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Phase diversity at THEMIS : first implementation

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Abstract. Phase diversity techniques actually provide robust post-processing methods to restore solar images degraded by seeing-optical aberrations. We present preliminary results of the application of a Partitioned Phase-Diverse Speckle (PPDS) technique at THEMIS. The images have been acquired using the IPM broad-band CCD camera and reduced using a suitable IDL code. The spectral analysis of unrestored/restored images shows a significant improvement of image quality, achieving diffraction limited resolution.

Key words. Phase diversity – Solar Convection – Numerical Techniques

1. Phase Diversity: general overview

Phase Diversity (PD) techniques are post processing procedures for correcting aberrations induced by instrument and by atmosphere in individual isoplanatic patches. These techniques do not require sophisticated observing instrumentation and are not based on theoretical models describing the atmospheric degradation, but work on simple optical principles. Their purpose is to determine the wavefront aberration expansion in terms of Zernike polynomials at the entrance pupil of the telescope, from the information contained in two simultaneously recorded images, one focused and the other affected by a known amount of defocus (Gonsalves and Chidlaw (1979)).

2. Partitioned Phase-Diverse Speckle restoring

A single pair of focused/defocused images may not contain enough information to correctly estimate wavefront aberrations, as information at certain frequencies may be irretrievably lost as a consequence of the aberrations themselves. This may lead to artifacts presence in restored image. In order to correct for this effect, multiple image pairs may be used, accomplishing a more robust estimation of the real scene. As suggested by its name Partitioned Phase-Diverse Speckle (PPDS) procedure blends

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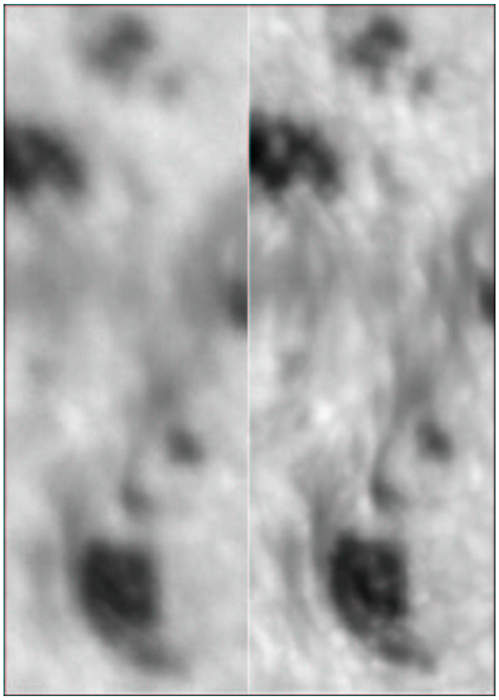

Fig. 1. Pair of focused (right) and defocused (left) images.

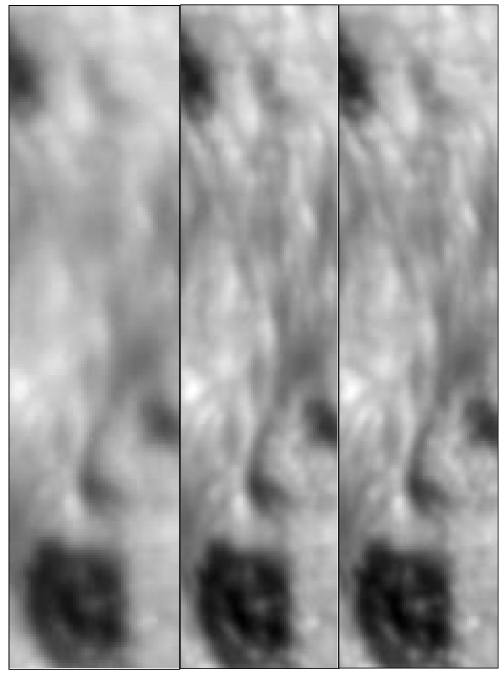

Fig. 2. Left: best of the three original images used in the PPDS process. Center: restoration without considering the central obscuration. Right: restoration taking into account the central obscuration.

the concepts of PD and Speckle imaging. It requires the collection of multiples image pairs in a relatively short time, to be sure we are imaging the same scene in all, as the goal of the PPDS is to estimate the common object and the phase aberration of each image of the pairs series (Löfdahl and Scharmer (1994); Paxman et al. (1996)).

3. Observations

Figure 1 shows a pair of near infrared (850 nm) continuum images (after dark current subtraction and flat-fielding) from the series acquired at THEMIS on May 15, 2002 between 12h05 and 12h16 in PD configuration. The PD system was implemented at the secondary focus environment of the telescope, using the white light channel of the IPM instrument. This implies that the low order aberrations we measure include the telescope and transfer optics as well as part of the optical path of the IPM system. The exposure time was of 20 ms and, due to the provisional PD set-up for testing, the field of view was reduced to 14" x 30". The pixel scale is 0.057".

Residual small aberrations were removed by implementing in the PPDS algorithm the option of considering a central obscuration in the telescope entrance pupil. Figure 2, from left to right, shows: a) the best of the three original images used in the PPDS process, b) a first attempt of restoration without considering the central obscuration of the THEMIS pupil, and c) the final result once the central obscuration is taken into account.

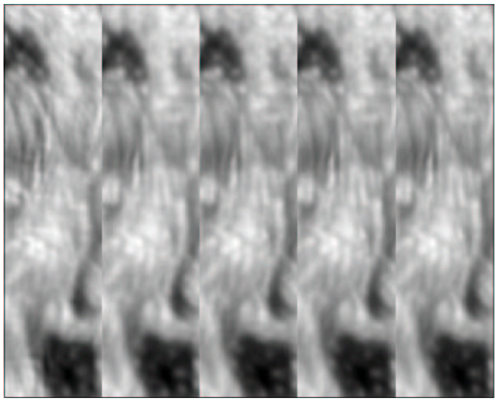

Fig. 3. From left to right: restored frames obtained by combining 1, 2, 3, 4 and 5 PD images respectively.

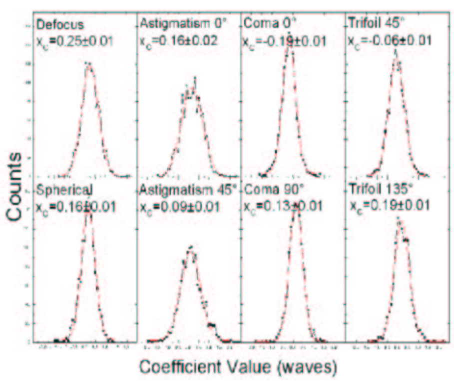

Fig. 4. Zernike coefficients histograms from 75 PPDS restorations.

In Figure 3 five restored images are shown, obtained by combining from 1 to 5 PD images respectively. In the first two cases some restoration artifacts can be distinguished. By adding more images in the speckle procedure, the artifacts disappear, leading to an optimal restoration.
The spectral analysis of the restored images revealed that all the frequencies until the cut-off due to diffraction limit of THEMIS (0.19" @850 nm) have been restored.

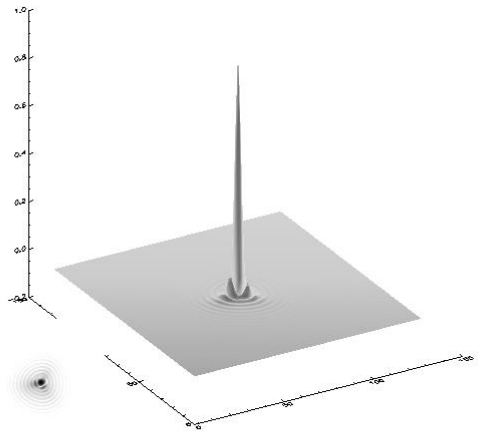

Fig. 5. 3D view and logarithmic view (lower left) of the PSF (Strehl ratio = 81%) reconstructed from the Zernike coefficient mean values from Figure 4.

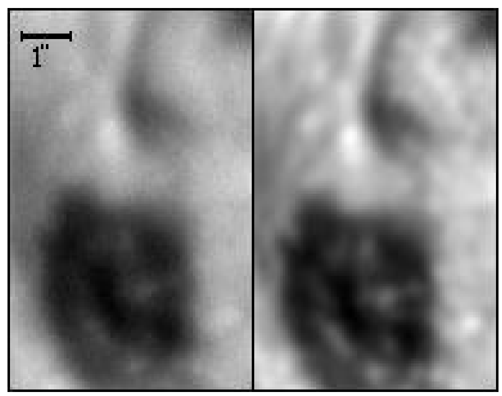

Fig. 6. Left: detail of original image used in the PPDS process. Right: same detail in restored image.

4. Estimation of the Telescope Aberration

A 1 min series of 75 images has been restored by PPDS (16 isoplanatic patches/image). From the single estimate of the wavefront error for each patch a total of 1200 sets of aberration parameters (Zernike coefficients) are obtained. For each coefficient the correspondent histogram has been produced. A Gaussian distribution is expected for the atmospheric aberrations. The mean of such a distribution should be zero when observing with a perfect optical setup. Consequently, the mean of the histograms empirically obtained, will reveal the amount of aberration stemming from the instrument. In Figure 4 we report the histograms for the Zernike coefficients from 4 to 11 (namely: defocus, astigmatisms, comas, trefoils and spherical aberrations). A Gaussian fit is overplotted to each distribution. The coefficient values are expressed in waves @850 nm, this implies a mean defocus value (the largest aberration obtained) smaller than 3.5 mm versus a focal length of ~ 57 m. The intrinsic PSF of this optical setup has been reconstructed (see Figure 5) from the mean values of the Gaussian fits. The FWHM of this PSF is 0.19 arcsec @850 nm and the Strehl ratio is 81%.

5. Conclusions

Phase diversity techniques actually provide robust post-processing methods to restore solar images degraded by seeing-optical aberrations. We have successfully PPDS restored a series of images acquired at THEMIS. Although in this first implementation was not possible to discern between aberrations stemming from the telescope or from the transfer optics, we want to emphasize the image quality reached, which allows s ub-granular structure studies (Figure 6): the results presented show that phase-diversity techniques allow diffraction-limited imaging even with a large solar telescope.

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