MADLaSR: Multi-Angle Detection of Lambertian and Specular Reflectivity

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Abstract

The goal of this project was to build a device capable of measuring both the specular reflectivity of black materials, as well as the Lambertian reflectivity of white materials over their full range of incident and observed angles, respectively. MADLaSR (Multi-Angle Detection of Lambertian and Specular Reflectivity) is a device designed for specular reflectivity testing in the range of $10^o < \theta < 160^o$ and for Lambertian reflectivity testing in the range of $10^o < \theta < 85^o$. The data collected from this device may be used to influence the design of optical systems, aerospace structures, or other devices in which maximum light control is a necessary consideration.

Introduction

When constructing optical systems, it is necessary to control the light that is present within the environment. The effects of stray or uneven lighting as caused by unexpected reflections may result in errors. Various materials, coatings, and finishes that may be used inside such systems have differing properties, and thus, may lead to these skewed outcomes. We have constructed a device that tests both a material's specular reflectivity over a range of angles $10^o < \theta < 160^o$, as well as a material's Lambertian reflectivity over a range of angles $10^o < \theta < 85^o$. Ideally, a black material will consistently produce minimal reflectivity over the full range of angles of incidence, while a white Lambertian material will consistently produce the same apparent brightness over the full range of observed angles. Previously, research has been conducted to test for total reflectivity over a range of wavelengths and specular reflectivity at a small number of angles (Marshall et al. 2014). This project aims to build upon those endeavors by increasing the range of angles tested and adding the ability to characterize Lambertian reflectivity.

MADLaSR Design

MADLaSR consists of two distinct assemblies: the system of rotating arms and the sample mount. The system of arms is composed of a pivot rod with two t-slotted aluminum bars branching off. They are mounted above two linear actuators and travel stages. Dowel pins are fitted into the travel stages and the grooves of the t-slot bars. The dowel pins are positioned on the travel stages such that they will remain symmetrical with respect to the pivot point and central axis during the full range of travel.

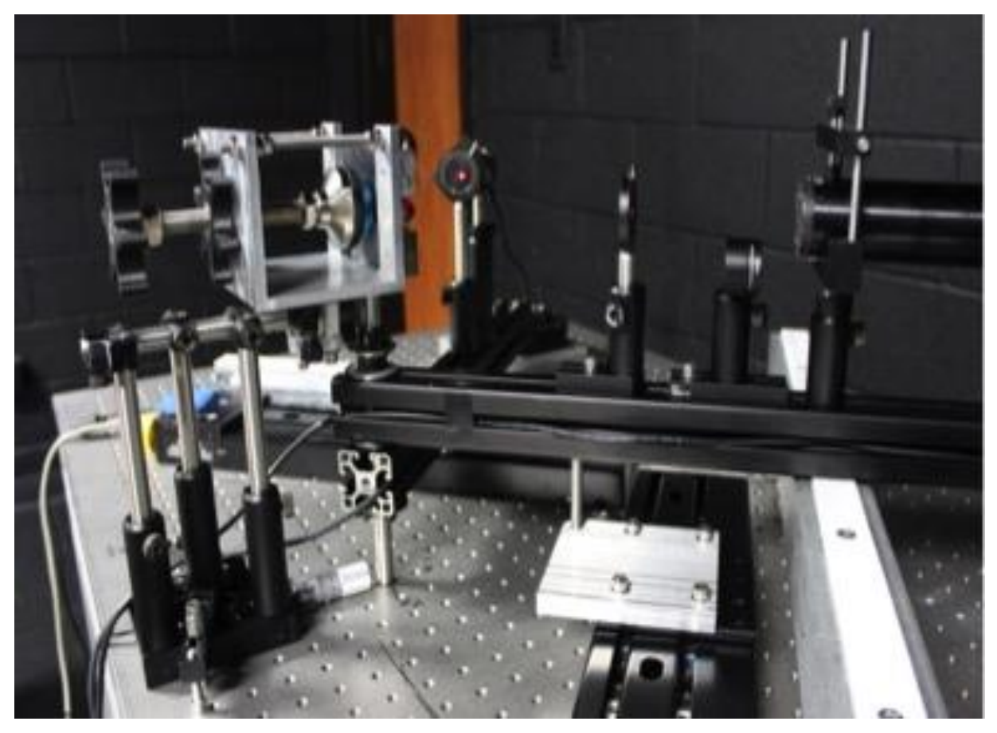


Figure 1: MADLaSR Setup

The sample mount is a machined square tube with a window in the front face in which the material is exposed and held in place by a swivel-leveling mount. This mount is supported by both a tilt stage and a translation stage in order to accommodate fine adjustments.

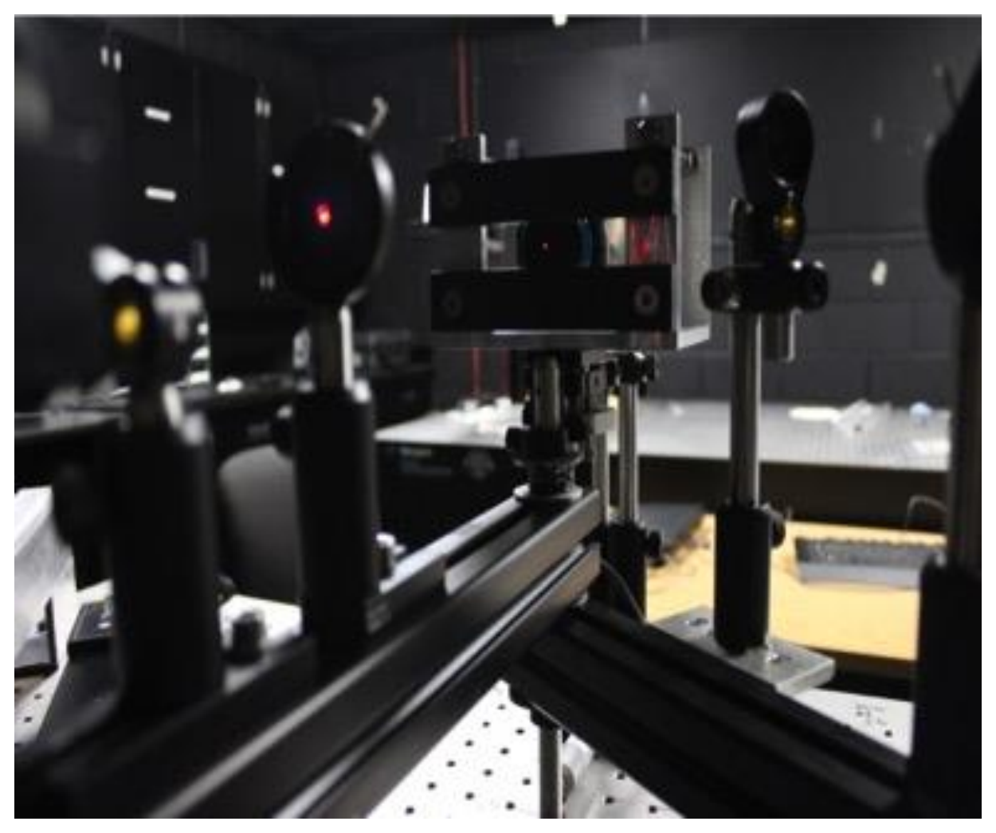


Figure 2: Mounted Material Sample

The two assemblies are then aligned together such that the surface of the material sample, the reflection plane, is positioned perpendicular to the central axis and directly above the center of the pivot rod as shown in Figure 1 and Figure 2.

Specular Reflectivity Testing

When testing for specular reflectivity, the laser and the sensor must be positioned symmetrically with respect to the central axis as defined by the pivot rod. An example of this setup is shown in Figure 3. By positioning multiple apertures in front of both the laser and sensor, the diffuse scattering of the laser beam is minimized to ensure that we are measuring solely the specular reflection.

The LabVIEW control interface developed for MADLaSR allows for full customization of settings, such as the range of angles to test and adjustments to the sampling of data points. As shown in Figure 4, we have constructed an intuitive user interface to control these options, in addition to the display of real time readouts of the collected data.

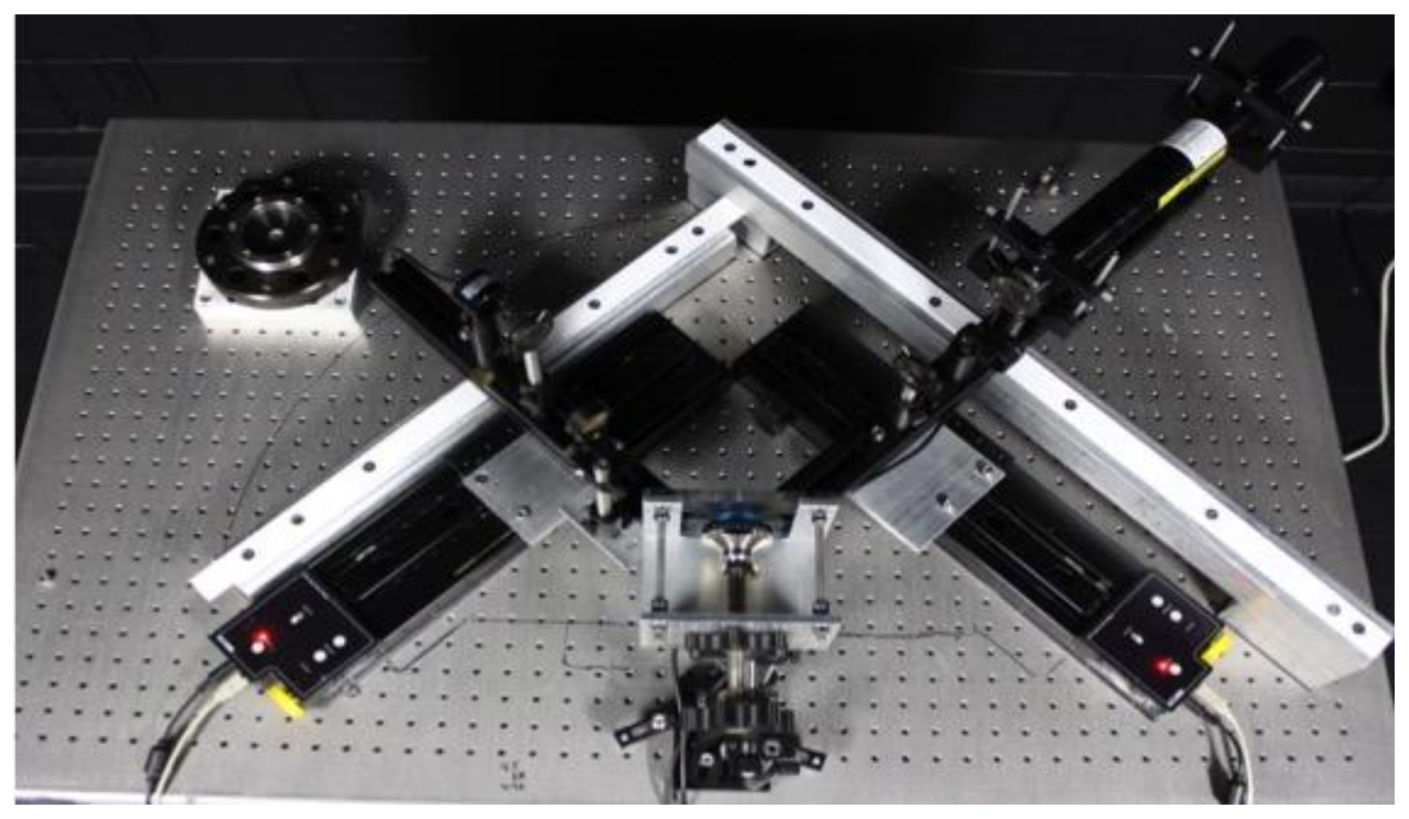
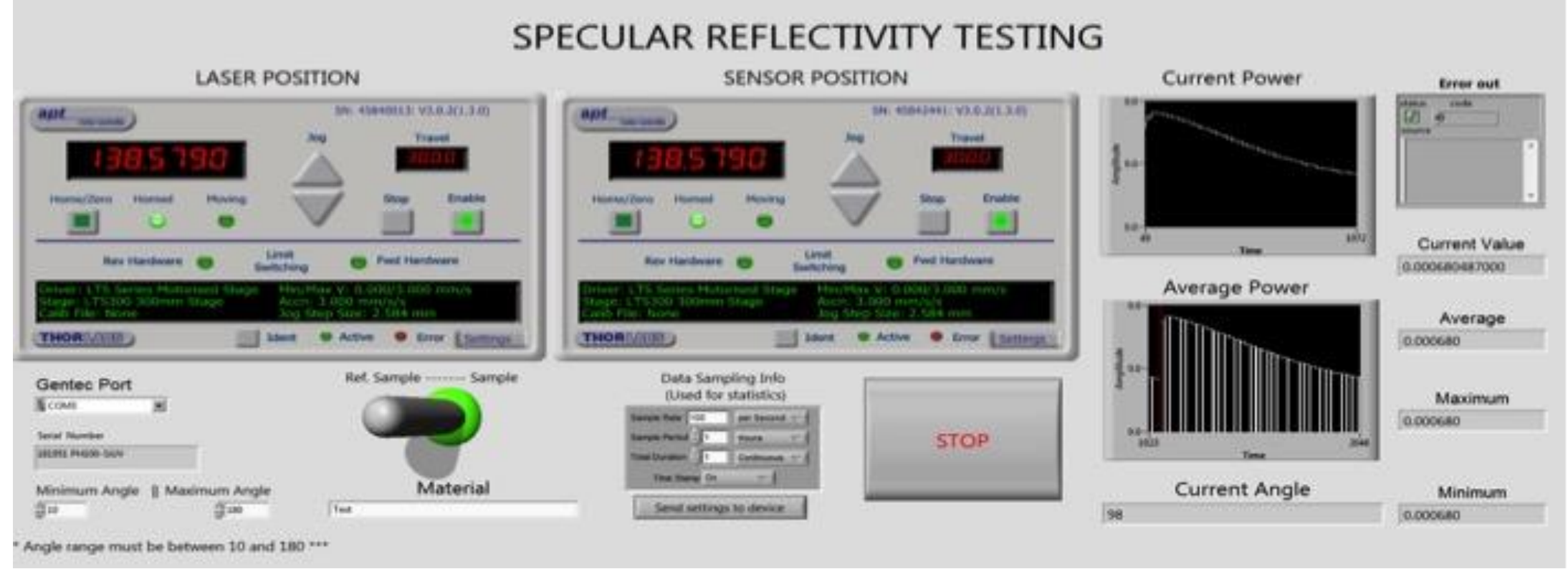


Figure 3: The MADLaSR During Specular Reflectivity Testing



SPECULAR REFLECTIVITY TESTING

Current Value: 0.000680487000
Average: 0.000680
Maximum: 0.000680
Minimum: 0.000680
Current Angle: 98
Minimum Angle: 10
Maximum Angle: 180
Material: Test

* Angle range must be between 10 and 180 ***

Figure 4: User Interface for Specular Reflectivity Testing

Lambertian Reflectivity Testing

When testing for Lambertian reflectivity, the laser must be positioned perpendicular to the surface of the material while the sensor is moved to different angles. This setup, as shown in Figure 5, is designed to test for constant apparent surface brightness regardless of the angle of observation. Similar to that of the specular reflectivity testing, this program's user interface allows for full customization of settings in an attempt to be adaptable for all potential uses in future projects. This interface is comparable to that of Figure 4.

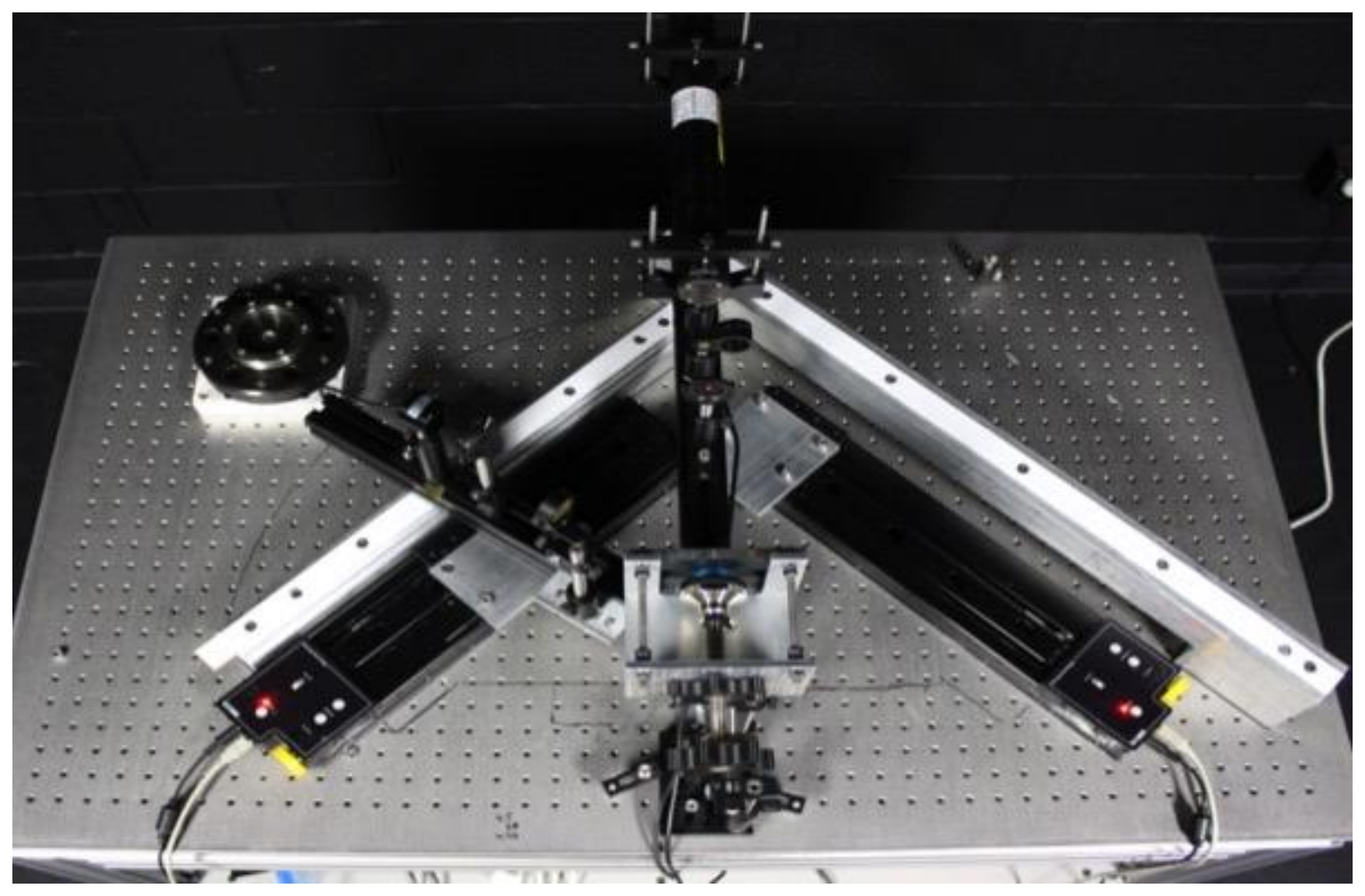


Figure 5: The MADLaSR during Lambertian Reflectivity Testing

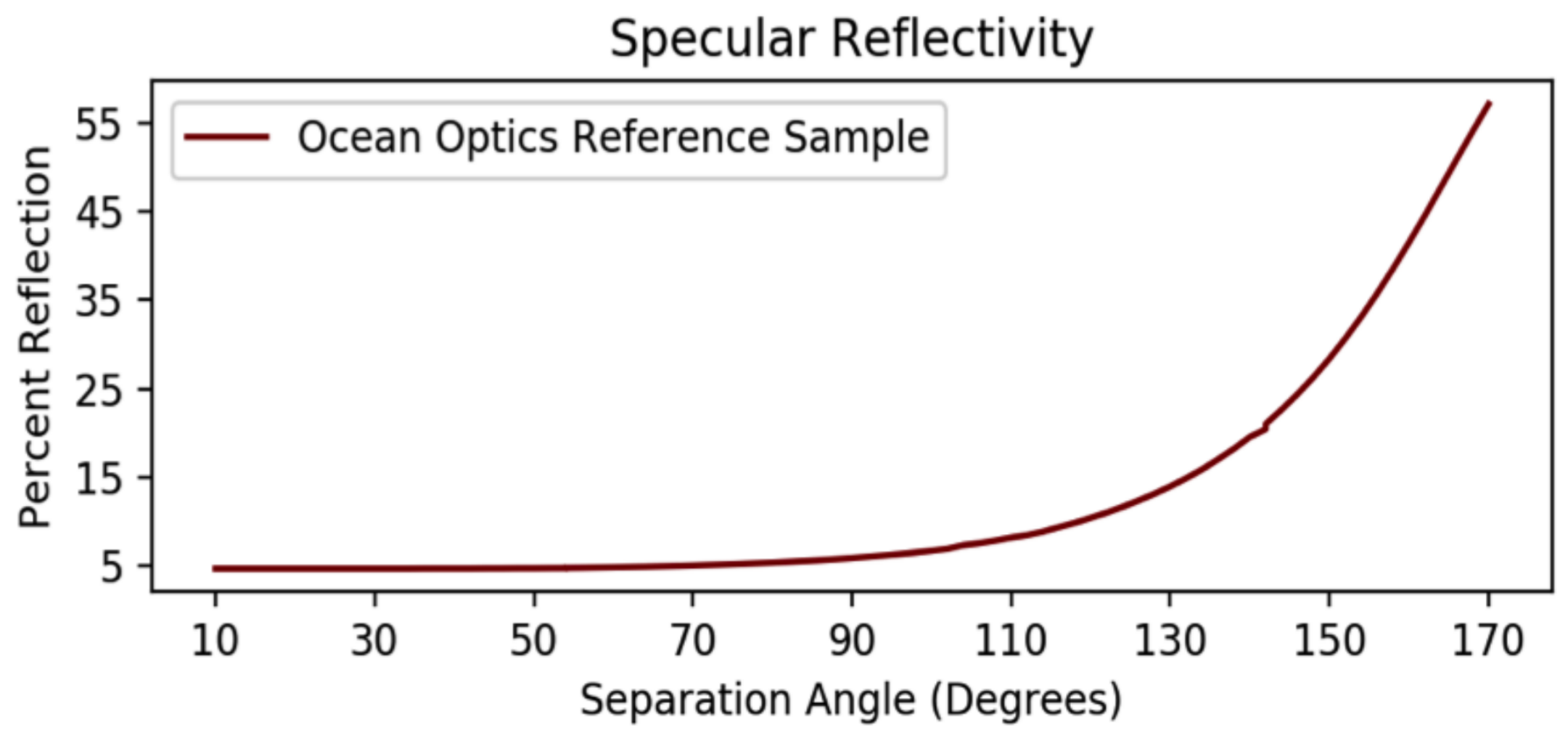


Figure 6: Plot of Reference Sample (Ocean Optics Low Specular Reflectance Standard) Data Used As Fiducial Marker For Subsequent Tests

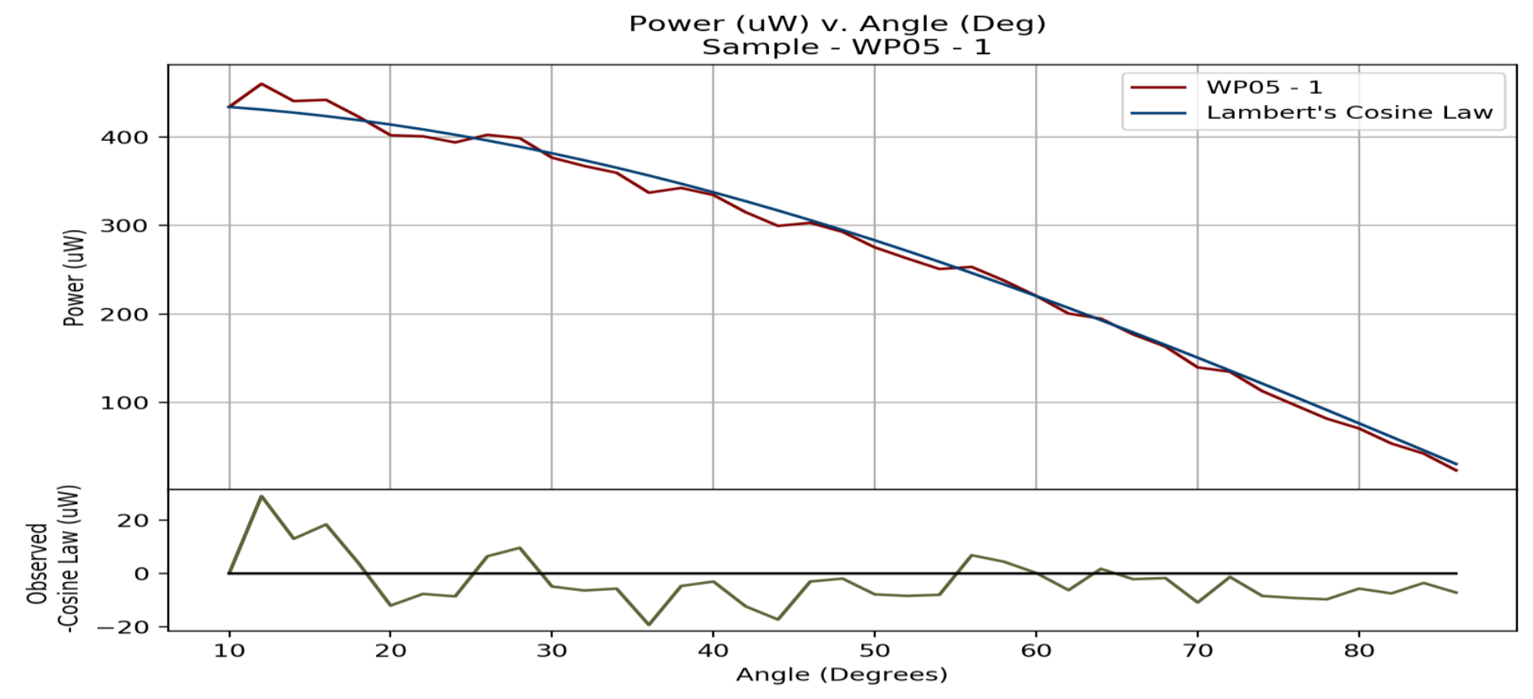


Figure 7: A plot of data collected from a Lambertian reflectivity test of a nylon-spandex fabric at a wavelength of 630 nm compared to an ideal Lambertian surface modeled by Lambert's Cosine Law. The residual is plotted below.

Data Collection

The data collected consists of two key components: the angle between the laser and the sensor, and the corresponding power output. An essential component of the data analysis is the conversion from the linear actuator's position to the angle. This conversion is made by equation 1, which is based upon the geometry as shown in Figure 8.

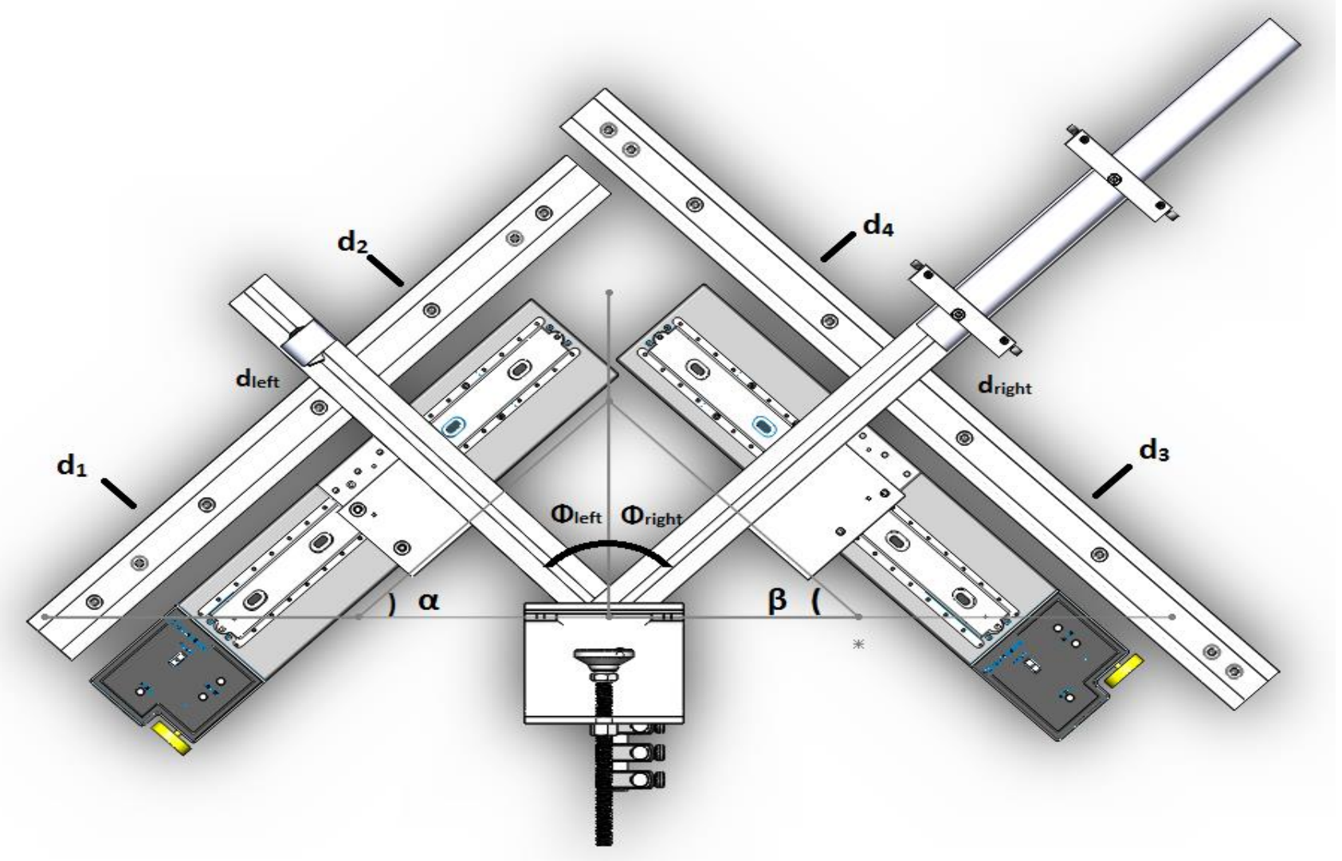


Figure 8: Solidworks Model of MADLaSR

The system is calibrated to ensure symmetry about the center axis. Thus, through a series of trigonometric relations, equation 1 is derived to govern the system. The values used are d_1=d_3=1.735mm and d_2=d_4=296.000mm.

$$\tan\left(\frac{1}{2}\theta\right) = \left(\frac{294.265}{d - 1.735}\right) - 1 \tag{1}$$

Conclusion and Future Work

We have described the construction and use of MADLaSR, which measures specular and Lambertian reflectivity over a range of incident and observed angles, respectively. This collection of data will expand upon our previous studies of a material's total reflectivity over a range of wavelengths and specular reflectivity over limited angles[1]. Future testing will also be done to investigate the correlation between properties of reflectivity with temperature variance, elapsed time, and exposure to the elements. The affect of wavelengths could also be retested over varying angles of incidence.

References

[1] Marshall et al. 2014, SPIE, 9147, 167

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