Design and Implementation of the All-Sky Cloud Monitoring System at Shenzhen Observatory (Postprint)

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Abstract

All-sky cloud monitoring is crucial for astronomical observations. Currently, most observatories have installed real-time cloud monitoring cameras, but a common challenge is achieving correct exposure under conditions with significant lighting variations. To address this issue, the Shenzhen Astronomical Observatory has independently developed an imaging control system that calculates an exposure value index curve based on the camera's available shooting parameters, adopts 0.3 as the exposure value error tolerance, captures correctly exposed all-sky cloud images under various environments with large brightness variations, and employs the maximum inter-class variance adaptive threshold algorithm for effective cloud identification. Extensive testing demonstrates that the system can capture correctly exposed cloud images under environments with large and rapid brightness variations, providing significant convenience for astronomical observation planning.

Full Text

Preamble

Design and Implementation of the All-Sky Cloud Monitoring System at Shenzhen Astronomical Observatory

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Abstract

All-sky cloud monitoring is essential for astronomical observation. While most observatories have installed real-time cloud monitoring cameras, a common challenge remains achieving correct exposure under highly variable lighting conditions. To address this issue, the Shenzhen Astronomical Observatory has independently developed a capture control system that calculates an exposure value (EV) index curve based on the camera' s available shooting parameters, using an exposure error tolerance of 0.3 to capture properly exposed all-sky images across various environments with significant brightness variations. The system employs the maximum interclass variance adaptive threshold algorithm for effective cloud identification. Extensive testing demonstrates that the system successfully captures correctly exposed cloud images in environments with large and rapid brightness changes, providing substantial convenience for astronomical observation planning.

Keywords: all-sky camera; automatic shooting; exposure parameters; cloud identification; image processing

1 Current Status and Limitations of All-Sky Cloud Monitoring

A critical challenge in all-sky cloud observation is achieving correct exposure under complex, changing environmental conditions with large variations in light intensity. Currently, cameras' built-in auto-exposure programs cannot adequately solve this problem. For example, Canon provides the EOS Utility software[1], which supports computer control of exposure parameters including shutter speed, aperture, ISO, and white balance, enabling interval shooting with sequential storage to designated directories. When the camera is set to automatic mode, the software adjusts exposure parameters based on the camera' s built-in metering. While this yields properly exposed images during well-lit daytime conditions, it results in overexposure or underexposure during periods of significant sky brightness variation such as sunrise and sunset, and particularly fails to produce correctly exposed images at night. [Figure 1: see original paper] and [Figure 2: see original paper] show sequences of overexposed and underexposed cloud images captured using the camera' s built-in metering program.

To compensate for these limitations in camera auto-exposure programs, Chinese observatories currently employ three main correction methods: (1) **Preset fixed exposure parameters**, which uses two predetermined exposure settings for daytime and nighttime respectively. While this yields correct exposure for day and night, it fails during sunrise and sunset transitions. This method is used by the all-sky cloud monitoring camera at the Xinglong Observatory of the National Astronomical Observatories, Chinese Academy of Sciences[2]. (2) **Sky brightness prediction**, which calculates the positions of the Sun and Moon based on geographic coordinates, altitude, date, and time to derive a sky brightness value and establish an exposure curve. This method only works for clear skies and fails during cloudy conditions or when light pollution is present. (3) **External light metering**, which uses a photometer to measure ambient brightness changes and automatically adjust camera exposure parameters for accurate results. The Lijiang Astronomical Observatory of Yunnan Observatories developed a control program using real-time sky brightness measurements to achieve correct exposure throughout 24 hours[1].

2 Design and Implementation of the All-Sky Cloud Monitoring System at Shenzhen Astronomical Observatory

The Shenzhen Astronomical Observatory has independently developed a capture control system that calculates an EV index curve based on available camera parameters, using an exposure error tolerance of 0.3 to capture properly exposed all-sky cloud images under various conditions with significant brightness variations, and employs the maximum interclass variance adaptive threshold algorithm for effective cloud identification.

2.1 System Architecture

The all-sky cloud monitoring system at Shenzhen Astronomical Observatory consists of three components: an all-sky camera, a capture control system, and a cloud identification system. The all-sky camera captures real-time all-sky images, the capture control system automatically adjusts shooting parameters, and the cloud identification system performs cloud discrimination on captured images. Monitoring results are published through multiple service channels including the Shenzhen Astronomical Observatory website[3], Shenzhen Integrated Meteorological Monitoring Business Platform, Shenzhen Astronomical WeChat account, and mobile App. [Figure 3: see original paper] illustrates the system architecture.

2.2 All-Sky Camera Installation

The Shenzhen Astronomical Observatory is located on the Nan' ao Peninsula in Dapeng New District, Shenzhen, Guangdong Province, 80 km from downtown, at geographic coordinates 22°28.94 N, 114°33.36 E, with an altitude of 170 m. Surrounded by the sea on three sides (east, south, and west) with no obstructions, the observatory installed the all-sky camera atop an outdoor water tank at its highest point. The system uses a Canon EOS 5D Mark II DSLR camera with a Canon EF 8-15mm f/4.0 zoom fisheye lens fixed at 8 mm focal length, providing 180° diagonal coverage. To ensure all-weather operation, the camera and a control microcomputer are housed in a protective enclosure with a 20 cm diameter hemispherical glass dome on top. The dome and side seals are waterproof, with ventilation openings at the bottom. A spiral 导流 fan inside the enclosure dissipates heat from the camera and microcomputer, maintaining consistent internal and external temperatures to prevent overheating or dome condensation. Captured images are transmitted via fiber optic to a remote server. [Figure 4: see original paper] shows the outdoor installation.

2.3 Exposure Parameter Configuration Based on EV Index

To obtain correctly exposed all-sky cloud images, the system pre-calculates exposure values based on the camera' s available aperture, shutter speed, and ISO parameters using the exposure value formula[2]:

$$EV = \log_2\left(\frac{F^2}{t}\right) + \log_2\left(\frac{ISO}{100}\right)$$

where EV is the exposure value, F is the aperture value, t is the shutter speed, and ISO is the sensitivity. By combining all available camera parameters, calculating their EV values, and sorting them by magnitude, an exposure parameter table () and EV index curve ([Figure 5: see original paper]) are generated. The difference between adjacent values on this curve yields the EV variation range ([Figure 6: see original paper]), with an exposure error tolerance of 0.3.

During operation, the system first captures an image using predetermined parameters and calculates its exposure value (EV_{ref}). The error is computed as:

$$\Delta EV = EV_{ref} - EV_{target}$$

If the error falls within the allowable range, the image is saved as the final result. If the error exceeds the range, the system looks up the correct exposure parameters from the EV index curve and recaptures the image. Extensive testing demonstrates that this method yields correctly exposed cloud images across various environments and during periods of rapid brightness change. [Figure 7: see original paper] and [Figure 8: see original paper] show correctly exposed images at night and during daytime, while [Figure 9: see original paper] through [Figure 12: see original paper] present correctly exposed image sequences during sunrise transition, sunset transition, midday direct sunlight, and nighttime.

2.4 Cloud Detection in All-Sky Images

Numerous studies have addressed automatic cloud detection in all-sky camera images. Reference[3] introduced a digital method for daytime cloud amount observation using appropriate radiation ratio thresholds for accurate cloud amount determination. Reference[4] proposed two methods for calculating cloud amount based on image histogram theory and threshold segmentation, both effective for daytime cloud images. This paper adopts the maximum interclass variance adaptive threshold algorithm proposed in reference[5] for daytime cloud identification.

Due to the fisheye lens distortion, preprocessing is required before cloud detection: the original image (2785×1856 pixels) is cropped to 1900×1800 pixels, non-sky portions are masked (pink regions), and the remaining pixels are divided into small grids for individual cloud judgment. The detection workflow is shown in [Figure 13: see original paper].

Example Process: (1) The original image is cropped from 2785×1856 to 1900×1800 pixels. (2) Non-sky regions are excluded (pink mask). (3) The adaptive threshold T is calculated for the entire image using Otsu' s method (in this example, $T = 167$). (4) Each pixel is evaluated: if the blue-red ratio meets cloud criteria, it is directly classified as cloud; otherwise, the pixel grayscale value is compared with threshold T, with values below T classified as cloud. (5) The proportion of cloud pixels is calculated (72.93% in this case), corresponding to 8/10 cloud cover. After cloud detection, image metadata including capture time, ISO, aperture, exposure time, cloud amount value, and filename are stored in the database, with processing executed every 10 minutes.

Since its deployment, the all-sky cloud monitoring system at Shenzhen Astronomical Observatory has operated stably, capturing correctly exposed all-sky images across all time periods and weather conditions, providing effective support for astronomical observations and quality control references for observational data. During significant astronomical events such as meteor showers, the system can adjust shooting intervals to record important phenomena—[Figure 14: see original paper] shows a captured fireball meteor. The observatory also operates a sky imager providing daytime low-resolution cloud images, cloud amount, and cloud height information, which will be used for future cross-reference and data calibration.

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[2] http://www.xinglong-naoc.org/weather/yuntu.jhtml
[3] http://www.szmb.gov.cn/yljc/

Note: Figure translations are in progress. See original paper for figures.