

Chang' e-2 CCD Stereo Camera Image Quality Analysis Postprint

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Abstract

Chang' e-2 satellite, as China' s second successfully launched lunar probe, obtained full lunar coverage 7m resolution images through its onboard CCD stereo camera during on-orbit operation, providing lunar scientists with important fundamental research data. A comprehensive analysis of the image quality of the CCD stereo camera was performed to provide reference for subsequent data processing algorithm selection, image data interpretation, and scientific data application. From an objective image evaluation standpoint, it was concluded that the image quality of Chang' e-2 images is comparable to that of existing foreign data of the same resolution. The analysis emphasized several quality issues requiring attention, such as the obvious regional characteristics present in Chang' e-2 images, quality degradation due to image compression, the existence of certain striping noise, and large image positioning deviations between adjacent orbits. These quality issues require focused attention in subsequent image processing.

Full Text

Image Quality Analysis of the Stereo Camera of Chang' e-2 Lunar Satellite

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Abstract

The CCD stereo camera carried by Chang' e-2, China' s second lunar probe satellite, successfully scanned full coverage of the lunar surface at 7m spatial resolution during its operation. Those images serve as important foundational data for lunar scientific research. However, until now, most studies have paid little attention to its quality issues, which could introduce errors and uncertainties in subsequent analysis, such as image processing algorithm selection, image interpretation, and scientific data application. In this study, we conducted a comprehensive objective assessment on the image quality of the CCD stereo camera. We found that the quality of images captured by Chang' e-2 is equivalent to that of foreign satellites at the same spatial resolution. We also analyzed several quality issues that need special concern in subsequent image processing, such as distinct geographic patterns existing in Chang' e-2 images, image compression-induced quality reduction, stripe noises, and large location deviation between adjacent images.

Keywords: Chang' e-2; CCD stereo camera; Image quality; Moon

1. Introduction

Chang' e-2 satellite, as the technical pathfinder for China' s second-phase lunar exploration program, was successfully launched from the Xichang Satellite Launch Center and directly injected into a trans-lunar trajectory. After two mid-course corrections, it smoothly entered a lunar orbit with an altitude of 100 km. One of its important mission objectives was to conduct high-resolution imaging experiments at 100 km orbit altitude. The two-line array CCD stereo camera on Chang' e-2 successfully captured forward and backward perspective images of the lunar surface. On October 1, 2010, the CCD stereo camera was powered on for the first time and successfully acquired image data from two perspectives. The camera completed its full lunar imaging mission in 2010.

2. Camera Design and Key Technologies

The CCD stereo camera is one of the main payloads onboard Chang' e-2 satellite, utilizing Time Delay and Integration Charge Coupled Device (TDI-CCD) technology to capture forward and backward perspective image strips along the satellite flight direction through push-broom imaging. The camera' s technical specifications include a pixel size of $10.1 \mu\text{m} \times 10.1 \mu\text{m}$. At an orbital altitude of 100 km, the spatial resolution is approximately 7 m with a swath width of about 43 km. At 15 km altitude, the spatial resolution is approximately 1.5 m with a swath width of about 9.2 km.

The two line arrays share a single optical system, with the camera optical axis parallel to the satellite body coordinate system Z-axis and installed on the focal plane. The spatial resolution varies with orbital height. The camera provides five levels of integration at 100 km altitude and five compression modes (un-compressed, 2.0-bit, 1.5-bit, 1.0-bit, and 0.7-bit). The integration level and gain

settings are determined by illumination conditions and the average reflectance of the lunar surface.

The schedule for the opening session of CE-2 CCD stereo camera

3. Data Acquisition

During the in-orbit testing phase, the two-line array CCD stereo camera on Chang'e-2 was first powered on and successfully acquired forward and backward perspective image data. The satellite entered a $100 \text{ km} \times 15 \text{ km}$ elliptical test orbit for 15 days, acquiring orbital image data. From October 24 to November 1, 2010, the camera conducted high-resolution imaging experiments on candidate landing sites for the Chang'e-3 mission. Starting November 2, 2010, the satellite officially entered long-term management operations. The CCD stereo camera achieved complete coverage of all areas under the existing orbital inclination, except for the polar regions, with some small gaps in the orbital data.

In 2011, the CCD stereo camera completed gap-filling for 14 locations during the first coverage process, achieving full lunar image coverage. The satellite then entered an extended mission phase, which included adjusting the orbital inclination parameters to fill polar gaps and conducting additional high-resolution imaging of the Sinus Iridum region at 15 km altitude. The camera acquired additional orbital image data before the satellite departed for the Lagrange point.

4. Image Quality Analysis and Comparison

Image quality represents people's subjective visual response to an image. Evaluation methods can be divided into subjective and objective approaches. Subjective evaluation uses human visual effects as criteria, where observers judge image quality. Objective evaluation uses mathematical models to quantitatively express human subjective perception. While subjective methods generally align better with visual effects, they are influenced by human factors. Objective methods, being theoretically rigorous, quantitatively analyze image quality through mathematical calculations to obtain scientific metrics.

This study evaluates Chang'e-2 stereo camera image quality from an objective perspective. Common objective quality metrics include grayscale mean, grayscale dynamic range, information entropy, and edge intensity. To comprehensively evaluate Chang'e-2 images, we selected reference data with identical imaging areas and similar conditions, calculating objective evaluation metrics for both Chang'e-2 and reference images.

For the 100 km altitude 7 m resolution images, we selected Chang'e-2 orbital data and compared it with Japanese SELENE (Selenological and Engineering Explorer) 7.4 m resolution images of the same geographic location near the Apollo 15 landing site. For the 15 km altitude 1.5 m resolution images, we

compared Chang' e-2 data with US Lunar Reconnaissance Orbiter (LRO) 1.5 m resolution images of the Sinus Iridum region.

The objective image quality evaluations of CE-2 and Kaguya

The objective metric comparison results indicate that Chang' e-2' s 7 m resolution images acquired at 100 km altitude are comparable to SELENE data in information entropy, while surpassing SELENE in grayscale mean and edge intensity. The 1.5 m resolution images from 15 km altitude show equivalent objective evaluation metrics to LRO' s 1.5 m resolution images.

5. Key Quality Issues

Several quality issues in Chang' e-2 images require attention during subsequent processing and application:

5.1 Regional Characteristics of Lunar Images Compared with Earth remote sensing images, lunar images have lower albedo and contrast. The lunar surface has uniform terrain types, with texture information primarily formed by illumination shadows of impact craters, rilles, and other topographic features. Texture characteristics vary significantly with illumination conditions.

Lunar images exhibit distinct geographic patterns. Highland images show better performance in brightness, image hierarchy, and clarity compared to mare images. Analysis of test areas with different lunar terrain characteristics reveals that, regardless of highland or mare regions, image quality in high-latitude areas is better than in low-latitude areas. When selecting image processing algorithms, these regional characteristics must be fully considered.

[Figure 3: see original paper] The comparison of images captured at the highland (left) and the mare (right)

5.2 Image Compression and Noise Issues Chang' e-2 images employ on-board compression, causing noticeable quality loss in some regions after ground decompression. The images contain both band-pass noise and random noise, with noise levels higher in mare regions than in highland areas. Subsequent processing must consider image denoising and enhancement. For instance, when selecting image matching algorithms, it is essential to choose methods with robustness against noise.

[Figure 4: see original paper] The comparison of images captured at the highland (left) and the mare (right)

The average value of the objective image evaluation indicators for the CCD stereo camera

5.3 Adjacent Orbit Position Deviation Satellite orbit and attitude stability and measurement accuracy significantly impact image quality and geometric

positioning precision. To evaluate these effects, we systematically analyzed orbit and attitude data provided by the TT&C system during satellite operation.

We selected orbital data from orbit numbers [range not specified in text], which cover 99.4% of the Moon except the poles. Overlap between adjacent orbital images increases with latitude, from approximately 14% at the equator. We extracted 2,667 uniformly distributed homologous points from overlapping regions to analyze relative positioning errors between adjacent orbital data.

The average positioning deviation is 187.690 m, with a standard deviation of 211.518 m. The maximum deviation reaches 1,880 m, dozens or even hundreds of times the original image resolution. This far exceeds the pixel-level mosaic requirement of 0.411 m. Therefore, image data requires geometric registration processing based on geometric positioning.

[Figure 5: see original paper] The stripe noises in the regional image of CE-2

[Figure 6: see original paper] The spatial distribution of the location deviation in the initial positioning between adjacent images

6. Conclusions

This study objectively evaluated Chang' e-2 image quality, demonstrating that the camera data has good application prospects. However, original image quality exhibits regional characteristics and several quality issues requiring focused attention in subsequent processing, particularly in image matching algorithm design. The average adjacent orbit image plane position deviation is 188 m, dozens or even hundreds of times the original image resolution. Using raw satellite orbit and attitude data cannot achieve seamless mosaic and high-precision absolute positioning of full lunar image data. Subsequent processing should employ photogrammetric adjustment methods to optimize raw orbit and attitude data, improving relative and absolute positioning accuracy to meet various application requirements.

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