On the application of speckle imaging using projection methods

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Motivations

Adaptive optics based on phase conjugation has been commonly used to compensate image blur due to atmospheric turbulence in astronomy. However, the adaptive optics is not directly applicable for extended scene imaging in turbulent conditions on horizontal paths due to strong anisoplanatism of the aberrated field [1]. Besides, in many practical cases the wavefront information cannot be obtained and/or used. Therefore, a cost-effective approach, with or without the use of adaptive optics, is required to obtain high resolution with extended field in conditions of strong blur. Methods of digital reconstruction of a high-resolution image from a series of short-exposure images, known as speckle imaging, have been used instead of or in addition to adaptive optics. Combining one of this methods with optimum image forming and image processing schemes seems to be promising for implementation of such an approach.

A number of speckle imaging methods have been suggested in the past. The cross-spectrum (known as the Knox-Thompson method) and bispectrum methods are based on estimation of the Fourier transform (spectrum) of the object by averaging second- and third-order moments of the spectra of short-exposure frames [2]. Methods of alternating projections onto convex sets (POCS) use iterative approach by starting from some trial reconstructed signal and then adjusting it by projecting on convex constraint sets with desired properties. A POCS algorithm suggested by Pakhomov and Losin [3] allows for reconstruction of unknown point-spread functions by joint iterative processing of several speckle images. In our simulations, this method has shown better performance compared to the bispectrum and cross-spectrum methods.

It is known that matching the aperture size to the Fried parameter r_0 may be used to increase the resolution of images obtained by post-processing of short-exposure data in astronomical imaging [4]. We can expect that segmentation of the aperture and selection of best frames can be combined with more advanced speckle imaging methods for achieving the optimum resolution in presence of irregular aberrations. Besides, a multi-aperture architecture allows for obtaining several images of the same object with different blur simultaneously, which allows for extracting diffraction-limited information in one measurement step.

Experiments

In this paper we present some experimental results of speckle imaging applied to ground-based scenery and astronomical objects. The results are compared with time averaged and best frame images, under different turbulence conditions. We have implemented several imaging schemes based on Sky-Watcher SKP25012EQ6 10-inch F/5.5 Newtonian telescope, with and without aperture segmentation. Image reconstruction was based on a combination of the following methods.

1. Selection of best frames based on sharpness functional

$$S = \frac{\sum I^2}{\left(\sum I\right)^2}, \tag{1}$$

   where I is the image intensity.

2. Stabilization of the image sequence using normalized cross-correlation for pattern matching.

3. Apodization at the edge to suppress edge ringing artefacts (optional).

4. Iterative reconstruction of point-spread functions according to the method described in [3]. At each iteration, the PSF is reduced to a limited number of the brightest points.

5. Deconvolution from the series of images using Wiener filtering with specified signal-to-noise ratio (SNR).

Optional pre-processing steps 1-3 were used to improve the performance of the reconstruction algorithm.

Two examples of imaging at the horizontal path are shown in Figures 1 and 2. In our experiments, we observed a detail of a metal construction on the top of the building in Rijswijk, The Netherlands, situated at a 560 m distance from the observation point. Figure 2 shows decent reconstruction using only one multiplexed frame, with the resolution improved in comparison to the sharpest and average sub-images. We also observed a certain sharpness improvement in imaging of the astronomical objects - planets and the Moon (Figure 3).

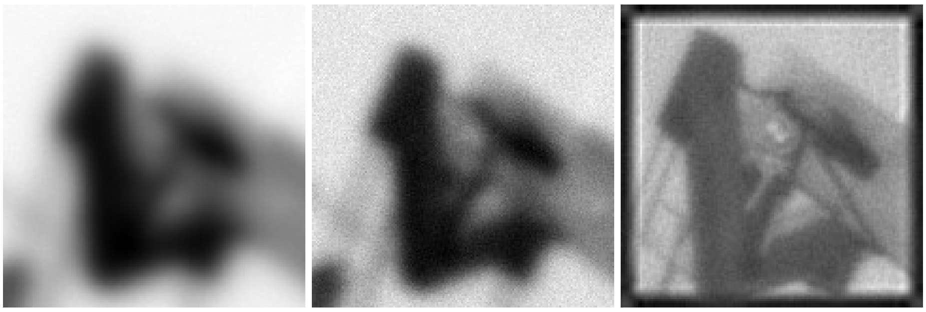

Fig. 1. Imaging at the horizontal path; reconstruction from 100 frames. Average (left), sharpest (center) and reconstructed (right) frames.

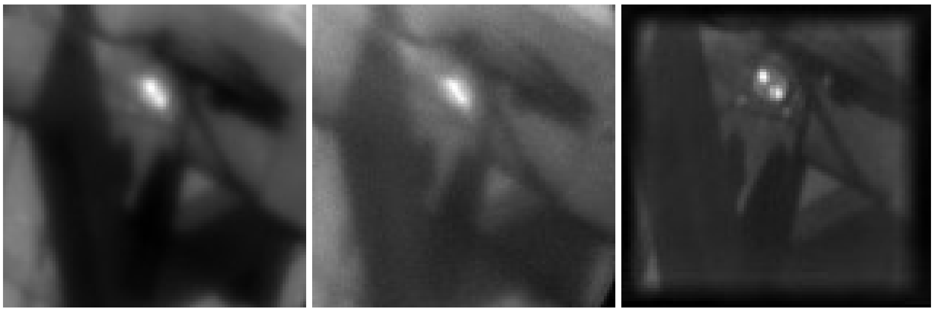

Fig. 2. Imaging at the horizontal path with aperture segmentation; reconstruction from 1 frame with 7 sub-images. Average (left), sharpest (center) and reconstructed (right) frames.

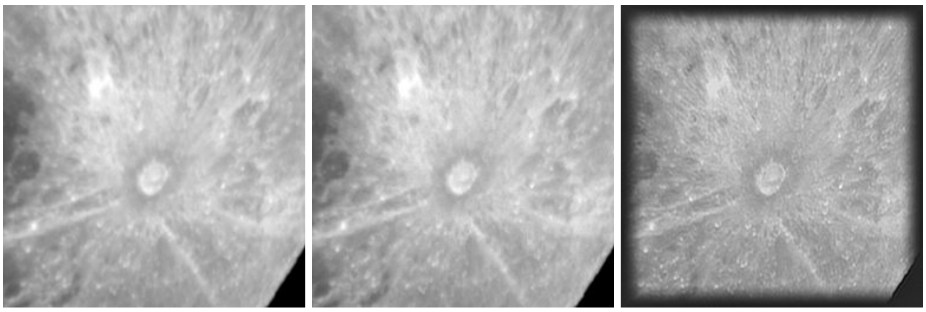

Fig. 3. Imaging of the Moon surface; reconstruction from 10 frames. Average (left), sharpest (center) and reconstructed (right) frames.

References

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