2001

Design and implementation of a LIDAR imaging system

Cynthia Scigaj

Recommended Citation

Scigaj, Cynthia, "Design and implementation of a LIDAR imaging system" (2001). Thesis. Rochester Institute of Technology. Accessed from

Design and Implementation of a LIDAR Imaging System

Evaluation of MISI for Addition of Lidar System and Proposed Design of Lidar System

Cynthia Scigaj

Table of Contents

Title Page

Design and Implementation of a LIDAR Imaging System

Evaluation of MISI for Addition of Lidar System and Proposed Design of Lidar System

Cynthia Scigaj

Abstract

LIght Detection and Ranging (LIDAR) is a valuable tool for collecting information along the coastline, which is also referred to as the littoral zone. Data collected in this area is useful for the study and analysis of algae growth, water depths, and identifying objects in shallow waters. A LIDAR system typically consists of a pulsed LASER, a light collection device, and a sensor. Currently at RIT we have an airborne imager called the Modular Imaging Spectrometer Instrument (MISI). MISI is a passive system and currently obtains data in the visible and infrared regions of the electromagnetic spectrum. My objective was to analyze the MISI optical path to determine whether or not a LIDAR could be incorporated into it, and if not, then to design a separate system. This research was conducted by creating several analyses of possible systems using an optical software package called Optical Software for Layout and Optimization (OSLO).

Table of Contents

Rochester Institute of Technology

Rochester, NY 14623-5604

This report is accepted in partial fulfillment of the requirements of the course SIMG-503 Senior Research.

Title: Design and Implementation of a LIDAR Imaging System

Evaluation of MISI for Addition of Lidar System and Proposed Design of Lidar System

Author: Cynthia Scigaj

Project Advisor: Dr. Anthony Vodacek

SIMG 503 Instructor: Dr. Anthony Vodacek

Table of Contents

Design and Implementation of a LIDAR Imaging System

Evaluation of MISI for Addition of Lidar System and Proposed Design of Lidar System

Cynthia Scigaj

Acknowledgment

I would like to acknowledge Dr. Anthony Vodacek, Dr. Robert Kremens, and Bryce Nordgren for their assistance on this project.

Table of Contents

Design and Implementation of a LIDAR Imaging System

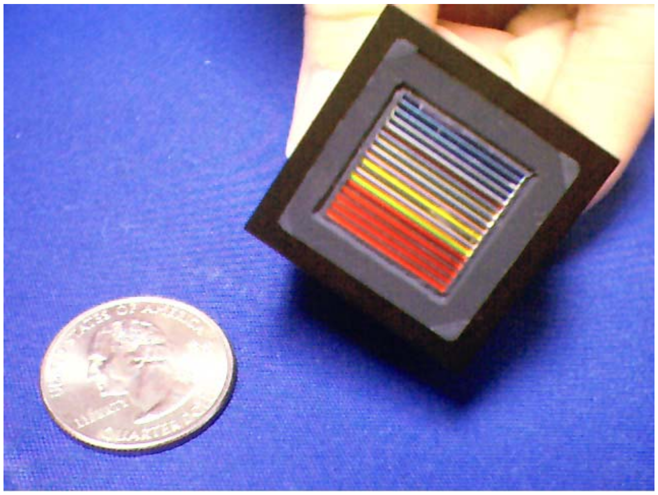
Evaluation of MISI for Addition of Lidar System and Proposed Design of Lidar System

Cynthia Scigaj

Introduction

It was decided that a lidar would be a useful and valuable instrument for the Digital Imaging and Remote Sensing group at RIT to have. Lidar can be used to detect aerosols in the atmosphere, chlorophyll or color dissolved organic material concentration in water, water depth profiles (bathymetry maps), and even to detect objects in shallow water. This would be able to provide data for multiple programs and research projects. A lidar consists of a pulsed laser, a light collection device, a spectral selection device, and a sensor. The typical sensor for a lidar is a photomultiplier tube (PMT) because of the low signal levels. One such PMT is the sixteen channel multianode PMT made by the Hamamatsu Corporation, which has sixteen interference filters permanently affixed to its front surface (See Figure 1).

Figure 1: Hamamatsu Corporation PMT Model Number R5900U-01-L16

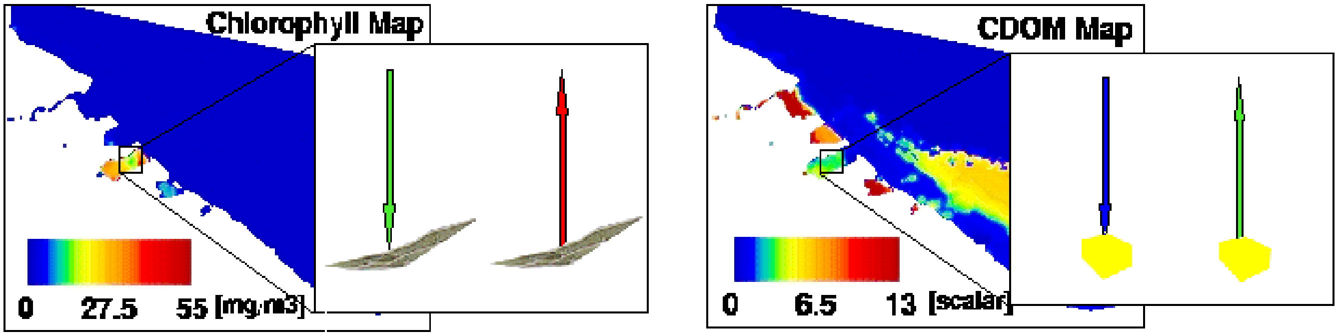


These sixteen channels allow light of different wavelengths to be detected and eliminates the need for a spectral dispersion device. As far as a light collection device, it was determined that RIT’s Modular Imaging Spectrometer Instrument, MISI, would be a suitable light collection device. It has been parts of previous research programs, such as the Landsat 7 calibration and it is an accessible instrument. Another reason to use it is that it is a modular instrument, so that detectors and systems can be added or removed while keeping the main structure of the device intact. The focus of my project was to evaluate MISI and determine if it would be a suitable base for the lidar system, as well as come up with a design for the lidar.

Background

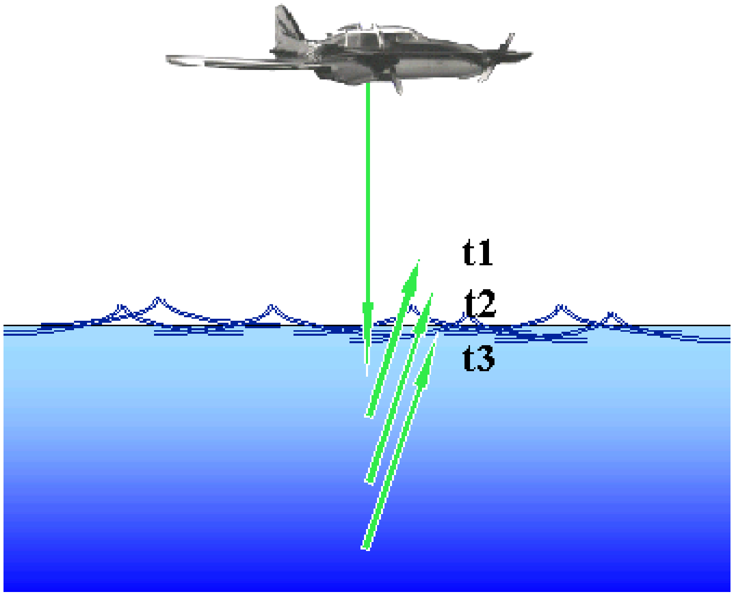
As stated earlier, lidar can be used for various types of research projects. However, different lidar techniques would need to be implemented depending on the type of project. The fluorescence technique is based on directing a laser pulse at the target substance. The laser light is absorbed by the substance which then fluoresces, and the fluoresced light is detected by the sensor. The return signal from the fluorescence is at a lower frequency than the excitance laser pulse, thus at a longer wavelength. This can be used to detect chlorophyll in green algae or color dissolved organic material (CDOM). This will also be able to detect the concentration of the target substance. For observation of the presence of green algae, a laser in the green region could be used (~535nm) and the return light would be expected to be approximately 685nm. To detect the presence of CDOM an excitance pulse in the ultraviolet can be used and a return signal can be expected in the blue region. Also, an exitance pulse in the blue region can be sent out, with expectations of a return signal in the green region (see Figure 2).

Figure 2: Illustrations of Fluorescence for Chlorophyll and Color Dissolved Organic Material



Elastic scattering techniques may be used to obtain water depth profiles that can be used to construct bathymetry maps for the littoral zone (area along the coastline). Elastic scattering is used when the excitance light, which is sent out from the pulsed laser, reflects off the material and is detected at the sensor at the same frequency as the excitance pulse. For water profiles an excitance laser in the green region would be used and a return signal in the same wavelength (see Figure 3). Time resolved signal detection (time gating) is necessary for this technique. The timing of the excitance pulses are compare to the length and time delay of the return signal, which gives information about depth.

Figure 3: Illustration of Elastic Scattering



For both of the aforementioned techniques, we would only look for spectral responses in the regions where we would expect the excitance and emittance light to be. A summary of the various wavelengths is Table 1.

Table 1: Summary Chart of Light Wavelengths and Detection Targets

-

Excitance Light	Emission Light	Detection
Ultraviolet (300-400nm) Blue (~430nm)	Blue (~430nm) Green (~450nm)	Dissolved Organic Material
Green (~525nm)	Red (685nm)	Chlorophyll (Green Algae)
Green (500nm)	Green (500nm)	Water Depth (Water Profile)

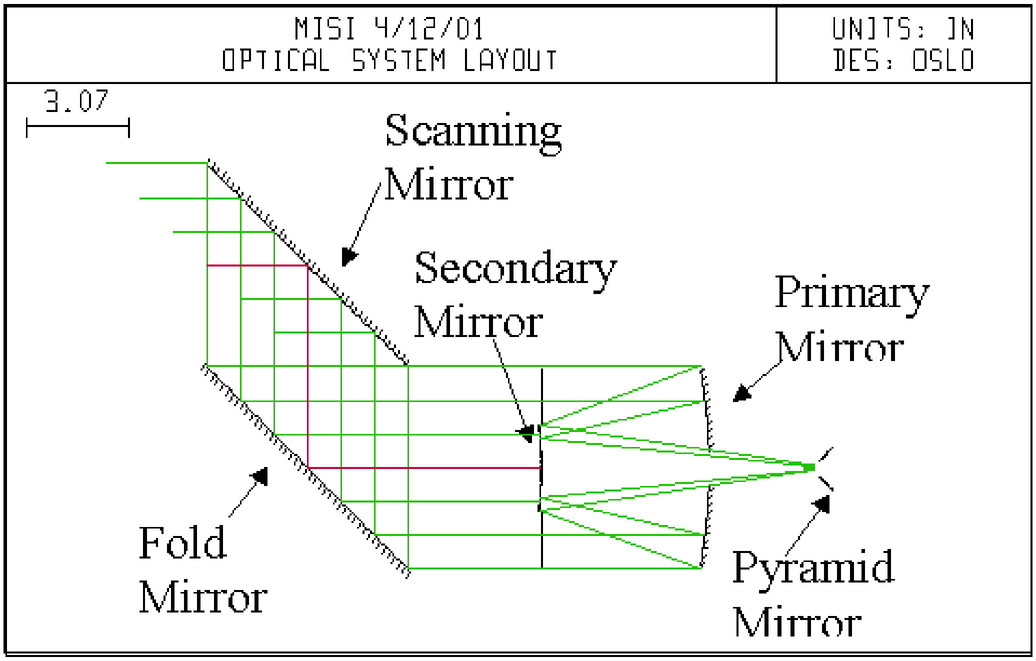
Objectives

My objective was to show that MISI would be a suitable base for this imaging platform based on its modular properties and its current ability to collect data, and to show that I could model the system in OSLO, which is an optical design software program. I will discuss more of the techniques and approaches taken in the methods section.

Methods

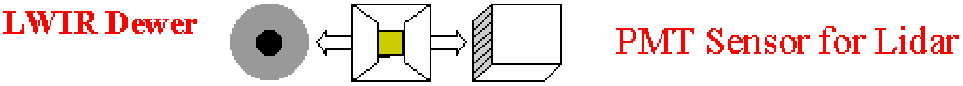
To determine MISI's ability to become a lidar, my first priority was to learn about how MISI works. Figure 4 is an illustration of the optical system.

Figure 4: MISI Optical Schematic



In Figure 4 we see that as the scan mirror revolves it collects light from the target (image) and in the same revolution also gets information from the two onboard blackbodies and the visible calibrator (light bulb). This is very important to the system because that means it collects information for calibration for every scan line. The light from the scan mirror continues through the system to the fold mirror, which directs it up into the Cassegrain telescope from there up into the pyramid mirror. Here light that is on axis goes straight up into the optical fibers to the visible to near infrared spectrometers (VNIR). Light also meets the surfaces of the pyramid mirror off axis by less than 2 degrees, hitting the four sides of the mirror (Feng, 1995). Currently only one side of the mirror is in use for the long wave infrared sensor (LWIR). One of the other sides of the pyramid mirror is where I theorized that the PMT sensor would go for the lidar. For visualization, I will place it directly across from the LWIR detector (See Figure 5).

Figure 5: Overhead View of Pyramid Mirror



In Figure 5 we see the pyramid mirror and the detectors from a top view. I left out the visible spectrometer since it would be blocking our view of the mirror from this angle. According to Feng (1995), the LWIR detector focal plane is along the scan direction (either leading or lagging the primary optical axis) as opposed to the other two sides which are along the track direction (one fore and one aft of the primary scan axis). Where I placed the focal plane for the PMT for this diagram, it too is along the scan direction and is either leading or lagging the primary optical axis (whichever the LWIR is not).

After I learned how the system worked together, I needed to find out the specific distances and mirror specifications in order to try and model it in OSLO. This turned out to be more complicated than I thought, since the only documentation I could find was in the Feng thesis, and was only ideal measurements. So, I went and physically made measurements of the mirrors and distances between surfaces, except for the Cassegrain mirror. I could not measure the surfaces due to the mountings and casing around it. For the height and sides of the pyramid mirror, I measured the length of the bottom and the top and knowing that the mirrors are all at 45° angles with respect to the bottom, I used trigonometry to calculate those lengths. Table 2 is the list of all the distances that I had for MISI's optical system.

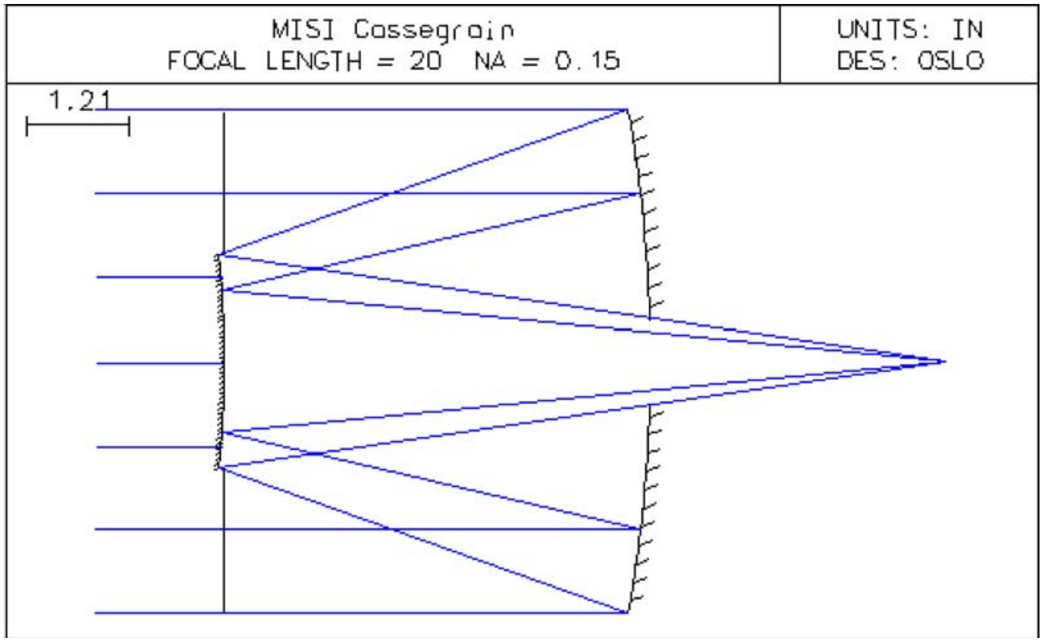
Table 2: MISI Optical Specifications

Object	**Diameter (in)**	**Orientation**
Scan Mirror	8.4375	45°
Air	6	
Fold Mirror	8.6875	45°
Air	7	
Cassegrain Secondary	2.55	0°
Air	5	
Cassegrain Primary	6	0°
Air	3.5	
Pyramid Mirror Base	0.4375	0°
Pyramid Mirror Top	1.25	0°
Pyramid Mirror Height	0.4063	0°
Pyramid Mirror Side	0.5745	45°
Black = Measured/Calculated Values		

Red = Values From Feng (1995)

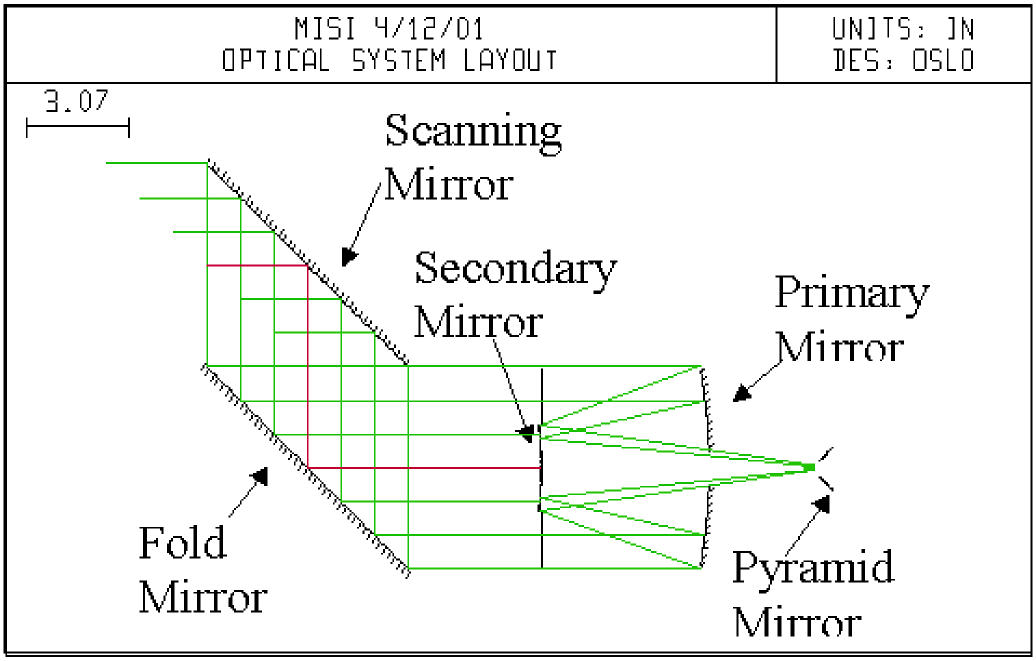
In addition to these specifications in table 2, the Cassegrain secondary has a curvature of 0.07647 inch^{-1} and the primary mirror is has a curvature of 0.0575 inch^{-1}
and aspheric factor of 0.51 (Feng, 1995). Using these values I modeled the Cassegrain mirror in OSLO. My finished Cassegrain is figure 6.

Figure 6: Cassegrain Modeled in OSLO



This model gave me a focal length of 20in and a working f-number of 3.3333. Since this matches values in the thesis I could conclude that it modeled correctly. Then stemming from the Cassegrain (which is really the main optics of MISI) I added the other mirrors into the model (figure 7).

Figure 7: OSLO Model of MISI Optical Path

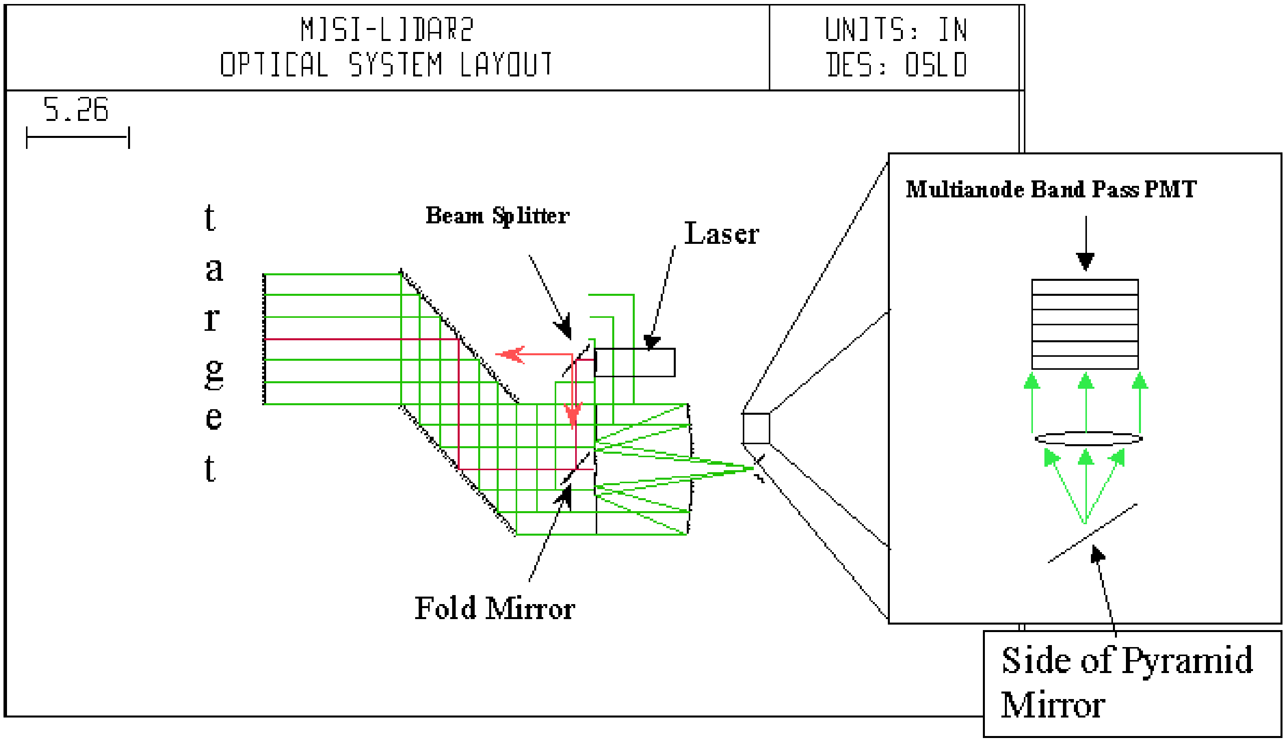


I was able to add the rest of the optics into the system correctly, with exception of the pyramid mirror. Of the different versions of OSLO available for this project I did not have the version which would allow for nonsequential ray tracing until last week. What I mean by nonsequential is that I needed OSLO to treat all of the pyramid mirror surfaces as the same surface number, so that the rays could have equal chances to come into contact with a side, or to travel up the center. In the other versions it appeared as though the program forced the rays to go from one surface of the mirror in order, no matter how unlikely the event was. Thus I could not rely on it for an accurate model.

Results

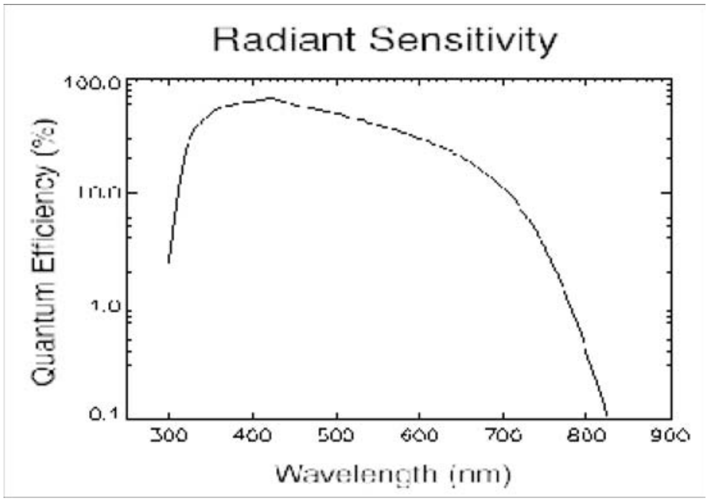
After constructing the model of the optical path for MISI I changed the location of the incoming light to model that of a laser for two different designs. I first placed the laser in the middle of the system, directing its light to a fold mirror placed at 45°
on the back of the secondary mirror for the Cassegrain. Then I made another design where the laser was in the middle of the system, but pointing down towards the scan mirror. It then goes through a beam splitter so that half of the light is directed straight down towards the scan mirror. When the scan mirror is in its rotation facing up, this portion of the light from the beam splitter is reflected back up through the rest of the system and can serve as a calibration source, just like the two onboard blackbodies and the visible calibrator. The other portion of the light from the beam splitter goes on to hit a fold mirror on the back of the Cassegrain secondary mirror. It then is reflected off the main fold mirror, the scan mirror, and then out to the target. The return signal light propagates from the scan mirror, to the main fold mirror, to the Cassegrain primary mirror, to the Cassegrain secondary mirror, and then back though a hole in the primary mirror. It then splits at the pyramid mirror, continuing any one of the five possible paths (through the pyramid mirror or off of any of the four sides). The PMT would be placed on one of the side focal planes. Light would reflect off the pyramid mirror, through beam expanding optics, and onto the PMT. This way that the spot size would be greater than that of the size of the PMT. Figure 8 is my diagram of this system with an added illustration for the side of the pyramid mirror with the PMT.

Figure 8: Optical Path Diagram for Proposed Lidar



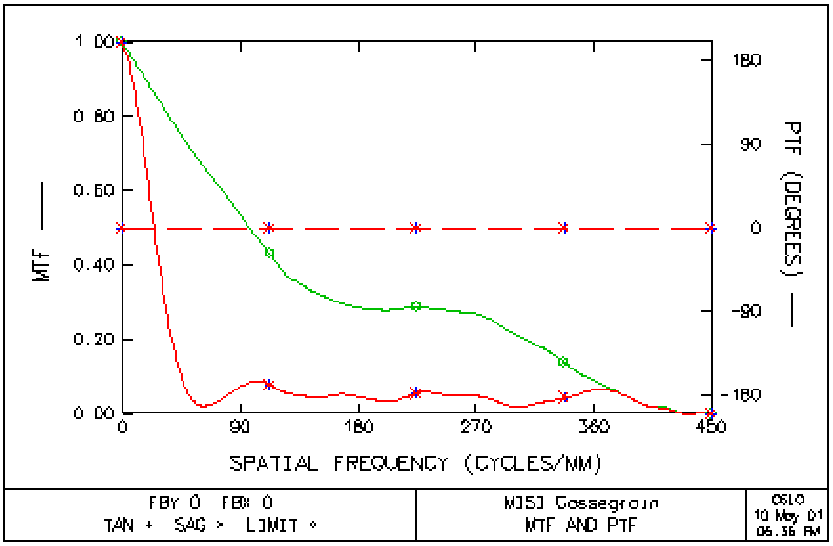
This detector (PMT model number R5900U-01-L16) arrived with a spectral responsivity curve from Hamamatsu (Figure 9).

Figure 9: Spectral Radiant Sensitivity of PMT



If you refer back to table 1, this chart covers all of the wavelengths discussed, which makes it desirable for the types of research discussed. However, this does not take into account the effects of the interference filters which are affixed to the front of the PMT. Thus, their spectral characterization was not included in this data. The PMT itself has a peak response to light between 400-730nm. I performed MTF and PTF analysis on the Cassegrain mirror for MISI for all of the different wavelengths in the table 1, but did not find any noticeable variance in the curves. The exception was that for the shorter the wavelength laser used, the higher the frequency to which the system could effectively respond. An example of this analysis is figure 10.

Figure 10: Sample MTF and PTF Analysis of Cassegrain Mirrors in MISI



This particular MTF and PTF was calculated for 0.6943μ m, which would be the expected return signal from green algae fluorescence.**694m**

Discussion

If MISI were the imaging platform base for the lidar system proposed, there would be some stipulations. For example, for light to go through the beam splitter and come in contact with the fold mirror on the back of the secondary mirror, a hole would have to be drilled in the casing surrounding the Cassegrain. Also, in order for the pulses to leave the system in order to come in contact with any target, the pulses would have to be timed in a manner in which they would strike the scan mirror when it is facing the target. In the same manner, the calibration light would have to have the pulses timed in a manner in which they would reach the scan mirror when it is in an upward facing position. Modifications would also have to be made in order for the fold mirror to be placed on the back of the secondary, due to limited space due to the mounting holding the secondary in place, and the location of the main fold mirror. Measurements would also have to be made to the existing imaging devices (the visible spectrometer and long wave detectors) to ensure that those detectors would not be damaged from the laser calibration light, or the return signal.

Conclusions

In conclusion, I still believe that MISI would be able to be a decent imaging platform from which to build the proposed lidar, but not without the stipulations discussed taken into account. Also, this project was a good source of documentation of MISI optical specifications. In terms of long range plans, it should be possible to develop a data collection method for the lidar system and integrate the system into MISI.

Design and Implementation of a LIDAR Imaging System

Evaluation of MISI for Addition of Lidar System and Proposed Design of Lidar System

Cynthia Scigaj

References

1. Feng, Xiaofan., "Design and Performance of a Modular Imaging Spectrometer Instrument", Rochester Institute of Technology Ph.D. Dissertation, (1995).

Table of Contents | Thesis