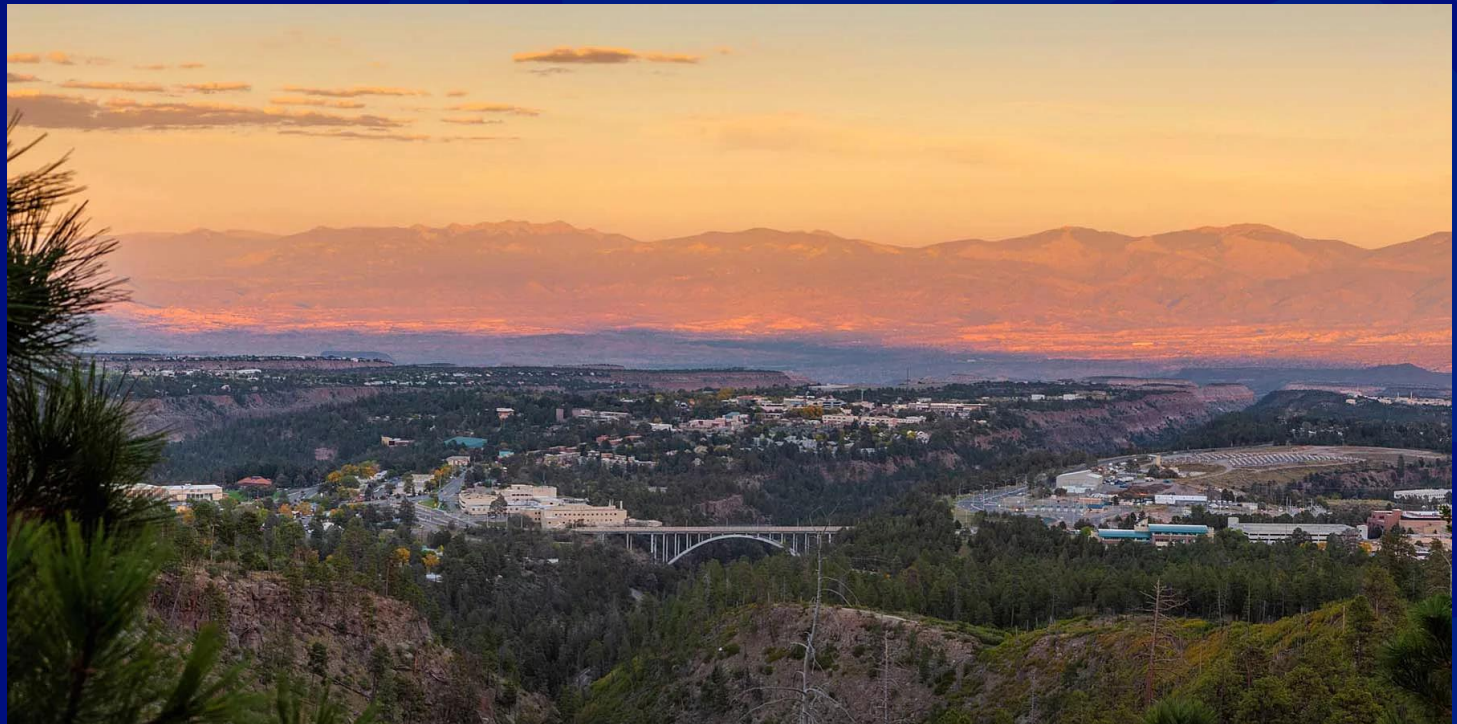


Automation and Machine Learning for Robust Self-Tuning of Magneto-Optical Traps

Cameron Calder

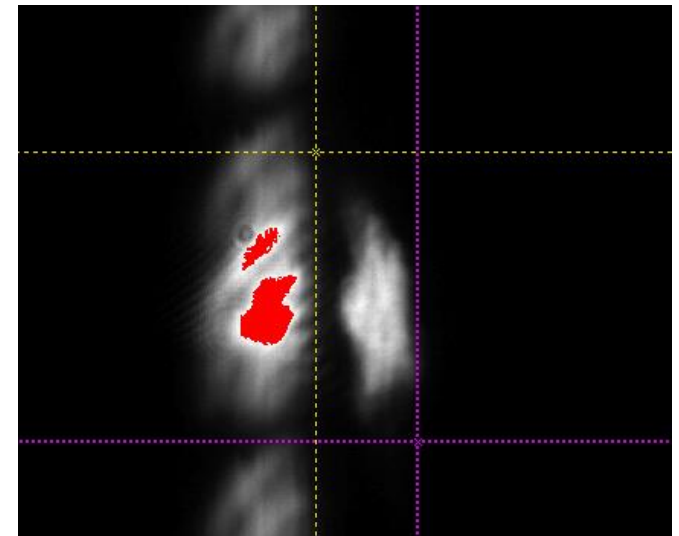
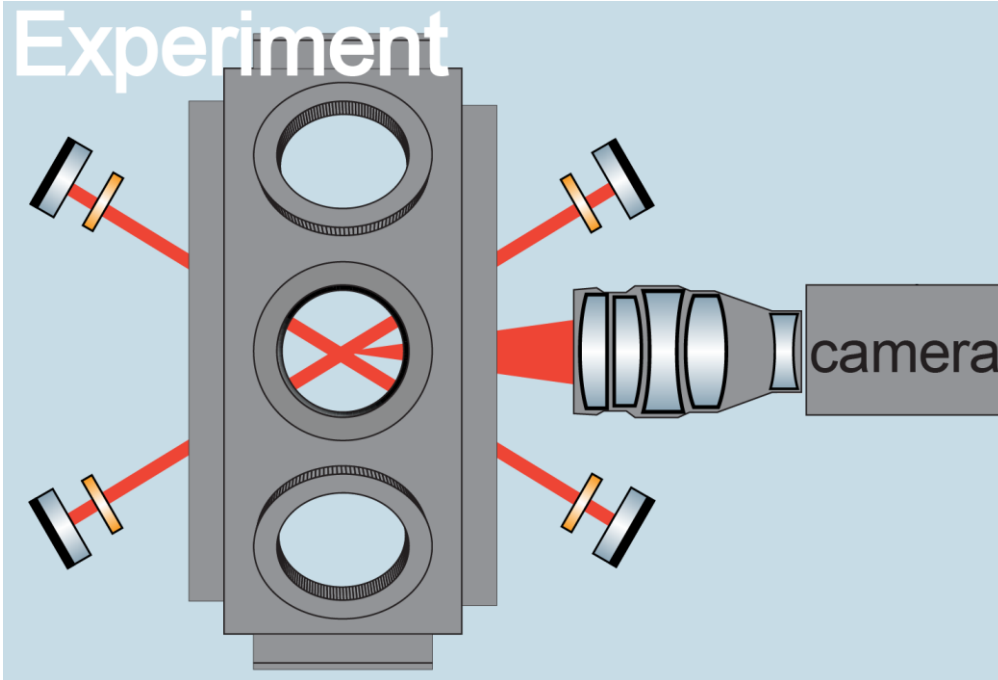
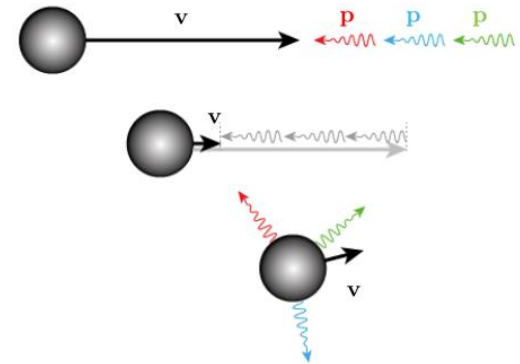
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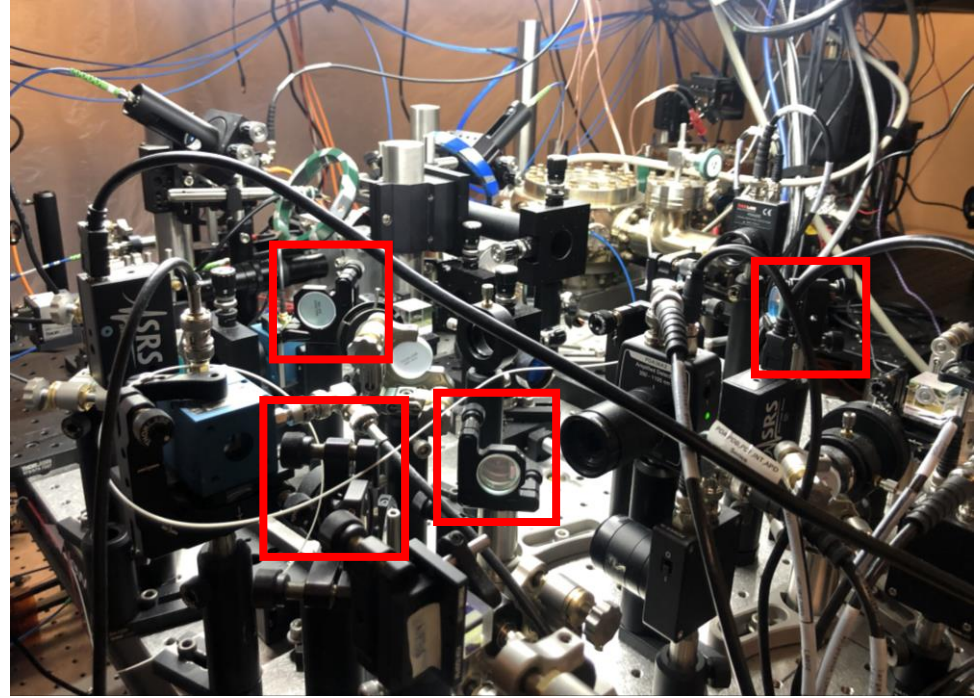
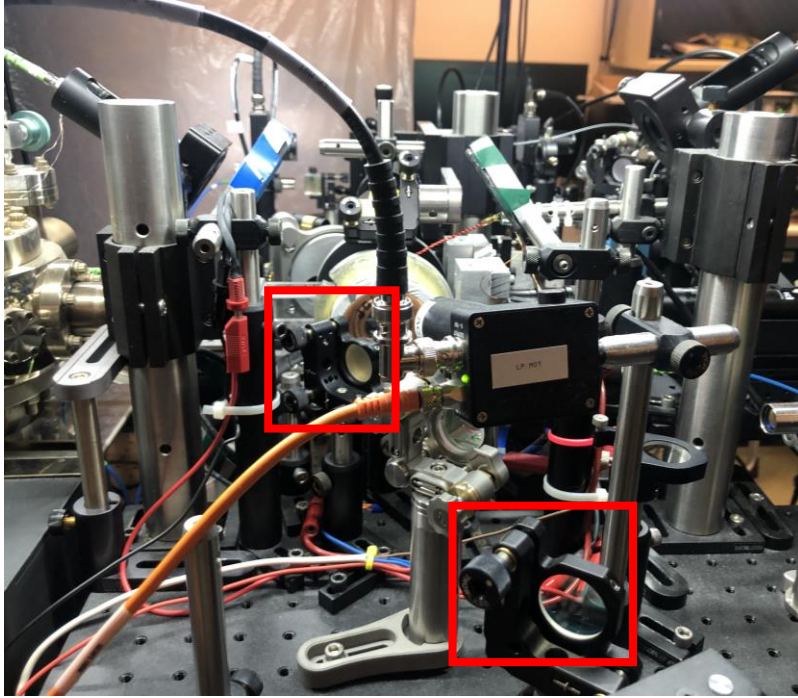
'LA-UR-21-27748

Motivation

- Rubidium Magneto-Optical Trap (MOT)
 - Uses lasers and magnetic fields to slow down (cool) atoms
 - Temperatures as low as $\sim 15\mu\text{K}$; 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



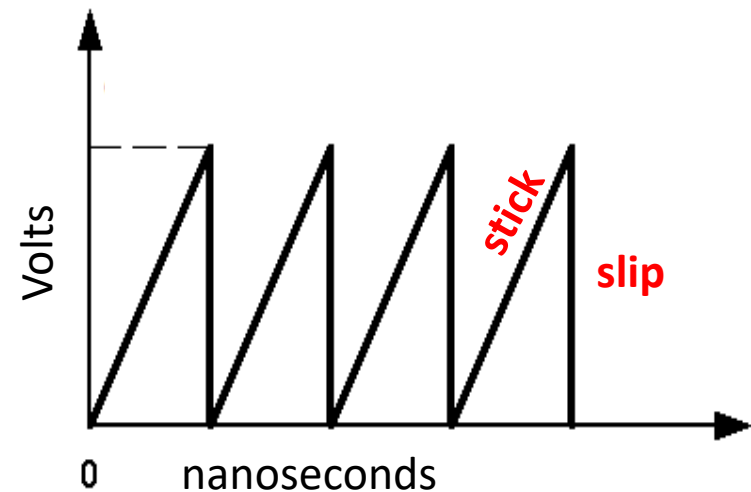
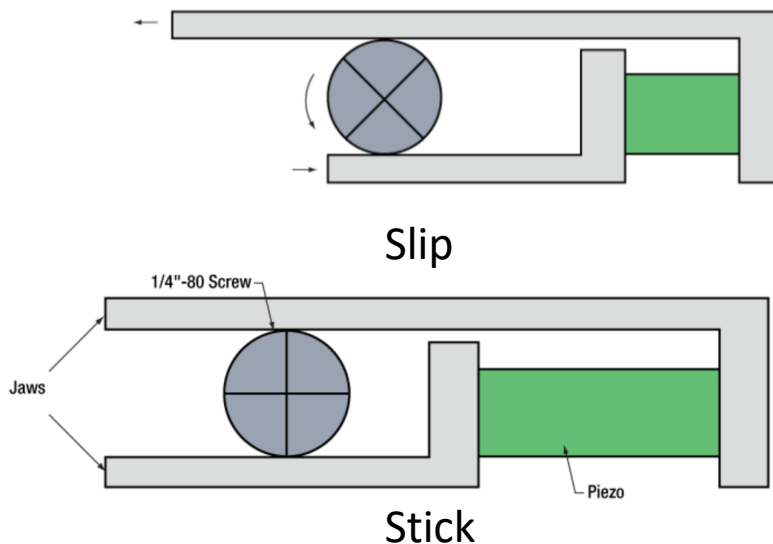
Manual Mirror Mount



Piezoelectric Mirror Mount

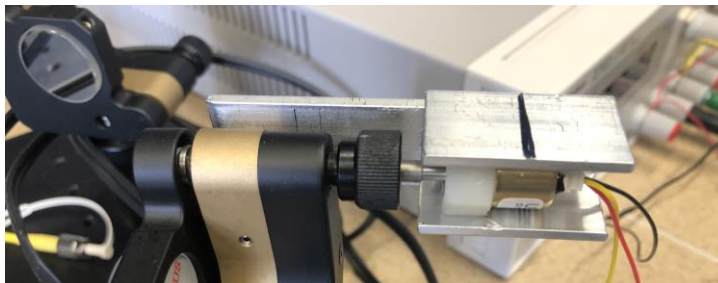
What is a Piezoelectric Mount?

- 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



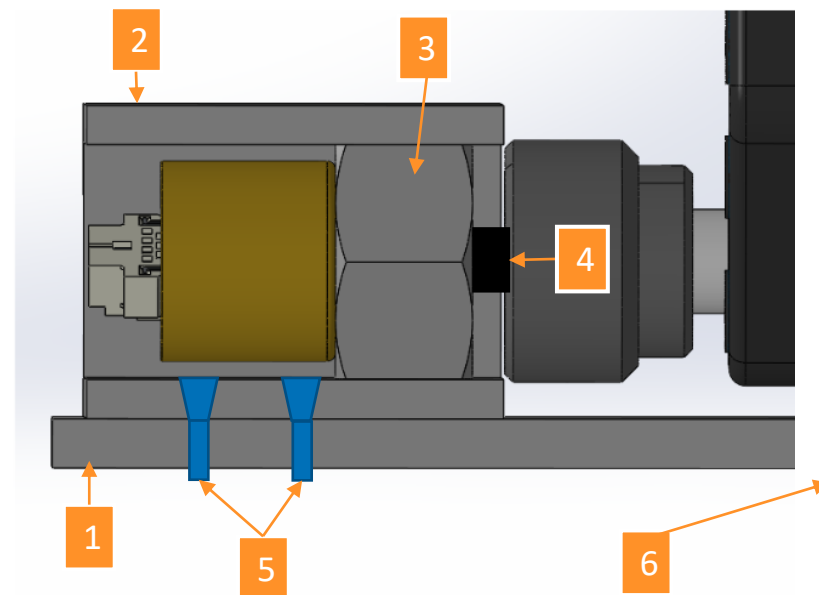
Repeatability Trade-Off

- 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



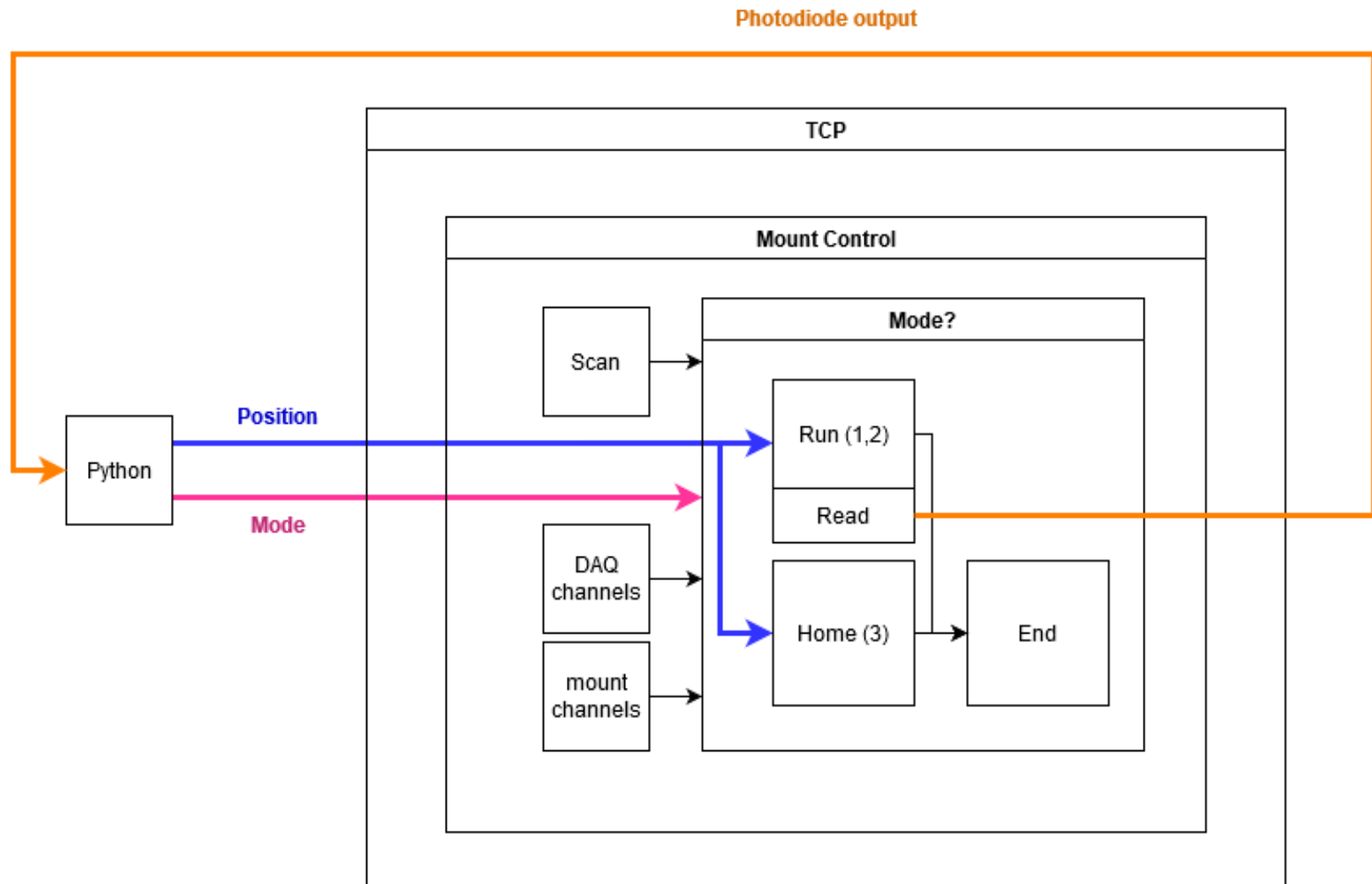
Why Our Design is Better

- Transducers are small and accurate
 - 1 step = 0.02 degrees
 - 70% the length of the mount
- Easy wiring and analog output
 - 3 wires- power, ground, output
 - Read using DAQ directly into LabVIEW
- Simple to attach and reproduce
 - One AI bracket (1)
 - One AI U-channel (2)
 - One nylon hex nut (3)
 - One plastic spacer (4)
 - Two flathead screws (5)
 - One mounting screw (6)
- Comparable price
 - Solution not exclusive to these mounts



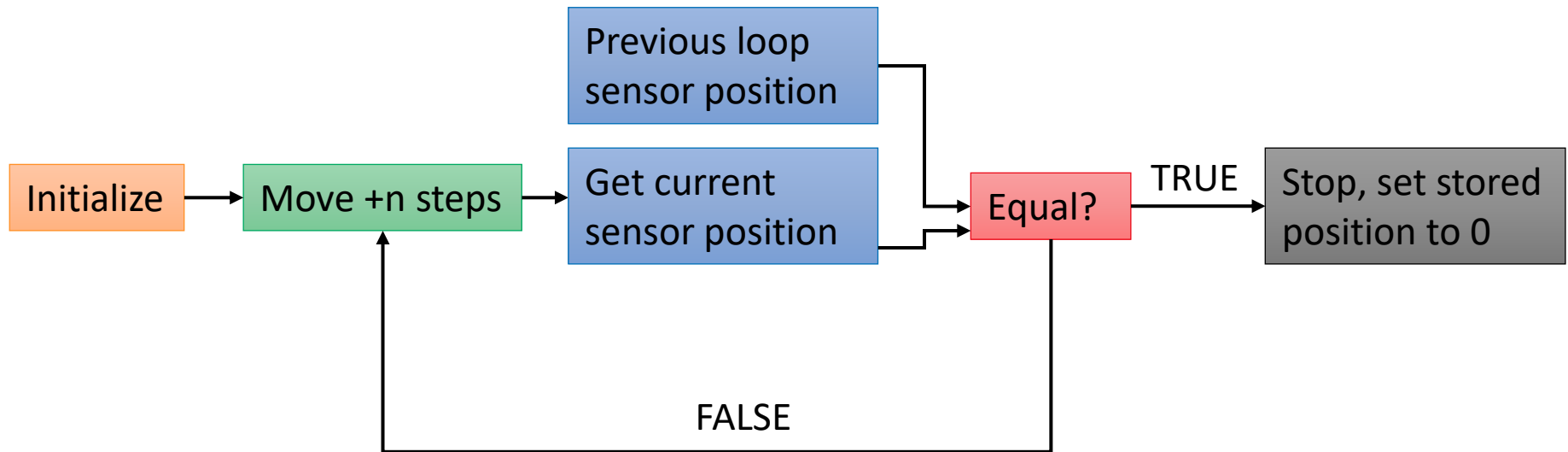
Solution	Parts Cost (\$)	Mount Cost (\$)	Total Cost (\$)
Rotary Encoder	130	1200	1330
Stepper Motor 1	2200	40	2240
Stepper Motor 2	1300	40	1340

Overall Adjuster Screw Control System



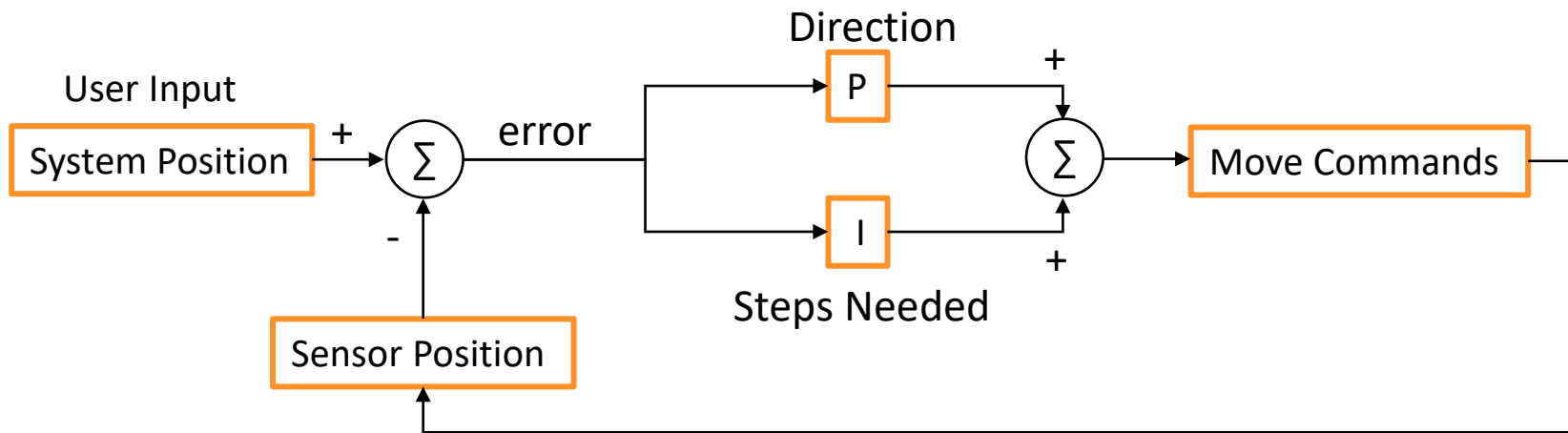
Finding Home

- Transducer only has range of 0-360 degrees
 - One rotation
- Overall screw range is 12.7 full rotations
- How can we control the screw over the entire range?



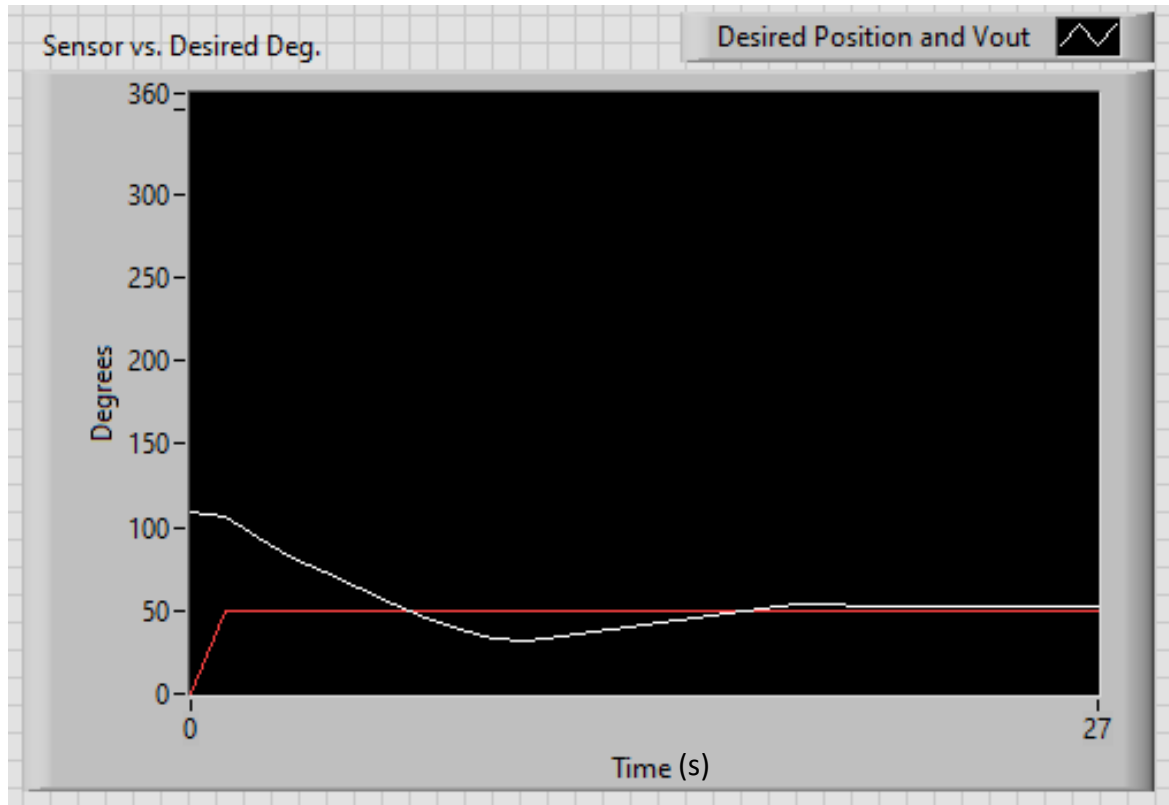
- Only have to initialize on first run
- Absolute position stored to file after screw adjustment based on step change from 0
 - $\text{Step position} / 360 = \text{rotation position}$

Using Feedback for Accurate Adjustment

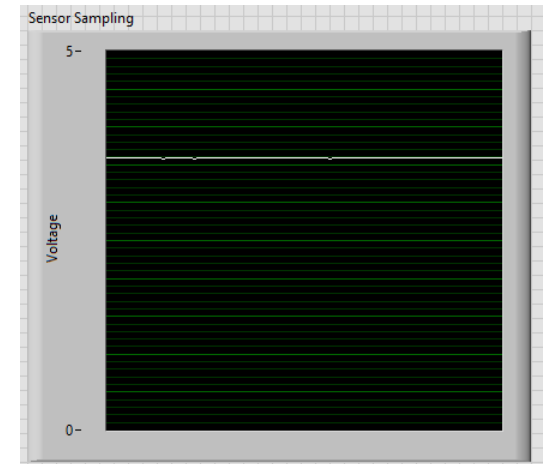


- User inputs desired position
- Average transducer voltage is converted to degrees
- PI controller scales n steps based on direction (P) and degree difference (I)
- Adjuster screw is moved 20% of n steps and degree error is checked
- Continues until error is within desired range of user input
 - If within range, set steps needed to 0

System Response



5% Error, +2.964 degrees



Voltage (0-5) vs. Time

STOP

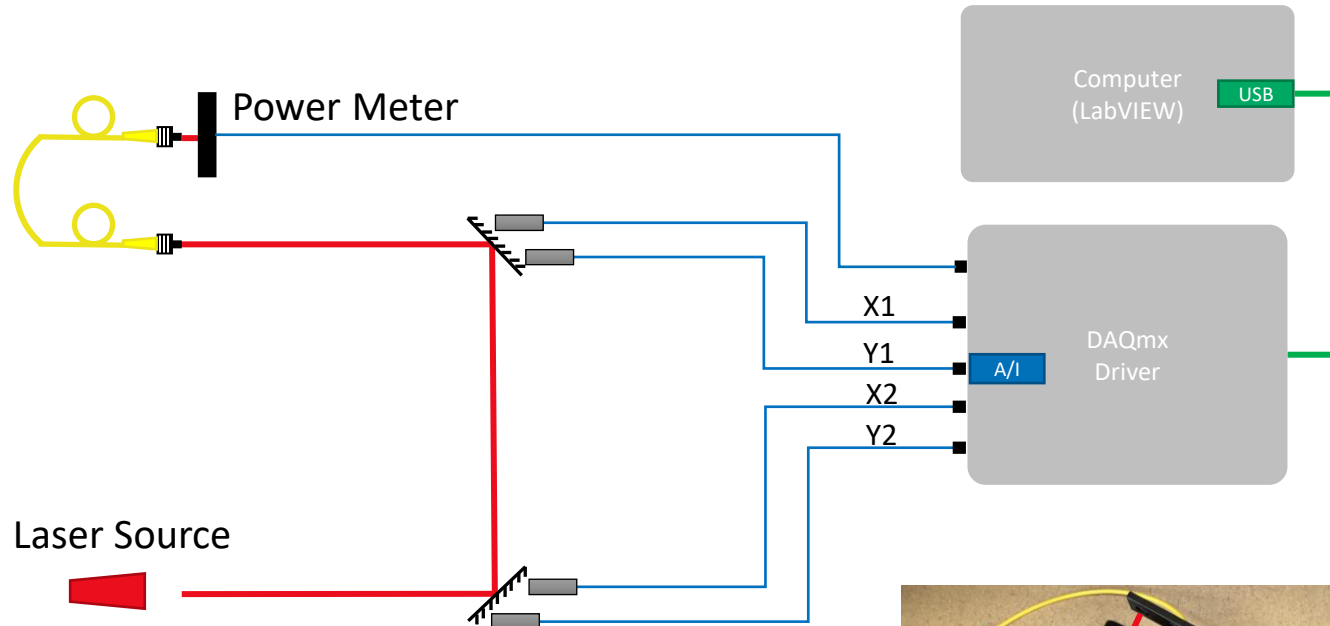
file path
%...\\saved position data.txt

Desired Position	Absolute Position
295	294.431
Sensor Position	Loop Difference
294.431	0.00275956

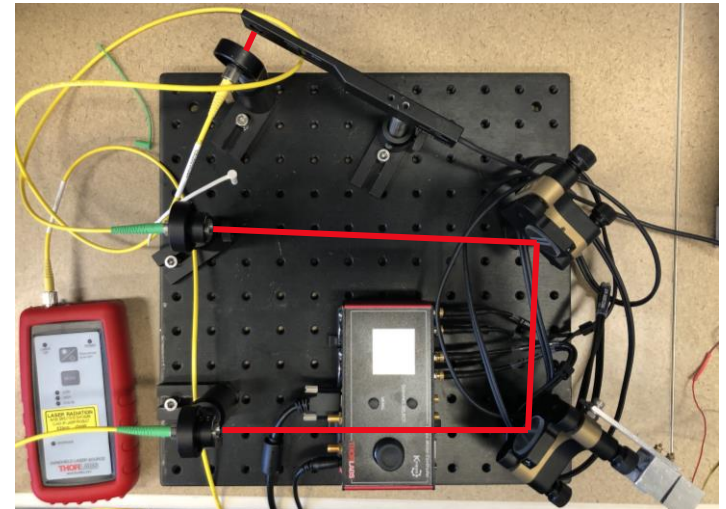
2% Error, -0.569 degrees

- 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
 - Cycle through X and Y channel of each mount until complete

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
- Continue to develop Python program for MOT self-adjustment using Python optimization and machine learning packages
 - SciPy.optimize()
 - Mystic, PyTorch

