Automated Optical Fiber Alignment for Trapped-Ion Quantum Computing

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Background

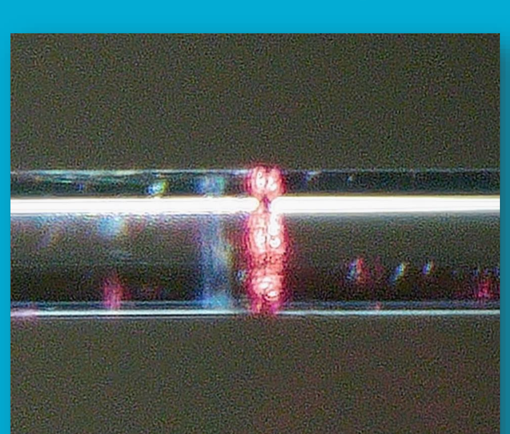
To make **quantum-computing** a reality, SNL is currently working to expand trapped-ion systems to support a larger number of ion qubits. This requires aligning arrays of fiber optics to microscopic precision; a frustrating, time intensive and inefficient process which is currently done by hand.

Objective

- Create an *automated* fiber optic alignment control system
- Streamline coupling process by reducing alignment time
- Create optical connections with less than 2 dB (40%) power loss
- Position fibers ~5 microns apart, while avoiding collisions
- Enable handling and transportation after establishing a connection

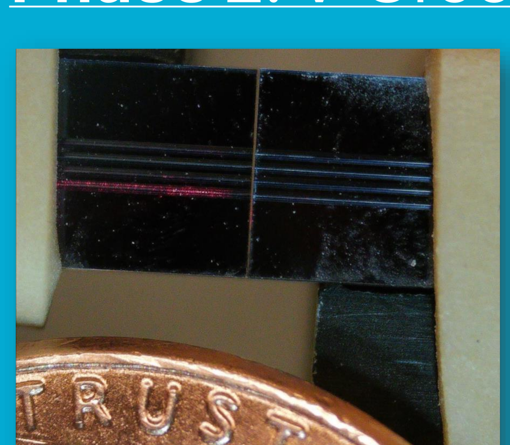
Project Phases

Phase 1: Optical Fiber Alignment



Fiber to fiber: Single optical fibers, with cores 4 microns wide, transmit light using total internal reflection.

Phase 2: V-Groove Alignment



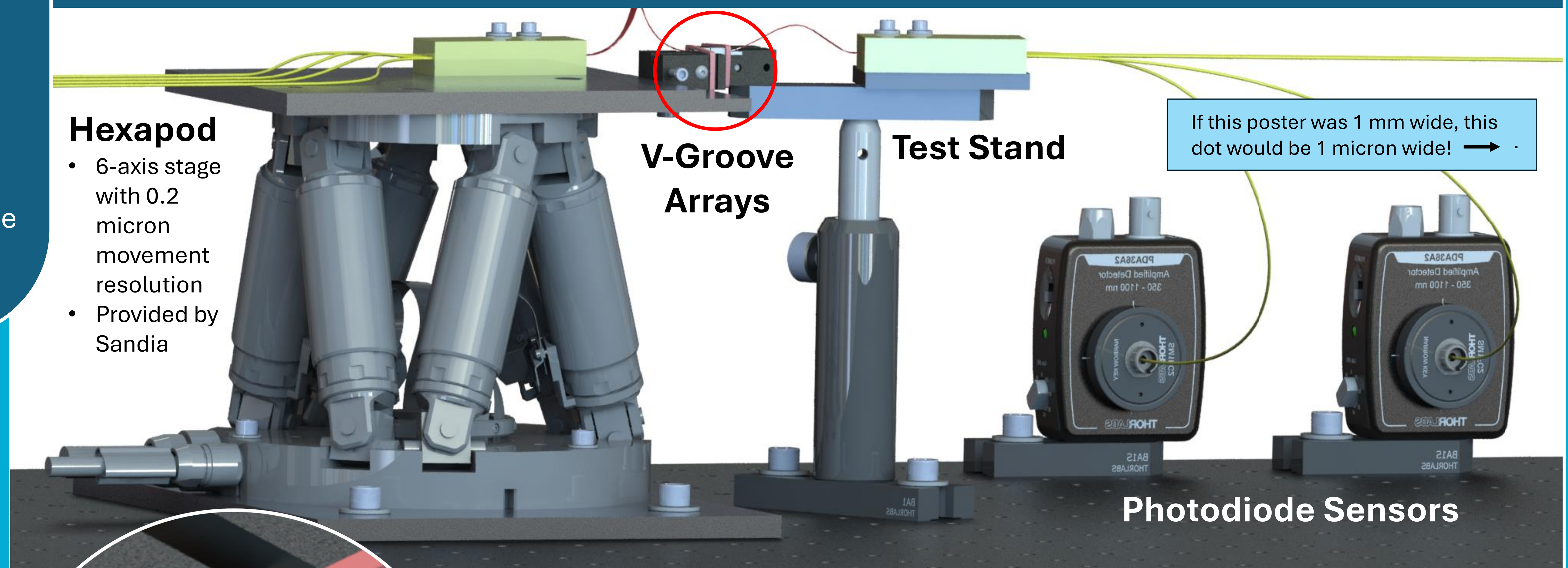
Multiple fibers arranged in a line form a V-groove array, which provides multichannel laser input and thus delivers more power.

Penny for scale

Phase 3: Epoxy Connection

Make connection permanent by applying optical epoxy

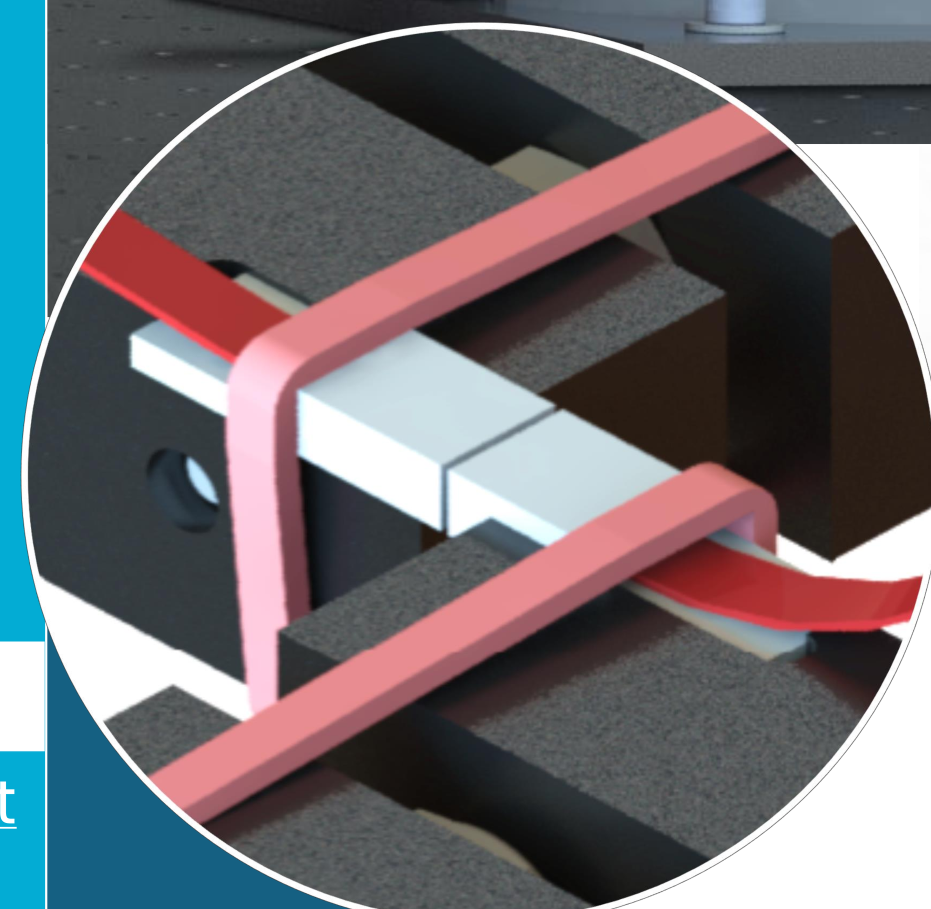
Test Setup

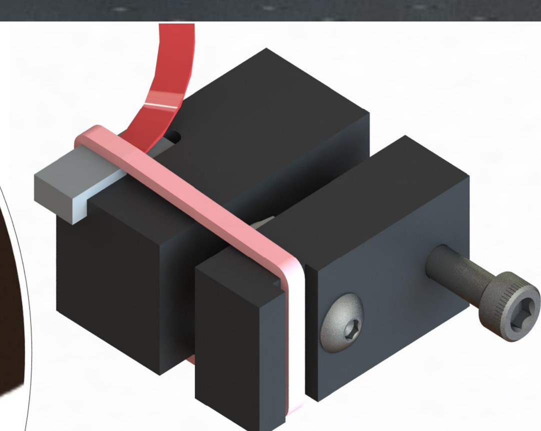


Hexapod

- 6-axis stage with 0.2 micron movement resolution
- Provided by Sandia

If this poster was 1 mm wide, this dot would be 1 micron wide! → ·

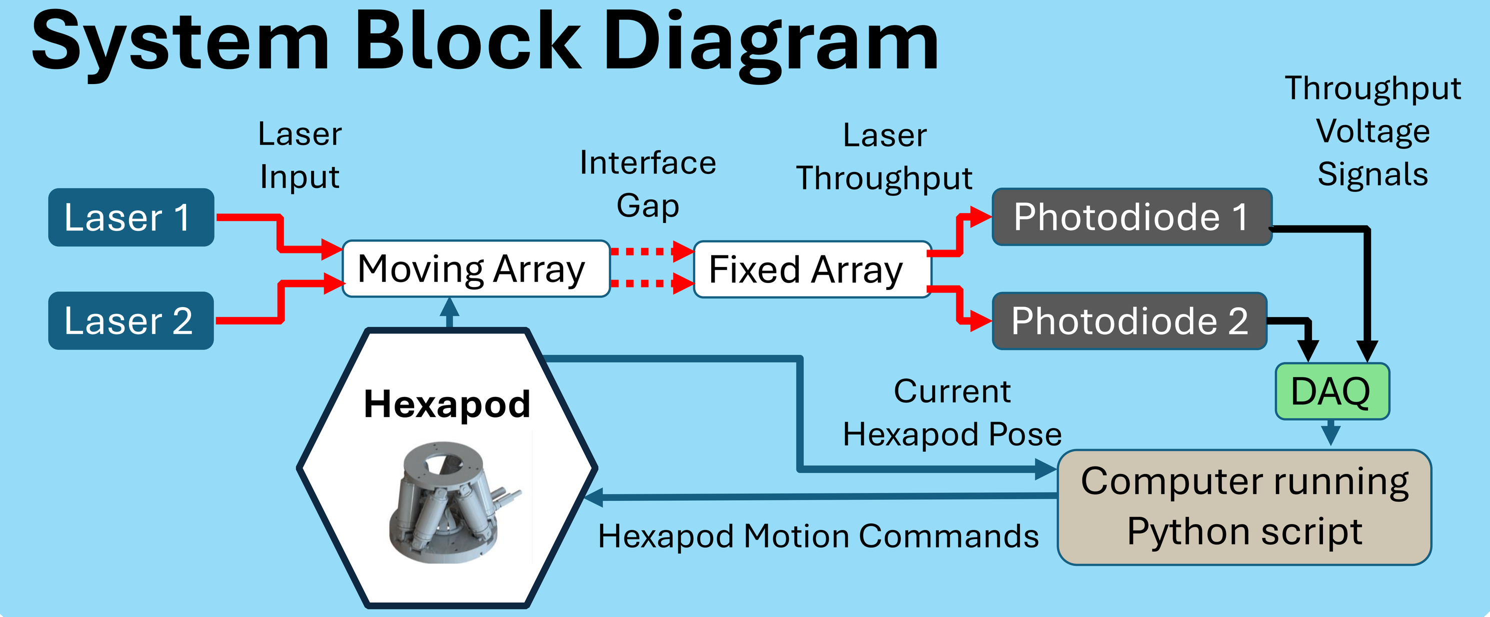




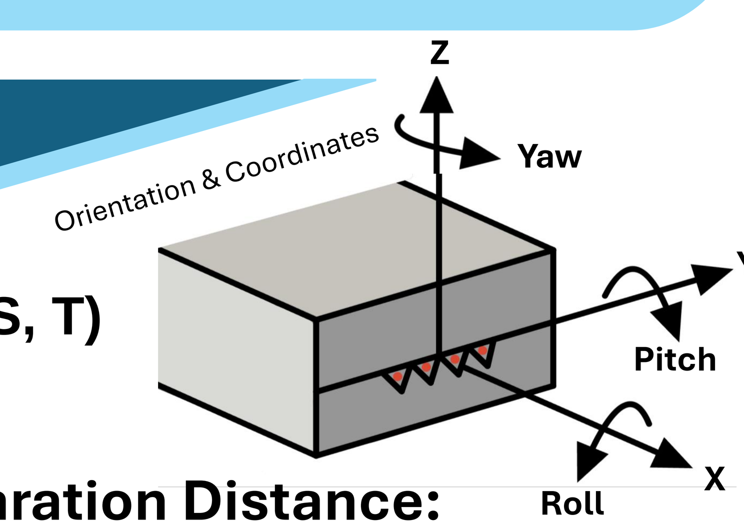
V-Groove Fixture

- Uses elastic band to hold V-Groove arrays in place without damaging them
- Adjustable tension with lead screw for fine-tuning

System Block Diagram

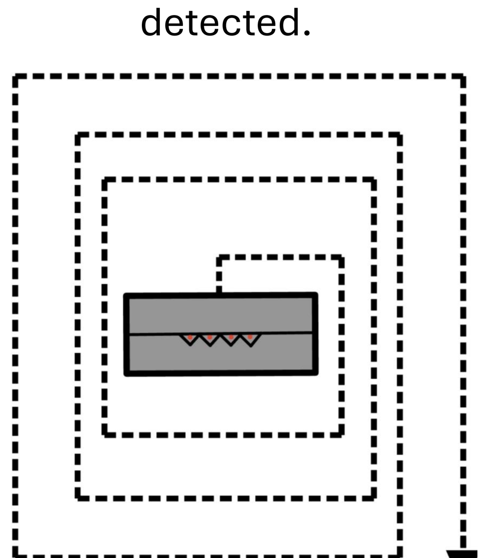


Alignment Procedure

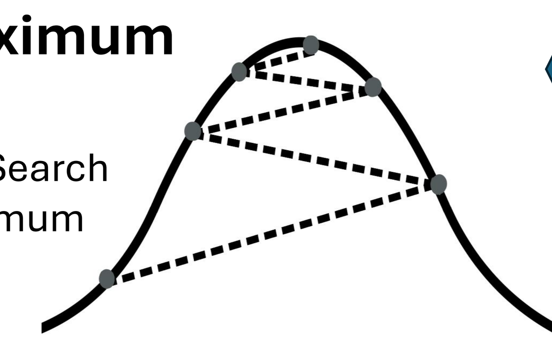


- Optimization problem with **9 degrees of freedom**
- *Inputs*: Cartesian Position **(X, Y, Z)**, Angles **(U, V, W)**, and Rotation Point Coordinates **(R, S, T)**
- *Outputs*: Voltage Readings from Photodiodes 1 & 2

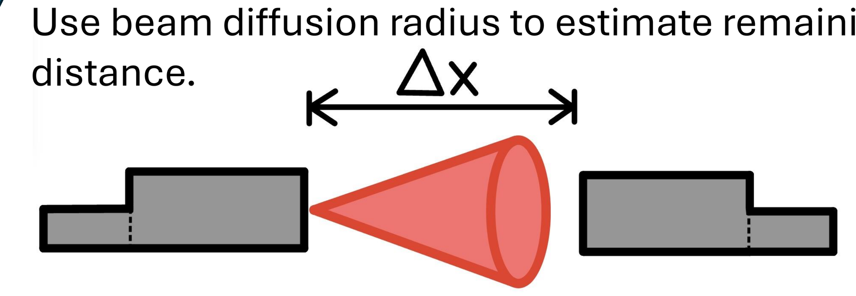
1 Initial Scan: After rough manual alignment, hexapod moves in a spiral pattern until significant signal is detected.



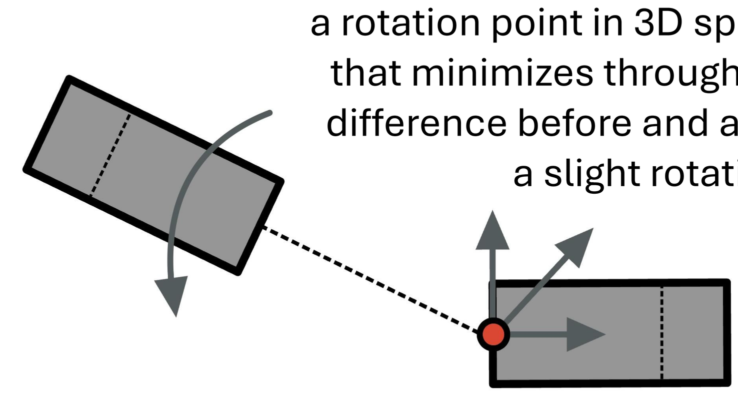
2 Find Local Maximum in YZ plane: Use Golden Section Search algorithm to find optimum power throughput at current distance.



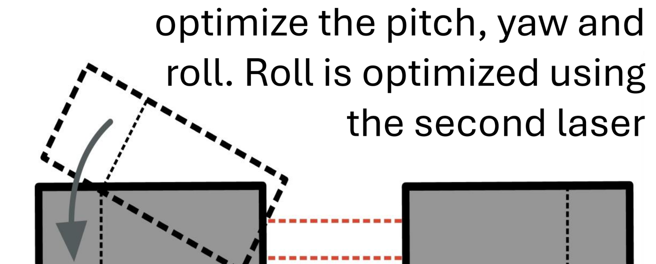
3 Calculate Separation Distance: Use beam diffusion radius to estimate remaining distance.



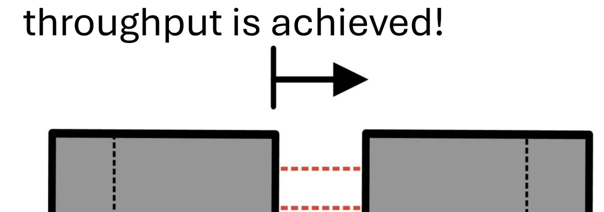
4 Optimize Rotation Point: Use Golden Section Search to find a rotation point in 3D space that minimizes throughput difference before and after a slight rotation.



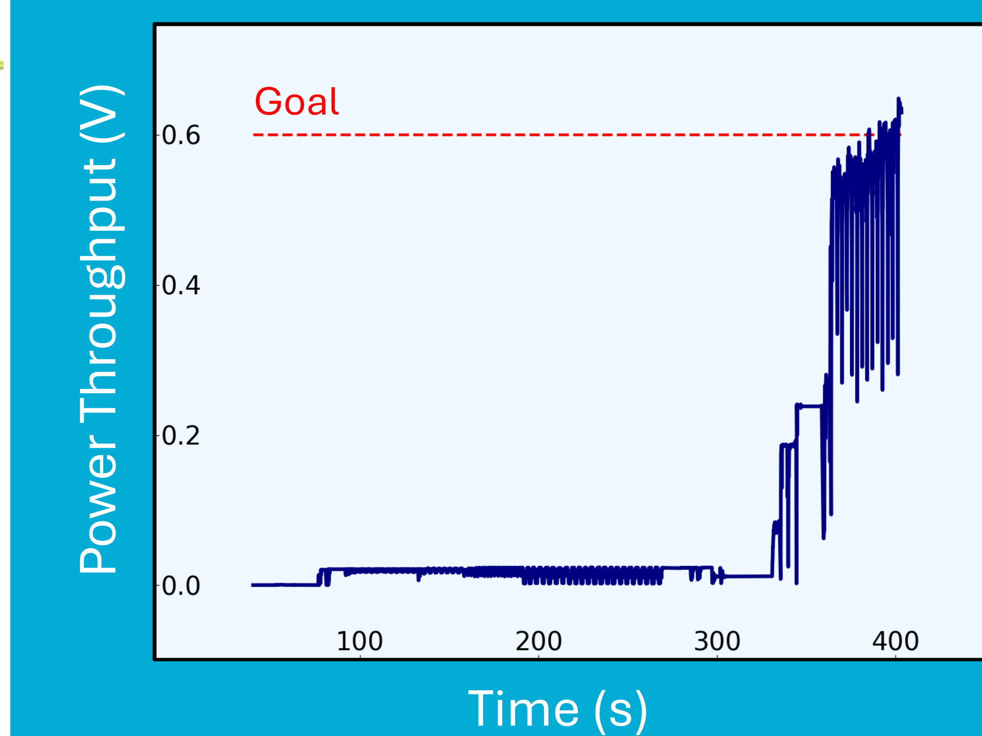
5 Align Angles: Now that the angles have been isolated from the cartesian dimensions, optimize the pitch, yaw and roll. Roll is optimized using the second laser

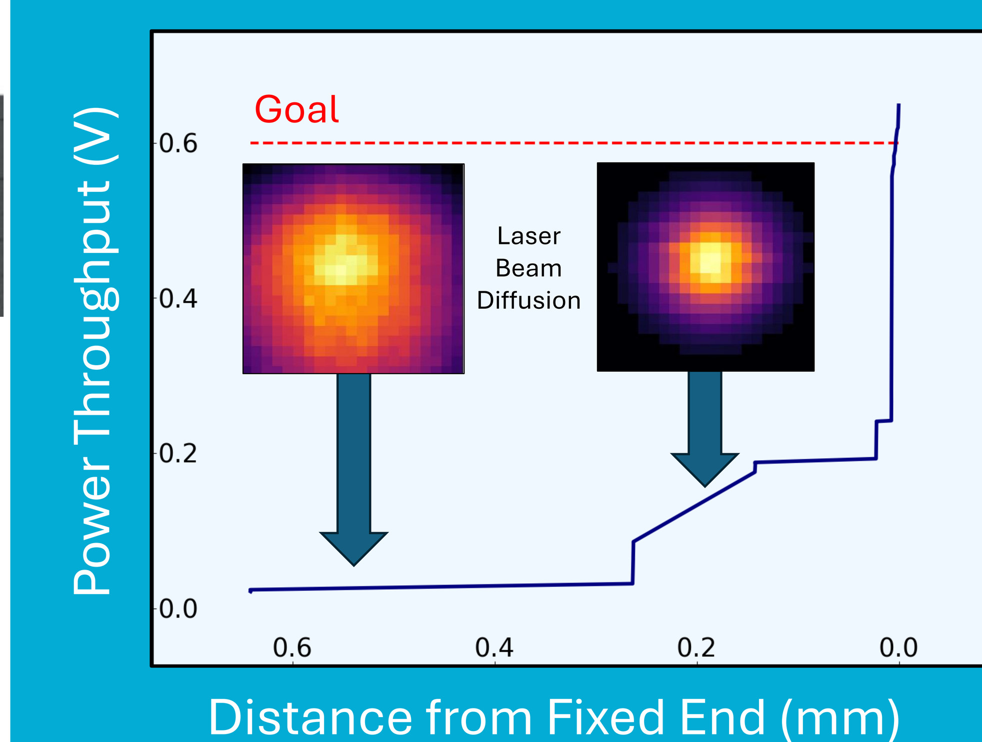


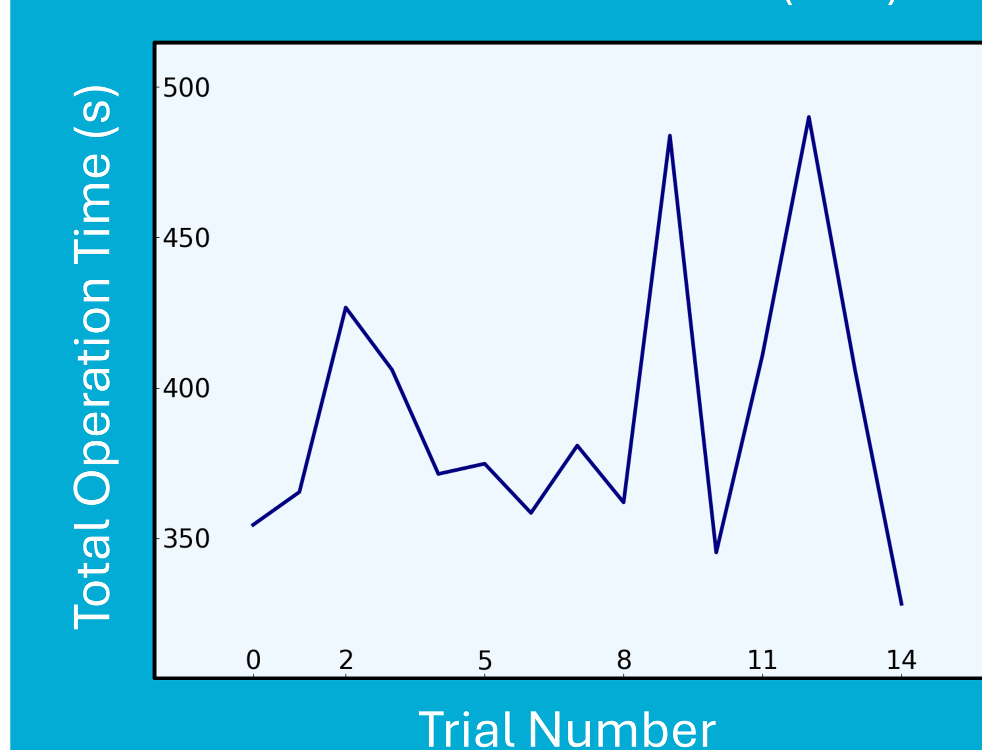
6 Final Approach: Move forward towards the fixed v-groove array. Distance is inferred based on throughput voltage. Repeat until desired throughput is achieved!



Results/Analysis







Impact

- ✓ Automation creates a consistent and repeatable process
- ✓ Alignment time reduced
- ✓ Opportunity for alignment using multiple fiber optic cables
- ✓ First step towards scalability with epoxied connection
- ✓ Paves the way for the quantum-computing revolution

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