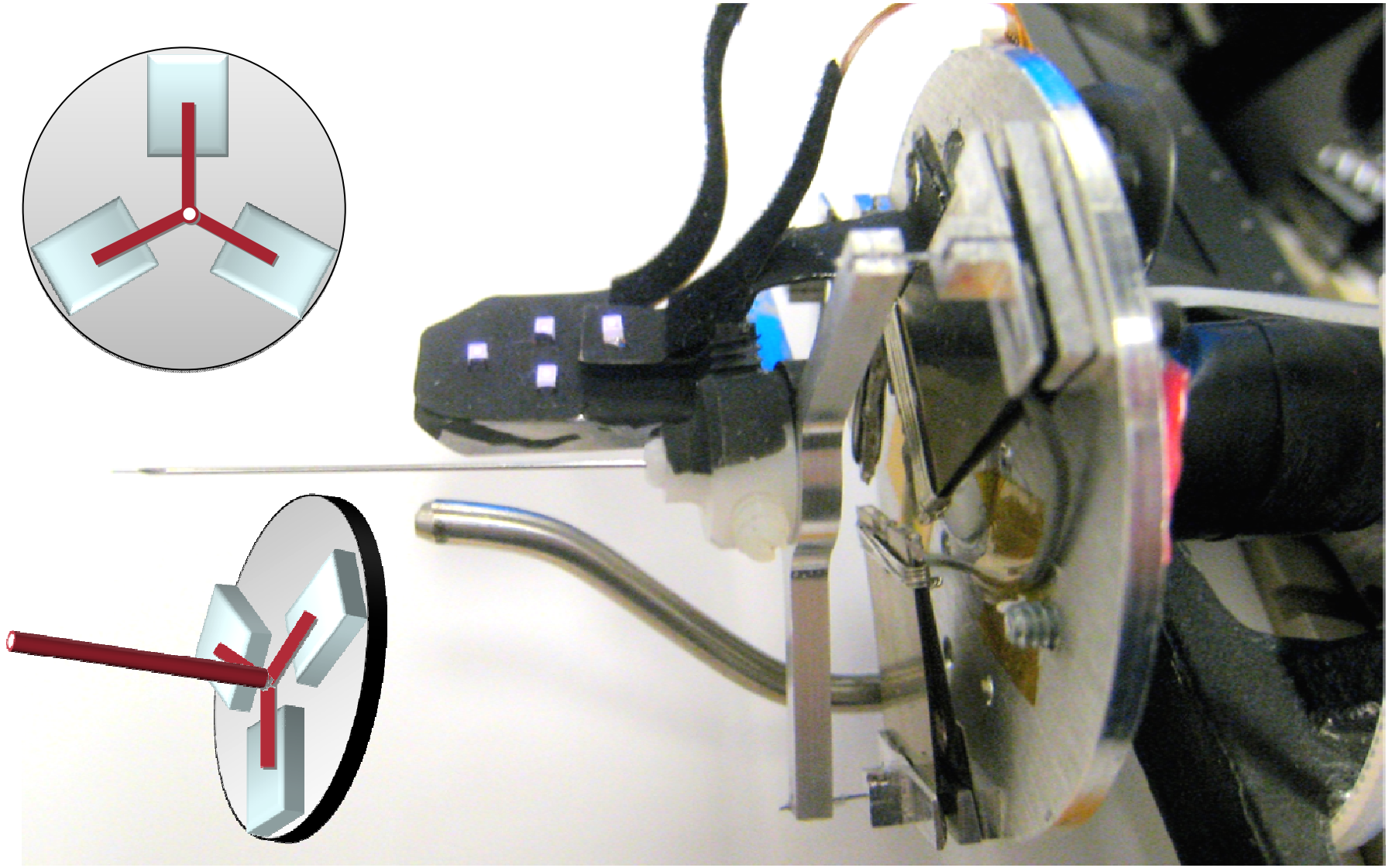
Micron Actuation

- Legs rigidly fixed to base plate
- Polypropylene monofilament flextures connectors
- Each leg is two actuators connected in series face-to-face
- Actuates ~600 microns vertical



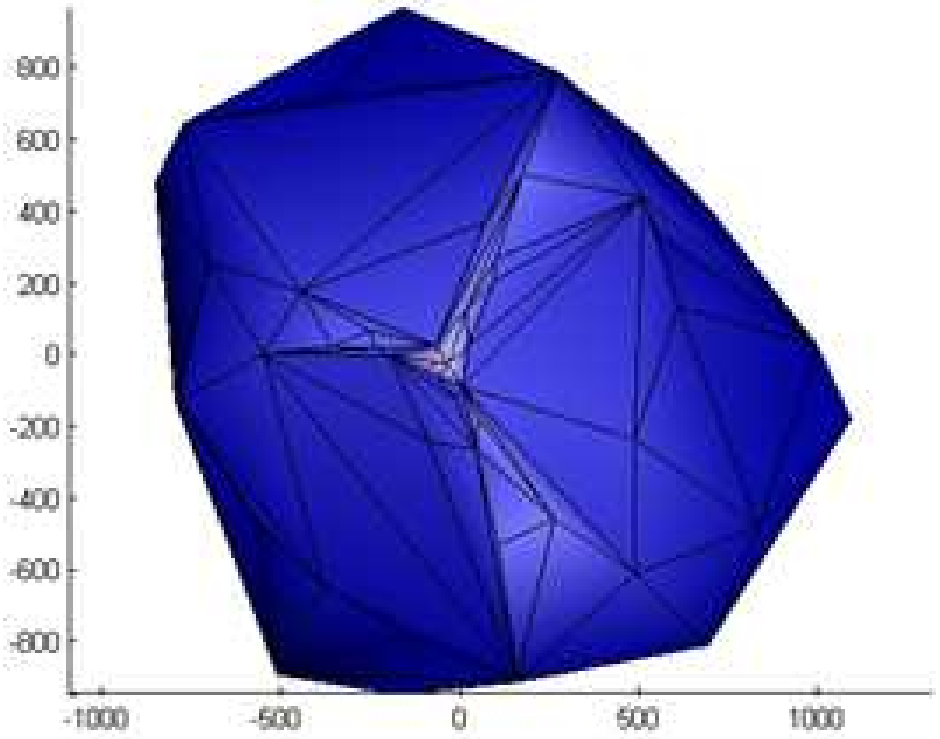


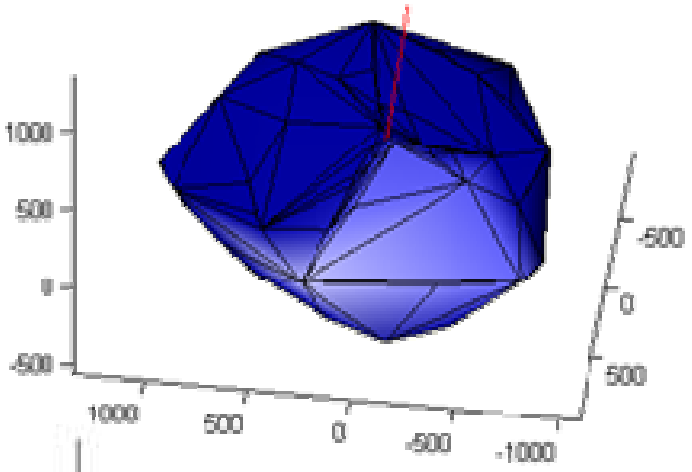
Micron Actuation

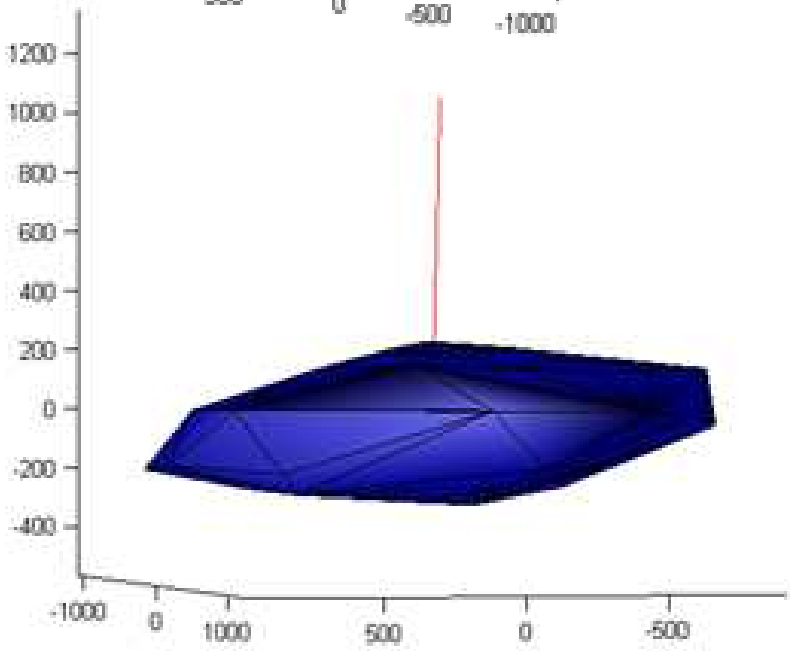


Micron Range of Motion

- Depending on end-effector length, range of motion is ~2x2x0.8mm

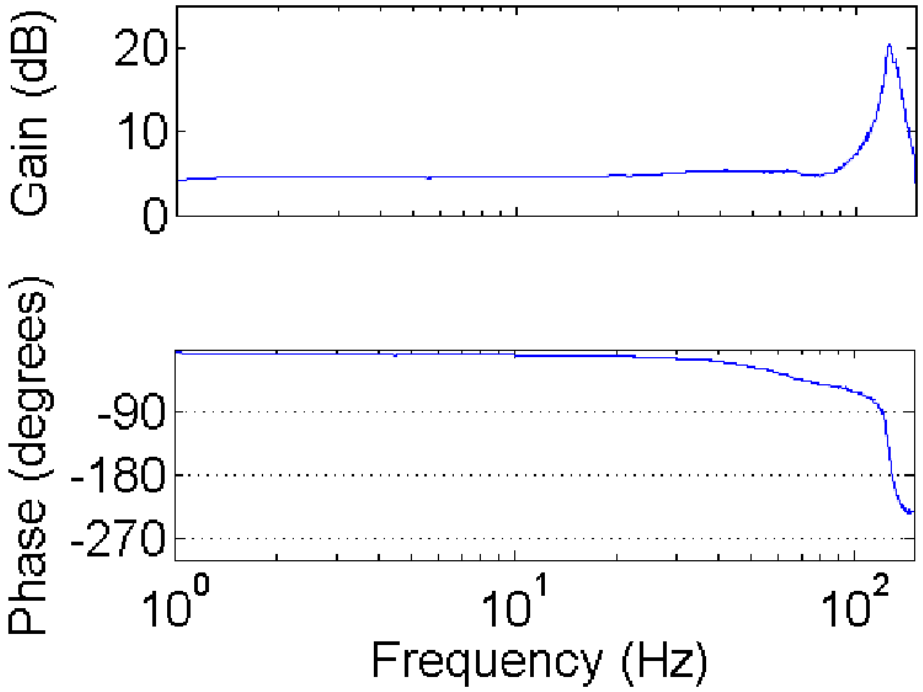






Performance

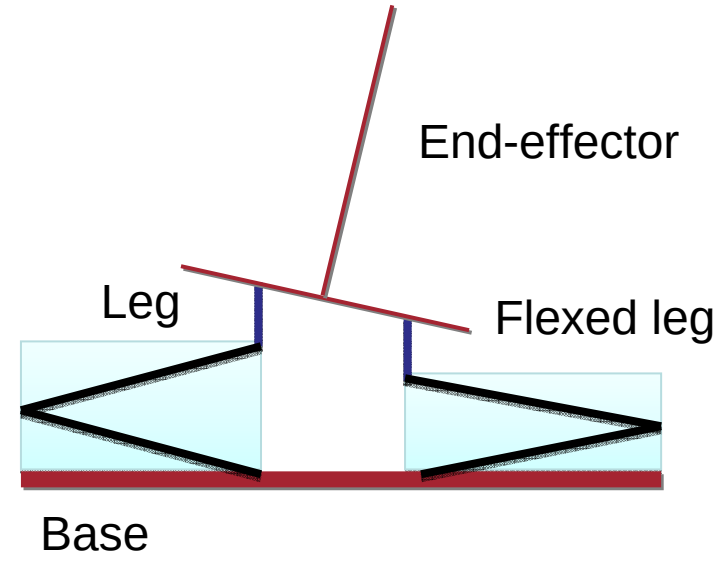
- Frequency Response
  - Resonance at 174 Hz
  - PID controller at 100Hz
  - Integral gain dominates <52 Hz

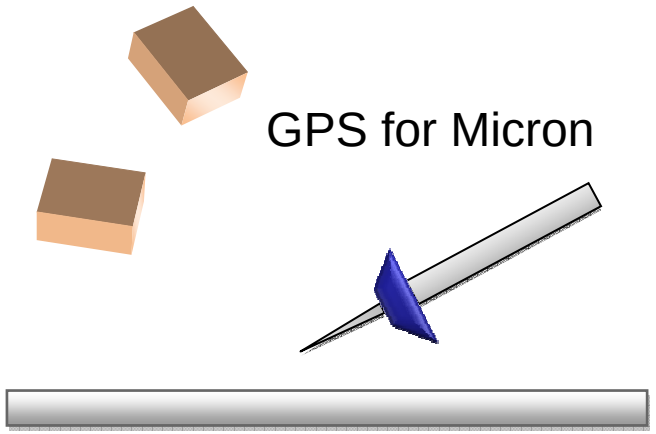


- Actuator Control
  - High voltage [-240, 480] V
  - Minimal current <1 mA
  - Driven by current source
  - Control charge, not voltage to reduce nonlinearity & hysteresis
  - Control output voltage with feedback loop to eliminate current error by servoing voltage drift to zero

Positioning System

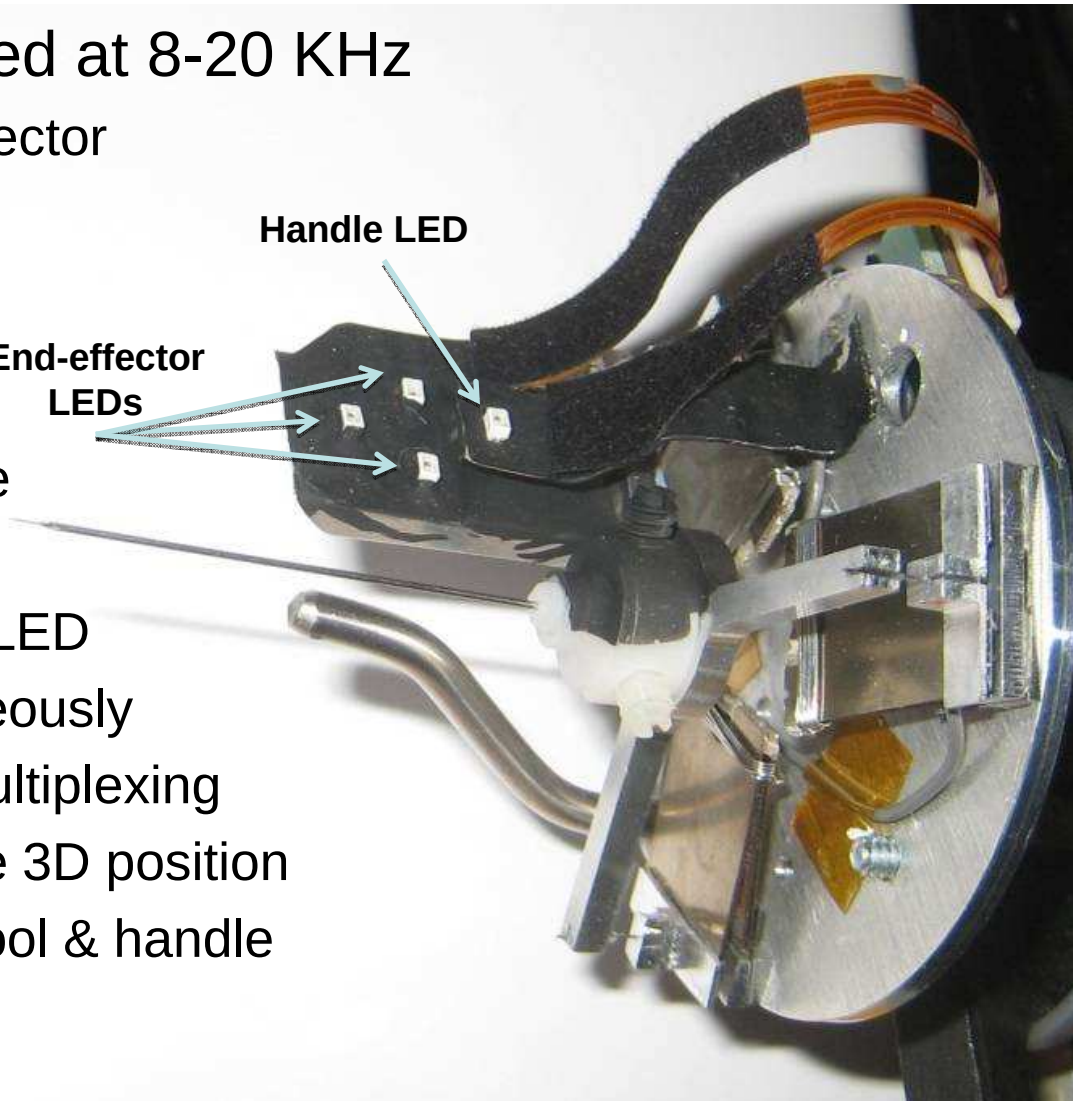
- Micron can actuate precisely relative to the instrument frame
- However, this doesn't help us cancel hand tremor
  - Don't know motion of the instrument
- Micron needs a low-latency, high-resolution, high-bandwidth global positioning measurement system
- Solution: Optical tracking at 2 kHz





Positioning System

- Four Infrared LEDs pulsed at 8-20 KHz
  - Three attached to end-effector
  - One attached to handle
- LEDs tracked at 2 kHz
  - Infrared Position Sensitive Detectors (PSDs)
  - Measures 2D centroid of LED
  - Tracks all LEDs simultaneously with frequency domain multiplexing
  - Two PSDs can triangulate 3D position
  - Reconstruct 3D pose of tool & handle

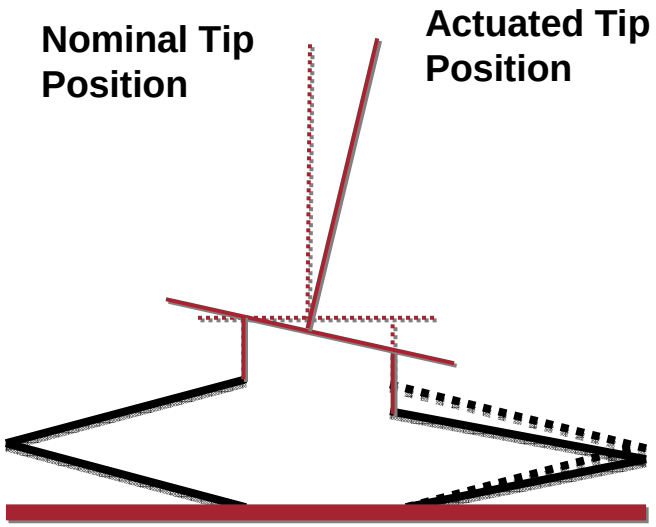


Positioning System

- 2 PSDs mounted at 60°
  - 4 cm workspace
  - Can be mounted to microscope
- Kinematics to calculate tip position
  - Accurate to ~10 microns RMSE

Control of Micron

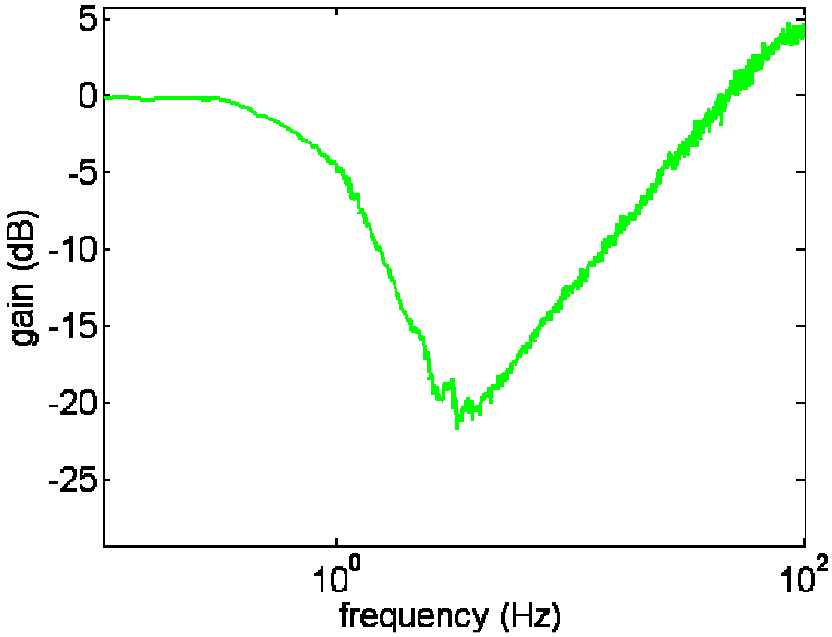
- With global positioning
  - Optically track 3D tip position
  - Set 3D tip position goal points
- Use inverse kinematics
  - Linearize inverse kinematics
  - Correct errors with feedback
- Nominal Tip Position
  - Where tip would be without any actuation
  - Calculated from handle LED
  - Very useful in tremor cancellation
  - Measures hand motion



Tremor Cancellation

- Tremor is at 8-12 Hz

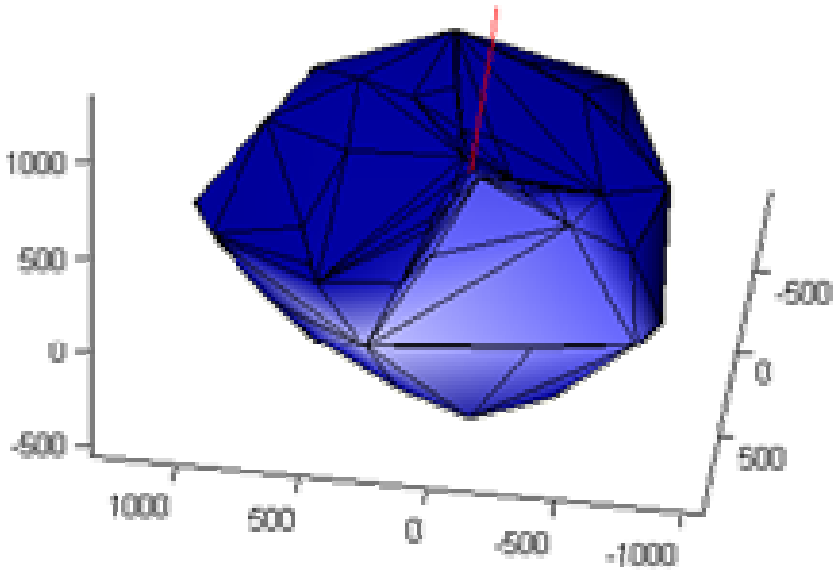
- Use lowpass filter
  - Removes jitter
  - Corner tradeoff: suppression vs. response time



- Actual response is a band stop
  - Unity gain at low frequencies: tip follows gross motion handle
  - Unity gain at high frequencies: finite cancellation bandwidth
  - High corner determined by integral stability and dynamics
  - Implementation: Tip goal ← low-pass filtered nominal tip position
  - Can affect “feel”, may feel twitchy or laggy

Saturation

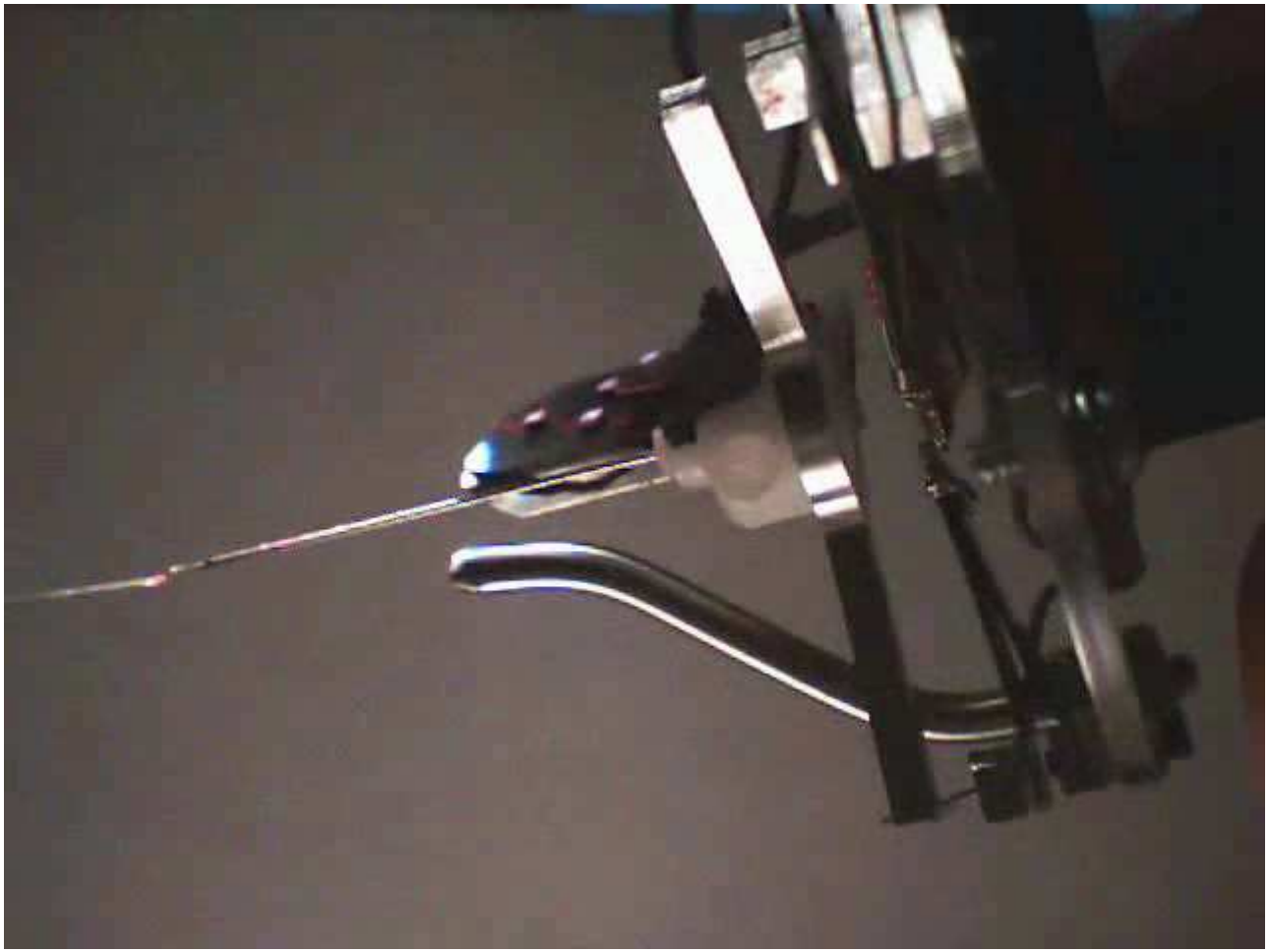
- Saturation occurs when actuators reach limits
  - Cause by large rapid hand movements
  - Prevents further tremor cancellation
  - Opens the feedback loop, causes integrator windup
  - Significant problem in handheld experiments



Range of motion

- Area of important future research

Results



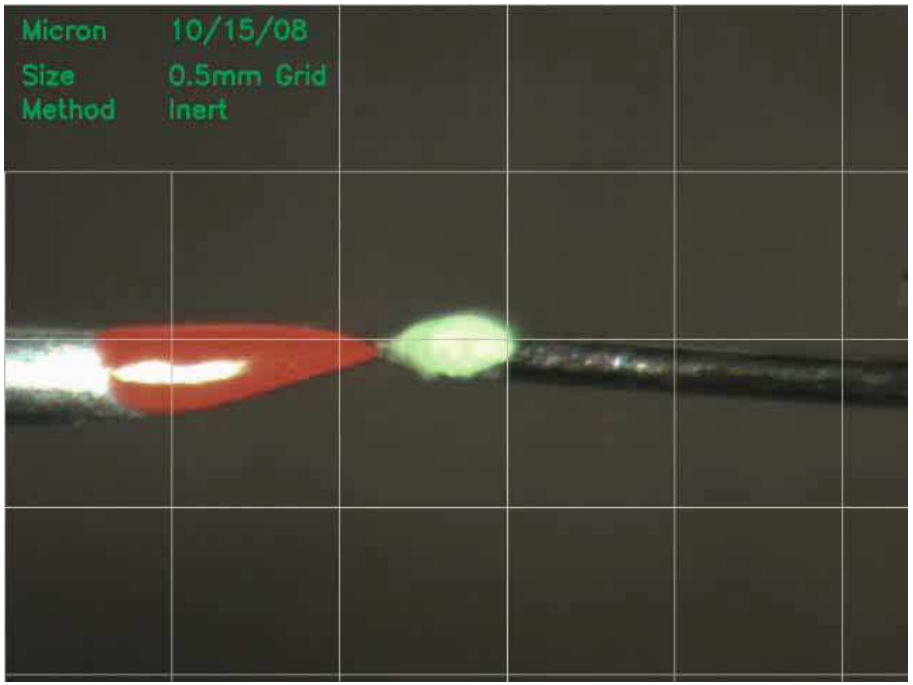
Results – Pointing Task

- Micron tip on right, target on left
- Roughly 20-30% reduction in RMSE
- Red bar indicates depth

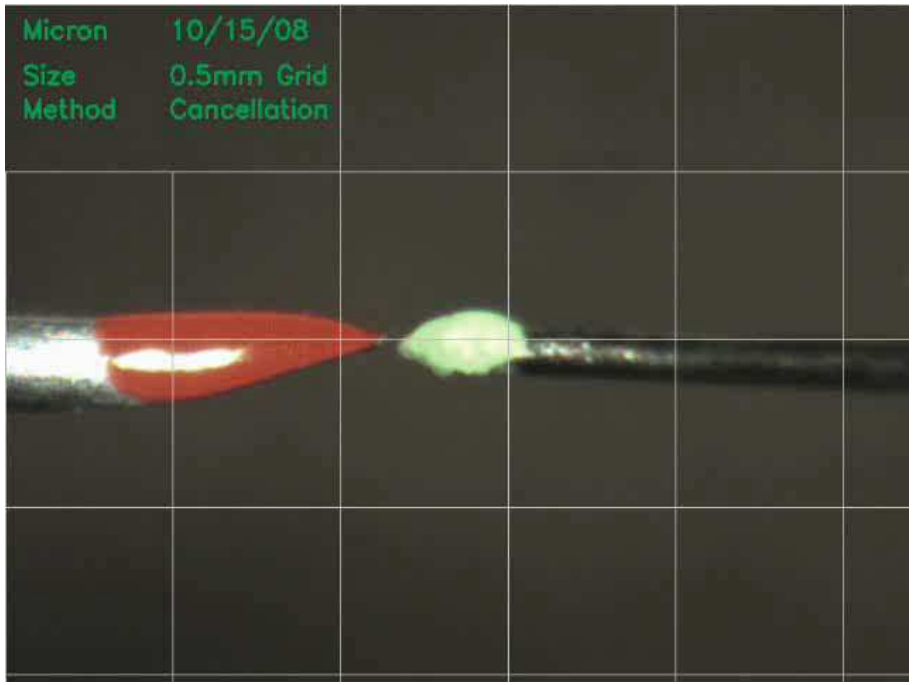
Micron instrument tip (200 µm diameter)

Red target needle

Without tremor cancellation



With tremor cancellation



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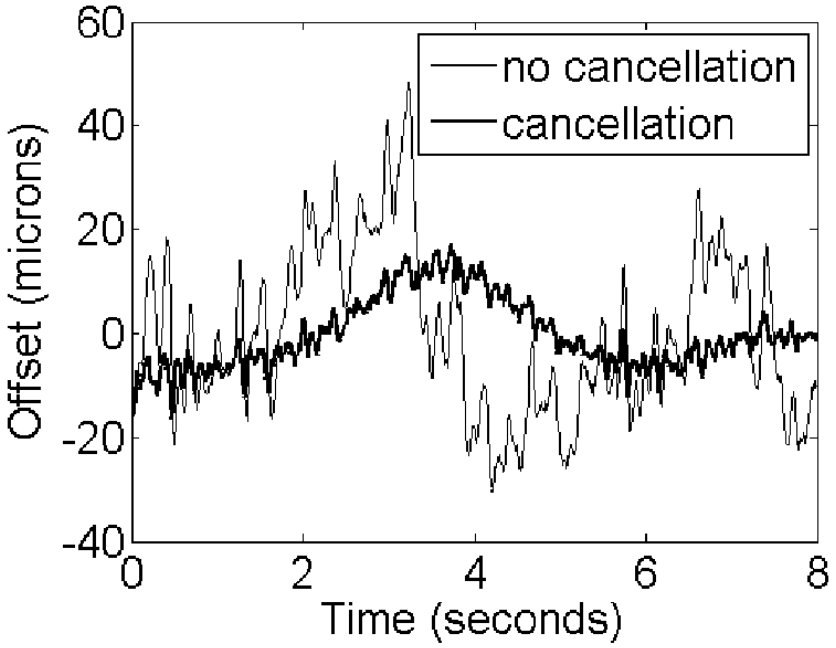
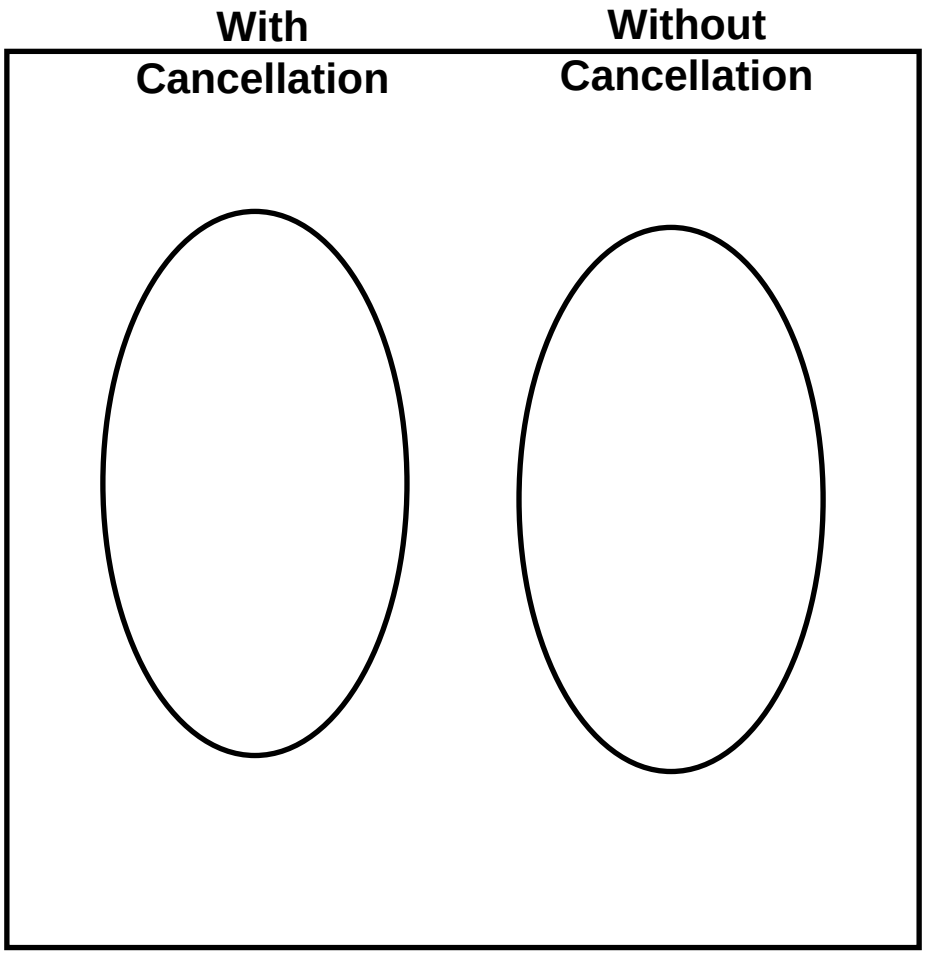


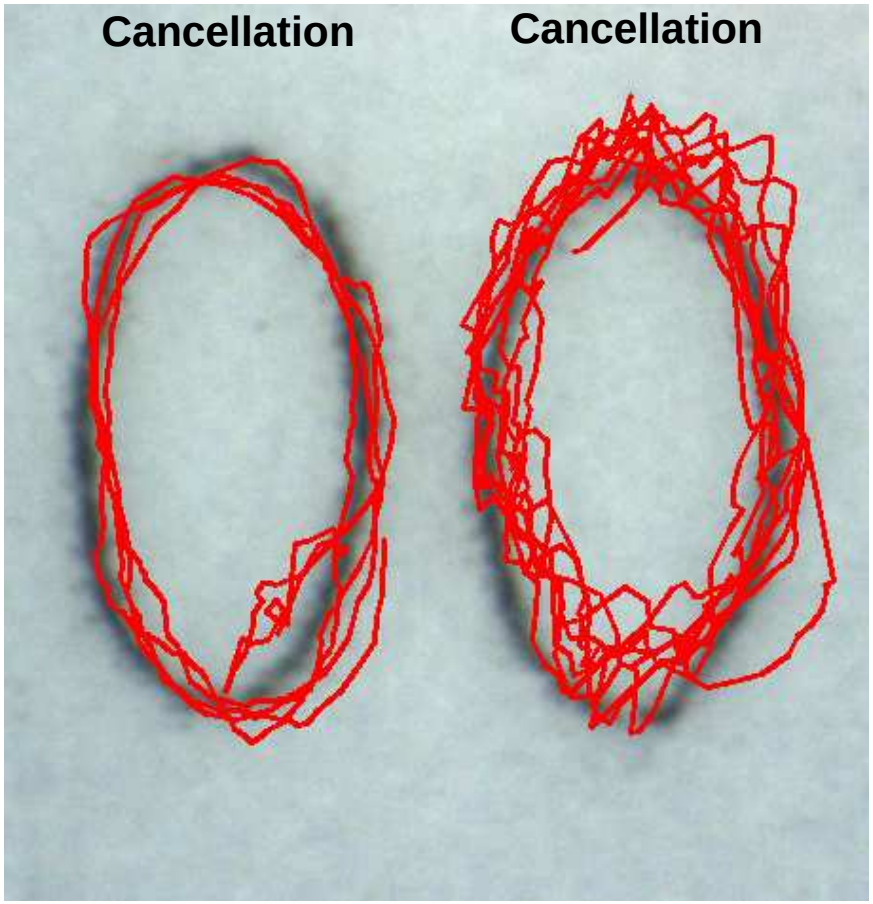
Results - Qualitative

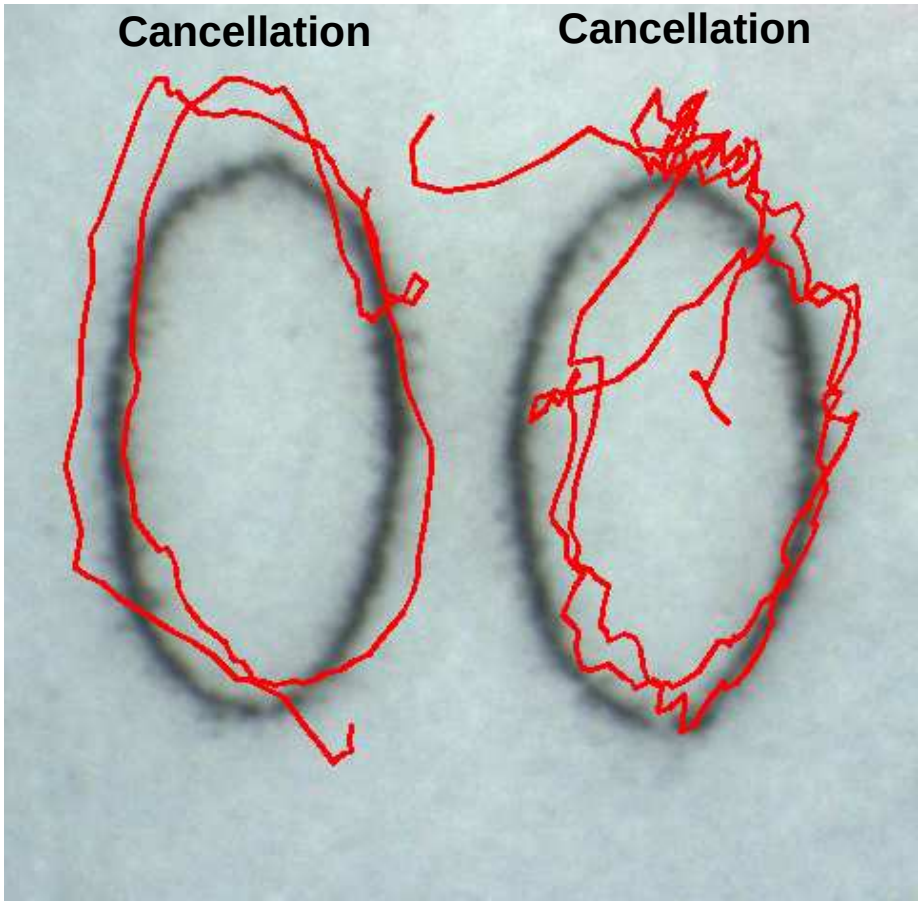
- Shape drawing test: trace an ~0.5mm oval
- Evaluating only 2D error
- Results from a random sampling of people at a demo at JHU
- Test with and without tremor compensation



Results - Qualitative

- Performance varies by person and with experience

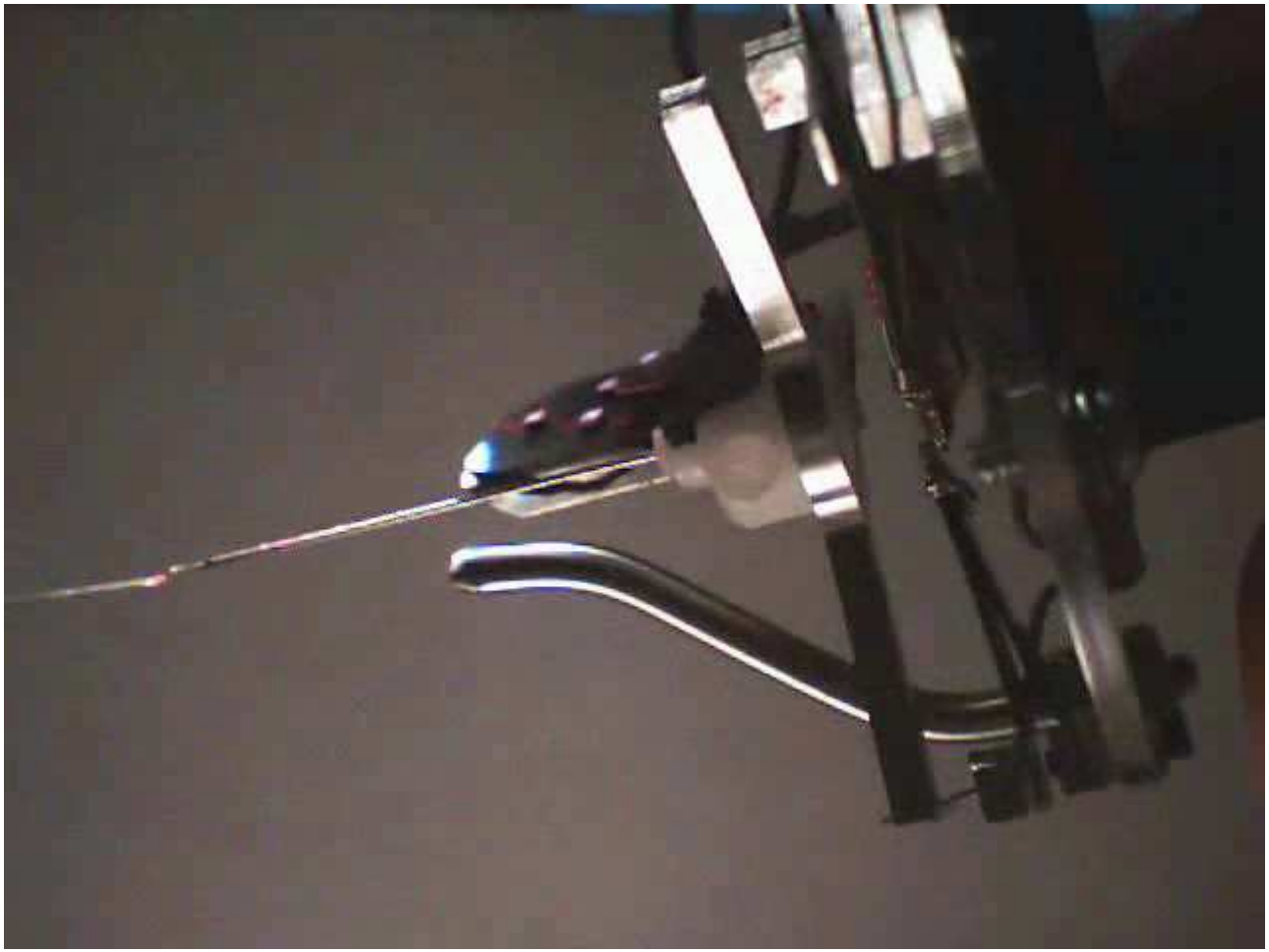




Conclusion/Future work

- Fully handheld micromanipulator
  - ~1x2x2mm range
  - Low latency, high bandwidth
  - Precision global positioning
- Tremor suppression
  - Low-pass filter
  - Effective at suppressing jitter/tremor
  - Lower frequency drifting motion remains
- Future Work
  - Improved handling of saturation
  - New manipulator with larger range of motion
  - Visual servoing to aid task specific procedures
  - Virtual fixtures for improved guidance

Questions?

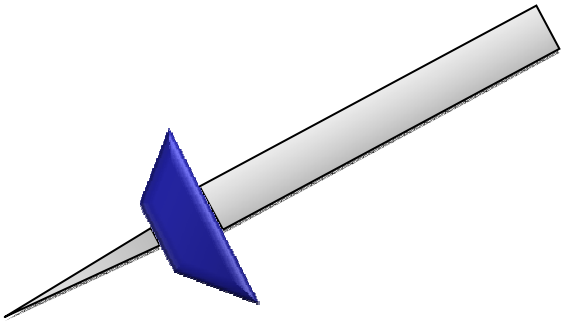


Overview

- Motivation
- Overview of systems (steady-hand, etc)
- Block diagram of system
- LEDs/PSDs sensors
- Actuation/thunder
- System performance
- Demos
- Conclusion/Future Work

Micromanipulator Designs

- Handheld Actuation
  - Actuators between hand and tip of the instrument



Micron System

- System components
  - Handpiece/manipulator
  - Custom driver and signal conditioning electronics
  - Two position-sensitive detectors (PSD)
  - PC interfaced with DAQ boards and LabVIEW realtime