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Methods and calculations applied to images of the new viewing systems of SAO RAS

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ABSTRACT

The paper describes the methods and calculations for processing images obtained from IP cameras based on CMOS matrices, used at the SAO RAS Upper Observation Area. We present two methods for automatic switching of camera operation modes (day/night) and select the most preferred one. We also present methods for processing images obtained in low-light conditions. A camera was built to obtain series of images of the Polar star, and a method for calculating seeing from these series was described. The potential of using these image processing methods for the needs of SAO RAS is assessed.

Key words: CMOS sensor, IP camera, image processing method

1 Introduction

The problem of video monitoring – from scientific cameras to security systems – has remained relevant at the Special Astrophysical Observatory of the Russian Academy of Sciences (SAO RAS) for several decades. Twenty years ago, a digital television complex for the 6-meter Big Telescope Alt-azimuthal (BTA) and 1-meter optical telescope Zeiss-1000 was developed and put into operation at the Upper Observation Area (UOA); being constantly modernized, it is still in use (Komarov, 2013). For this complex, we select highly sensitive mass-produced matrices (Komarov, Semenko, 2018), which allow creating dozens of cameras for viewfinders of scientific equipment, telescope guiders, night sky surveys, dome cameras, for which infrared illumination cannot be used.

As is known, for a long time, Complementary Metal-Oxide-Semiconductor (CMOS) matrices could not compete with Charge-Coupled Device (CCD) matrices in terms of light sensitivity and image quality, and their application was mainly in the field of security video surveillance systems. Since 2008, progress in the implementation of CMOS matrices has advanced significantly, and technologies currently used in producing CMOS matrices allow them to compete with CCD matrices (Shaldyrvan et al., 2022).

Currently, we use photodetectors based on CMOS matrices in round-the-clock sky monitoring systems in the vicinity of the largest Russian optical telescope BTA with a 6-meter primary mirror, as well as in the dome control system of the BTA and Zeiss-1000.

Modern IP cameras based on CMOS matrices have peculiarities in the control unit software, which reduce the capabilities of the cameras, so it is necessary to apply various processing methods to the images obtained by these cameras. This paper describes the processing methods used for images obtained from IP cameras based on CMOS matrices, used at the UOA of SAO RAS, as well as calculations applied for these methods.

2 Method for automatic switching of camera operation modes (day/night)

Modern IP cameras based on CMOS matrices allow obtaining acceptable images in low-light conditions and have a web interface convenient for control; they use unified data transfer protocols, but usually have a software for mode control built into the control unit. Although the sensitivity and dynamic ranges of these matrices allow for operation both during the day and at night, this range is conditionally divided into areas by the control unit software.

This feature of the cameras is especially important in the particular case of using a camera pointed to the BTA from the Zeiss-1000 site (Komarov et al., 2022), since the latitude of the UOA and the field of view of the camera are such that in winter, the solar disk passes across the camera's field of view during the day, whereas in summer, the full Moon disk passes across it at night, which even more affects the sensitivity range at which the camera obtains images acceptable for the observer.

Since the camera's controller software also controls its network settings, while the web interface is part of this software, it is not possible to avoid using it at the moment. Therefore, in order to use the entire sensitivity range of the data

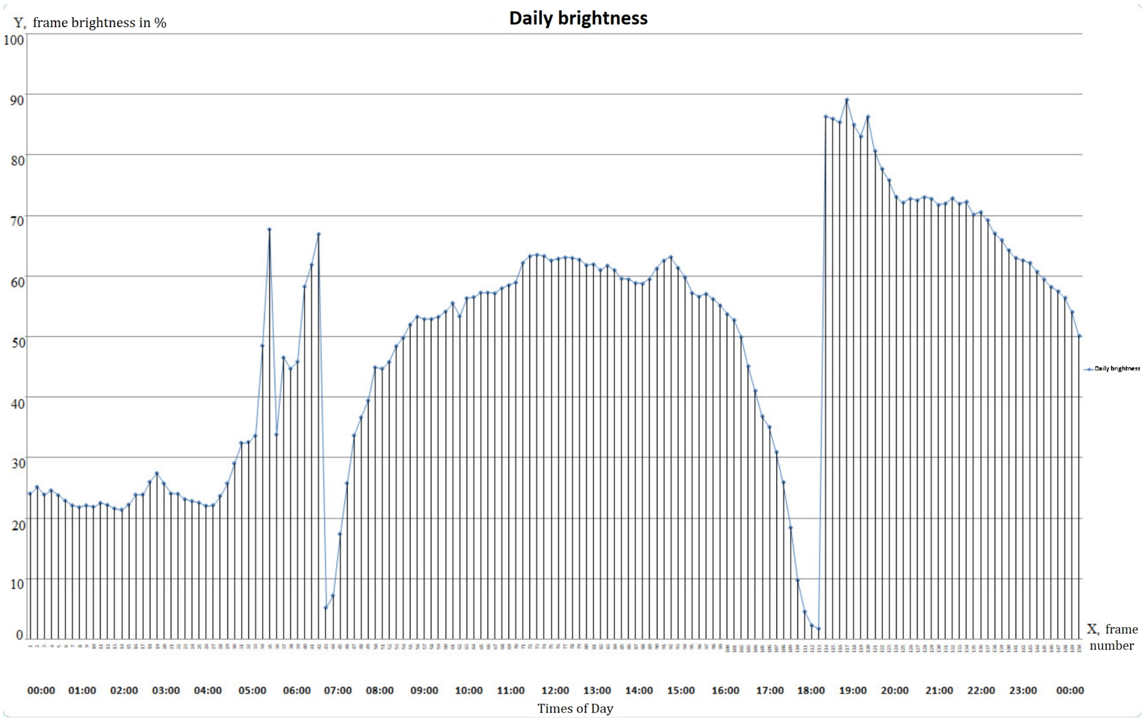

Fig. 1. Daily brightness graph, first method.

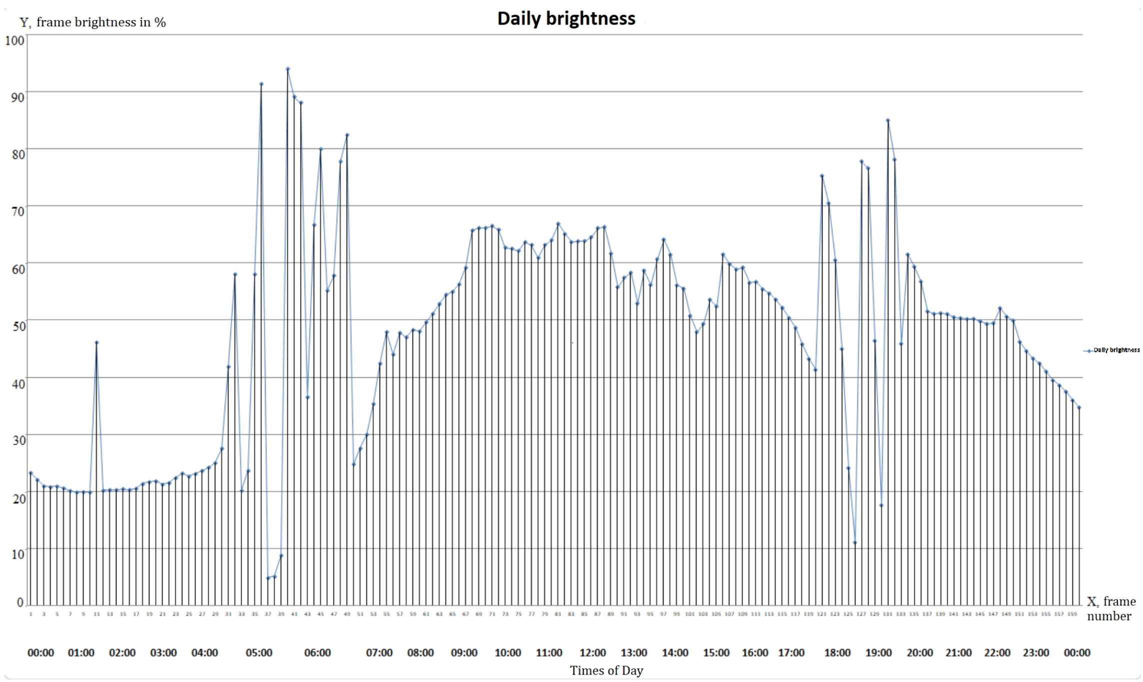

Fig. 2. Daily brightness graph, second method.

from these matrices, two methods for automatic switching of the camera operation modes were elaborated: with reference to the time of day and with reference to the calculated brightness level of the obtained images. Both methods use saved camera operation configurations with preset sensitivity settings and specified exposure ranges. In the first method, the camera operation mode is switched by changing the camera operation configuration with reference to the time of day. In the second method, this process is implemented with reference to the calculated brightness level of the last obtained image. To calculate the image brightness, we apply a script written in the `Python` programming language (`Python`

Fig. 3. Image of the Zeiss-1000 dome without processing with `ImageMagick` software.

Fig. 4. Image of the Zeiss-1000 dome processed with `ImageMagick` software.

script) using freely distributed `numpy`, `scipy`, and `cv2` libraries. For automation, both the first and second methods use freely distributed software and a control .bat file running in the operating system console. The frame brightness levels that start the process of switching the camera operation mode have been established empirically, and two additional camera operation configurations have been formed and saved.

Figure 1 shows a graph of the change in brightness of the images obtained with a periodicity of 10 minutes during a day by the camera pointed to the BTA from the Zeiss-1000 site. The images were obtained on February 27, 2023, using the first method of changing the camera operation mode.

Figure 2 shows a graph of the change in brightness of the images obtained under the same conditions, but using the second method of changing the camera operation mode. The peak in frame 11 is the illumination from the headlights of a passing car; in the interval between frames 33–48, as well as between frames 120–130, the periodicity was not 10, but 5 minutes. The images were obtained on March 28, 2023.

Applying the first method has a number of disadvantages: a complex implementation of the reference to the time of sunset, which changes throughout the year, as well as a long interval at the moment of switching modes with insufficient or excessive image brightness. Based on the graphs, it can be seen that the second method gives totally a 2–2.5 times shorter interval with insufficient or excessive image brightness during the twilight period per day.

A simplified version of the method of linking the last obtained image to the calculated brightness level is also used in processing the image of the Zeiss-1000 dome. This method

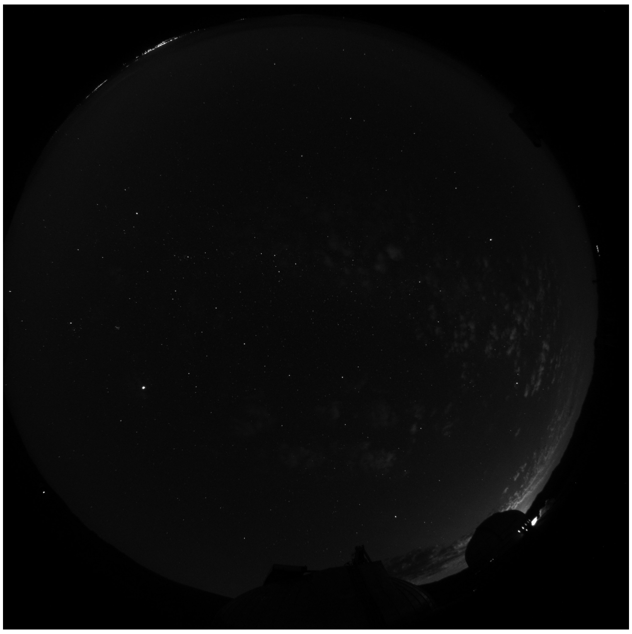

Fig. 5. Image of the Miratlas night sky survey system without processing with `ImageMagick` software.

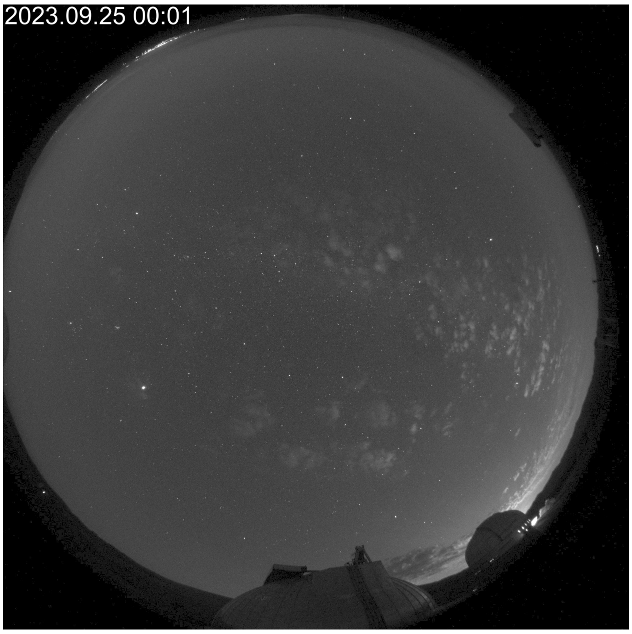

Fig. 6. Image of the Miratlas night sky survey system processed with `ImageMagick` software.

is applied in conjunction with the use of freely distributed `ImageMagick` software to lighten frames obtained in low-light conditions. This software also functions in the operating system console. Images of the Zeiss-1000 dome before and after processing with this software are shown in Figs. 3 and 4, respectively.

The same freely distributed software is also used to lighten frames obtained with the modern night sky survey system from the Miratlas company based on the Basler CMOS matrix. To display the date and time on the obtained image, this software is used together with a script for obtaining the date and time of file creation, launched by a bat file. Images of the entire sky obtained by this system before and after processing are shown in Figs. 5 and 6, respectively.

3 Method for calculating image quality (seeing) from a series of images of the Polar star

Having the ability to convert images obtained with IP cameras to the .fits format, we open up additional methods for studying various parameters of star images. Thus, we acquired an IP camera with a Sony IMX335 CMOS matrix with a resolution of 2592×1944 pixels, a 4/3 image format, and a lens with the focal length (FL) = 63.5 mm, with a field of view H = 4.7° and V = 3.5°.

Calculations show that when using this camera and lens, one pixel in the resulting image has an angular size of $\approx 6.5''$. A housing for this camera, made of weather-resistant materials, was designed and manufactured, as shown in Fig. 7.

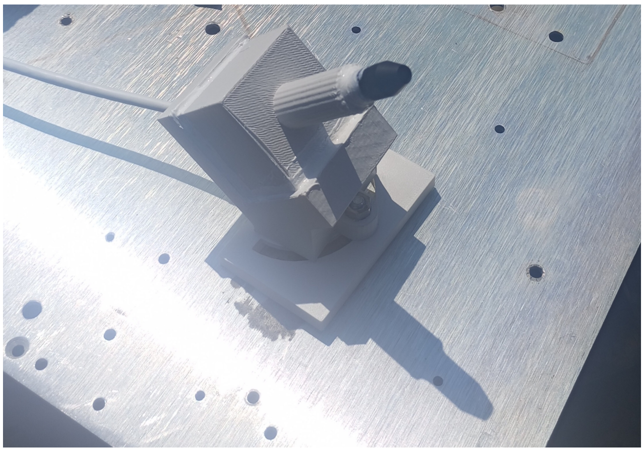

Fig. 7. Camera housing, with dimensions not exceeding $10 \times 10 \times 10$ cm.

Using `Python` libraries (`numpy`, `scipy`, `matplotlib`, `os`, `pylab`, `astropy`), the star's center (centroid) and the full width at half maximum (FWHM) were calculated from the converted to the `.fits` format images obtained with this camera, pointed to the Polar star. Based on the obtained results, we calculated the values of astronomical visibility due to the state of the atmosphere (seeing) and the Fried radius (r0). Having these values and knowing the latitude at which the camera is installed, it is not difficult to calculate the seeing and r0 values at the zenith. To reduce the influence of diurnal aberration on the obtained values to negligible magnitudes, for these calculations it is required to have a series of images with short intervals between them and short exposures, which can be obtained by cameras with CMOS matrices.

Figure 8 shows an enlarged image of the Polar star obtained with this camera. The elongated image indicates that it is a binary star with a distance between the components of ≈ 2.5–3 pixels or $\approx 18''$.

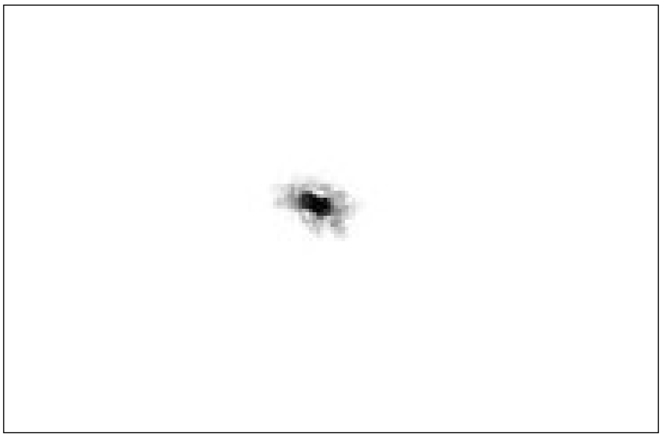

Fig. 8. Image of the Polar star.

```
D =  0.004 (m)
F =  0.0635 (m)
Pixel =  2.0 (um)
Latitude =  43 (deg)
Scale =  6.496535433070866 (arcsec/pix)
Frames: 99
STDV_X= 0.185 (pix)
STDV_Y= 0.145 (pix)
Rf polar = 0.072 (m)
Seeing polar = 1.544 (arcsec)
Rf zenith = 0.091 (m)
Seeing zenith = 1.227 (arcsec)
```

Fig. 9. Result of studying a series of images.

Figure 9 shows the result obtained on the example of a series of 100 images with an exposure of 0.1428 s and delays between images of 4 s for August 4, 2023; the camera is installed on the roof of the SAO RAS laboratory building.

The obtained data correlate with the observation data for this night, which allows using the method in practice.

We also note that the panorama method is used to obtain an image of the entire celestial hemisphere by applying the freely distributed set of utilities and libraries `Panorama Tools`, developed by Professor of Physics and Mathematics Helmut Dersch (HFU Furtwangen). This method is used in image processing of the 3D monitoring system of the celestial hemisphere and allows reducing image distortions relative to the visually observed picture, as well as increasing the image quality for the used camera/lens pair (Fokin et al., 2022).

4 Conclusions

The technologies used in the production of CMOS matrices in the past decade have made it possible to create inexpensive IP cameras with acceptable characteristics for operation at night. Applying IP cameras allows using more unified methods of information transfer, which simplifies the topology of systems and therefore has good potential. The methods and calculations described in this paper allow obtaining more information for monitoring the night sky near the UOA of SAO RAS and also have the potential for use in amateur astronomy, since they are applicable to mass-produced cameras and can be implemented on the basis of the widely used `Windows OS`.

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