Performance Predictions for the Adaptive Optics System at LCRD's Ground Station 1

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Abstract: NASA's LCRD mission will lay the foundation for future laser communication systems. We show the design of the Table Mountain ground station's AO system and time series of predicted coupling efficiency.

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1. Introduction

NASA's Laser Communication Relay Demonstration mission [1] will lay the foundation for future laser communication systems. The mission features a hosted payload on a commercial geosynchronous satellite communicating with two ground stations. The ground station located at Table Mountain will use the Optical Communications Telescope Laboratory (OCTL) 1-m telescope [2]. The large aperture of the telescope and the requirement to couple over 50% of the downlink light into a single mode fiber forces the use of an adaptive optics (AO) system. The AO system will operate day and night on a single unmoving target. The AO is being designed to work with targets as low as 20° above the horizon. The low elevation and the daytime operations mean that the AO system will be operating in quite poor turbulence conditions. These factors drive the design and are discussed below.

2. Design of the AO System

2.1. Hardware Design

The AO system is the major component of the Integrated Optical System (IOS). In addition to AO, the IOS also incorporates the uplink laser transmit system and the target acquisition camera. The AO system is a two deformable mirror (DM) design with the Low Order DM (LODM) correcting for low spatial frequencies with large amplitude and the High Order DM (HODM) correcting for high spatial frequencies with small amplitude. The LODM is a 12×12 actuator Boston Micromachines (BMC) MEMS Mini-DM and the HODM is a BMC Kilo-C with 34 actuators across a circular mirror. These DMs have diameters on the order of 1 cm, reducing the size, cost and complexity of the remaining optical train components.

A Shack-Hartmann WFS measures atmospheric distortions by taking 20% of the downlink beam. The speed of the WFS measurement is critical for the AO system to keep up with the rapidly changing atmospheric turbulence conditions at the 20° elevation and nominal 5.2 cm r_0. Our models have shown that we need to have frame rates on the order of 20 kHz to achieve our desired level of performance in the specified atmospheric conditions. The WFS camera is an off the shelf Xenics Cheetah InGaAs camera and is the fastest frame-rate InGaAs camera on the market. The AO system has 29 actuators across the 1-m OCTL primary to meet the specified atmospheric turbulence correction. Each lenslet in the WFS will illuminate an array of 2×2 quad cells.

The IOS system will be located on a large optical bench in the coudé room of the OCTL facility. The optical layout in Figure 1 shows the mounting of the optical components on the three separate optical breadboards of the optical bench. The major part of the AO system is mounted on the green and tan colored breadboards. This separation of components facilitates moving the system from the laboratory to the telescope. The WFS mounted on the small purple breadboard allows the WFS components to be aligned separately. In addition to the WFS pickoff beamsplitter, 10% of the light is diverted from the downlink beam to a scoring camera, which records the PSF, allowing the measurement of the Strehl ratio. This provides a measurement of the AO system performance during operations.

The systems also has an atmospheric turbulence simulator (ATS). A mirror can be slid into the beam path to inject light into the AO system from the ATS. The beam has the same optical properties as the downlink from the telescope

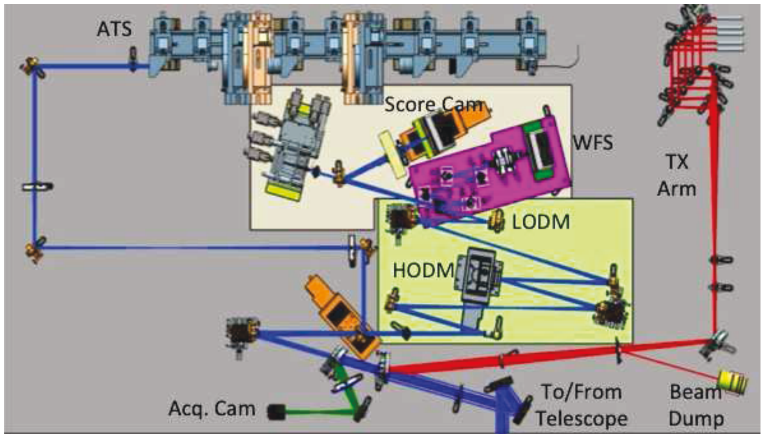

Fig. 1. The IOS opto-mechanical layout. The transmit arm is marked in red the Acquisition arm in green and the AO arm in blue. The WFS is mounted on the purple breadboard. The remaining components in the AO arm are divided between the tan and green breadboards. The Atmospheric Turbulence Simulator (ATS) is at the top of the layout.

and forms pupil images at the same locations. The ATS consists of two spinning phase plates with computer controlled rotation rates to simulate a variety of turbulence conditions [4]. It enables testing of the system in the lab before installation at GS-1 and during set up for operations.

2.2. *Software Design*

The IOS software is based on the Palm 3000 software design [3]. Where functionally possible, existing Palm 3000 software will be reused. The system design is divided into four main components: a command/automation server, a device driver server, the real-time control component, and the graphical user interface running on a computer in the operators room. The publish/subscribe communication method is used to transfer messages between components, a particularly effective method for systems with components running in physically separate locations. For the IOS, we intend to reuse the Palm 3000 command/automation and device driver servers, although only some of the Palm 3000 automations will be reused by the IOS, and so several new automations will be needed. Where possible, opto-mechanical hardware will be chosen so that device driver software can be reused; otherwise new device driver components and drivers will be required. The real-time component will use a Digital Signal Processor (DSP) board with eight on-board DSP chips. We will use direct memory access (DMA) to get data from the framegrabber directly to the DSP board enabling us to achieve the required frame rates. All published data is written to the database, in the form of commands, status messages, and telemetry data. A separate component acts as the interface to the database; a slightly enhanced version of the Berkeley DB database engine. The Palm 3000 system incorporates one RAID controller for the database hardware. For the IOS, we intend to implement implement a solid state device in the IOS control computer capable of capturing all data types at the high log rates required for telemetry analysis in order to meet data write requirements at high burst rates.

3. Simulations

we simulated time series of the coupling efficiency of the system using a standard wave optical simulation code based on FFT-based propagation and FFT-based phase screen generation. Five Kolmogorov turbulence layers were used for the simulations. Long simulation run times are enabled by slowly breaking the frozen flow hypothesis and adding a small component of a new Kolmogorov phase screen at each time step. The simulations were run for two cases. The first case was with nominal atmospheric conditions for Table Mountain of r_0 = 5.2 cm and a ground layer wind speed of 2.3 m/s. The second case was for conditions at 90% of the cummulative distribution function: r_0 = 2.7 cm and a ground layer wind speed of 5.3 m/s. In both cases, the wind profile used was the January San Diego wind profile [5]. This wind profile is the average of decades of twice daily radiosonde launches and was the nearest launch site to Table Mountain. The wind direction was set to be transversal to the line of sight. The simulation produced 10 runs with a duration of one secone each for both conditions. The sampling rate was 10 kHz. The coupling efficiency time series is plotted in Figure 2. The plot includes two consecutive 1 sec runs for the nominal conditions and for the 90th percentile case. At the higher wind speed and lower Fried paramter, the performance is more variable and produces a lower coupling efficiency. For the nominal case, the coupling efficiency is always above the required 0.55 value, while for the 90th percentile case, the average is just below the required level and sometimes much lower. This will result in degraded communiation rates.

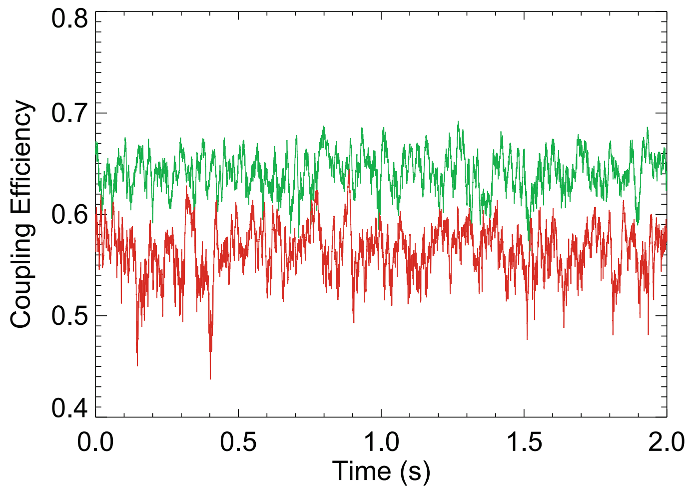

Fig. 2. The time series of coupling efficiency. The green curve is the coupling for the nominal conditions, while the red curve is for the 90% condidtions. The nominal conditions have an average value of 0.64 with a standard deviation of 0.0186, while the 90th percentile conditions have an average coupling of 0.53 with a standard deviation of 0.0294.

4. Summary

When operational, the IOS AO system will be capable of achieving coupling efficiency's of greater than 50% in nominal atmospheric conditions at Table Mountain in California during daytime and nighttime. The current status of the system is that the optical path has been aligned with the exception of the WFS, which will be assembled in FY2016. The effort this year has concentrated on the software. We expect to have first light in the lab in FY 2016 and first light on the sky in FY2018.

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