Application of the PPPP method for the determination of DLR pointing, tip/tilt and wavefront errors

James Webb[1*], Nazim Ali Bharmal[2], Craig Smith[3], Huizhe Yang[2], and Mark Blundell[3]

[1]The Australian National University, Canberra, ACT 2600, Australia
[2]Centre for Advanced Instrumentation, Durham University, Durham DH1 3LE, UK
[3]EOS Space Systems Pty. Ltd., 55a Monaro Street, Queanbeyan, NSW 2620, Australia

ABSTRACT

Optimal transmission of pulsed laser energy to a target is essential for the maximisation of reflected signal power in Debris Laser Ranging (DLR) systems. We describe the use of the PPPP measurement technique to allow compensation for both wavefront aberration, tip/tilt and errors arising from misalignment of the transmit and receive optical axes. This paper provides an update on the bistatic Wavefronts Obtained by Measuring Beam-profiles through Atmospheric Turbulence (WOMBAT) trial[1] conducted with the EOS Space Systems 1.8m DLR system[2] on Mt Stromlo, Australia, using an adjacent telescope to observe the 170 Hz PPPP intensity profiles.

Keywords: Adaptive Optics, Lidar, Laser Beam Transmission, Debris Laser Ranging

1. MOTIVATION

DLR is an important tool in the area of Space Situational Awareness (SSA), involving the measurement of the time-of-flight of a short, high-intensity laser pulse from a beam-directing telescope to an orbital target and the subsequent detection of the reflected energy. As the laser pulse propagates through the atmosphere, however, its fluence diminishes through the accumulated effects of refractive index variations from optical turbulence (OT). Sensing of the resulting wavefront error permits pre-distortion compensation of the transmitted pulse to restore near diffraction-limited energy on target, with corresponding improvement in the reflected signal energy. This subsequently allows improvements in the measurement systems' range and/or minimum target size capability.

DLR systems also present significant optical alignment problems in that the receiver and transmitter paths are necessarily separate, yet both must be aligned with the orbital target. Although practical pointing problems such as mount models and moving steering mirrors make on-sky, on-target optimisation unreliable, PPPP allows independent information to be obtained about each propagation path, permitting independent optimisation of the two to be performed.

2. PPPP WAVEFRONT SENSING ALTERNATIVE TO LASER GUIDE STARS

The laser guide star (LGS) is a key wavefront sensing technology in astronomical adaptive optics. In addition to involving extra alignment and system complexity though, the atmospheric volume probed by the back-scattered light (a cone with tip at the LGS) is not the same as the cylindrical volume of interest in a DLR system. To overcome this disparity, the Projected Pupil Plane Pattern[3] or PPPP method was proposed for wavefront sensing using a collimated laser beam. Illustrated in Fig. 1a, the technique relies on sensing the changes in the intensity of the laser beam-profile as it propagates via Rayleigh scattering. Due to diffraction, the beam-profile at two or more distances from the projection plane encode wavefront derivatives into intensity fluctuations. Using the transport of intensity equation[4] it becomes possible to use these height-dependent changes in beam-profile to estimate the wavefront which the original laser beam encountered.

In a DLR system, laser projection in itself is the fundamental goal of the telescope. PPPP allows the use of this very energy to measure the relevant perturbed wavefronts via observations of the scattered pulse as it propagates to target. Each pulse thus informs the correction of the next. At a sufficiently high pulse repetition rate - which

* james.webb@anu.edu.au

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is compatible with improved orbit determination in subsequent processing - an optimally compensated optical uplink my be achieved. High measurement (frame) rates and weak Rayleigh scattered wavefront intensity data at the infra-red wavelengths typically used for DLR have posed technical implementation difficulties for PPPP to date. Recent advances in IR detector technology,[5] however, have rekindled interest in the technique.

3. TIP/TILT AND POINTING INFORMATION

Fig. 1b illustrates the introduction of tip/tilt of the propagating energy resulting from atmospheric inhomogeneities. As the transmitted and received energy traverse approximately reciprocal paths, the determination of tip/tilt from direct focal plane measurements is normally precluded. However, if the technique is used in conjunction with astrometry from suitable stars, the net atmospheric tip/tilt may be deduced from instantaneous displacements between the observed conjugated backscatter measurement and the image of the star. Although turbulence will result in a time-dependant distribution of observed relative displacement values, the mean, time-averaged offset of the distributions corresponds directly to the degree of alignment between the systems' laser transmit and receive imaging paths. By adjusting the system alignment such that the mean location of the image of a reference target or star is coincident with the mean centroid of the laser illuminated column of scatter, optimal registration of the transmit and receive axes can be achieved.

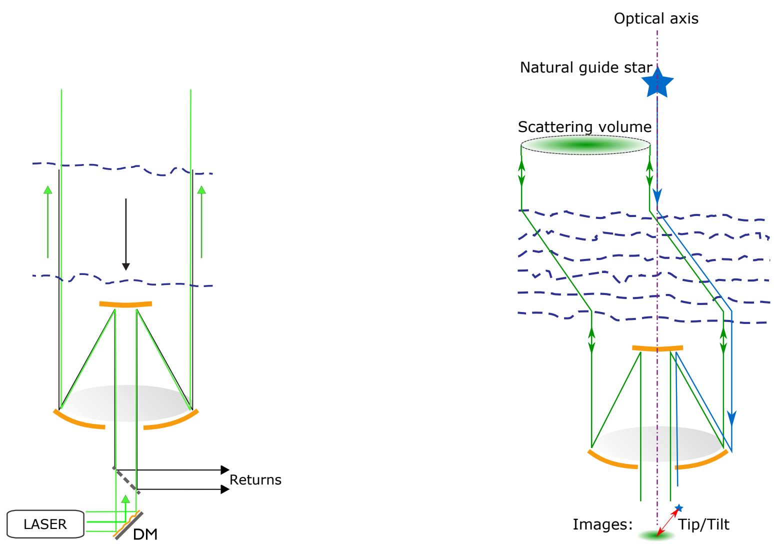

Figure 1. *Left (a):* The laser output pulse (green) from the afocal DLR telescope expands to fill the entire pupil and encounters turbulence (blue) as it ascends. Scattered returns (black) are range-gated to yield altitude-dependant intensity profiles. *Right (b):* Tip/tilt error imposed on the laser pulse (green) is apparent in the detector image when combined with imagery of natural guide stars (blue). Daytime operation is possible at infra-red wavelengths.

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