Cloud Cover Measurement from All-Sky Nighttime Images

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Abstract. The site quality of astronomical observatory critically depends on cloud coverage, and the measurement of cloudiness is particularly important for site survey. A method to deal with all-sky images in no-moon nights is described. By identifying the positions of bright reference stars and making photometry for a set of all-sky images in clear nights, we can set up a reference image with median smoothing differential magnitude values. The standard image can be taken as the threshold for clear nights, and the detectivity of stars on other images can be utilize to reveal cloud coverage. Four types of all-sky images, clear night, icy lens, part of cloud, and full of cloud, are selected to check up the method. For the moonlight image, the formula of the CIE (Commission International de l'Éclairage) standard general sky model are used to fit the luminance distribution of the image, then to estimate the cloud cover of the image from the difference between the fitting image and the real image.

1. Introduction

The cloudiness is one of the most important parameters for evaluating the quality of the astronomical site. In recent years, the all-sky-camera is widely used to monitor the cloudiness in site testing campaign. The cloudiness image taken with the camera has a higher spatial resolution, and its analyzed result can accurately determine the local cloudiness and the characteristics of its variation. For the project of the astronomical site survey in Western China, the all-sky camera is actively adopted to make the monitoring and analysis of the cloudiness over the observatory and candidate site, such as Gaomeigu observatory, Karasu, Oma and Ali sites.

However, the methods for automatically processing the cloudiness images are quite few and remain to be deeply researched, and the cloudiness itself also lacks a clear and united quantization standard. As for the daytime cloudiness images, the luminance ratio of the blue wavelength to the red wavelength (B/R) is used to distinguish the cloud and clear sky[1], due to there exists the difference in the light scattering between cloud and atmosphere. As for the nighttime cloudiness images, the threshold cutting of B/R is not enough to distinguish the cloud and the night sky. By means of a more glancing method the images are made into the corresponding animated cartoon and the cloud cover is judged with the naked eyes[2], but the influence of the artificial factors can not be neglected. Smith et al. proposed a kind of more accurate method, the cloud cover is judged from the extinction of atmosphere or opacity of cloud, which obtained by the photometry of the bright background stars[3-4]. However, this method needs a lot of clear-night images to be accumulated as the standard image to compare.

Based on the cloudiness data of Gaomeigu observatory, we had developed the effective method to determine the cloudiness of night image. The photometry method of bright stars and the CIE model are adopted for the no-moon image and the moonlight image, respectively.

2. Cloud monitoring and image processing

The SBIG All-Sky-340 camera is adopted as the cloud monitor. The field of view (FOV) of the SBIG All-Sky-340 camera is 140°×185°, of which the CCD system has a very high sensitivity. The exposure time is automatic adjustment, and the brightness variation of stars or the fluctuation of sky luminance with moonlight can be detected.

2.1. The no-moon image

The all-sky camera adopts the fixed-point photography mode, the coordinates of the bright stars in the image are correlated to the earth's rotation and geographical position, therefore, the astronomical position of a bright star can match its position in the image through a coordinate transformation. The matching method proposed by Pickering[5], which can be used to carry out the coordinate transformation between the image and the catalogue.

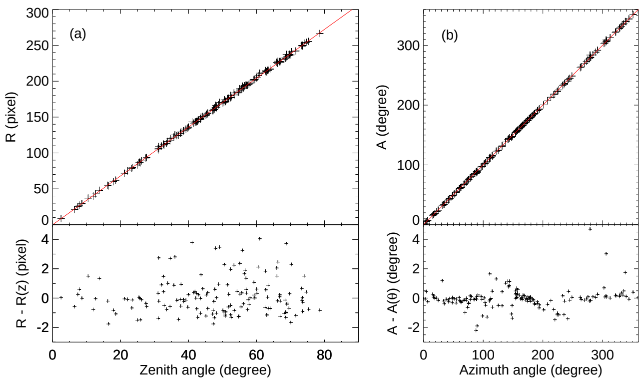

Figure 1. Comparison between the fitting position of the bright star in the image and its horizontal coordinates converted from the catalogue. (a) the comparison between the polar distance of the bright star and the zenith distance, (b) the comparison between the two groups of azimuthal angles.

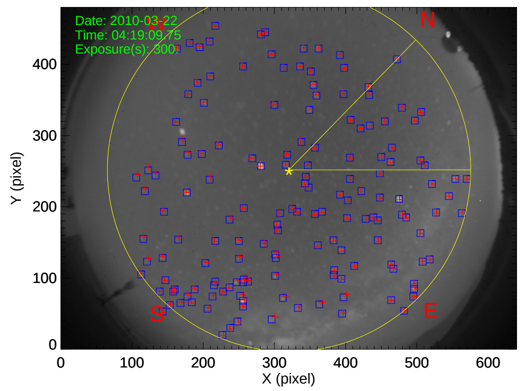

Figure 2. Comparison between the fitted result of the bright stars and the actual coordinates, where the blue square and red sign "+" show the actual coordinates of the bright stars and the fitted result, respectively.

The right ascension, declination, apparent magnitude and name of the bright stars are obtained from the Yale bright star catalogue. The bright stars selected from the catalogue are converted from the equatorial coordinates (α, δ) into the horizontal coordinates (A, h or z). In the image, the polar distance R from the center of the image has a linear relation to the zenith distance z, and a constant offset exists between the polar angle θ and the azimuthal angle A. Thus, the corresponding relation between the polar coordinates (R, θ) and the image coordinates (x, y) can be given as follow:

$$R = a \times z, \tag{1}$$
$$\theta = \theta_{\text{off}} - A, \tag{2}$$
$$x = x_0 + R \times \cos\theta, \tag{3}$$
$$y = y_0 + R \times \sin\theta. \tag{4}$$

(x_0, y_0) indicates the coordinates of the zenith in the image, θ_{off} is the constant offset.

Fig.1(a) shows the comparison between the two sets of coordinates of the bright stars, the abscissa is the horizontal coordinate converted from the Yale catalogue and the ordinate is the polar coordinate converted from the image coordinate. In Fig.1(b) the ordinate is $A = \theta_{\text{off}} - \theta$, which corresponds to the azimuthal angle of the bright stars. The comparison is also shown in Fig.2, with circle $z = 75°$ and the acute angle θ_{off}.

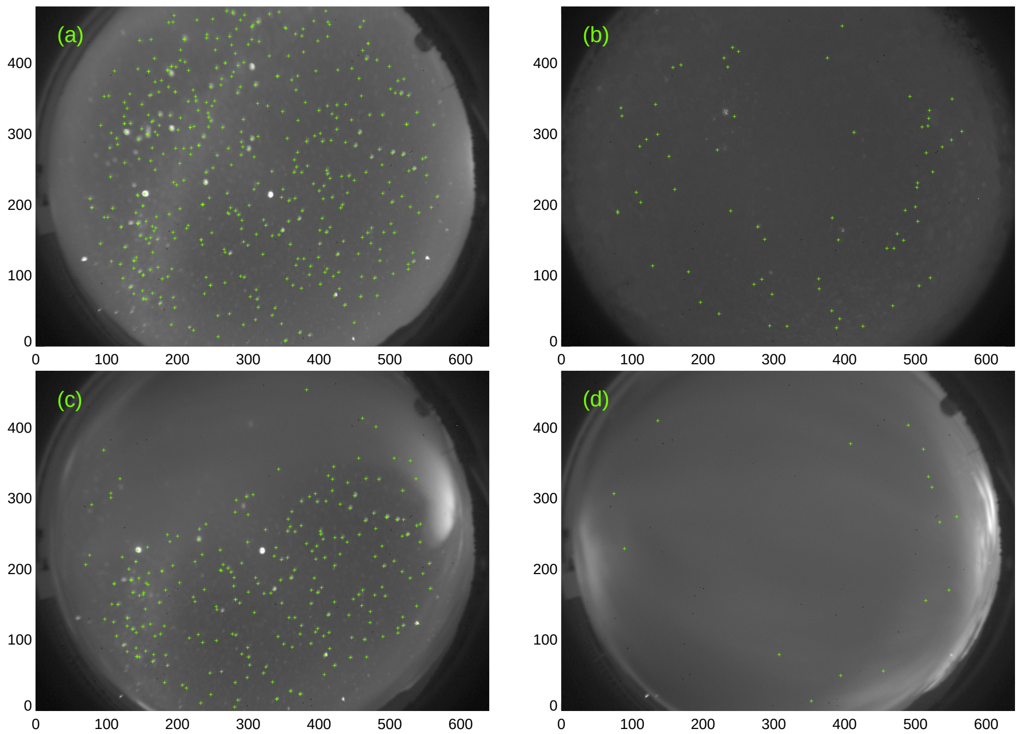

Figure 3. The test images with detected stars: (a) clear-night image, (b) the icing lens, (c) part clouds and (d) full of clouds, respectively.

Based on the matching method, most bright stars of the catalogue can be easily found in the all-sky image, and then be estimated the photometric magnitude (m_{phot}) of the bright point at its position. The magnitude difference of the stars can be calculated as formula $\Delta m = m_{\text{phot}} - m_{\text{tab}}$, m_{tab} can be obtained from the catalogue. The magnitude difference Δm of a few clear night images are computed to construct the reference image, which reflects the atmospheric extinction on the position of the bright star for the clear image. The difference Δm of the other position (pixel) in the reference image is obtained from the median value of Δm at 30 adjacent position.

After the reference image is constructed, the absorption of clouds can be described as formula: $A_{\text{cloud}} = \Delta m - \Delta m_{\text{std}}$. Δm_{std} is the corresponding value of Δm in the reference image. For the clear-night images, the statistical distribution of A_{cloud} exhibits the standard normal distribution. The Gauss fitting on the A_{cloud} distributions of the clear-night images is carried out, and then the mean σ is calculated. For the images with clouds, their A_{cloud} distributions is slant to the right side, not a standard normal distribution. The 3σ value is taken as the threshold to distinguish the bright stars, which become dimmer for the absorption of cloud or not be affected (N_{good}). Therefore, the cloudiness of one cloud image can be represented as $P_{\text{cloud}} = 1 - N_{\text{good}}/N_{\text{std}}$, N_{std} is the average value of the N_{good}, which is obtained from the clear night images.

There are 4 sorts of cloudiness images selected to test the usability of the above-mentioned method, including the clear image, the image with icing lens, the image with part clouds and the image full of clouds. Fig.3 shows the result of detected bright stars for 4 types of images, the cross sign "+" expresses the position of the detected star which satisfies the threshold condition.

2.2. The moonlight image

The night-time images with moon are seriously affected by the moonlight, especially for the full moon time. The bright stars can not easily to extract from the image with moon, and can not be used to estimate the cloudiness of the image. If one can get the luminance distribution of the sky with moonlight, the cloud cover can be determined by the difference between the luminance distribution and the cloudiness image. Krisciunas[6] proposed a model of brightness of moonlight, which is a function of the Moon's phase, the zenith distance of the Moon, the zenith distance of the sky position, the angular separation of the Moon and sky position, and the local extinction coefficient. The IDL software package is adopted to fit the model of the moonlight and a clear night image, but the difference between the fitting result and the night image is not good enough to distinguish the cloudiness.

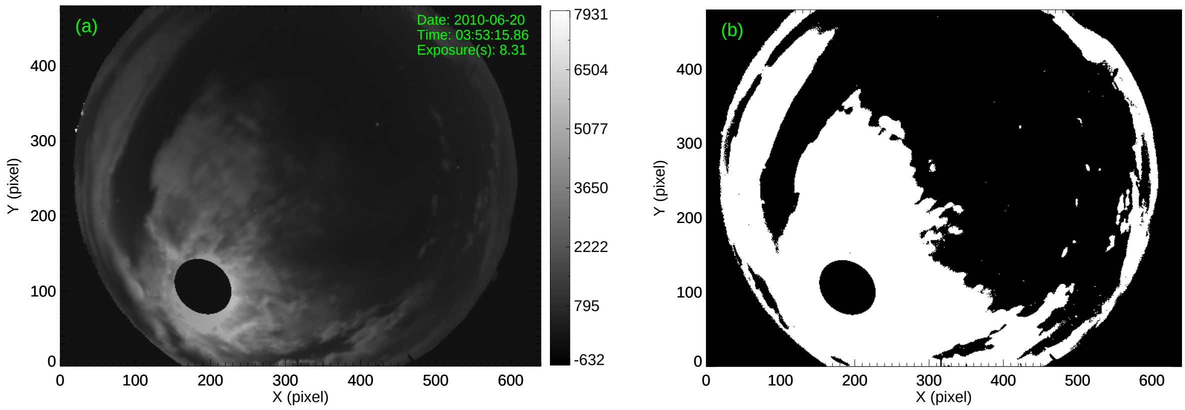

Figure 4. (a) The selected cloud image with moon, (b) the binary image obtained from the difference between the CIE model and the cloud image.

For the nighttime luminance of moon from the sunlight reflected, there is a similar luminance distribution between the moonlight and the daylight. The CIE standard general sky model is considered to carry out the moonlight distribution, like the moonlight model, to estimate the cloud cover by the difference between the fitting result and the cloudiness image [7-8]. The formula of CIE model as following :

$$L_\mathrm{s} = \frac{(1 + C(e^{D\chi} - e^{D\pi/2}) + E\cos^2\chi)(1 + Ae^{B/\cos z_\mathrm{s}})}{(1 + C(e^{Dz_\odot} - e^{D\pi/2}) + E\cos^2 z_\odot)(1 + Ae^{B})} \cdot L_z, \tag{5}$$

and,

$$\chi = \arccos(\cos z_\odot \cos z_\mathrm{s} + \sin z_\odot \sin z_\mathrm{s} \cos(|A_\odot - A_\mathrm{s}|)). \tag{6}$$

where, χ is the distance of sky element from the sun, $(A_\odot,\ z_\odot)$ and $(A_\mathrm{s},\ z_\mathrm{s})$ indicates the horizontal coordinates of the sun and the sky element, respectively. The L_z is the zenith luminance of the clear night image. The parameters A, B, C, D, E of the CIE model is determined by the comparison between the fitting result and a clear image with moon, which similar to the parameters of CIE standard clear sky with low illuminance turbidity. With the fitting parameters, the reference image is computed from the formula of the CIE model for one moonlight image with cloud. Fig.4(a) shows the difference between the reference image and the moonlight image. A certain threshold is set to distinguish the cloudiness, and get the binary image (as shown in Fig.4(b)).

3. Conclusion and discussion

We develop a method to estimate the cloudiness of the all-sky nighttime image without moon, and the feasibility of this method is tested by four types images. The result of testing shows that the cloud cover in the no-moon image can be determined effectively by the method. For the image with moon, we try to use the CIE model to estimate the cloud cover of the image. The difference between the clear sky luminance of the CIE model and the cloud image mainly caused by the cloud cover, which can be used to estimate the cloudiness of the image.

The determination of the cloudiness still exists some deviation, such as the unstable atmospheric conditions. As the no-moon image, the photometry method is accurate enough to quantize the cloudiness, the simplification of atmospheric extinction will be better. As the image with moon, the CIE model can be used to estimate the cloudiness of image, while the zenith luminance of image need to been obtained, which is difficult to the image with cloud. Moreover, a reasonable approach should be develop to obtain the certain threshold to distinguish cloud cover.

Although the photometry method or sky models can be used to estimate the cloudiness of images, the processing is not easily and directly. If more characteristic of the cloud can be given in the image, including multi-band information, light polarization, absorption of cloud, etc, the statistics of the cloudiness will be easier and more accurate than just using the grey level information.

Acknowledgments

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