Automation and Machine Learning for Robust Self-Tuning of Magneto-Optical Traps

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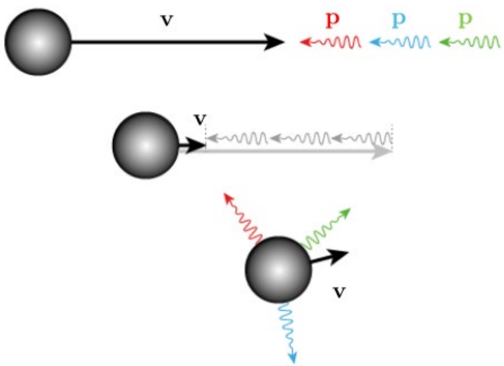
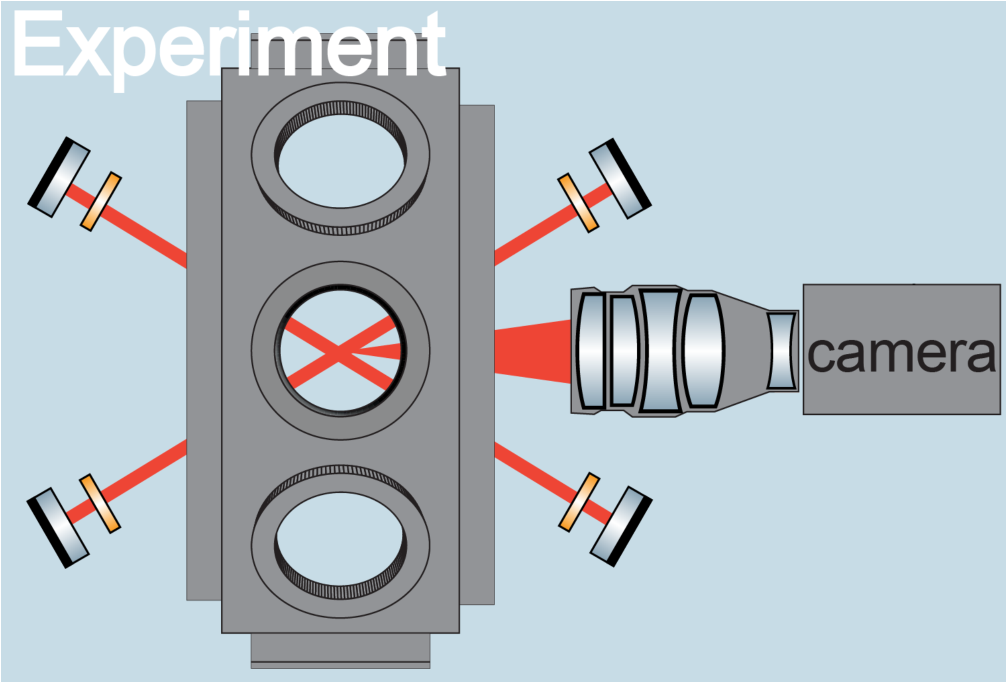
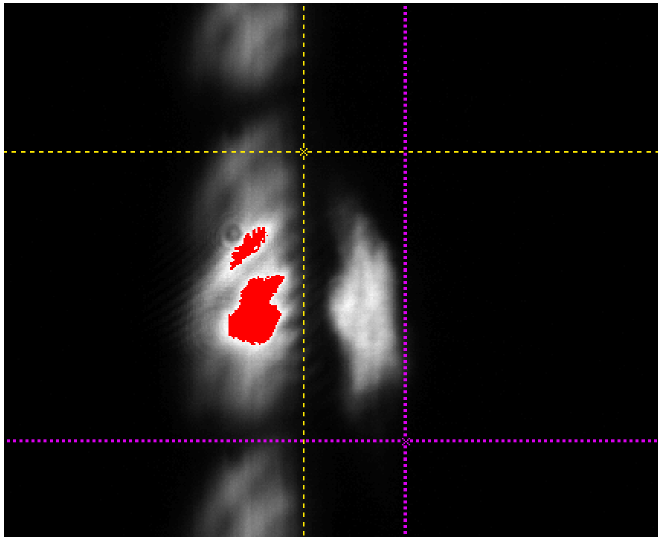
Motivation

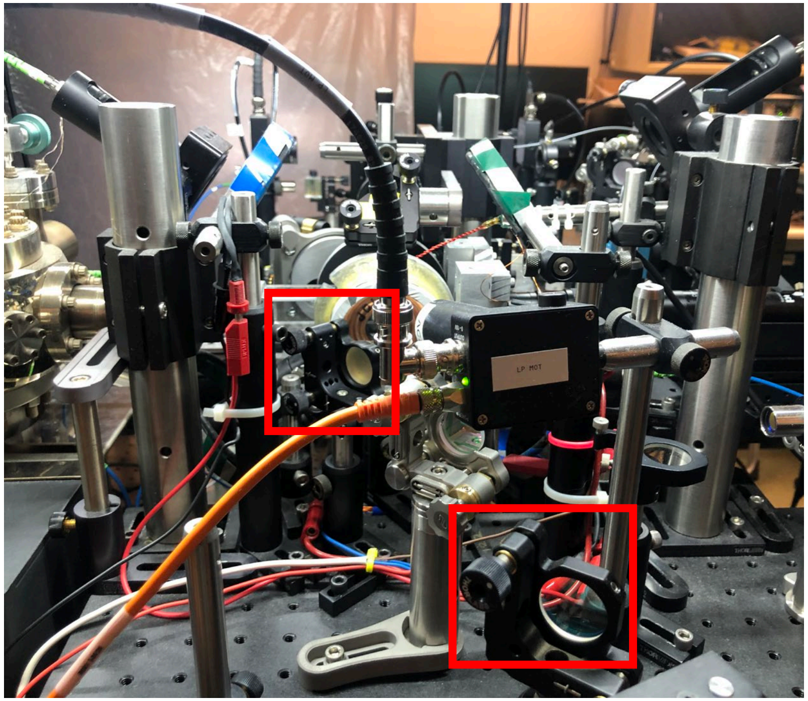
- Rubidium Magneto-Optical Trap (MOT)
  - Uses lasers and magnetic fields to slow down (cool) atoms
    - Temperatures as low as ~ 15uK; almost absolute zero
  - Easier to study characteristics of a quantum system
  - **Goal: Create a cloud of atoms as dense and cold as possible**

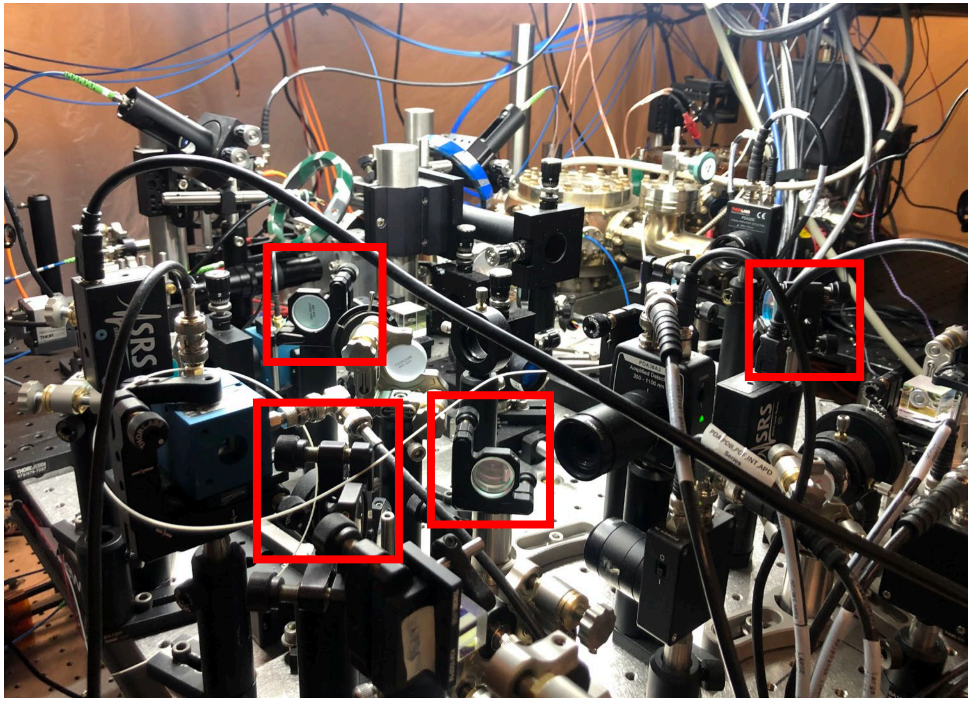






Experimental Set-Up





- Laser beam alignment adjusted using manual mirror mounts
- Currently performed hands-on by skilled experimentalists
  - Tedious
  - Safety concerns
- Crowded experimental setup that is constantly changing

Manual Mirror Mount

Commercial Solutions and Limitations

- Current mounts allow fine adjustment, but can only be moved manually

Manufacturer Solutions

- Stepper Motors
  - Too large
  - Unstable
- Piezoelectric Inertial Actuator
  - Cannot move full screw range
  - Still requires external feedback

4:1 Length

5:1 Length

2:1 Length

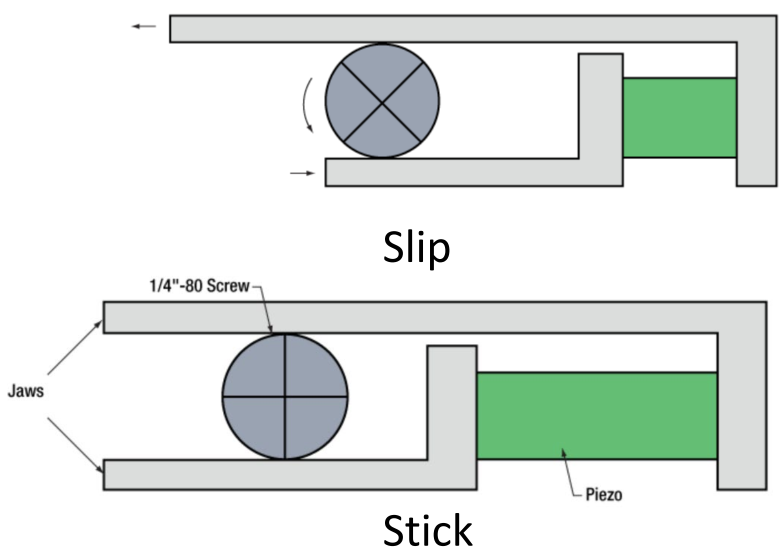
- Piezoelectric mounts can be moved remotely, but screw distance traveled not repeatable
  - Fine adjustment
  - Similar size

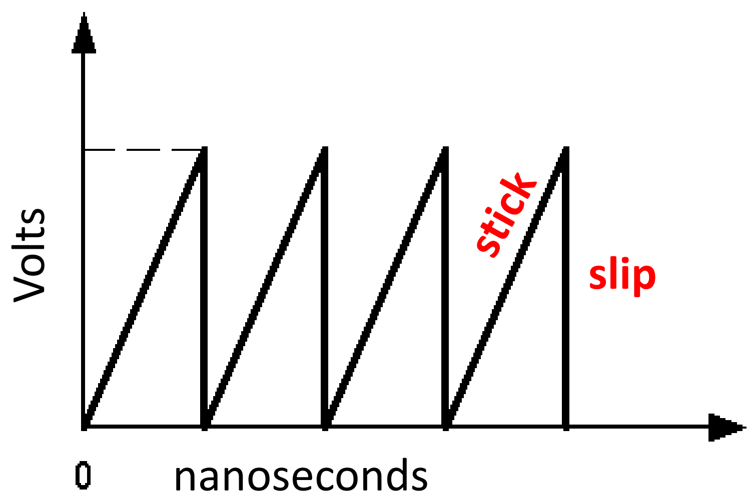
Manual Mirror Mount

Piezoelectric Mirror Mount

What is a Piezoelectric Mount?

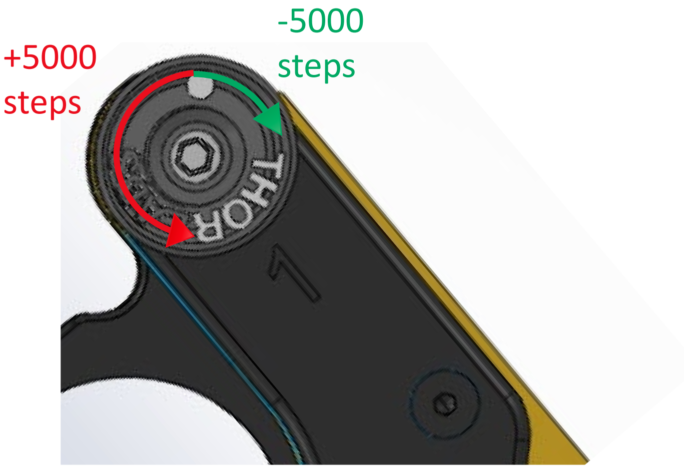
- Piezoelectric material mounted perpendicular to screw
- Very fine adjustment possible due to piezoelectric effect
  - Material contracts when voltage is applied, reversible process
- Jaws “stick” during ramp and “slip” during voltage drop
  - Similar to how a person would turn a screw with their thumb and forefinger

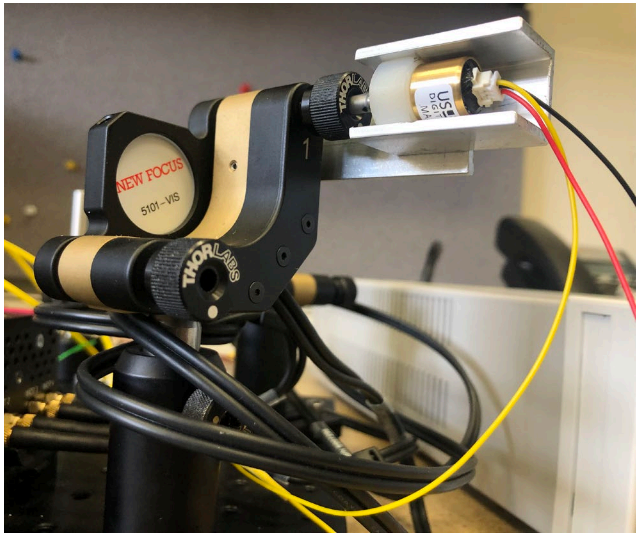


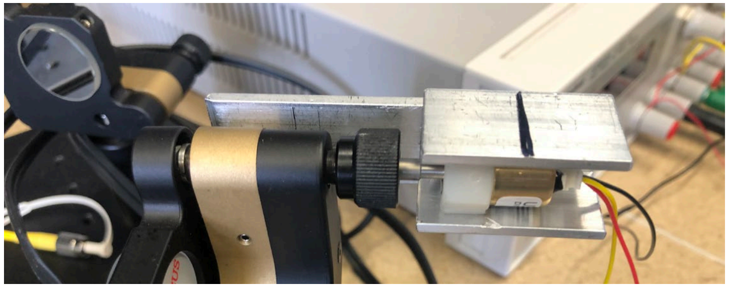


Repeatability Trade-Off

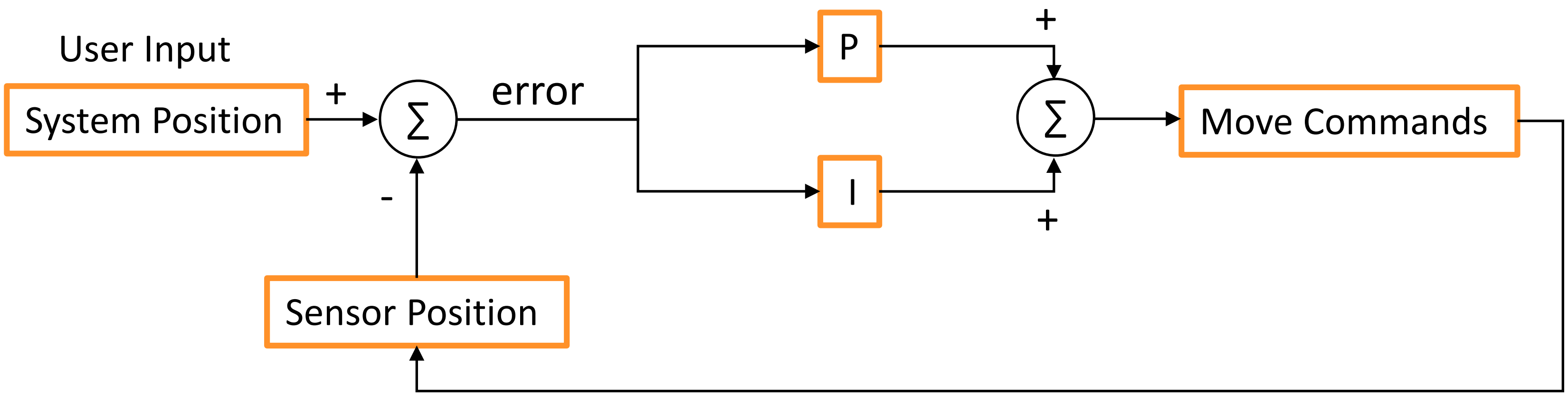
- Benefits:
  - Can be adjusted manually or by series of small steps
  - Self-locking when at rest or no power applied
  - Compact
- Drawbacks:
  - Adjustments are not repeatable
    - Open loop design
    - Variation between mount components
    - Variable friction in forward and reverse directions
    - Individual steps vary up to 20%
- Rotary encoders are used to compensate for error
- Rotate with the screws to give relative position
  - 0-5 V analog output = 0-360 degrees
- Forward direction approx. 3x as fast as reverse





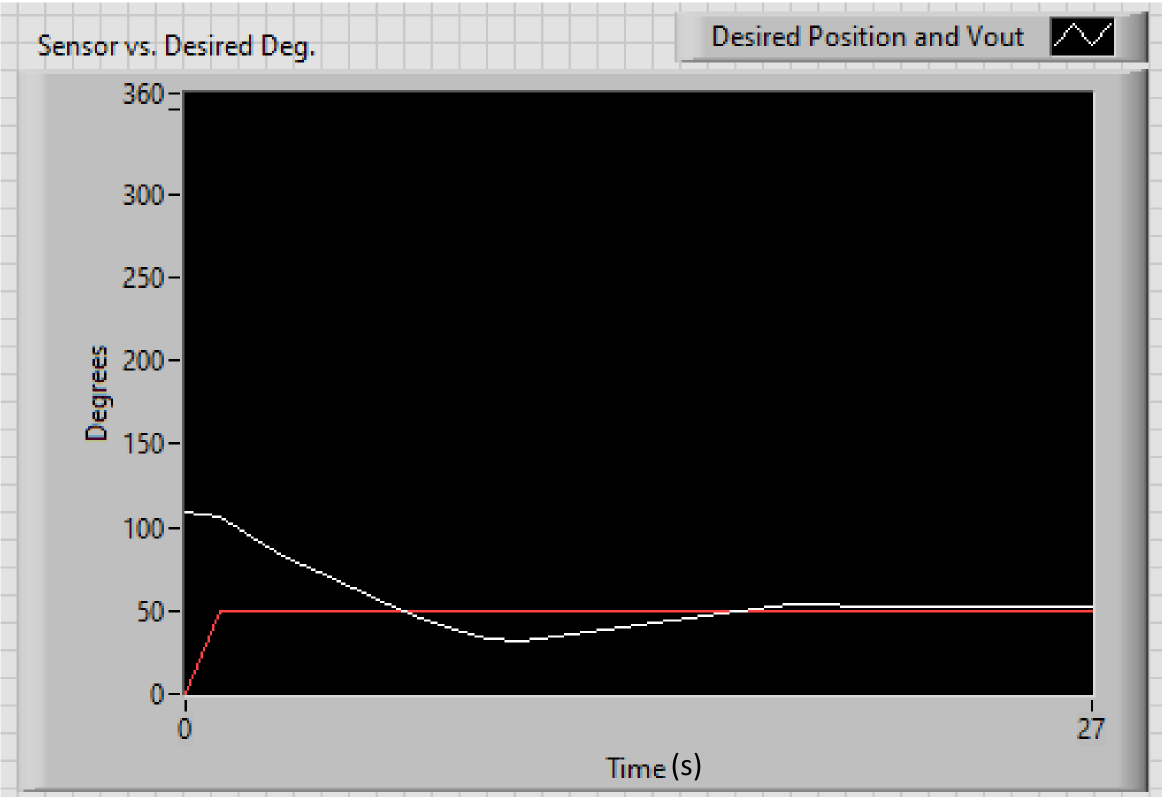


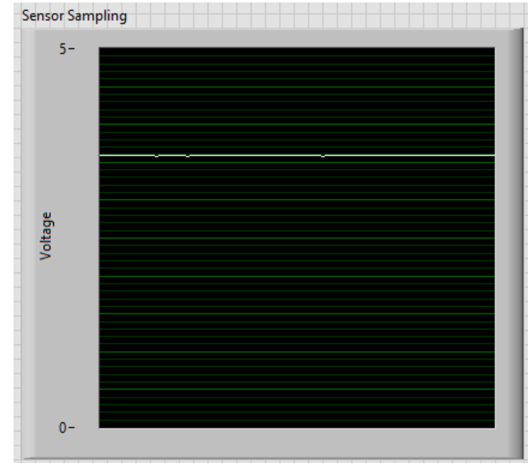
Using Feedback for Accurate Adjustment



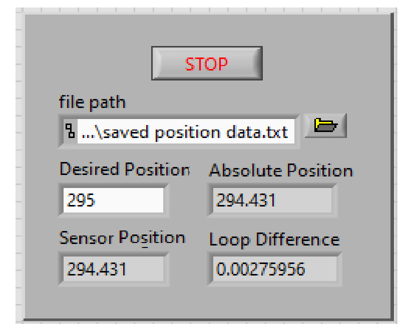
- User inputs desired position
- Average transducer voltage is converted to degrees
- PI controller scales steps based on direction (P) and position difference (I)
- Adjuster screw is moved n steps and error is checked
- Continues until error is within desired range of user input
  - Change in degrees after moving summed to determine absolute position

System Response





Voltage (0-5) vs. Time

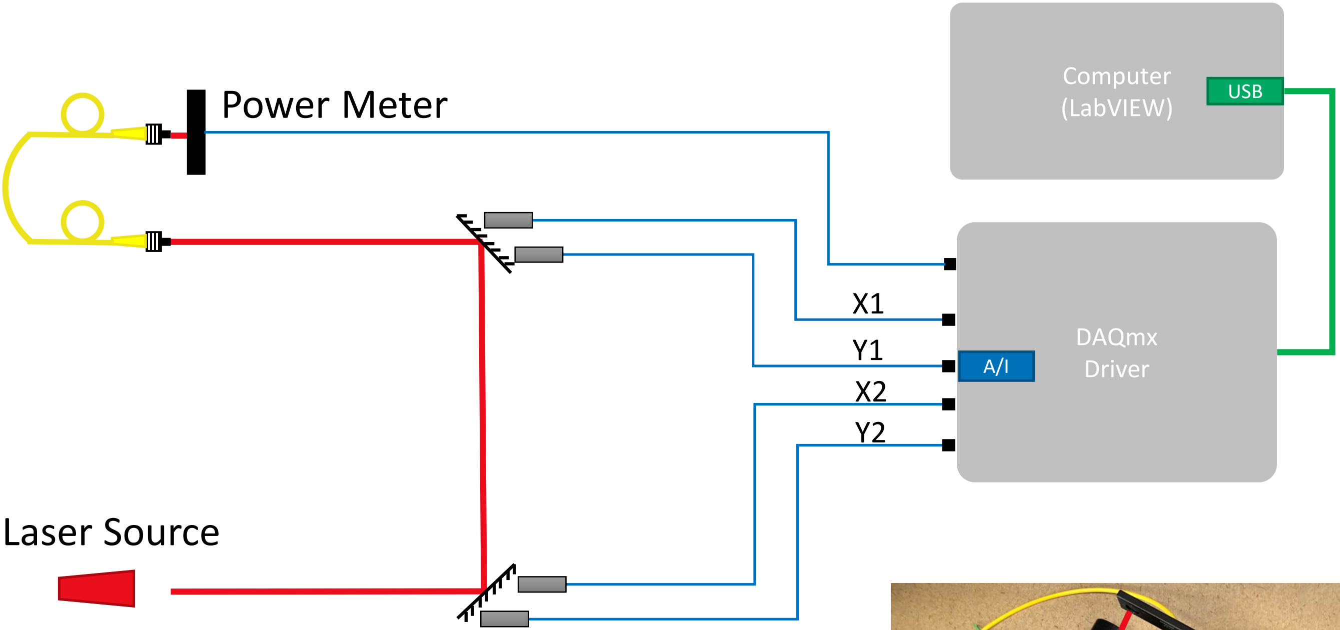


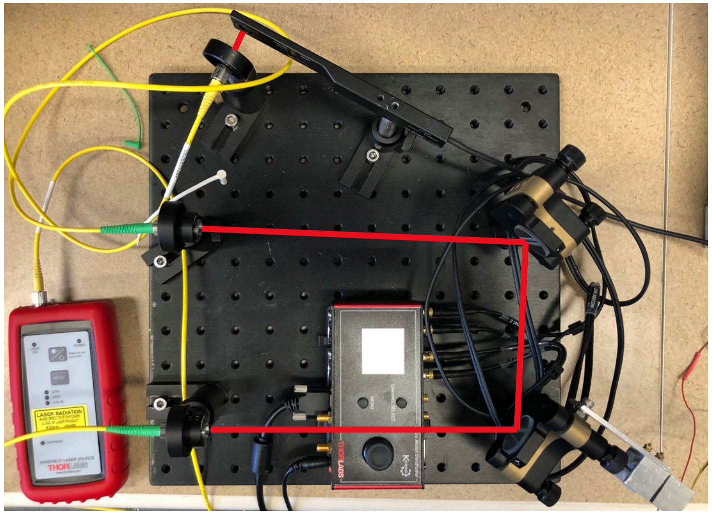
5% Error, +2.964 degrees

2% Error, -0.569 degrees

- Constant V output as sensor rotates relative to 360 degrees
- User inputs desired position
- Mount moves n steps, overshoots, and adjusts until position is reached

Testing and Optimization





- Testing accuracy of the program with fiber coupling
- Good test of accuracy
  - More sensitive than MOT to mirror adjustment

Summary and Outlook

Summary

- Found suitable transducers for screw position
- Designed simple mount assembly
- Scalable control of piezoelectric stages in LabVIEW including:
  - Automatic adjusting with custom PI controller
  - Homing procedure
  - Output of absolute position over full screw translation range
  - Storage of end position to correct unwanted changes between runs
- Assembled coupling system for testing

Outlook

- Automated fiber coupling
- Develop Python program for MOT self-adjustment using Python optimization and machine learning packages
  - SciPy.optimize
  - Mystic