The 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. The MADLaSR (Multi-Angle Detection of Lambertian and Specular Reflectivity) is a device designed for specular reflectivity testing in the range of 10º < θ < 170º and for Lambertian reflectivity testing in the range of 10º < θ < 85º. The data collected from this device may be used to influence the design of optical systems, aerospace structures, or other devices in which maximum lighting control is a necessary consideration. In this paper, I will discuss the design and functionality of the MADLaSR.

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 finishings 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 10º < θ < 170º, as well as a material's Lambertian reflectivity over a range of angles 10º < θ < 85º. 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 their full range of angles of observation. Previously, research has been conducted to test for total and specular reflectivity over a range of wavelengths (Marshall et al. 2014). This project aims to build upon those endeavors by including the angle's influence.

MADLaSR Design

This device consists of two distinct assemblies: the system of rotating arms and the sample mount.

The arms system 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.

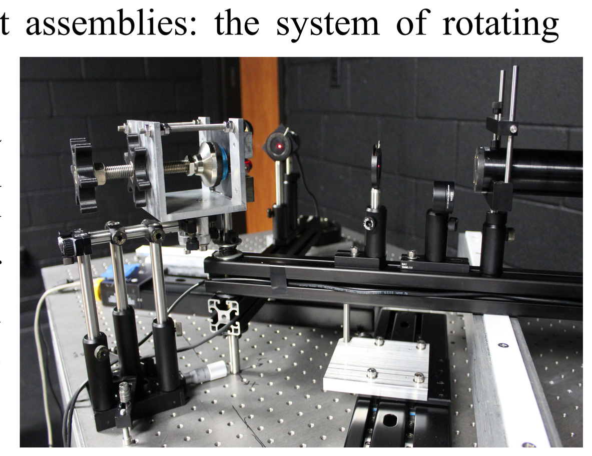

Figure 1: MADLaSR Setup

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.

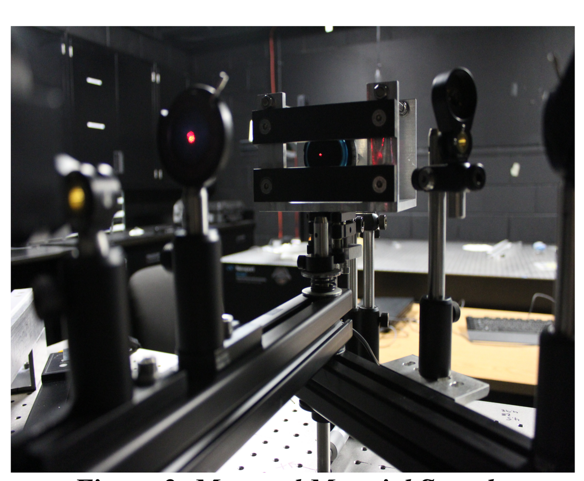

Figure 2: Mounted Material Sample

The two assemblies are then calibrated 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.

Due to physical limitations, the minimum angle the MADLaSR can be positioned at is 10º. While it is capable of reaching a maximum spread of 180º, our results become potentially inaccurate past 170º. Thus, we choose to constrain our range of motion between 10º < θ < 170º for specular testing and 10º < θ < 85º for Lambertian testing.

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 iris diaphragms 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 program made to accompany this device allows for full customization of settings, such as the range of angles to test through and adjustments to the sampling of data points. As shown in Figure 4, we have constructed an intuitive user interface to easily control these options, in addition to the display of real time readouts of the collected data.

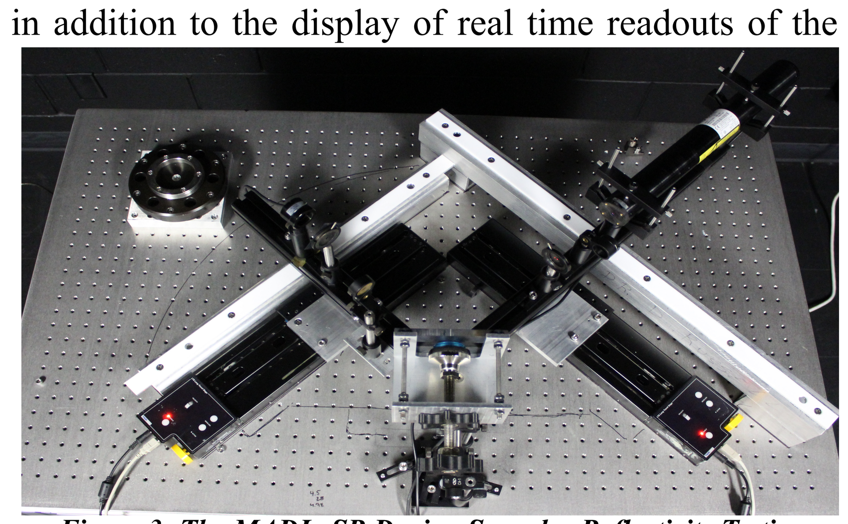

Figure 3: The MADLaSR During Specular Reflectivity Testing

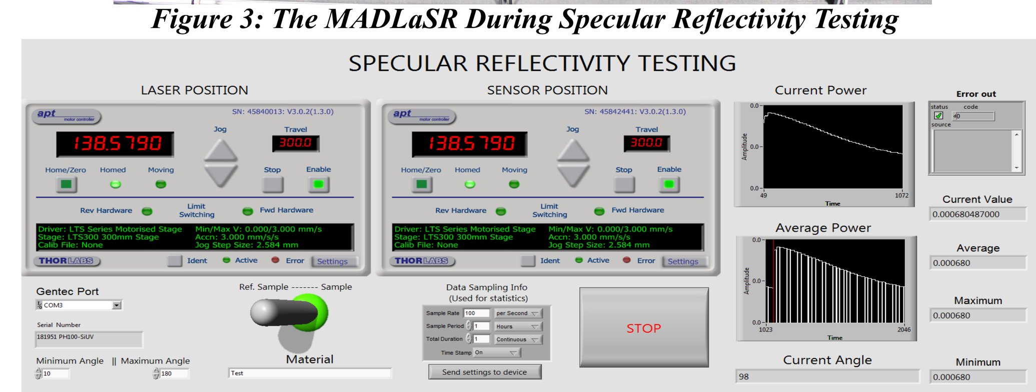

Figure 4: User Interface for Specular Reflectivity Testing

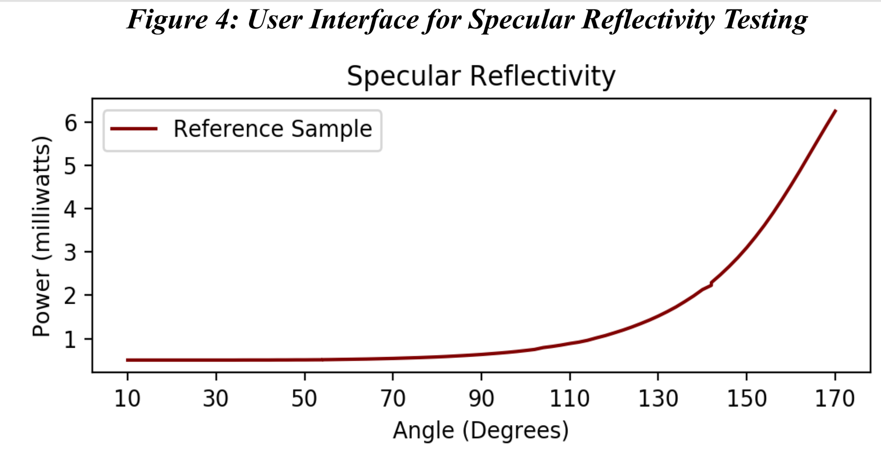

Figure 5: Plot of Reference Sample (Ocean Optics Low Specular Reflectance Standard) Data Used As Fiducial Marker For Subsequent Tests

Lambertian Reflectivity Testing

When testing for Lambertian reflectivity, the laser must be positioned perpendicular to the material while the sensor is moved to different angles. This setup, as shown in Figure 6, is designed to test for an even dispersion of light 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 Figure 4.

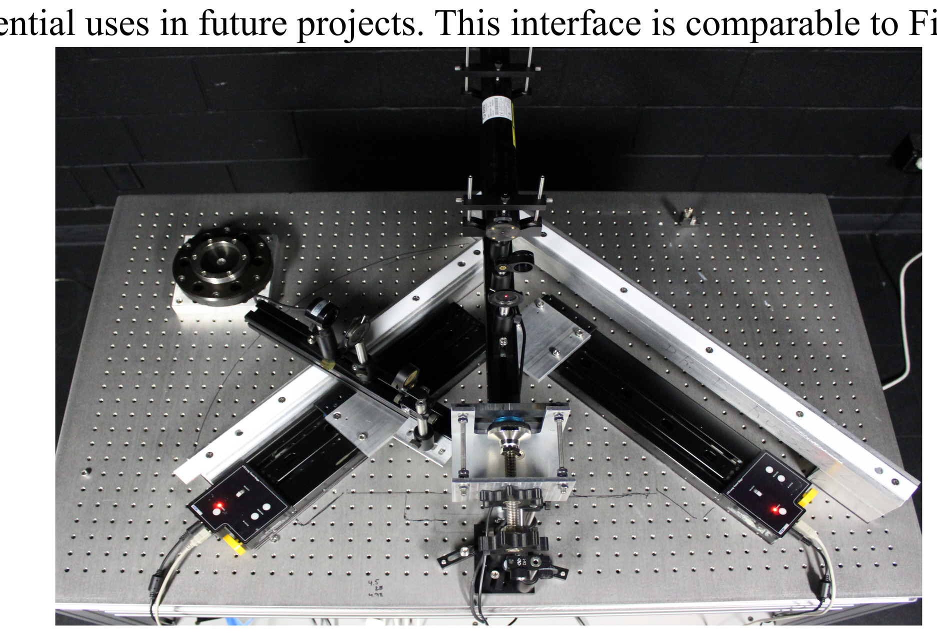

Figure 6: The MADLaSR during Lambertian Reflectivity Testing

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 the following equations, which are based upon the geometry as shown in Figure 7.

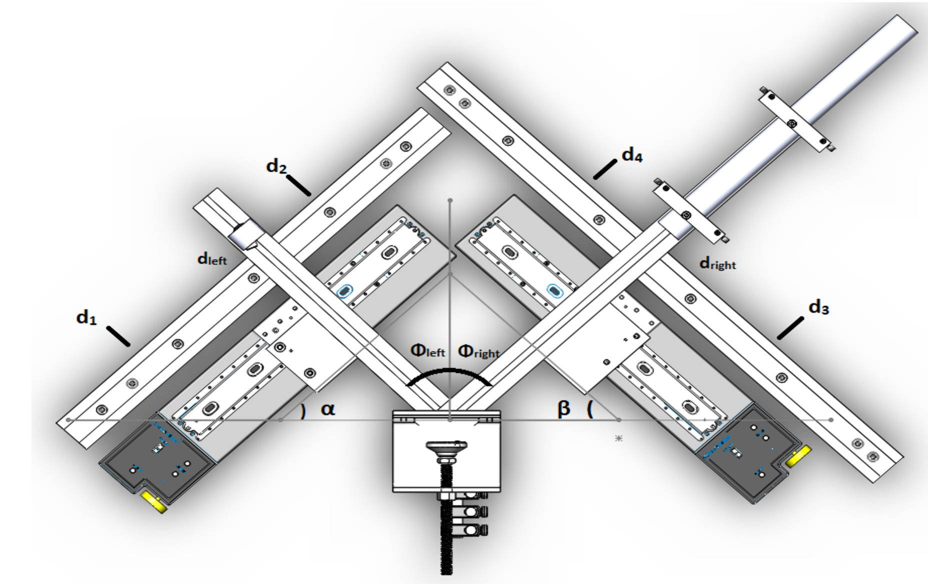

Figure 7: Solidworks Model of MADLaSR

Positioning the travel stages at d_1 and d_3 results in θ =180º while positions of d_2 and d_4 will result in θ = 0º. From the model shown in Figure 5, we have established that:

$$\theta = \phi_{left} + \phi_{right} \qquad (1)$$

And thus through a combination of trigonometric relations, one can see that:

$$\theta = \text{atan}\left(\frac{1}{\tan(\alpha)}\left(\frac{d_2 - d_1}{d_{left} - d_1} - 1\right)\right) + \text{atan}\left(\frac{1}{\tan(\beta)}\left(\frac{d_4 - d_3}{d_{right} - d_3} - 1\right)\right) \qquad (2)$$

By calibrating the system to ensure symmetry relative to the center line, equation (2) can simplify to:

$$\tan\left(\frac{1}{2}\theta\right) = \left(\frac{d_{max} - d_{min}}{d - d_{min}}\right) - 1 \qquad (3\text{ a.})$$

The initial values that we are using are d_{min}=*1.735mm* and d_{max}=*296mm*, which makes our final numerical equation:

$$\tan\left(\frac{1}{2}\theta\right) = \left(\frac{294.265}{d - 1.735}\right) - 1 \qquad (3\text{ b.})$$

While this equation is based upon the specular reflectivity setup, the equation for Lambertian reflectivity is identical, without the ½ multiplier.

Once the travel stages move to their positions, they wait while the sensor collects data. The photodiode records 25 data points and averages them together at each angle interval. While the arms are moving to new positions, the average is reset and prepares for the next sampling period.

Conclusion and Future Work

This paper describes the design and construction of The MADLaSR: a device capable of testing materials of their specular and Lambertian reflectivity over a wide range of angles (10º < θ < 170º and 10º < θ < 85º, respectively). We intend to use this device for future testing of a variety of commonly (and uncommonly) used black and white materials. This collection of data will expand upon our previous studies of a material's reflectivity when exposed to varying wavelengths (Marshall et al. 2014). Future testing can also be done to observe the effects on reflectivity properties of temperature variations, elapsed time, and exposure to the elements.

References

Marshall et al. 2014, SPIE, 9147, 167

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LSST Large Synoptic Survey Telescope

DARK ENERGY SURVEY

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