Automation and Optimization for Robust and Self-Tuning Magneto-Optical Traps

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Abstract

In recent years the Magneto-Optical Trap (MOT) has become a standard technology used in almost every AMO laboratory (Atomic, Molecular, and Optical Physics). While technology of individual components has improved over time, the alignment of the trap still requires tedious maintenance performed hands-on by skilled experimentalists. The project focuses on developing a custom control system for piezoelectric mirror mounts responsible for the position adjustment of the lasers beams in the experimental setup. The implementation consists of a LabVIEW interface to move the mirror mounts and a Python algorithm to optimize laser positioning, supported by rotary encoders to correct for hysteresis of the devices. The control system's efficiency is tested by coupling a laser into an optical fiber, typically performed manually, with the overall goal of full automation. This contributes to the group's goal of automating the MOT as a whole, thereby saving time and making experimental results more repeatable.

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Introduction

This project focuses on the development of a custom control system for piezoelectric mirror mounts responsible for the mechanical adjustment of the position of laser beams and implementing an algorithm to automatically align them. These mounts and lasers are used for a cold atom trap for quantum state experiments, so their controls need to be highly accurate and able to make precise movements.

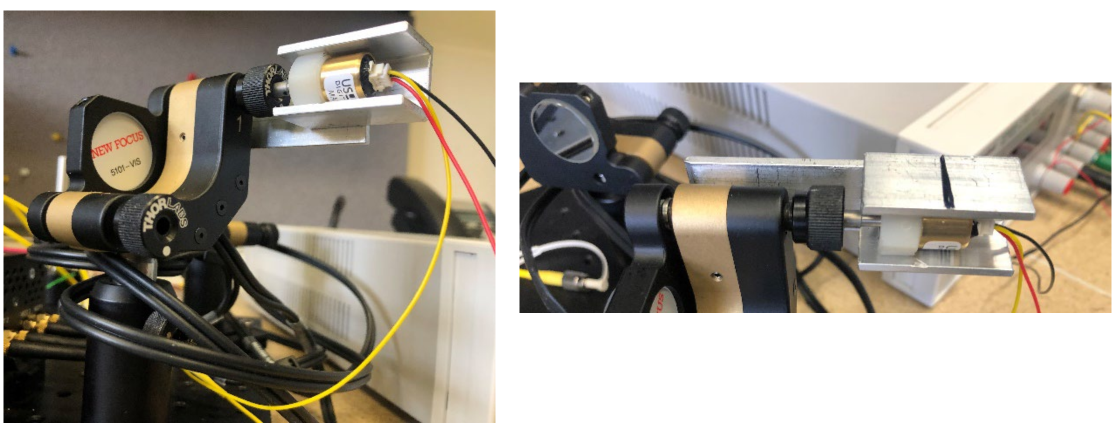
This project aligns with my interests in autonomous robotics and machine learning. Creating custom closed loop control systems is a large part of automation and general robotics. Learning how to optimize these control systems and being exposed to different machine learning algorithms and techniques while working on this project has been a valuable learning experience and helped to clarify how these techniques are applied.

Project Description

The overall objective of this project was to use automation approaches and optimization and machine learning techniques to remove the need for a trained operator to tune the MOT. The individual goals were to:

- Find appropriate transducers to get the relative position of the mirror mount adjusters
- Design and build a mechanism to attach the transducers to the mounts
- Make a LabVIEW program to:
    - Remotely control the mount adjusters
    - Determine their absolute position using the transducers
- Make the control system closed loop to compensate for hysteresis
- Write a Python program to run the LabVIEW program and optimize mirror adjustments

The first part of this project consisted of finding appropriate transducers and figuring out how to integrate them with the mirror mounts. The experimental setup for the MOT is very cramped, so the transducers had to be very compact and simple to attach and wire. The output of the sensors also had to be easy to read out in LabVIEW and use.



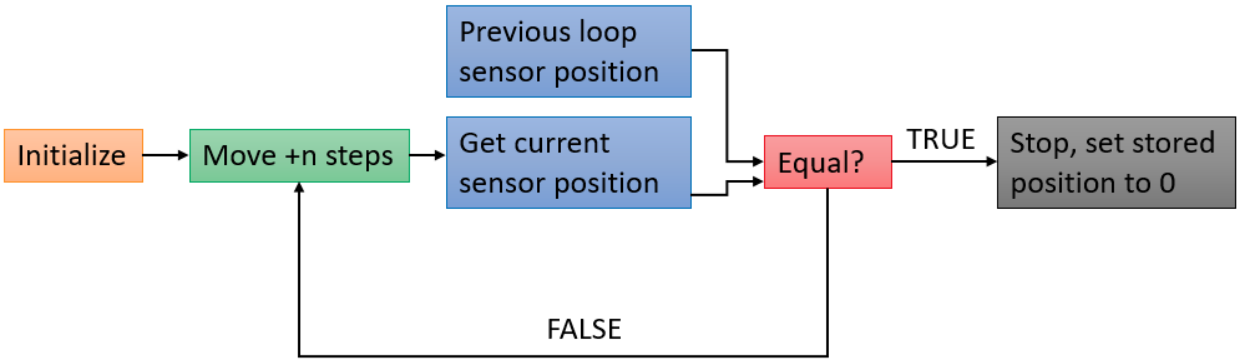
Mounting and integration of a single transducer. (Left: side view. Right: top view.)

Once transducers were selected and a mounting assembly was designed, the next step was to characterize the mirror mount adjuster's position. The mirror mounts are adjusted by rotating two screws either manually or with a motor controller. The motor controller moves the screws using a piezoelectric material, but it is not very accurate or repeatable due to intrinsic characteristics of the design.

The controller moves it by a controllable step size, but the system is open loop and has no way of outputting the degree rotation of the screw or the overall position of the screw in relation to its full range of movement. To solve this, an appropriate transducer was found to quantify the rotational position of the screw. A simple and easily reproducible mounting assembly for the transducer to the mirror mount was designed and built.

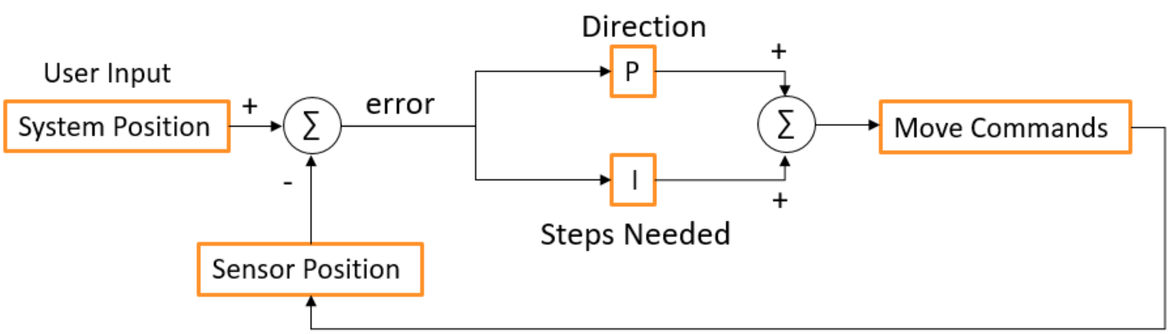
To move the mount adjusters remotely, a closed loop control system was designed in LabVIEW. Previously, the adjusters had been controlled using manufacturer software, but it was very limited and had no way of compensating for error in the step size, adjustment speed, and resulting adjustment distance. LabVIEW was used to connect to the motor controller and each mount adjuster and move them to an absolute distance in each adjuster's movement range.

To accurately figure out the adjuster's absolute position, transducer rotational position was used to create a custom proportional-integral (PI) controller and determine the end of the screw range. A homing procedure was made by moving the adjuster by a constant step size and checking the transducer output after each movement. If there was no change between movements, then that means the adjuster has reached the end of its range and the screw is no longer turning. This "home" position was set as zero.



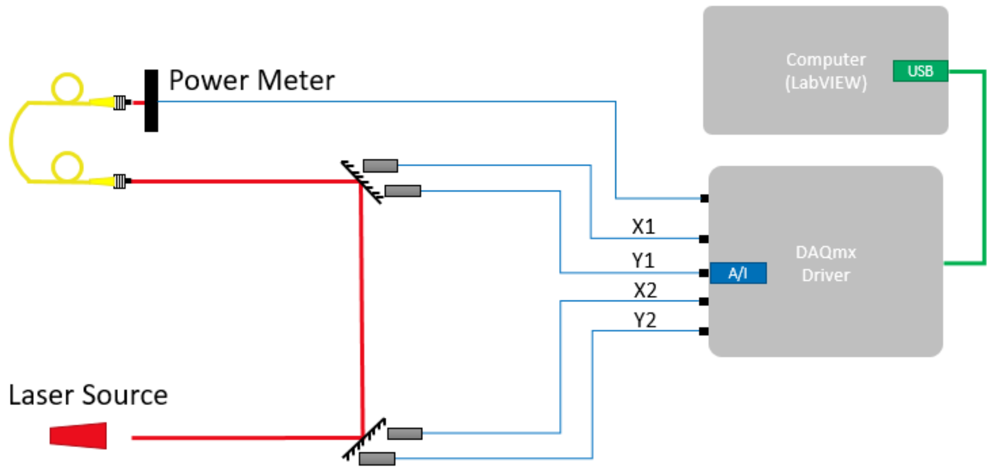
Homing system block diagram.

When the adjusters are moved to an input position, the PI controller checks the error between the user input and current position. Based on this error, the PI controller provides a step size to move by. The difference in sensor degrees before and after moving is added to the current absolute position and is written to a file once the desired position is reached.



PI controller system block diagram.

To test this LabVIEW program, a laser fiber coupling system was assembled and a power meter connected to determine the percentage of laser light that has been coupled. A Python script was written to send inputs to LabVIEW for adjuster position and select a run mode. Coupling percentage is sent back to Python, which is then run through an optimizer to maximize this value.



Laser fiber coupling testing system diagram.

Contributions Made

Over the course of the summer many personal contributions were made to the project. This project started with only the piezoelectric mounts and the manufacturer software to adjust them remotely. By finding transducers compact enough to fit in the experiment and using them to make a closed loop control system to move the adjusters, the need for a trained operator and time in the lab can be greatly reduced. Being able to accurately and remotely control these mirror mounts using the LabVIEW and Python programs created to automatically align lasers improves repeatability and the robustness of the overall experiment. By designing a way of knowing where the adjusters are and being able to return to a specific position it is easier to see how the mirrors are effecting experimental results and make corrections.

This also makes it possible to create a procedure to self-tune the MOT and improve the output of the experiment. The experiment takes a long time to set up and run and many times does not produce any results. If laser alignment is accurate enough and a cold atom cloud can be consistently produced, then these results can be used with machine learning techniques to optimize the trap.

Another contribution during this project was presenting at the Los Alamos National Laboratory Student Symposium and the EERE Summer Internships presentations. This allowed the work to be clearly shared with both the host site and the project group as well as EERE.

Skills and Knowledge Gained

The most important thing learned during this experience is how to approach problems and task prioritization. It was important to learn what to focus on and what to leave for later to not get caught up on small issues. Initially, the program was controlling all the adjusters at once, which caused many issues in controlling the adjusters together rather than the controls themselves. Once the program changed to controlling a single adjuster and then repeating for each one, progress was much faster. This showed the importance of prioritizing one thing at a time rather than everything at once and reducing the number of variables in the problem.

Learning how to approach problems and identify errors was also a good experience compared to solving similar problems in a university setting. In class, there is more of a focus on output than process. While I had done things like wiring circuits, soldering wires, and coding in Python and LabVIEW in school, it is usually recreating a wiring diagram or a creating a program using specific methods and functions. Learning how to think through how a system is connected and how data is being moved and identify sources of error is very important when there is no examples of what you're doing or extensive models to work from. This also requires being able to think of custom solutions to problems instead of using standard parts, which provided a lot more freedom than previous experiences to try new techniques and consider unique solutions.

Relevance to Host Mission

The mission of the DOE is to address America's nuclear, environmental, and energy challenges through transformative science and technology. Quantum information and better understanding the state of a quantum system is beneficial for a wide range of applications, such as secure communication, encryption, and sensor design. The control system and automatic alignment procedure saves time spent adjusting the mirrors by the experimentalist and makes the experiment more repeatable. This allows for more time to run the experiment and improves efficiency. The conclusions drawn from this experiment can lead to innovations across many scientific fields and benefit the DOE and American society at large.

Impact on Academic and Career Planning

This experience has impacted my academic and career planning by giving a better idea of what options there are for a career in robotics and automation. I learned that I enjoy systems design and optimization problems. This helped me choose my senior design project that I will be working on over the upcoming year and has helped to reinforce my decision to attend graduate school for artificial intelligence with a concentration in electrical engineering. While I have had some experience in robotics research and control systems, none of it has been outside of my university. This experience gave me a better idea of what it is like to work in research at a national lab and whether or not I would like to pursue a PhD in the future.

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