AUTOMATING THE PURPLE CROW LIDAR

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ABSTRACT

The Purple Crow LiDAR (PCL) was built to measure short and long term coupling between the lower, middle, and upper atmosphere. The initial component of my MSc. project is to automate two key elements of the PCL: the rotating liquid mercury mirror and the Zaber alignment mirror. In addition to the automation of the Zaber alignment mirror, it is also necessary to describe the mirror's movement and positioning errors. Its properties will then be added into the alignment software. Once the alignment software has been completed, we will compare the new alignment method with the previous manual procedure. This is the first among several projects that will culminate in a fully-automated lidar. Eventually, we will be able to work remotely, thereby increasing the amount of data we collect. This paper will describe the motivation for automation, the methods we propose, preliminary results for the Zaber alignment error analysis, and future work.

1. INTRODUCTION

The Purple Crow Lidar (PCL) is located 10km north of the University of Western Ontario at the Environmental Science Field Station. It uses a Neodymium: Yttrium-Aluminium-Garnet (Nd:YAG) solid state laser to produce a 532 nm beam, with an average power of 950 mJ and a repetition rate of 30 Hz [1]. The initial beam diameter is 12mm, but it is quickly passed through a 5X beam expander, to produce a 60mm beam. It is then reflected off of a series of three mirrors, the last of which is the motorized Zaber mirror that controls the alignment of the system (Figure 1). The laser is directed skyward and backscattered photons are collected and focused by the 2.6 m liquid mercury primary mirror onto 4 photomultiplier tubes (PMTs). Two of the channels simultaneously measure analog and digital photocounts and are used for the Rayleigh-scatter and vibrational nitrogen channels, as well as aligning the laser. The other two channels are digital; one channel is used with an attenuator for the elastic return, the other for water vapour. With these channels, the PCL is capable of measuring temperature, density, pressure, and water vapour mixing ratio profiles[1]. In time, we may increase the altitude range of the lidar as well as expand our detection capabilities to include particulates.

In the past, the PCL alignment has been conducted manually, whenever the observer notices a drop in signal. This is not only inefficient, but also compromises the integrity of sections of the data throughout an observing night. The focus of my project is to use MATLAB to program the Zaber mirror and lidar control system to automatically align the laser beam, and keep it aligned throughout the course of the night. The process for this will be described in the Methodology section. We will then compare the new data with previous observations and look for any significant improvement in data quality.

2. METHODOLOGY

There are two concerns that our automation method must address: 1) staying within the field of view (FOV) of our telescope, and 2) small, stray clouds confusing the Zaber mirror program. To avoid both, we will oscillate the Zaber mirror between two positions over the course of a minute, or "dither", thereby gaining two profiles, one from each position(Z1 and Z2). We then pick the position that has the best signal, move to it, and then begin dithering again in a direction orthogonal to the previous movement. Dithering will always keep us in the FOV of the telescope and will also remove cloud bias.

Clouds move across the FOV of the telescope on the scale of minutes. If we do not dither, and instead integrate the signal over the course of a minute at each position (the current method), the cloud would cause a dramatic increase in counts in the resulting profile. We would be unable to determine if the increase in counts was due to a cloud or if the signal at that position was valid.

However, dithering the Zaber mirror on the order of seconds (much faster than the speed of the cloud) should provide reliable information.

Now that the alignment algorithm is established, we must determine the Zaber mirror's positioning error. If the error is significant, the alignment algorithm will need to compensate. I will investigate three aspects of the mirror: its movement step size, the relevance of its movement speed, and how accurately the mirror's actuators return to the same position. The smallest increment the mirror can move is 1 microstep, which translates to 1.48 μrads of tilt [2]. In order to document any change in position, the mirror movement must be visible to the human eye, so we have created a set-up so that 50 microstep increments are measurable. A small, red, laser is shone on the Zaber mirror and is directed down a hallway of 13.44 meters. The mirror is then commanded to move according to each test's parameters. The movement is recorded on graph sheets at the end of the hallway. Preliminary results from the first tests are located in the preliminary results section.

3. RESULTS

Before conducting the first error test, it was necessary to calculate the required accuracy of the PCL system at our highest observational altitude. First, we considered the full width FOV of the PCL telescope, which is 0.39 mrad [3]. The highest observable altitude, using the Inversion Method[4], is 105 km [5]. Therefore, the full FOV at that altitude is 43.55 m. Next, this must be compared to the laser beam size at the same altitude. This calculation is much less trivial, as one must know the divergence of the beam and the distances between each mirror that directs the beam. With a beam divergence of 17 μrads [6], a path length of 13.418m [1], and an initial size of 60mm after expansion, we can calculate the final diameter of the beam to be 1.85 m at an altitude of 105 km. The maximum positional error of the Zaber mirror must be the difference of the radius of the field of view and the laser radius, which is 21 m. This corresponds to 198.5 μrads of movement of the Zaber mirror, or 134 microsteps. The Zaber mirror has a positional error of roughly 10 microsteps, therefore it is not necessary to do a complete analysis on the Zaber movement at small command values.

However, it *is* necessary to measure the error of the second two scenarios. The motor speed's effect has not yet been analyzed, and will be left for future work. The last scenario is crucial, as it models the "dithering" technique. Preliminary tests have shown that there is no significant drift when the mirror oscillates, however, we have not tested if oscillation step-size is a factor. A longer hallway is also needed in order to produce statistically significant results.

4. CONCLUSIONS

The goal of this project is to automate the alignment procedure of the PCL in order to improve data collection and integrity. Future work will include testing the Zaber motor speed and its effect on positional error, and conducting a more comprehensive test of the dithering error. We will also be comparing the lidar signal received using the new alignment method against that which is received while using a manual alignment. Automation of the alignment will result in more complete climatologies and increased accuracy of water vapour profiles. As part of the Network for Detection of Atmospheric Composition Change (NDACC), the new data will be added to data from 70 other lidars, and used to study long term changes in atmospheric composition.

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FIGURES

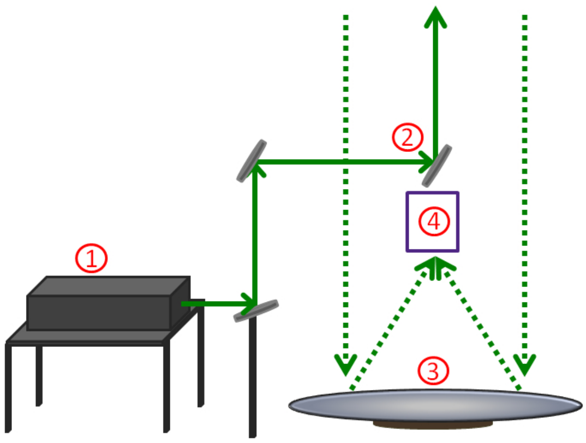

Figure 1: In numerical order: The Nd:YAG 532 nm Laser, Zaber Alignment mirror, 2.6 m Liquid Hg mirror, Detector Box

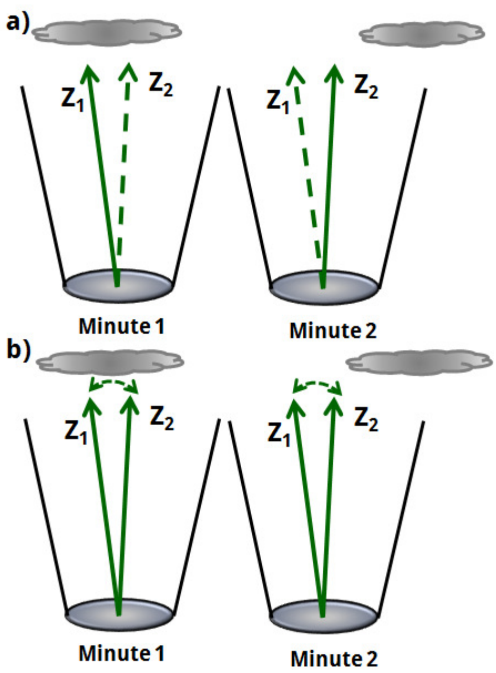

Figure 2: a) No Dithering: Integrating for one minute in each position can result in a false positive/better position at Z2. We are unable to tell if Z1 or Z2 is better due to cloud interference. b) Dithering: Both Z1 and Z2 are affected simultaneously by the cloud in the first minute. Both are open in the second – we will get a clear picture of the better position at both times.