Manufacturing Metrology Team

The University of Nottingham

Design and Construction of a Custom Measurement Device

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Project Background and Motivation

This study explores the next step in customised measurement instruments by reconsidering the assumption that confocal measurement devices cannot be manufactured using consumer-grade equipment. Historically, these devices have required specialised manufacturing due to complex optical components like ground glass lenses, which are expensive, bulky, and difficult to customise.

The key challenge—optimising light propagation, focusing, and image processing—has been addressed with simple, innovative solutions, including the development of confocal Fresnel lenses. These lenses, characterised by concentric grooves, offer a lightweight, cost-effective alternative to traditional lenses while maintaining strong optical performance.

Modelling and testing have demonstrated the Fresnel lens's advantages, particularly in reducing weight, cost, and simplifying integration. While it may not outperform traditional lenses in all high-precision applications, its lower production costs and adaptability make it ideal for systems with size and budget constraints. This combination of benefits and limitations expands its practical use across various fields, offering a balance between performance and efficiency.

Experimental Setup

This setup enables precise optical measurements by focusing light through a Fresnel lens onto an object and splitting the light for analysis using a prism and camera. The Fresnel lens focuses the light, and the prism disperses it into a spectrum for detailed analysis, making the system ideal for high-precision tasks.

1.Collimated White Light Source: Produces parallel light rays and directs them towards the beam splitter.

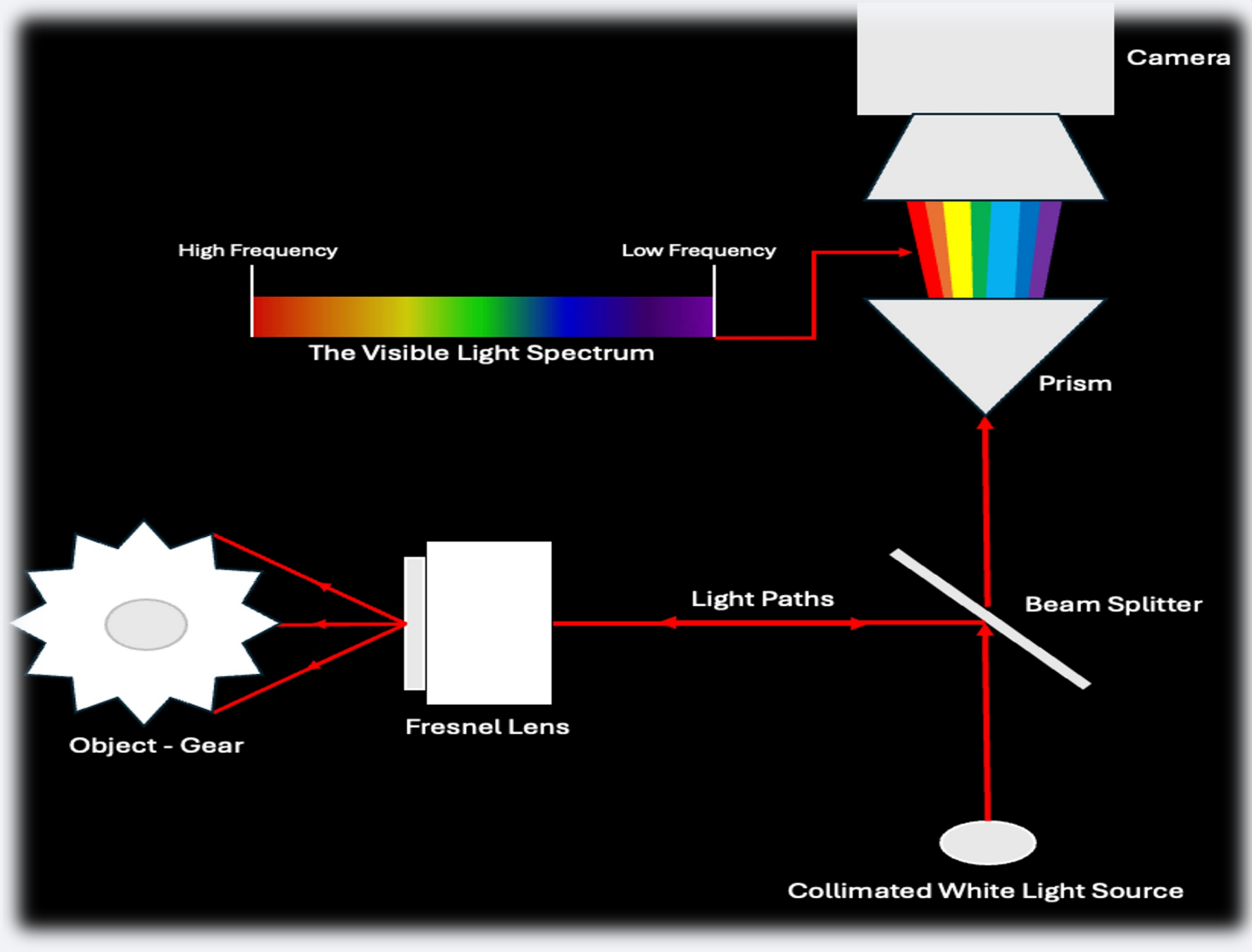
2.Beam Splitter: Splits the light between the Fresnel lens (for the object) and the prism (for spectrum analysis).

3.Fresnel Lens: Focuses light on the object for precise measurement.

4.Object: Receives the focused light, with reflected light sent back for analysis.

5.Prism: Disperses the light into a spectrum based on wavelength.

6.Camera: Captures the spectrum for analysis of the optical properties.



Complete Experimental Setup for Optical Testing and Analysis

Problem

This project addresses the need for a precise and compact opto-mechanical measurement device. Traditional optical systems, while effective, present significant limitations:

- **High Cost**: Specialist manufacturing of conventional optical components, such as ground glass lenses, increases costs, limiting customisation.
- **Weight and Bulk**: Traditional lenses are bulky and heavy, unsuitable for applications requiring portability and compact design.
- **Difficult Customisation**: Tailoring these systems is costly, time-consuming, and demands expert manufacturing.
- **Reliance on Specialist Manufacturers**: Dependence on specialists restricts rapid prototyping and design adjustments.

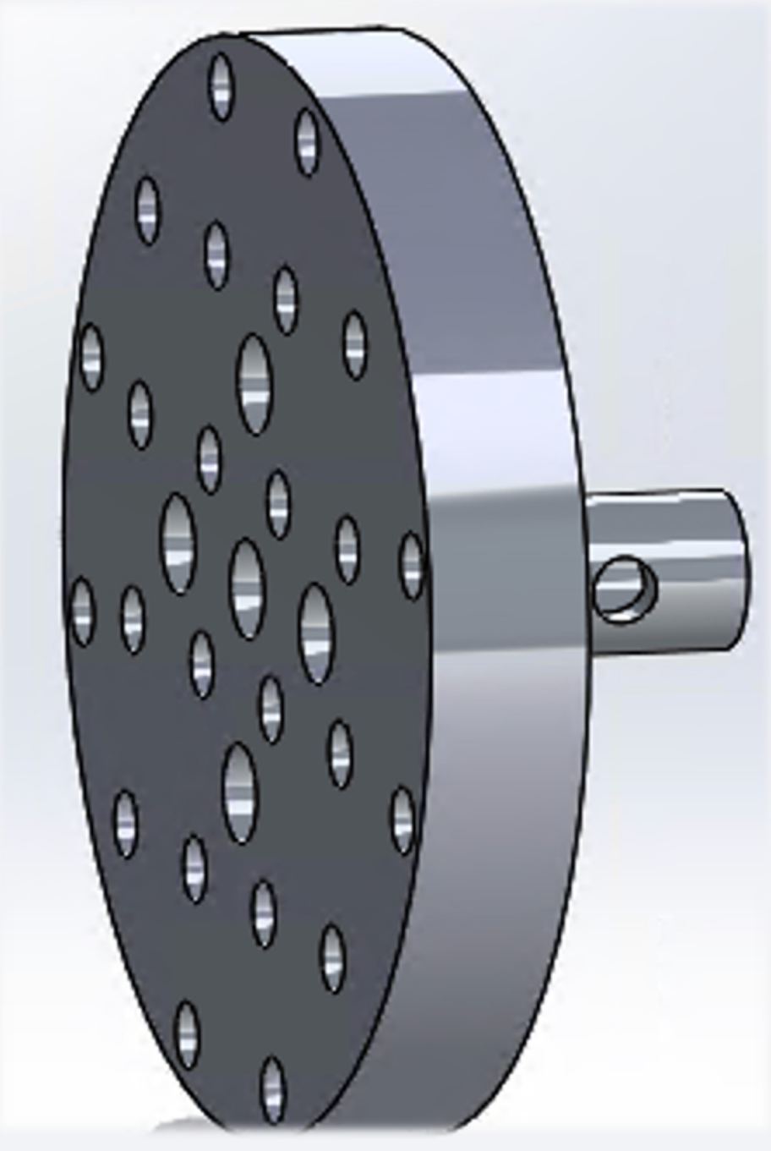
This project explores the use of consumer-grade optical components to address these challenges, offering improvements in weight, cost, and customisation.

Solution

A custom opto-mechanical device has been developed to tackle the identified challenges, using cost-effective, high-performance technologies. Key aspects include:

- **Custom Fresnel Lens**: The lens, with its innovative concentric groove design, is thinner, lighter, and reduces both cost and weight while maintaining strong optical performance
- **Off-the-Shelf Components**: A camera, prism, and beam splitter were used to optimise both performance and affordability.
- **Consumer-Grade LED**: A phosphor-coded LED provides reliable, cost-effective illumination, easily available due to photography applications.

To facilitate testing and setup, a rotation stage was designed and built on top of a stepper motor to mount the object. This configuration was crucial in verifying the accuracy of measurements after component integration, ensuring precise rotational control throughout the testing process.



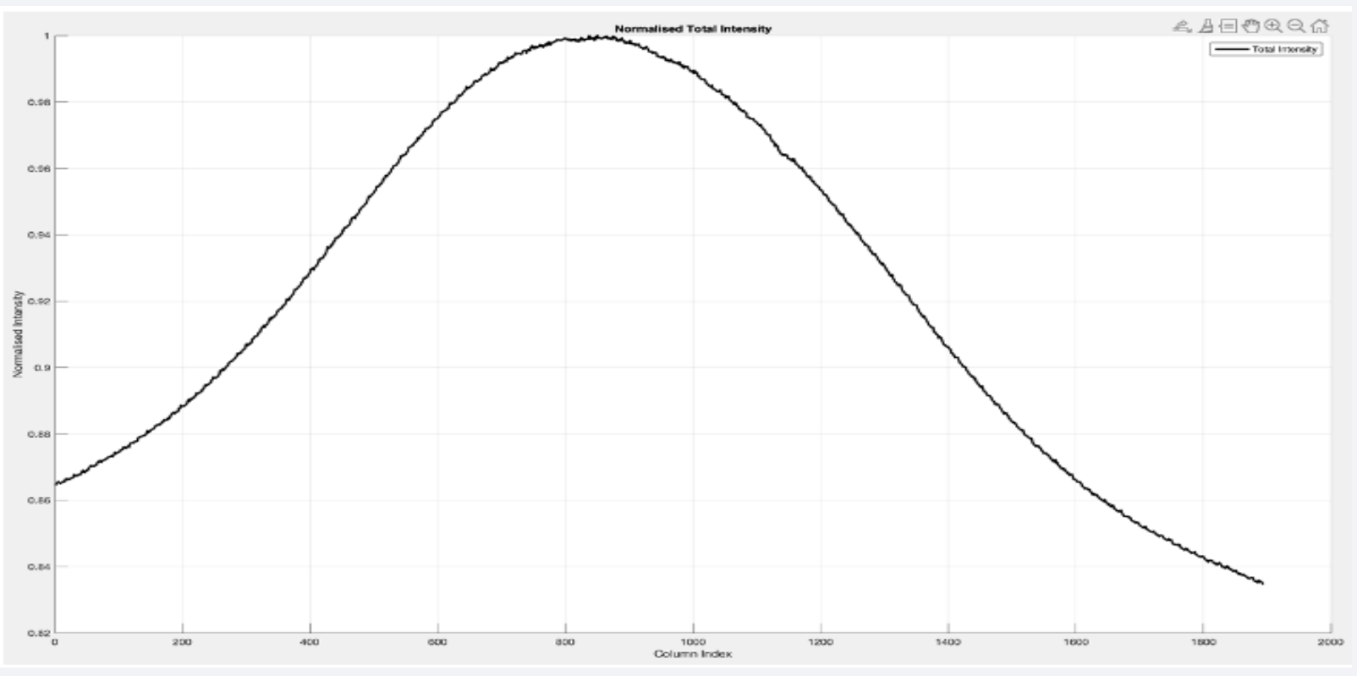
Motorised Rotation Stage – CAD Model

Simulations and Testing

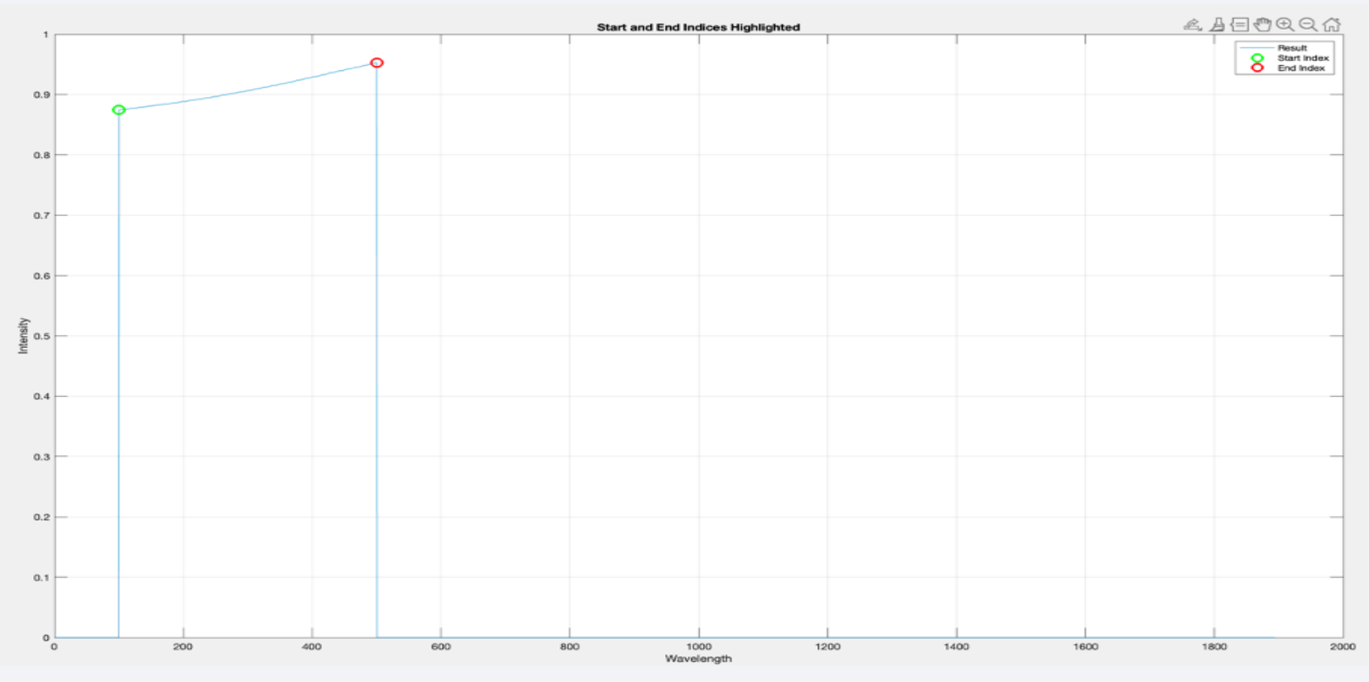
Simulations allowed for theoretical refinement and analysis of critical components, ensuring an optimal design was established. Key areas of focus include:

- **CAD Modelling**: Advanced CAD software was used to model components like the Fresnel lens and micro gears, allowing for in-depth design refinement and virtual testing of mechanical aspects.
- **Optical Efficiency**: Simulations were performed to assess the Fresnel lens's ability to focus light and tailor the design to the new application. Focal length calculations and optical efficiency predictions were made to ensure the lens would perform as required. it's the light gathered by the lens
- **Wavelength Selection**: A virtual setup with a prism and camera was used to simulate wavelength-dependent light patterns, ensuring the design would enable precise wavelength selection and focusing.
- **Simulation Tool**: A custom tool was developed to generate visual schematic diagrams, helping refine the optical configuration and confirm design choices.

Rainbow Pattern (Light) Gathered By The Camera Lens



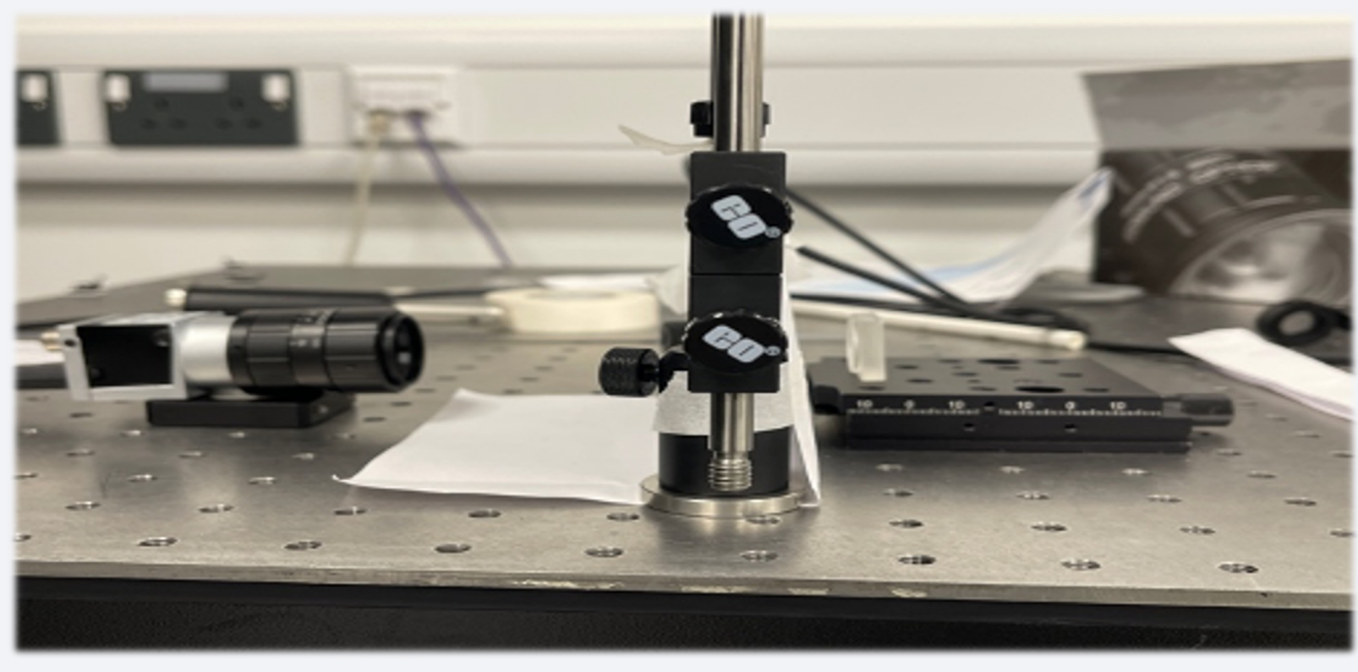
Normalised Total Intensity – MATLAB Analysis



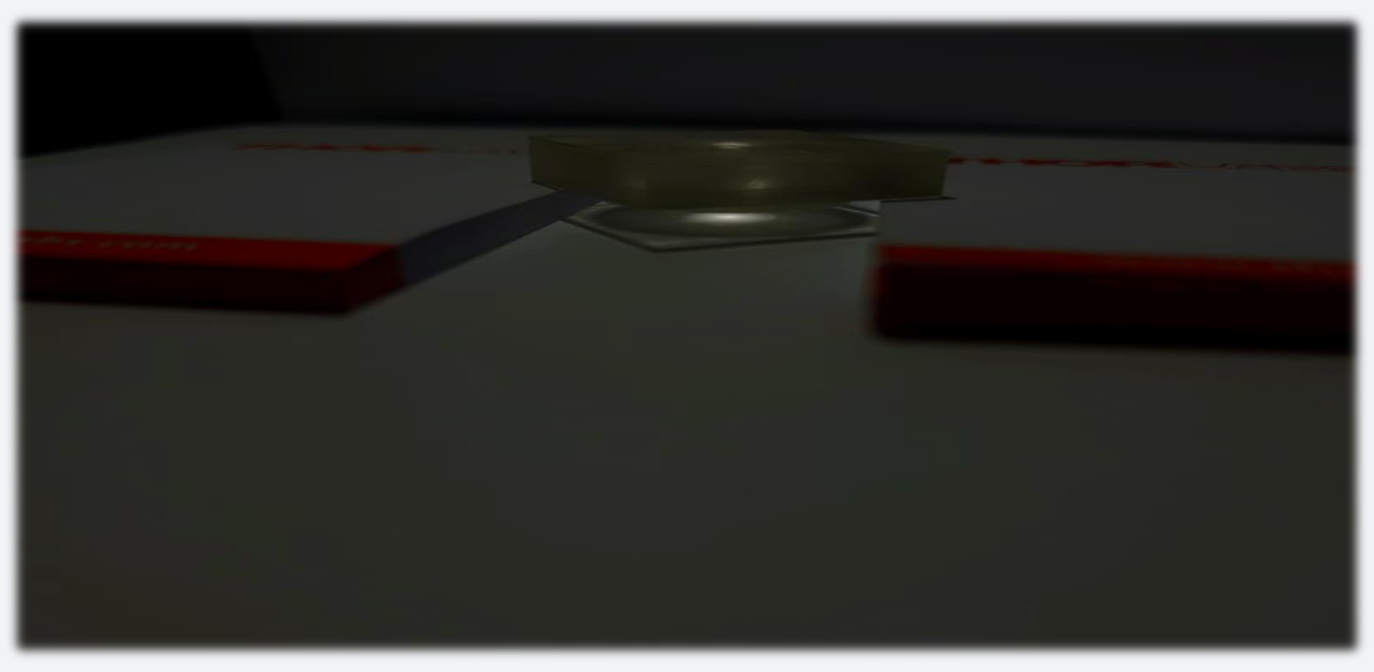
Wavelength Selection – MATLAB Analysis

Following simulations, rigorous physical testing was performed to validate the device's performance.

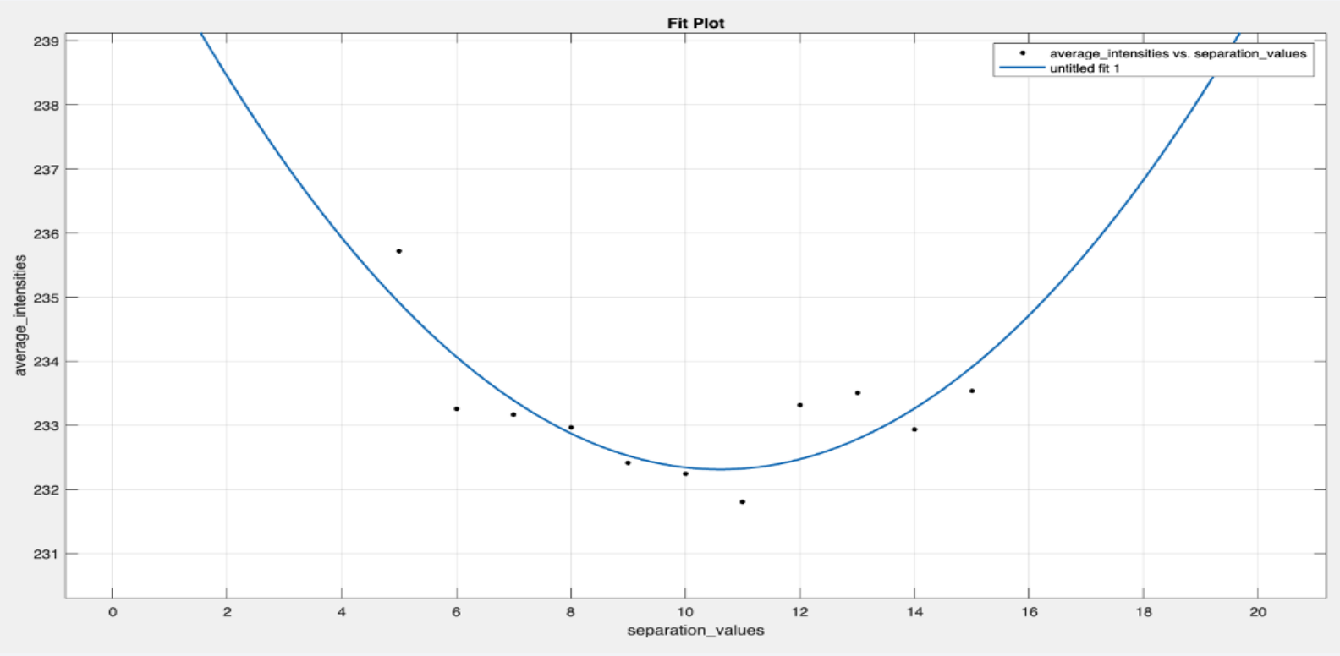
- **Optical Testing**: Each Fresnel lens was physically tested for its ability to focus and collimate light. A custom lab setup was used to determine, which allowed us to precisely measure how effectively each lens focused light, ensuring the chosen lens met the optical performance standards required for the device.
- **Regression Analysis**: Regression analysis was applied to the measured focal power curves to evaluate and compare the performance of different lenses.
- **Functional Testing**: The complete opto-mechanical device was tested under real-world conditions to verify it met all technical requirements, with specific attention given to its performance in ambient lighting.
- **CFTool Validation**: The final validation involved using the CFTool to confirm that the lens provided consistent, strong focal power under diverse conditions, reaffirming the success of the design.



Custom Lab Setup for Testing Lens Designs



Lens Focusing Performance Under Ambient Lighting



Focal Power Determination Using Curve Fitting – MATLAB Analysis

Conclusion

In conclusion, it has been demonstrated that consumer-grade equipment can be successfully used to develop innovative optical solutions.

Bulk, cost, and complexity have been reduced, showing the potential for more accessible and customisable measurement systems. This project paves the way for further advancements in precision measurement technology.

Future Work

To address the small discrepancies between theoretical predictions and experimental results, future work will focus on:

- Improving Experimental Procedures: Refining the experimental setup to reduce discrepancies and increase accuracy.
- Enhancing Testing Environments: Implementing more controlled environments to ensure consistent results.
- Increasing Trial Numbers: Conducting additional trials to improve data reliability and reduce uncertainties.
- Optimising Lens Alignment: Improving alignment precision for better optical performance.

These efforts aim to enhance the accuracy and performance of the device.

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