Introduction

Problem Overview

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Algorithmic Approaches

Main Results

Hysteresis

Automated System Heuristics

Fibre coupling automation project

NQCC Summer Placement
William Caiger

National Quantum Computing Centre

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What is the problem?

Fibre coupling is the process of maximising the amount of light transferred from one optical fibre into another

The task is to create a system to **automate this process**

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- **Lasers in the ion trapping system**
- Fibre coupling
- Why alignment needs automating

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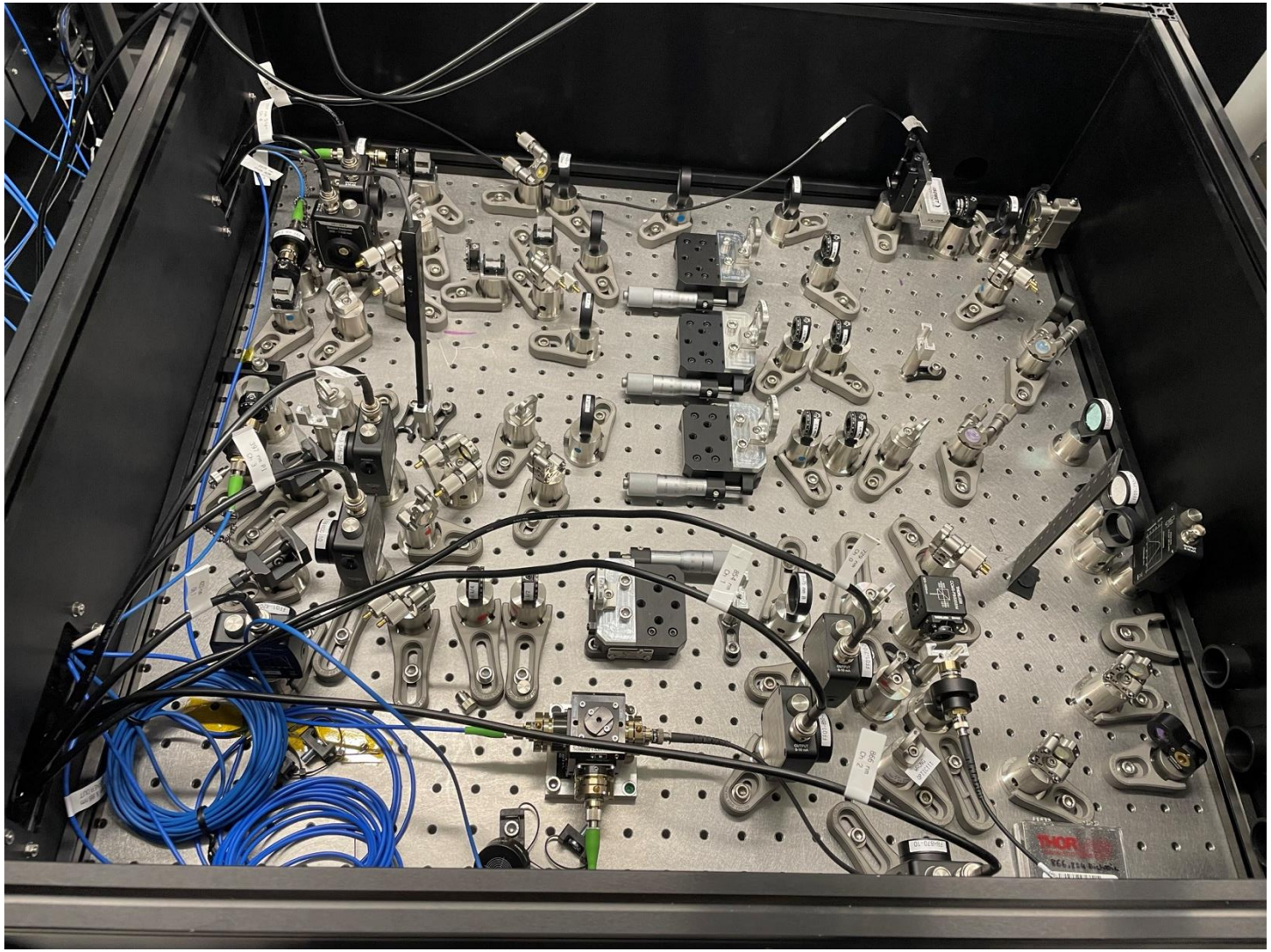
How are lasers used in the ion trapping system?



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Optical fibres for laser delivery

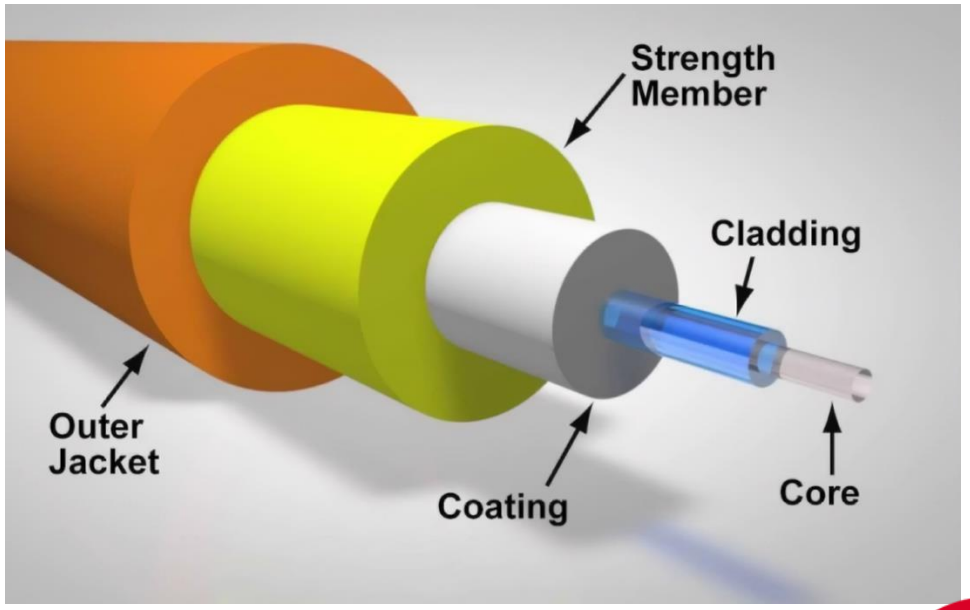

Image credit: Introduction to Fiber Optics (thorlabs.com)

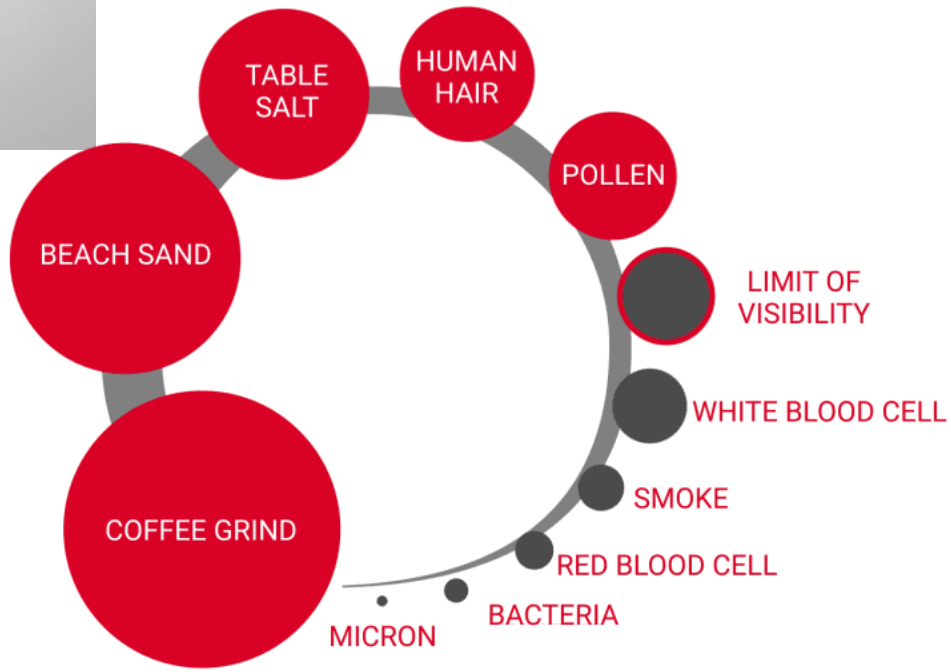

Image credit: What is a Micron? Understanding the Measurement Unit - API Metrology

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- **Fibre coupling**
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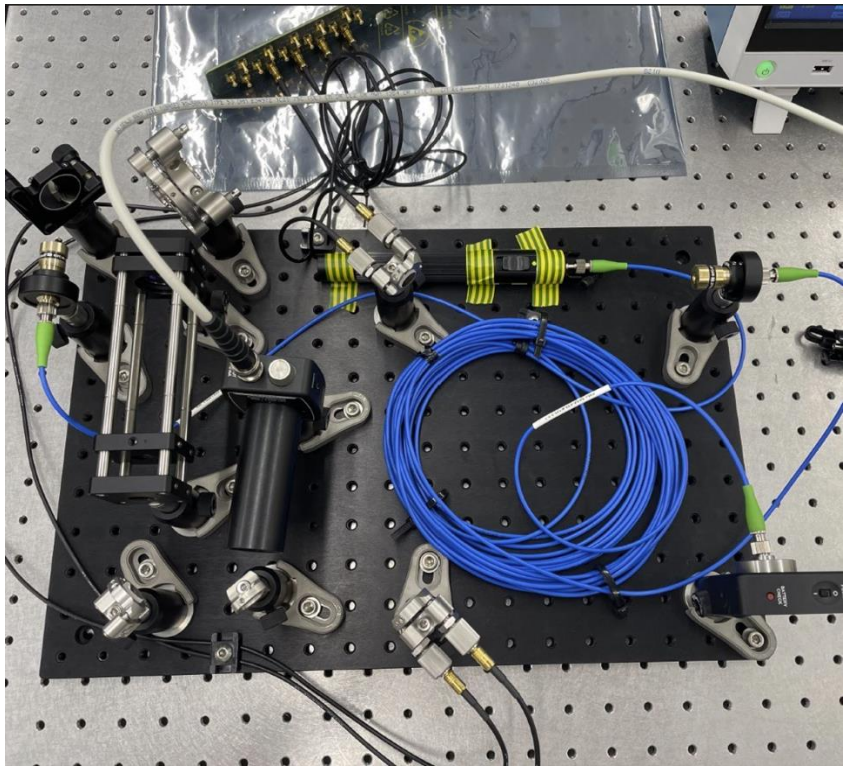
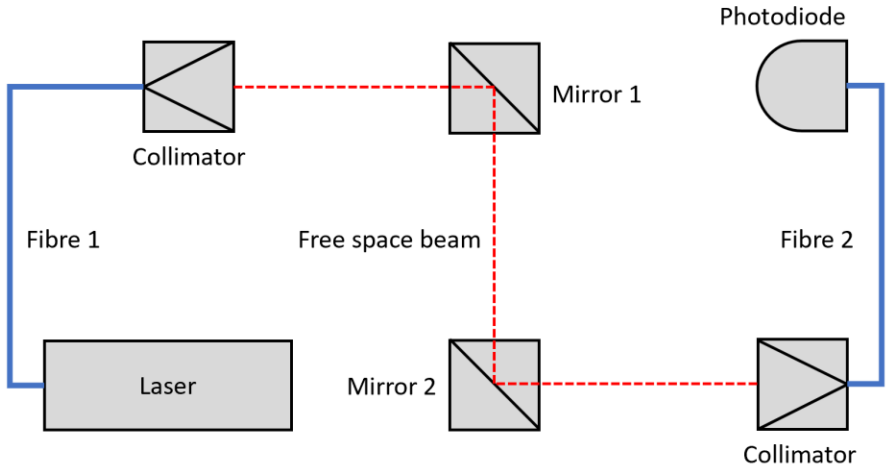
What is fibre coupling?





$$\text{coupling efficiency} = \frac{\text{coupled power}}{\text{total power}}$$

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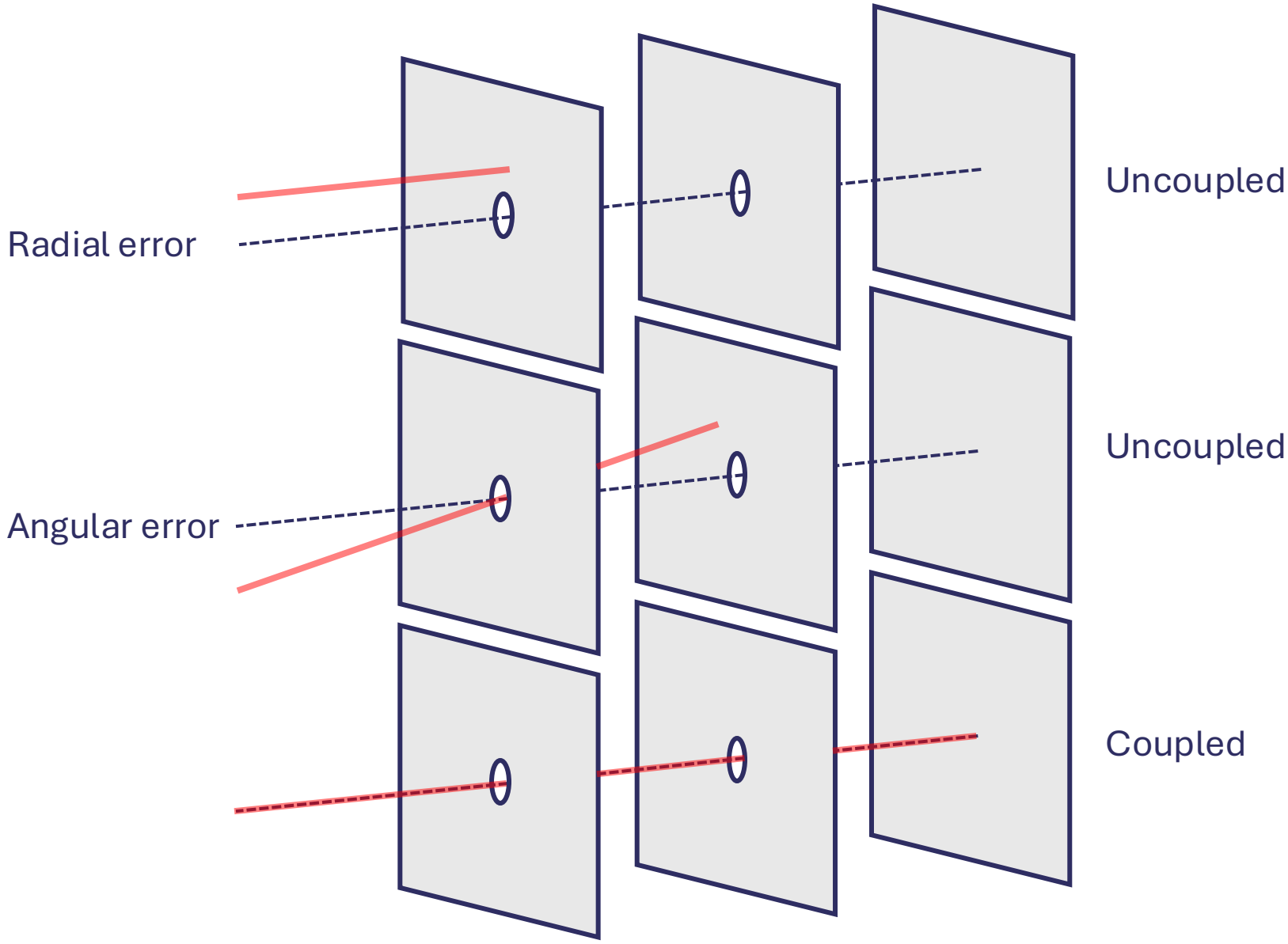
Why do we need two mirrors?



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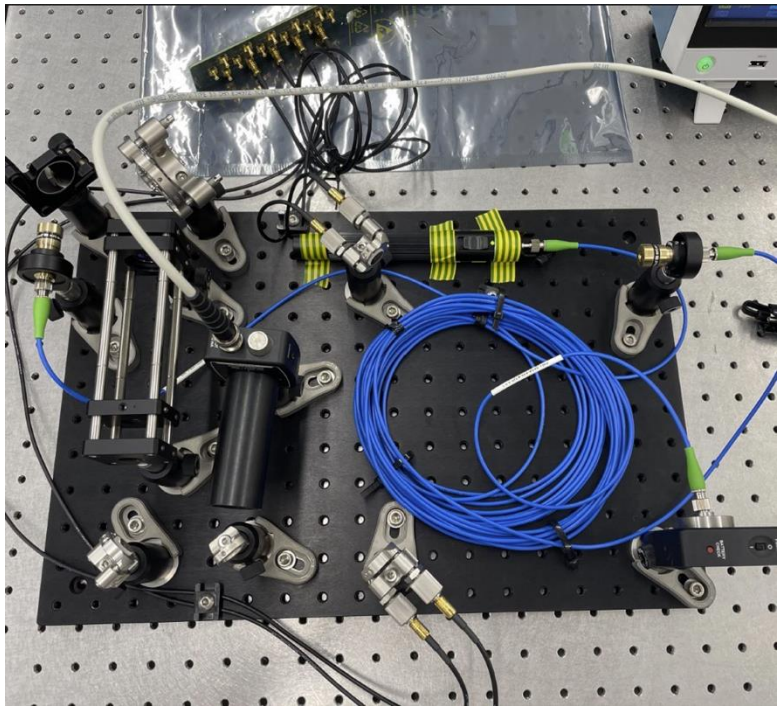
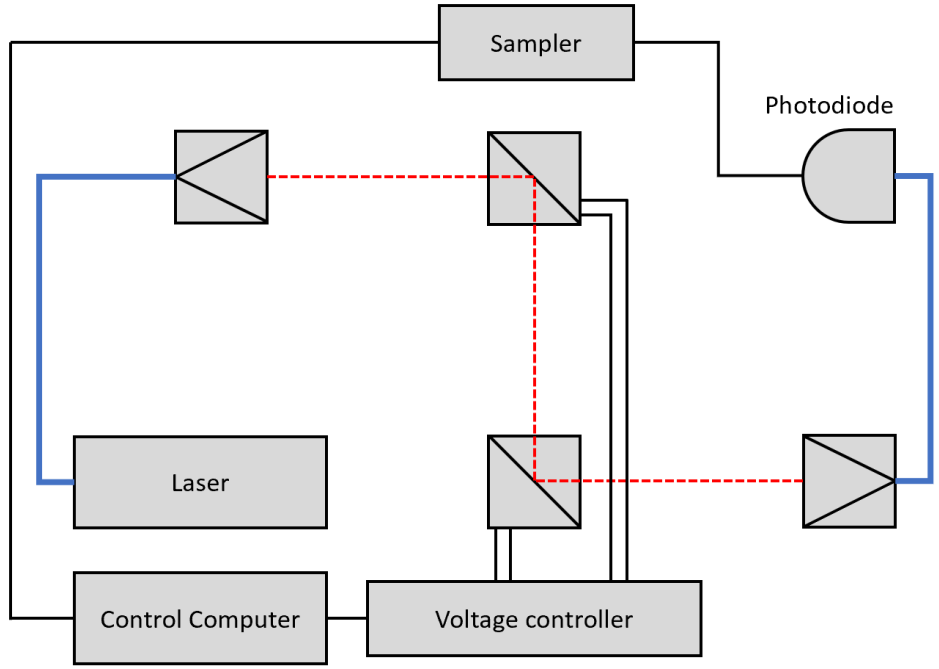
How can we automate the coupling process?





Mirror angles are adjusted using **piezoelectric** components which change shape when a voltage is applied

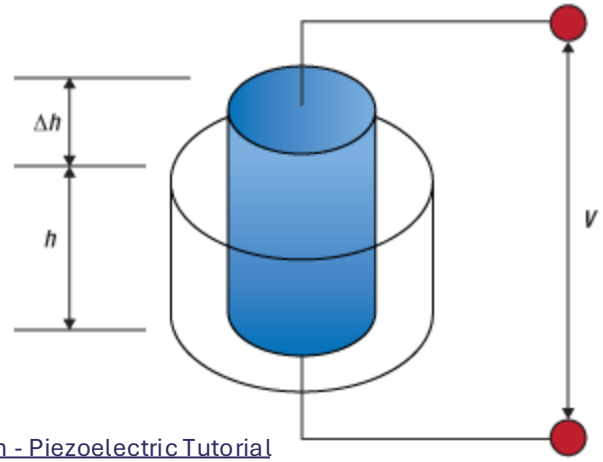


Image credit: Thorlabs.com - Piezoelectric Tutorial

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Why does alignment need automating?

- Time cost
- Drift to misalignment
- System accessibility

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Respecifying the problem

Overall Problem Scope

- Integrated into lab environment (hardware and software)
- Achieves optimisation on short time scale (relative to manual process)
- Can function in situ

Sub-problem 1:

Alignment from nothing

- To achieve good coupling efficiency from a totally misaligned system
- For setting up new systems

Sub-problem 2:

Maintaining alignment

- Maintaining best coupling efficiency in a near-aligned system
- For use during experiments

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Simple but ineffective

My solution

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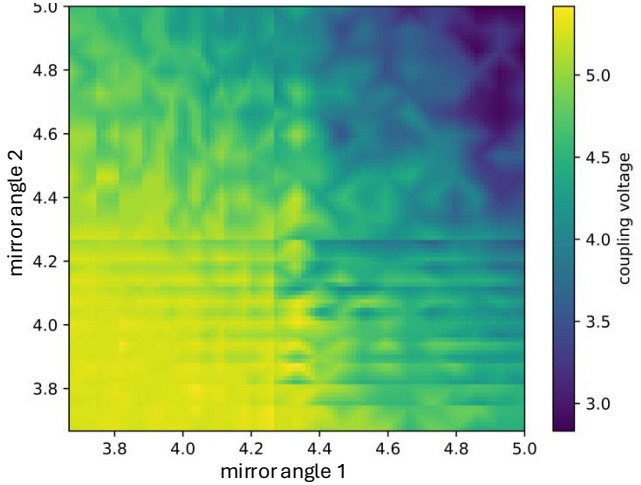
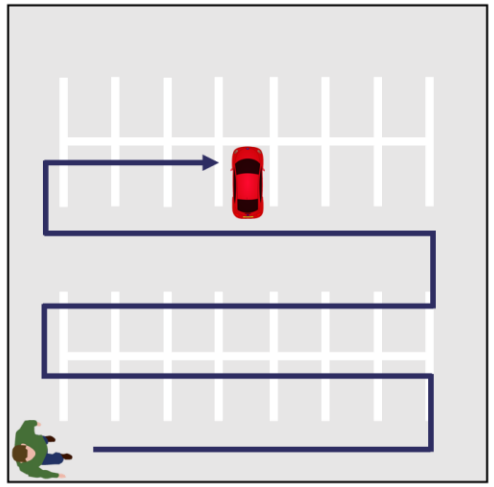
The simplest approaches

Scan the Full Parameter Space

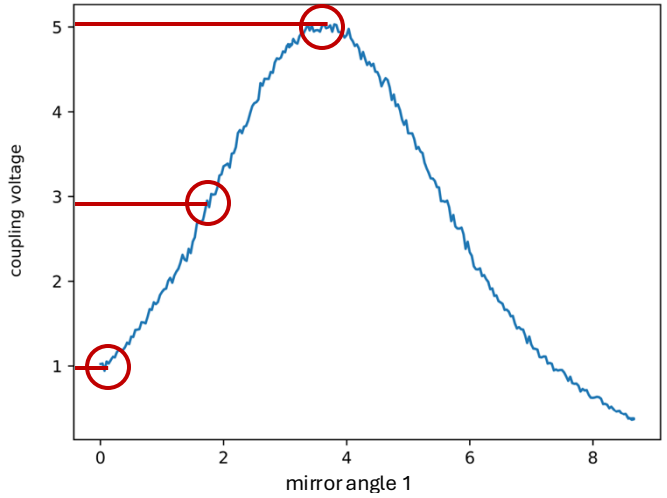
+ Thorough
- Time inefficient
- Poor granularity

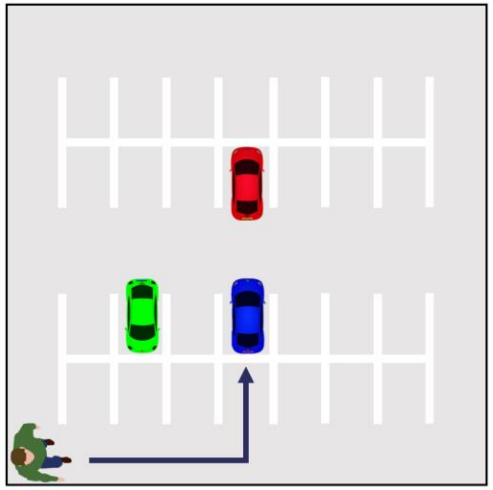




Single parameter sequential optimisation [1]

+ More efficient space searching
- Stuck in local maxima
- Still time inefficient





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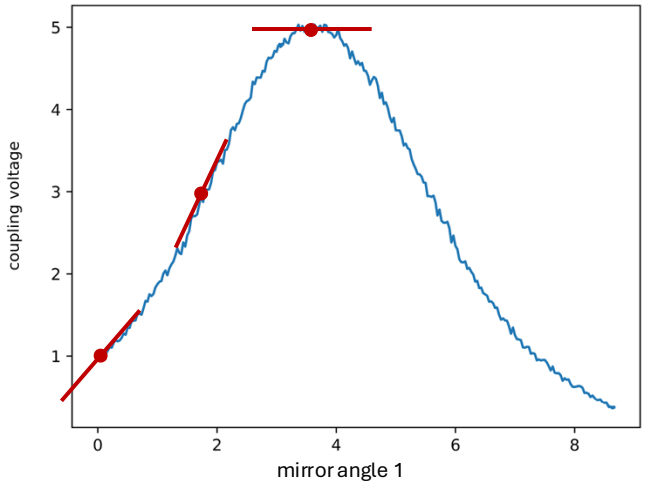
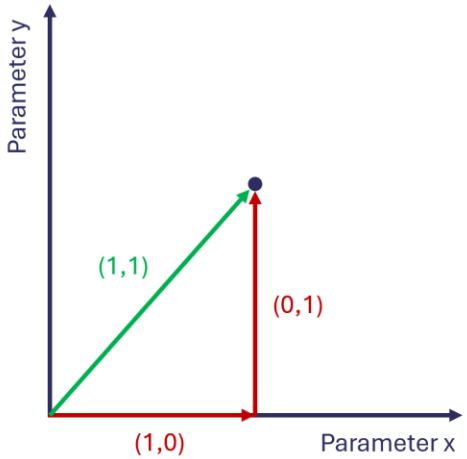
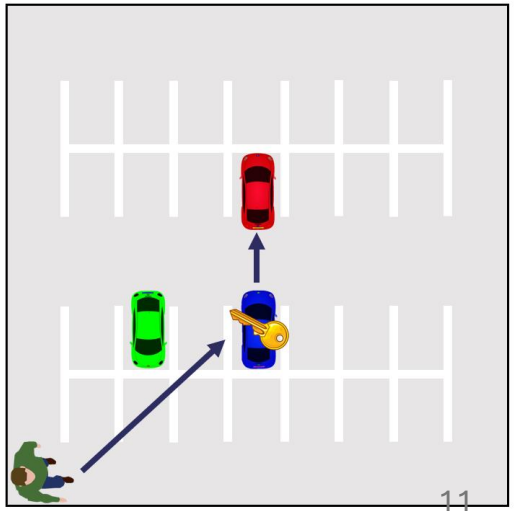
Stochastic direction-weighted gradient descent with adaptive learning rate



- Gradient descent method



- Smarter directional travel through parameter space



- Adaptive learning rate

Algorithm design was partially guided by this work [2,3]

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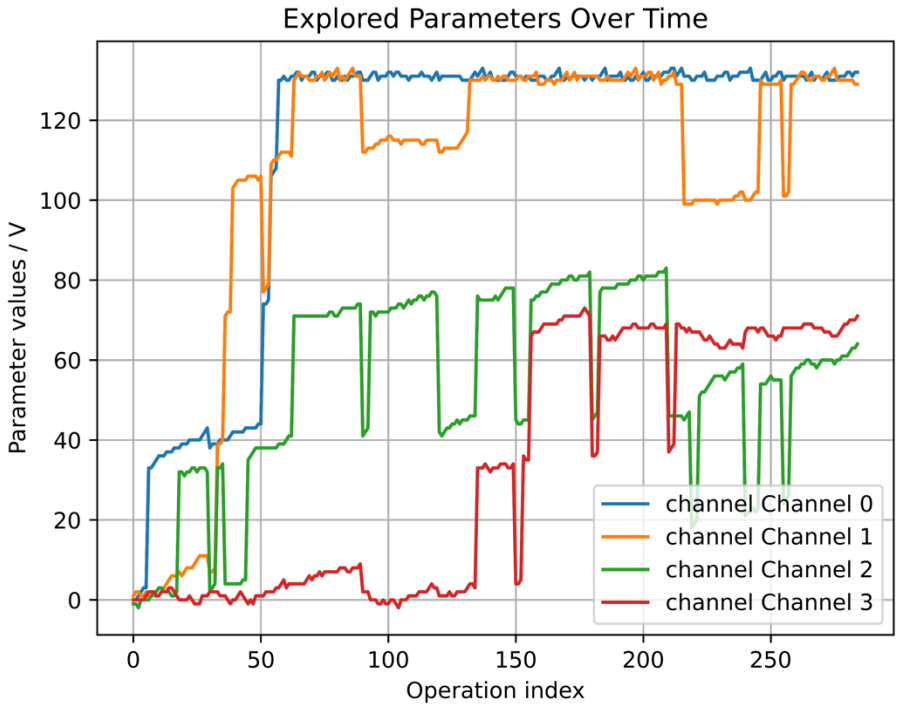
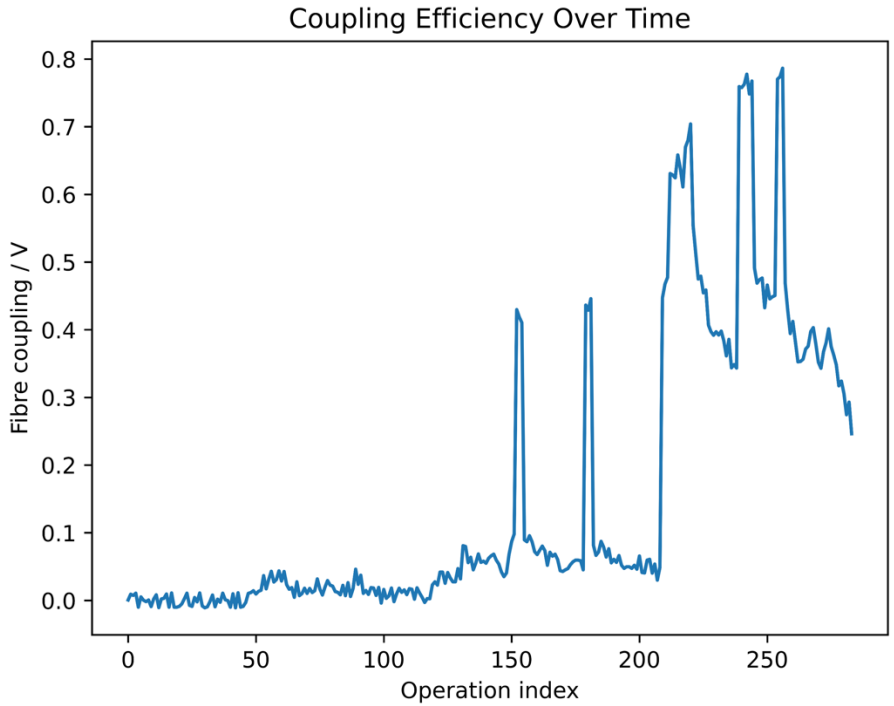
The main results





Key Takeaway:

The algorithm went from an arbitrary starting point with near-zero coupling to high coupling efficiency in **under 20 minutes**

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What is hysteresis?
A way around the problem
Modelling on the system
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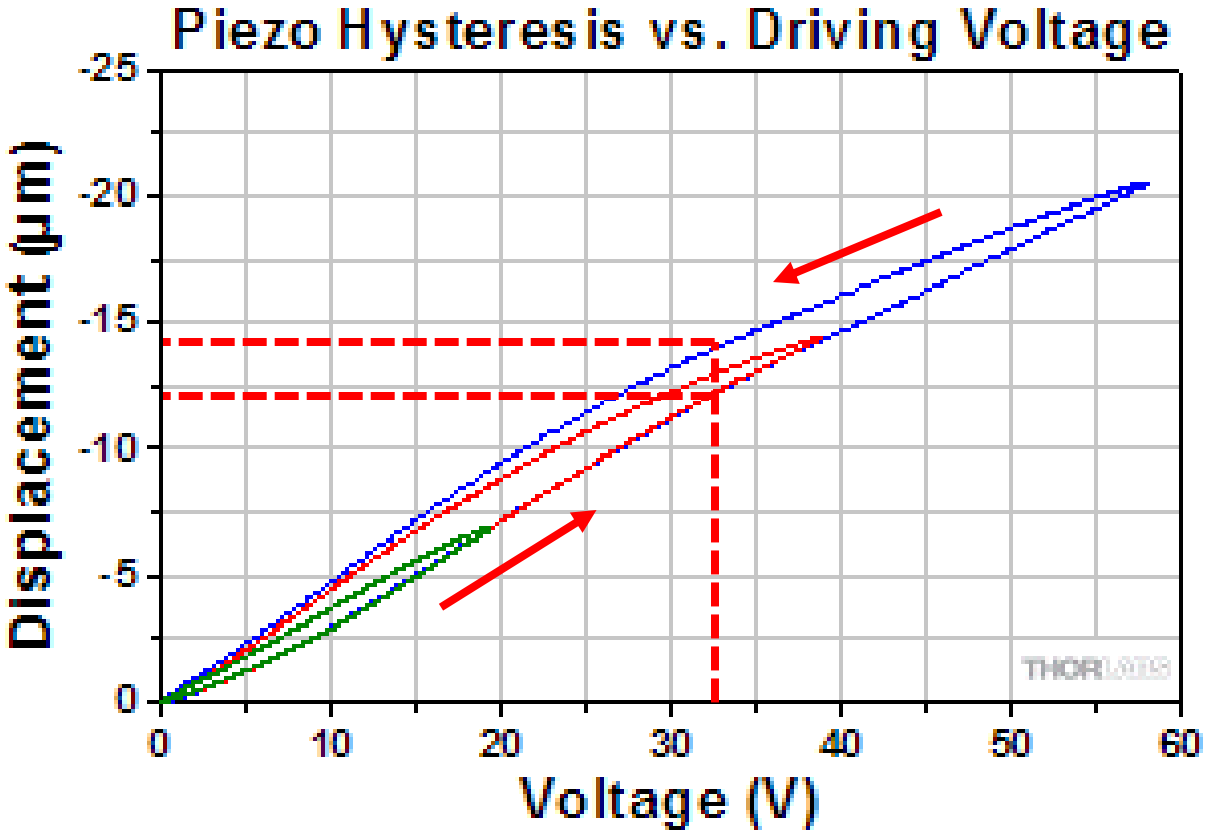
Hysteresis – a hardware problem



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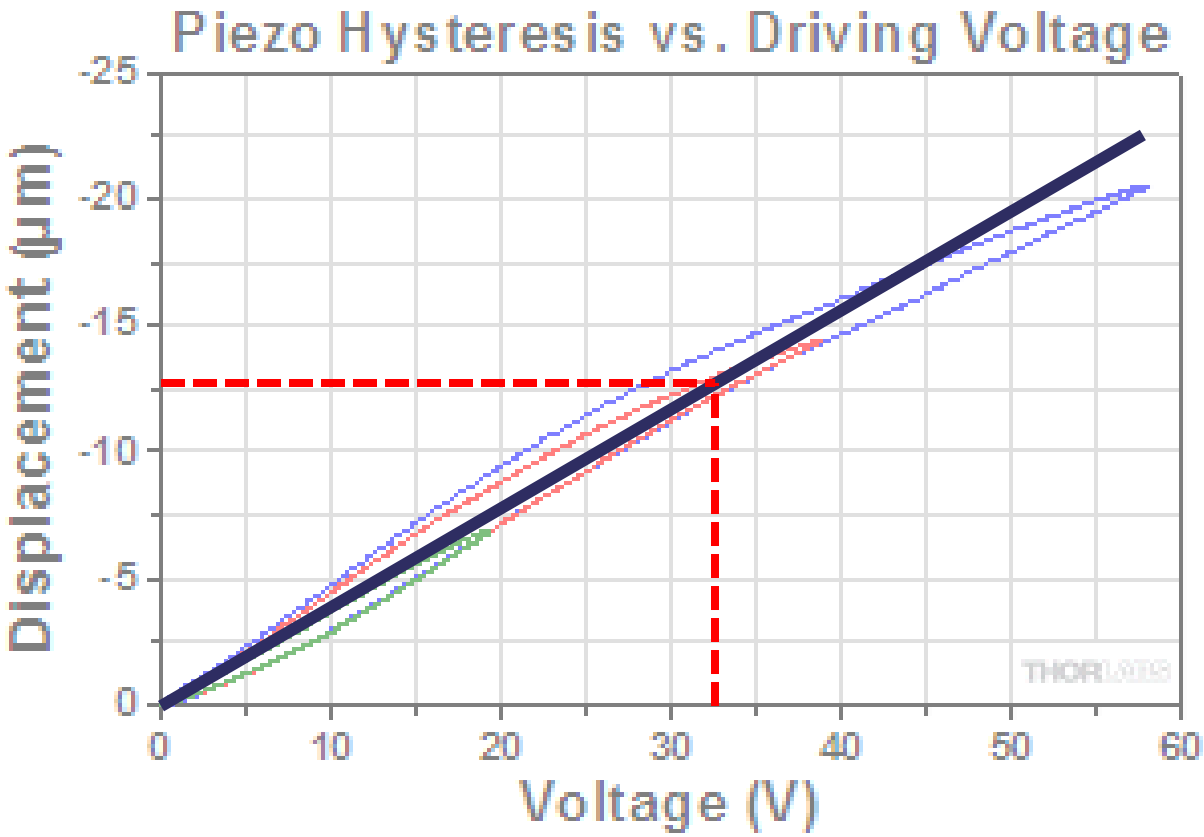

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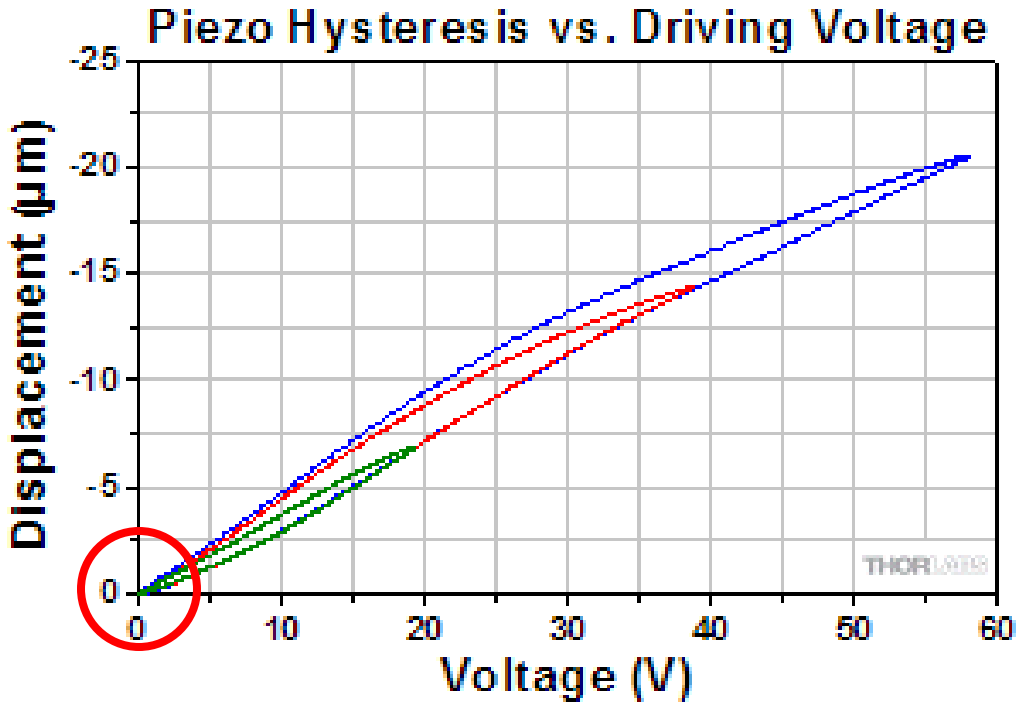
How can we solve the problem of hysteresis?



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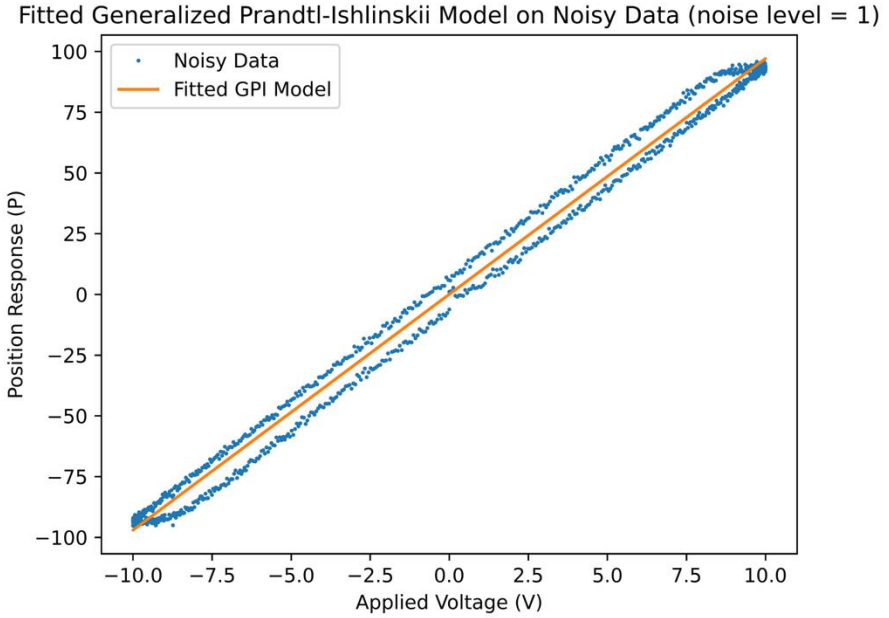
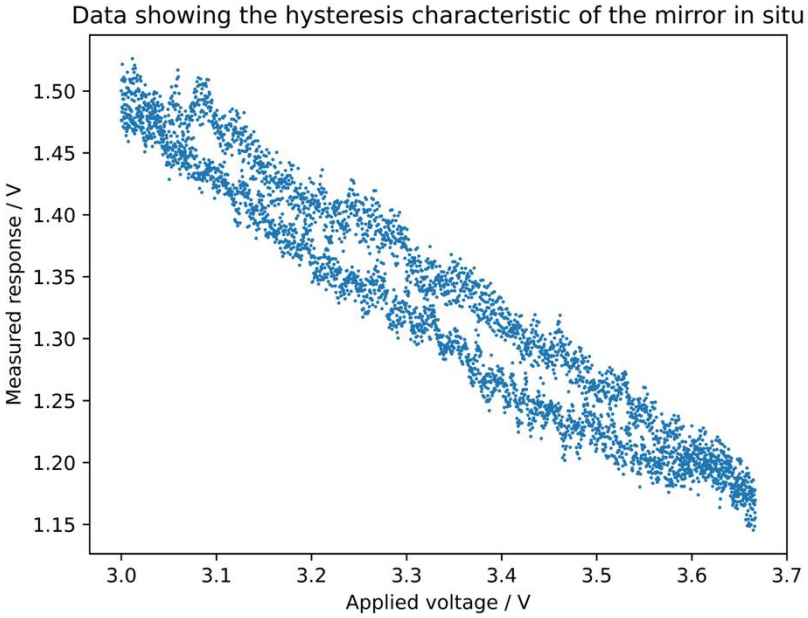
Modelling hysteresis





The Prandtl-Ishlinskii model is used to characterise the hysteresis [4]

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Automated systems heuristics

	Safety	
Data collection	vs.	Speed
Flexibility	vs.	Efficiency
Usability	vs.	Control

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Summary

- Successfully automated the fibre coupling process to be used outside of running laser experiments
- Upwards of 90% coupling achieved in under 20 minutes
- Pathway to improving the algorithm to achieve continuous coupling maintenance through hysteresis modelling
- Lots of transferable knowledge gained about the ARTIQ environment

Thank you!

Presentation References

1. Han S, Kye H, Kim C-S, Kim T-K, Yoo J, Kim J. Automated Laser-Fiber Coupling Module for Optical-Resolution Photoacoustic Microscopy. *Sensors*. 2023; 23(14):6643. https://doi.org/10.3390/s23146643

2. Ke, X., & Yin, B. (2021). Experimental Research on Automatic Alignment and Control Algorithm of Spatial Light-Fiber Coupling. *International Journal of Optics*, *2021*(1), 8481146.

3. Ke, X. (2023). *Spatial Optical-Fiber Coupling Technology in Optical-Wireless Communication*. Springer.

4. Al Janaideh, M., Al Saaideh, M., & Tan, X. (2023). The Prandtl–Ishlinskii hysteresis model: fundamentals of the model and its inverse compensator [Lecture notes]. *IEEE Control Systems Magazine*, *43*(2), 66-84.

Lensing: the third kind of error