（別紙様式２）

フォトンサイエンス国際卓越大学院プログラム（XPS）
光科学特別実習　報告書

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Auto-alignment of light beam through optical resonator

Alignment of mirror, lens, and optical resonator is the most fundamental skills for researchers working with optical systems. It is required for interferometer and optical resonator to have high mode matching so that they would have low loss and would work as intended. As time passes, components, mostly mirrors, of the experimental system will slightly drift as the result from vibration, heat expansion and other causes. Therefore, realignment of the optical system must be done repeatedly in every experiment. Although it is a repetitive task and time consuming, it requires mastery in a certain level to do it. This is where AI can be benefited from. The goal of this project is to develop a machine learning algorithm for alignments of optical systems. We chose a relatively simple system which contain 2 mirrors and 2 lens; just enough parameters to characterize the trajectory and size of a light beam sending through an optical resonator. The free spectral range (FSR) of the optical resonator is measured with a photodetector behind the resonator. The algorithm for this simple system can be further developed into more general cases and would make experiments with optical system more efficient.

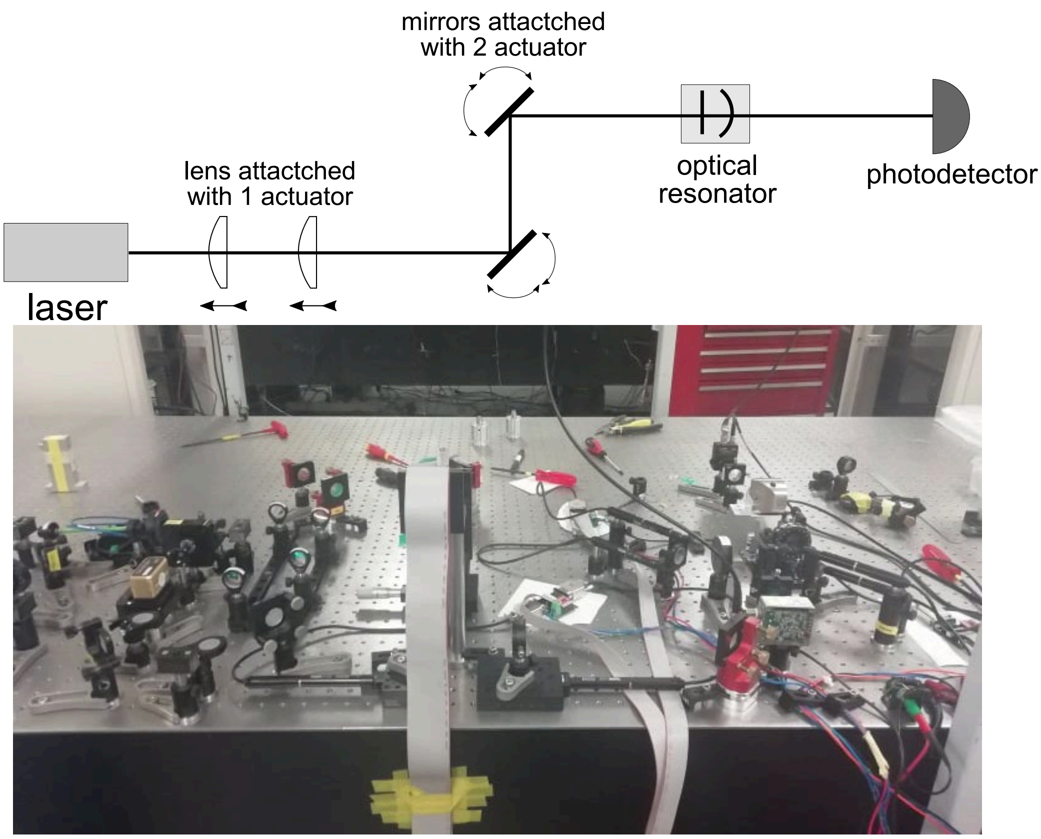

Fig 1. Experimental setup

Since the influence of COVID-19 outbreak, the project had to be done online, and direct using of the experiment system is not possible. ANU researcher would do the data runs while I obtained the data and provide data analysis and data visualization. The input data is the displacement of each motor actuators attached to two convex lens (one actuator each) and two plain mirrors (two actuator each), and the output is the FSR of the optical resonator. We needed to convert the FSR information into a cost function which will feedback to determine the next displacement of each motor actuator. Here, we use several methods such as using peak detection, or the Fourier transform of the FSR. Before we can test the algorithm, many imperfections of the experimental system had to be address. For example, the power of the laser fluctuates, and the motor actuator have some hysteresis where the displacement of the actuators is different moving forward and backwards. After these issues have been addressed accordingly, we assign the actuators to comeback to the original position after a few steps to confirm the stability of the system.

The algorithm used in the experiment consisted of two phases. The first phase is to search the parameter space randomly to gather some data points. We used the point to train a model to predict the entire parameter space, then the model would suggest additional points to be tested out with the experimental system again. Repeating this process, the model will sample more points near the global minimum while sampling some other points to prevent conversion at local minima which sometimes occurs when using conventional gradient decent methods. The result finds an FSR as fine as a if a researcher would align the mirrors oneself.

After some experimental runs we would want to present the data in the simplest way as possible. Since the input is a 6-parameter space, it was hard to present these with only static graphs and diagrams. Here, I learned to plot interactive plots using Plotly and Dash; a package in python programming language which makes the interactive plot in Figure 2. While the figure is small and difficult to see, the left side of the figure shows the input parameter space in which each point is linked with each other across the three plots and can be shown by hovering cursor on the points. Also, while hovering, the FSR according to the points will be shown on the top-right plot, and by clicking the points, the FSR can be saved on the bottom-right plots. The color of the left plots also shows the value of the cost functions where higher cost ones are black, medium ones are red, and low ones are blue. This way we clearly can see the dynamic the points determined by the algorithms. Which started with random sampling into sampling points near the optimal points while still searching for other random points in the space. The reason where the optimized FSR does not show a clean delta function-liked plot is that the choice of the lens is not appropriate. The curvature of the lens will be calculated carefully when we do the additional runs for our final presentation.

Working on this project was a great experience for me that I met other researchers who are skillful in various fields. I learned more about machine learning algorithms and programming which are skills that would be incredibly useful for me and for my future research. I feel that being able to learn and use multiple new set of skills to solve a problem is enjoyable and increases the motivation to work on projects.

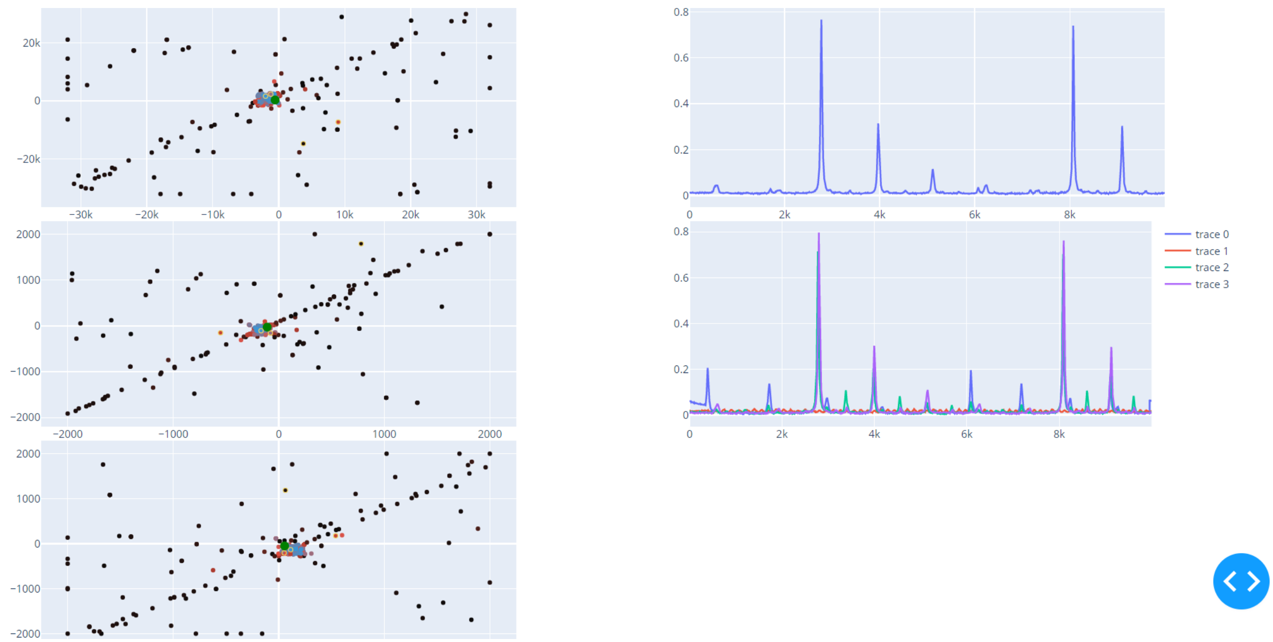

Figure 2. Interactive plots representing
Left: Parameter space of the motor actuators. Right: FSR according to each point.