Development of an in-orbit measurement of a ground based adaptive optics corrected laser

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ABSTRACT

Adaptive optics can be used for more than astronomical imaging with large telescopes. The Research School of Astronomy and Astrophysics (RSAA) and the Space Environment Management Research Centre (SERC) at the Mount Stromlo Observatory in Canberra, Australia, have been developing adaptive optics (AO) for space environment management.

Turbulence in the atmosphere causes optical signals to become degraded during propagation, which reduces the effective aperture of your transmitting or receiving telescope. An AO system measures and corrects for the turbulence in the atmosphere, allowing for greater resolution of optical signals. AO can be used to correct a laser beam propagating from the ground into space for space situational awareness. We are developing an AO system to correct a high-power CW laser to measure the flux in-orbit. The ultimate goal of this project is to provide a photon pressure experiment in which a ground-based laser is used to perturb the orbit of a debris object.

SERC is launching a payload consisting of laser irradiance measurement payload for a CubeSat, and beacon lights into a low Earth orbit in order to measure the flux of the ground-based laser and AO system. This will provide information on the performance of the AO system, telescope, and confirm our atmospheric propagation models and simulations. We present simulations along with experimental results for the development of space-based photodiodes which can be used to directly measure AO system performance with a ground-based laser

INTRODUCTION

The Space Environment Management Research Centre (SERC) have developed a space-based sensor to measure the in-orbit flux from a ground-based laser system. This experiment aims to provide experimental verification of our high power laser system and adaptive optics, with the goal of using photon pressure for a remote manoeuvre. The high power laser will impart momentum on the illuminated object with photon pressure, and the added momentum will perturb the orbit of the target to provide a remote manoeuvre.

Adaptive optics (AO) is used to correct atmospheric turbulence which distorts the image of a telescope, typically restoring the diffraction limit to the telescope regardless of atmospheric conditions. The Research School of Astronomy and Astrophysics (RSAA), Electro Optic Space Systems (EOS), and SERC at the Mount Stromlo Observatory in Canberra, Australia, have been developing adaptive optics (AO) for space environment management. Turbulence in the atmosphere causes optical signals to become degraded during propagation due to turbulent flow of layers of the atmosphere. This reduces the effective aperture of a telescope because the received optical wavefront is distorted by the turbulence. An AO system measures and corrects for the distortions caused by the atmosphere, allowing for greater resolution of optical signals by flattening the received optical wavefront. An AO system measures these distortions with a reference light source. In astronomical applications this is a guide star, which is a bright star near your target of interest. A wavefront sensor takes light from this guide star and measures the wavefront distortions at a high rate (typically between 300 and 2000 Hz). A layer of Sodium atoms in the atmosphere at 90 km altitude can be illuminated with a special guide star laser, which creates an artificial Laser Guide Star (LGS). A beacon such as a bright LED can be used as a beacon to create an artificial guide star on an object being tracked. We apply the same techniques used in astronomy to resolve smaller objects in orbit [1] and to concentrate a laser beam projected from the ground into space. The AO system[2] uses a Shack-Hartmann wavefront sensor, laser guide star, tip-tilt wavefront sensor, and the satellite itself as the tip-tilt source. The maximum closed loop rate is 2 kHz.

PAYLOAD

To enable a direct measurement of the laser irradiance achieved in-orbit by the high power, ground based CW-laser corrected by adaptive optics, a payload has been included on a 3U Cubesat developed by UNSW Canberra Space[3]. The satellite is expected to be launched later in 2018.

The payload architecture is shown in the Fig. 1. The payload has two InGaAs photodiodes with transimpedance amplifiers (called photon flux detectors) which are converted to digital readout to be stored and downlinked for analysis. A sample rate of 1 kHz enables studying the high frequency content of the signal which will assist to characterise the adaptive optics performance. Each photodetector has a 700 micron diameter aperture providing a well defined area. It has been designed to measure irradiance up to over 1 kW m^{-2}.

Fig. 2 is a photo of the payload assembled. Two photodiodes are mounted behind an aperture, with baffles to limit the field of view. While the spacecraft does not have extremely accurate pointing capability, we will be able to determine the attitude with enough accuracy based on integrated gyroscope information, flight telemetry, and relative illumination between the two diodes. To facilitate this, each diode is angled differently, allowing for approximation of one angle.

The expected orbit will not provide dawn-dusk passes where reflected sunlight can be used, therefore the to support tracking during nigh time the payload includes an LED beacon. Two strings of three LEDs providing the beacon are in between the diodes (Fig. 2). The wavelength is in the far red spectrum for which the quantum efficiency of the tip-tilt sensor is reasonable and the atmospheric losses are lower than for shorter wavelengths, as well as avoiding the sodium guide star laser wavelength necessary to separate the light received from the artificial sodium guide star from the light directly received from the payload.

IN-ORBIT EXPERIMENT

The basic concept for operating the payload is illustrated in Fig. 3. As the satellite enters the optical ground stations field-of-regard the payload is turned on, the spacecraft

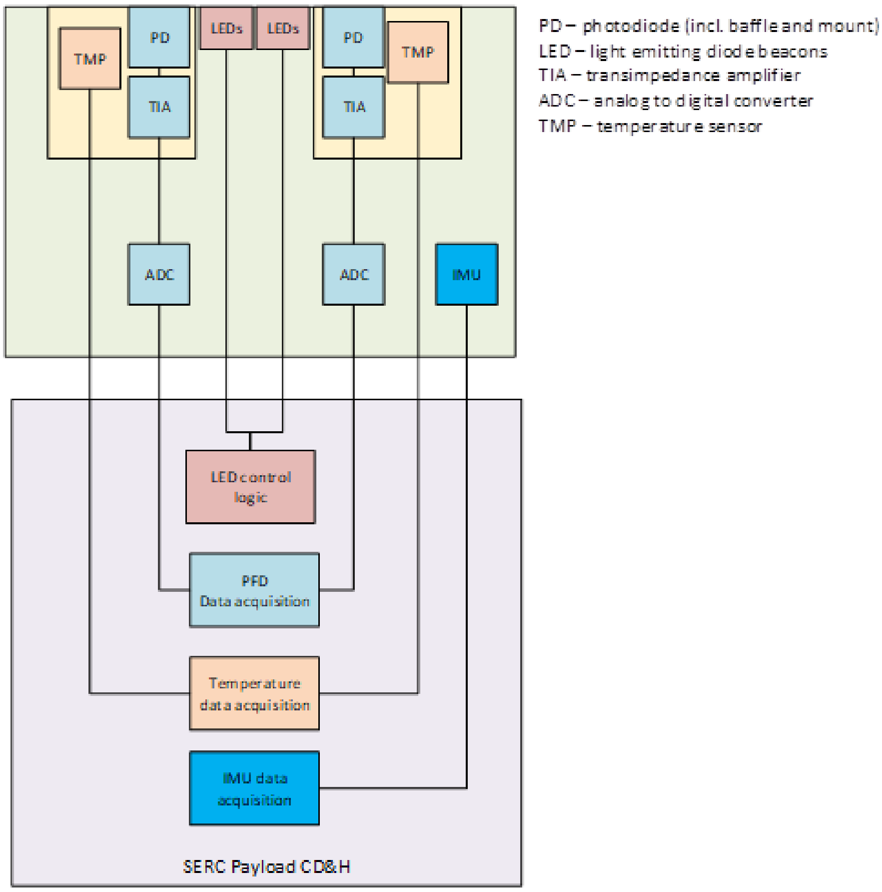

Figure 1: Payload architecture

must ensure that the payload is pointed towards the optical ground station within its field-of-view, which has been maximised as far reasonably possible. The optical ground station then acquires and tracks the light from the beacon after which the high power laser will be turned on. The AO systems (guide star laser, wavefront sensor, deformable mirror and control loops) are operating in parallel to correct for the effect of atmospheric turbulence. Data recorded in the photon flux detectors on the SERC payload will be downlinked and analysed to assess the performance of the optical ground station systems in particular the performance of the adaptive optics correction to the high power laser.

The LED beacon provides operation outside sun-illuminated passes. This beacon provides light for the AO system tip-tilt wavefront sensor to provide telescope guiding and tip-tilt correction, which is otherwise unavailable with a laser guide star AO system. The ground-based infra-red laser is pre-corrected using the AO system and propagated through a 1.8 m telescope to orbit. The two photodiodes record a time series of flux illuminating the payload. We are able to measure the absolute flux with accuracy better than a few percent due to pre-flight calibration of the photodiode response to illumination from different angles. The data and satellite telemetry will be sent to the ground following the experiment, and compared to data collected from the AO, laser, and telescope systems. We expect to be conducting experiments with the payload during the second half of 2019.

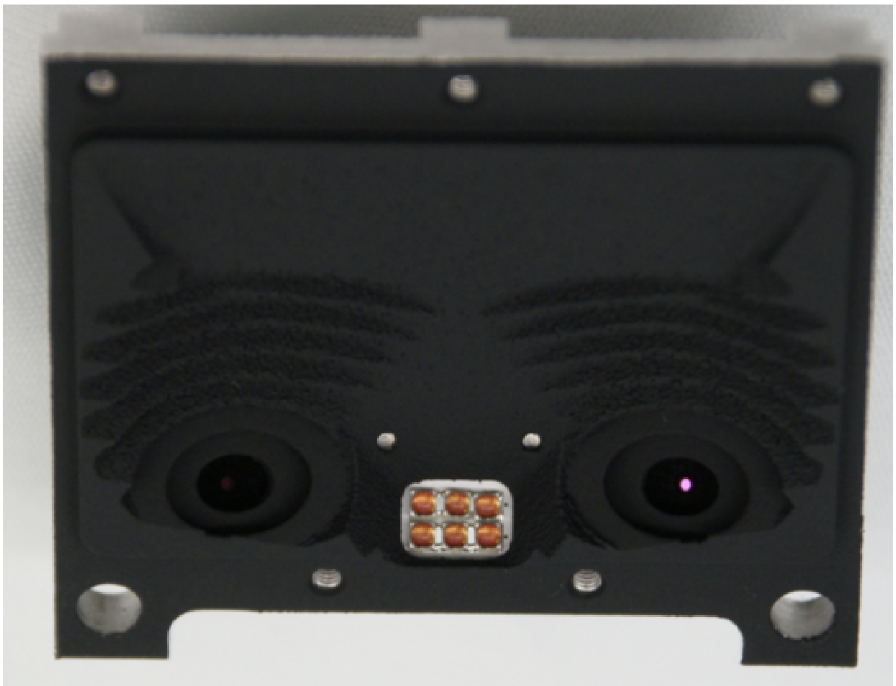

Figure 2: Photo of the external side of the payload. Two photodiodes with small apertures face the station and collect irradiance data of the illuminating laser, and two strings of three LEDs provide a beacon for acquisition and tracking.

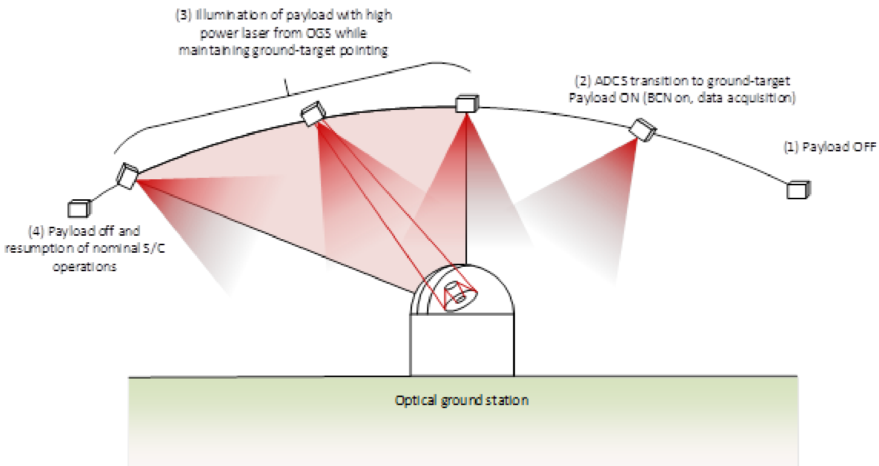

Figure 3: Operational concept: payload switches beacon LED on while station pointing, and is illuminated with ground-based laser. Flux is recorded during the pass, and transmitted to ground.

CONCLUSION

SERC has developed a payload consisting of laser irradiance measurement, and beacon lights into a low Earth orbit in order to measure the flux of the ground-based laser and AO system. This will provide information on the performance of the AO system, telescope, and confirm our atmospheric propagation models and simulations.

References

[1] F. Bennet, I. Price, F. Rigaut, M. Copeland, "Satellite imaging with adaptive optics on a 1 m telescope", in AMOS 2015, p. 3318202, (2016)

[2] M. Lingham, D. Grosse, F. Bennet, et al., "Adaptive optics tracking and pushing system for space debris manoeuvre", Proc. SPIE 10703, Adaptive Optics Systems VI, (2018)

[3] S. Barraclough, et al., "RAAF M1: UNSW Canberra Royal Australian Air Force Space Situational Awareness and ISR Pathfinder Mission", Proceedings of IAC-17,B4,4,9,x39587 (2017)