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MULTI-TELESCOPE INSTRUMENTS COPHASING FOR ASTRONOMY

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Abstract. Interferometry is used to combine light from several telescopes to obtain a resolution equivalent to a single telescope with the diameter of the combined spread of beams. However, the performance of the intrument thus synthetized is linked to the measurement and the correction of the aberrations between the telescopes. For cophasing a large number of beams, focal-plane approach has been selected due to its simple opto-mechanical device. Several focal-plane algorithms, developped at ONERA, were validated by simulations and by experiments on a laboratory test bench; the results we obtained demonstrate that a simple focal-plane fringe sensor can be easily implemented on most instruments such as VLTI Very Large Telescope Interferometer /2nd generation (4 to 8 beams) or spaceborne interferometers.

1 Introduction

The next generation of multi-telescope interferometers will have more cophasing requirements. For nulling, a very accurate OPD correction is required, and for imaging, an increasing number of apertures will be used. The measurement of higher orders than differential piston, at least differential tip/tilt, for real-time of post-facto correction is also required.

When cophasing a large number of beams, new approachs should be considered because the classical pairwise combination leads to an unreasonable complexity. Two focal-plane algorithms, the "Phase Retrieval" and the "Phase Diversity" (described in section 2), inherited from wavefront sensors on monolithic telescopes or interferometric fringe sensors were developped at ONERA. These algorithms were validated on a laboratory test bench; the analysis of these results are presented in section 3. Finally, the validity of the simple focal-plane approach is given in conclusion.

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2 Cophasing a multiple-beam instrument: requirements and solutions

Spaceborne interferometers and 2nd generation instruments for the VLTI will have stringent requirements: they will use 3 or 4 beams, 8 at the most; not only piston/tip/tilt correction[1], but also higher orders stabilization will be required. Furthermore, cophasing on a wide field can also be specified. Such multi-purpose sensors has already been investigated at ONERA for two projects with similar requirements. The first one is DARWIN (Detection and Analysis of Remote Worlds by Interferometric Nulling) composed by 4 flyers dedicated to the search of habitable terrestrial exo-planets. For the fringe sensor (ref. 1), correction from piston to spherical aberration is required with nanometric accuracy. The second project is GEO (ref. 2), an imaging interferometer for Earth observations from a geostationnary orbit. In this case, the main difficulty is the cophasing on a wide field.

Due to that new requirements, ONERA have developped several focal-plane algorithms inherited from wavefront sensors on monolithic telescopes:

- For **"Phase Retrieval"**, only the focal plane is used, when the object is known (unresolved reference star). Although Phase Retrieval is known to lead for centro-symmetric pupils (case of monolithic telescopes) to a sign ambiguity on the even part of the phase, a non-redundant multiple-beam configuration allows to uniquely solve for piston/tip/tilt.

- For **"Phase Diversity"**, 2 images are taken, in the focal plane and in an extra-focal plane (or with any other known aberration). In this case, the two data sets allow to fully retrieve the two macro-unknowns (object and phase): phase ambiguities are resolved and the object can also be estimated.

These algorithms, gathered in the MASTIC code (Multiple-Aperture Software for Telescope Imaging and Cophasing) were validated by simulations and by experiments on the laboratory test bench BRISE (Banc Reconfigurable d'Imagerie sur Scènes Étendues).

3 Experimentals results on the BRISE bench

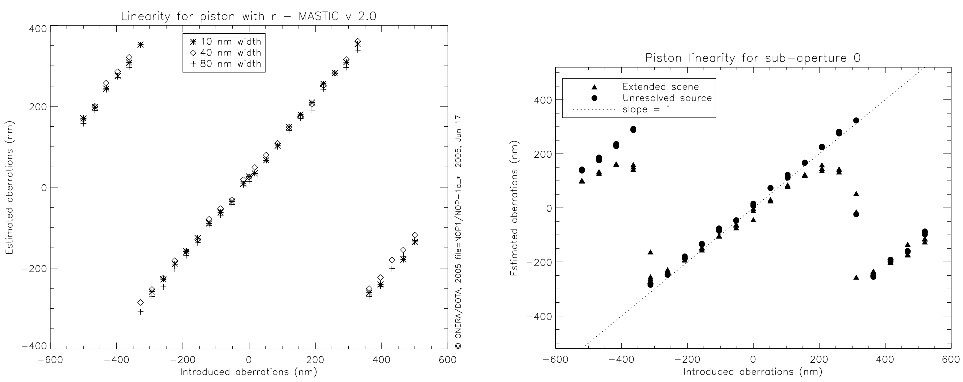
Brise is mainly composed by (ref. 3) **two objects**, an unresolved monomode fiber (He-Ne laser) and a photographic plate illuminated by a white cell, **an aperture mask** and three planar mirrors monted on piezo-electric plateforms which can introduce calibrated piston/tip/tilt aberrations, **the cophasing sensor**, which records simultaneously the focal and extrafocal images of each object in a single frame of a CCD camera, **a control software** and an **efficient isolation** against environmental disturbances (air turbulence, vibrations, thermal drifts).

Piston linearity:
To check the correct behavior of the estimators, a linearity test was first made. A 30-point piston slope from -500 nm to +500 nm is applied on a given sub-aperture.

[1] In this article, all the aberrations mentionned are differential aberrations.

The estimated piston with Phase Retrieval (Figure 1a) or Phase Diversity (Figure 1b) is linear between $\pm\lambda/2$ and wrapped as expected. Because diffraction is chromatic, whereas our numerical model is monochromatic, the spectral bandwidth is an important parameter to optimize. All curves where measured at $\lambda = 650$ nm with $\Delta\lambda$=40 nm for the extended scene and three filters (width= 10 nm, 40 nm and 80 nm) used for Phase Retrieval. The slope is close to one: the piston cophasing on polychromatic source is possible with the phase retrieval algorithm (80 nm @ 650 nm = $\lambda/8$).

Figure 1b, for each introduced piston, three measurements are realized. As a comparison, the result obtained with the Phase Retrieval (unresolved object) is reported, showing that the linearity is excellent from $-\lambda/2$ to $+\lambda/2$. With the extended object, the wrapping at 635 nm is not clear; this phenomena can be explained by the object form. However, it's not a problem in closed loop. We also performed repeatability measurements that have shown the excellent behavior of our estimator(standard deviation of estimated piston under 10 nm in photon-noise mode).



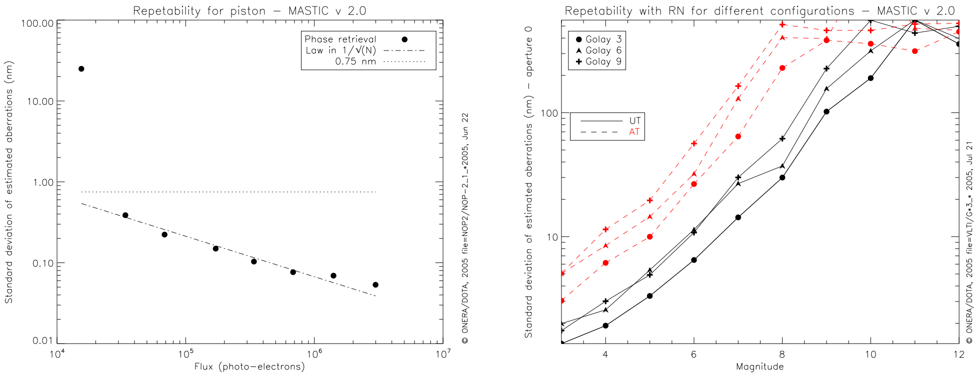
(*a*) (*b*)

Fig. 1. a: Piston linearity with Phase Retrieval and different bandwidths. **b:** Comparison between Phase Retrieval and Phase Diversity.

Piston repeatability:

Figure 2a shows the repeatability obtained on the piston measurement at 650 nm. Experimental data are compared to the simulation: images simulated are generated with photon noise and RON, at the same wavelength and with the same flux than experimental one. First, we note that in photon-noise mode, the aberrations follows the expected $1/\sqrt{N}$ law, whereas at low fluxes, the piston estimation is dominated by the detector noise. The piston performance is excellent, and the 0.75 nm repeatability specified for DWARF is reached.

A similar simulation has been performed for VLTI. The number of sub-apertures was progressively increased, based on Golay aperture configurations for simplicity. The result Figure 2b shows that the repeatability is better for UT configuration,



(*a*) (*b*)

Fig. 2. a: Piston repeatability for DARWIN with Phase Retrieval. **b:** Piston repeatability for the VLTI with Phase Retrieval.

as expected; we also notice that the piston measurement error increases with the number of apertures. However, a good estimation is possible (with a Golay3 in UT configuration, 100 nm @ V9 = $\lambda/22$).

4 Conclusion and perspectives

With the BRISE test bench, the use of the focal-plane approach for a fringe sensor have been validated; piston can be well-estimated with nanometric retetability using Phase Retrieval or Phase Diversity (Golay3 configuration), not only on unresolved objects but as well as wide fields. We also demonstrate that it can be applicable to a variable number of beams. Focal-plane fringe-sensing is thus a simple solution wich can be easily implemented on most instruments such as VLTI/2nd generation or spaceborne interferometers. Future investigations will enable us to understand the infuence of the pupil configuration, and to caracterize the behaviour of ours algorithms in higer orders.

References

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