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Implementation of the α UMi monitoring system at SAO RAS

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Abstract. A new α UMi monitoring system based on an IP camera with a CMOS photodetector has been developed and installed at the Upper Scientific Site of the Special Astrophysical Observatory of the Russian Academy of Sciences (SAO RAS). The main aim of the development is to measure the astronomical seeing and monitor its variation. Here we briefly describe the method of differential image motion monitoring (DIMM) used as the device operational principle and give some details on the characteristics and operation of the monitoring system developed.

Keywords: methods: observational; techniques: image processing

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1 Introduction

Monitoring systems are widely used in SAO RAS. They have been constructed for different purposes and instruments such as scientific equipment viewing cameras, telescope guidance, night-sky monitoring systems, in-dome cameras, etc. The idea of video monitoring is not limited by watching the night sky in the visible range of the spectrum. Of great importance is the examination of the star images for continuous estimates of the astronomical seeing quality and its variation caused by the atmosphere turbulence, weather conditions, etc.

To estimate the seeing, we chose the classical method of DIMM (Tokovinin 2002) with a non–classical analysis of a large number of images obtained through a single aperture (one imaging device) and applied it to the images of Polaris.

2 Method of differential image motion monitoring

As described in Tokovinin (2002), DIMM is currently a commonly accepted tool for measuring the astronomical seeing. In this method the Fried parameter is estimated by the variance of the differential image motion within two small apertures, usually cut out by a mask in one large pupil of the telescope.

This approach has a practical advantage, because it is insensitive to the shaking and tracking errors, at least of the first order. Usually, the difference in the slopes of the two DIMM subapertures is proportional to the second derivative of the wavefront, or the curvature. Thus, a DIMM module is a kind of a curvature sensor.

The success and a wide spread of DIMM has led to some confusion. It is often considered that a DIMM module is a reliable and self-calibrated tool that always gives correct measurements of the seeing. However, a number of subtle instrumental effects in the DIMM modules can distort the results. The accurate calibration and the elimination of bias in the DIMM results become a critical issue for comparing the astronomical sites and the prediction of the seeing. The equations given in Tokovinin (2002) and Sarazin & Roddier (1990) allow us to relate the variance of the image center position, the diameter of the telescope D_{t}, and the Fried parameter r_0:

$$\sigma_*^2 = K\lambda^2 \left(\frac{1}{r_0}\right)^{5/3} \left(\frac{1}{D_{\mathrm{t}}}\right)^{1/3}. \tag{1}$$

An important conclusion from formula (1) is that to construct a device for the seeing measurements by applying this method, it is advisable to use a small-diameter lens. In this case the variance increases, and it can be measured with better accuracy. All further calculations are performed for $\lambda = 550$ nm. The parameter K depends on the ratio of the distance between the apertures and the diameter of the apertures. For the zero distance (one aperture as in our case), $K = 0.358$.

Unlike the classical DIMM, we use a single aperture to take many images (about 100) of Polaris without guiding, these calculations require a series of images of short exposures with short intervals between them, which is not a problem for cameras with CMOS matrices.

Based on the images taken with this system, it is possible to determine the exact position of the star image center (X, Y) by the calculation of the center of mass (centroid) or by profile fitting. Since the star is shifting slightly from exposure to exposure, it is necessary to remove this trend. For short episodes of 100 frames (1-min duration approximately), it is enough to fit X and Y with a polynomial of the 2nd degree. The residuals in this case will be quite small.

After subtracting the corresponding trends from X and Y, it can be assumed that the data contain only random "wandering" of the star in the focal plane caused by wavefront tilts in the turbulent atmosphere, as shown in Fig. 1. The value characterizing the point spread is the variance σ^2.

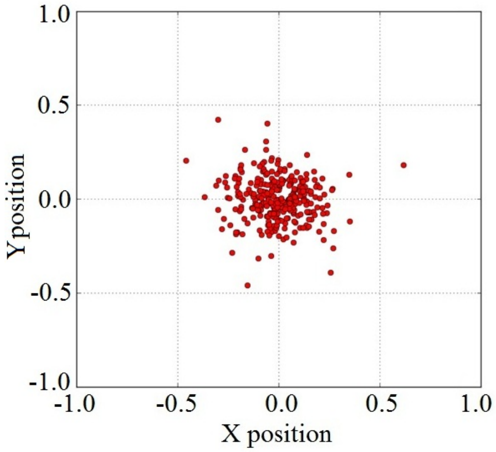

Fig. 1. Star position scattering due to atmosphere turbulence, $D_{\mathrm{t}} = 0.05$ m, scale $= 5\overset{''}{.}5$/pix.

In this case, after removing the trend the average value of the coordinate will be equal to zero. The square root of the variance is the standard deviation. We are interested in the variance of the distance for the center of the star in each frame. It can be calculated as the sum of the variances for X and Y.

3 Polaris monitoring system

By converting images obtained with IP cameras into the FITS format, we get an opportunity to study various parameters of star images (Shaldyrvanet al. 2023). To measure the seeing, an IP camera with a Sony IMX335 CMOS matrix with a resolution of 2592 × 1944 px (aspect ratio of 4:3) and a lens with a focal length $F = 63.5$ mm and the field of view $\mathrm{H} \times \mathrm{V} = 4\overset{\circ}{.}24 \times 3\overset{\circ}{.}18$ was purchased. The resulting image scale is approximately $6''$/px. It has been verified by the astrometric calibration of the image obtained with a similar camera–lens pair mounted on the cage of the SAO RAS 6-m telescope prime focus.

We have modeled the camera enclosure and made it of weather-resistant materials. The dimensions of the enclosure allow avoiding system fluctuations due to the wind loads.

The camera has been installed on the Zeiss-1000 telescope dome roof. It is pointed at the polar region of the sky. Series of 100 images of Polaris are saved to a local network server with subsequent round-the-clock processing with a frequency of 20 minutes. For technical needs, it is also possible to access the live stream of the video signal from this viewing camera via the local network.

We use the `Python` libraries `numpy`, `scipy`, `matplotlib`, `os`, `pylab`, and `astropy` to determine the star centroid and the full width at half maximum (FWHM) and then calculate the seeing and the Fried radius r_0. The measurements are saved as a CSV-format table and stored on a server in the local network of SAO RAS as well as displayed on a web page in the form of a graph.

4 Conclusion

Thanks to the new technologies used in the production of CMOS matrices in the last decade, it became possible to create inexpensive IP cameras with characteristics acceptable for work at night time. The methods described here allows one to use images obtained by an IP camera with a CMOS matrix to calculate the astronomical seeing and the Fried radius r_0. Based on the DIMM method, we have developed the Polaris monitoring system and put it into operation at SAO RAS, where it works round-the-clock with data updating every 20 minutes.

References

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