Experimental results for infrared aberration tracking using a correlation algorithm on two star extended field

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Abstract

The GRAVITY aberration sensor [1] is used to characterize the four AT/UT VLT beams quality and it can also improve the performance of star beam injection into the fiber-fed beam combiner. The aberration sensor is equipped with four Shack-Hartmann lenslets operating in the near-infrared. Each telescope beam wavefront aberrations are measured simultaneously by imaging the Galactic Center field using a Shack-Hartmann. The wavefront aberrations are in general measured in three steps: a) compute the centroids of the Shack-Hartmann spots; b) measure the wavefront slopes by comparing the measured centroids with a reference grid; c) retrieve the aberration coefficients with the computed slopes. The standard point source Shack-Hartmann spot centroids are computed out using a weighted centroid algorithm. Since the aberration sensor Shack-Hartmann images are filled with the crowded Galactic Center objects, the shifts of the distorted images have to be estimated with a correlation algorithm.

We report a simulation of the Shack-Hartmann lenslet images of the Galactic Center. A NACO Galactic Center image was obtained and later it is interpolated to the pixel scale of the aberration sensor. The image was next convolved with the point spread function of the lenslet sub-aperture. The resulted image was then projected on the Shack-Hartmann grid. This image is free of the VLT aberrations.

The accuracy of seven existing correlation centroid algorithms [cf. Tab. 1] [1] for the Galactic Center field is studied numerically. The centroid is computed by finding the mismatch between a reference image and a target image. The reference image should be locally tilt free to get a good centroid estimate. The generation of reference image was accomplished by averaging 50 lenslet sub-aperture images of a single frame.

The comparison of the above algorithms is carried out at different signal to noise ratio levels and known input shifts. From the analysis we found out that the zero mean sum of square difference, sum of square difference are the best in performance in comparison to others. The zero mean sum of square difference performs better than sum of square difference with an additional computational cost. In this work the sum of square difference algorithm was chosen to compute the slopes of the aberration sensor.

Next studied the performance of wavefront aberration measurement accuracy. The absolute wavefront aberration error is defined as the absolute difference between the input wavefront aberration and the measured wavefront aberration. The experimentally measured wavefront aberrations

Table 1: Correlation algorithms, I_0, I_L reference and live images, * is complex conjugation, $\bar{I}_0$ is the mean intensity of I_0.

Name	**Correlation coefficient**
Cross correlation, image domain (CCI)	$\sum I_L(x \pm \Delta x, y \pm \Delta y) \times I_0(x,y)$
Cross correlation, Fourier domain (CCF)	$FT^{-1}\big\{FT[I_L(x \pm \Delta x, y \pm \Delta y)] \times FT^{*}[I_0(x,y)]\big\}$
Sum of square difference (SSD)	$\sum \big[I_L(x \pm \Delta x, y \pm \Delta y) - I_0(x,y)\big]^2$
Zero mean sum of square difference (ZSSD)	$\sum \big[\big(I_L(x \pm \Delta x, y \pm \Delta y) - \bar{I_L}\big) - (I_0(x,y) - \bar{I}_0)\big]^2$
Sum of absolute difference function (SAD)	$\sum \big\lvert I_L(x \pm \Delta x, y \pm \Delta y) - I_0(x,y)\big\rvert$
Zero mean sum of absolute difference (ZSAD)	$\sum \big\lvert\big[I_L(x \pm \Delta x, y \pm \Delta y - \bar{I_L}\big] - \big[I_0(x,y) - \bar{I}_0\big]\big\rvert$
Sum of absolute difference squared (SADS)	$\big[\sum \lvert I_L(x \pm \Delta x, y \pm \Delta y) - I_0(x,y)\rvert\big]^2$

were added to the Galactic Centre image in three folds: a) applied the aberrations induced phase in the Fourier plane of the Galactic Centre image; b) shifted the Galactic Center image with the computed slopes from the VLT aberrations induced point source Shack-Hartmann; c) generated the artificial Galactic Centre image by the shift and add method using the VLT aberration induced Shack-Hartmann spots. The methods measures the absolute wavefront aberration with an accuracy better than 100 nm for a 2 s integration (2000 photons/sub-aperture) image.

The GRAVITY calibration unit provides the artificial stars to characterize the performance of the acquisition camera. Two stars were implemented by using the two single mode fibers separated by nearly 1 mm. This corresponds to two stars separated by 1.5" in the sky. The stars beam is reflected by a parabolic telescope is then guided to the acquisition camera by using a set of mirrors [2].

The two star field illuminated aberration sensor images are acquired in the presence of phase screens and also with moving the tip-tilt devices. The performance of the correlation algorithms were analyzed for the experimental aberration sensor image data. The analysis was carried out in four steps: a) generation of the reference image from the target aberration sensor image itself; b) select the known input shifts image (target image); c) apply the correlation algorithm between the reference and the target image. d) repeat above steps for different signal to noise ratio images. The sum of square difference algorithm is the best in performance when compared with others. The experimental aberration sensor image with 2000 photons/sub-aperture allows it to measure the wavefront aberrations with an accuracy better than 250 nm. Presently the optimization work is progressing. The calibration of the software is being adapted with the instrument data.

References

[1] Anugu, N. et al., *Near-infrared aberration tracking using a correlation algorithm on the Galactic Center*, SPIE Astronomical telescopes + Instrumentation, Montreal, Canada, 9148-207 (2014)

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