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General Design of space Optical Remote Sensing Camera Based on High-precision Surveying and Mapping Requirements

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ABATRACT

Space mapping satellites play an increasingly important role in Space mapping satellites play an increasingly important role in mapping and mapping. The positioning accuracy of mapping satellites is the core and key index for evaluating the performance of Surveying and mapping. At present, it has developed to the precision of the meter level. Therefore, in the design process of Surveying and mapping camera, it is not only necessary to ensure that the image has good MTF, signal to noise ratio, dynamic range and other basic radiation characteristics, but also need to focus on the high precision calibration of the interior orientation elements of optical system distortion, optical axis, focal distance and other questions of orbit stability.

In 2012 and 2016, China successfully launched ZY-3 (01/02) satellites, with a three-line-arrays camera and a multispectral camera. It is mainly used for the production of basic geographic information products of 1:50000 scale, and modification and updating of 1:25000 and larger scale topographic maps in China. The satellites have achieved good application results. Based on these experiences, driven by higher precision surveying and mapping requirements, as the main development and research organization of the Chinese space optical remote sensing camera, BISME has carried out a serial of research in the overall design of the space optical surveying camera. This paper gives some own views about the research for discussion and exchange.

Keywords: High-precision Stereoscopic mapping camera System design

1. INTRODUCTION

Surveying and mapping plays an important role in all aspects of economic development, national infrastructure construction and national defense construction. Especially in the overall and strategic level, most of them need to apply geospatial information. Geospatial information acquired through surveying and mapping technology has become an important strategic resource. Because space photography is faster, cheaper and unrestricted by regions and borders, countries around the world are scrambling to develop their own mapping satellites.

Space mapping cameras are developed with the continuous application of Surveying and mapping technology in the field of space technology. It has gone through two stages: film imaging and digital imaging. Film imaging requires the use of satellite return technology to obtain images captured on orbit. So there are shortcomings such as short orbit time and unable to get real-time images. With the rapid development of optoelectronic technology, the digital surveying and mapping satellite with CCD linear array as the detector has become the main development direction[1].

Typical surveying and mapping satellites in the world such as MOMS in Germany, SPOT-5 in France, ALOS of Japan, CARTOSAT-1 in India and ZY-3 in China and so on. These satellites have the ability to produce 1:50000 to 1:25000 scale topographic maps. And with the dramatic improvement of the attitude maneuver ability of remote sensing satellites, some satellites using single line array detectors can also achieve stereoscopic mapping through fast attitude excitement. Such as IKONOS, WORLDVIEW-1/2, GEOEYE-1. With the support of ground control points, 1:25000 or even larger scale topographic maps can be drawn.

Space-borne stereo mapping camera is mounted on the spacecraft and takes photograph of planets' surface far away from the earth. In this way various map, digital surface model as well as orthophotograph can be obtained efficiently at lower costs. Film-based space-borne stereo mapping cameras have been widely used in the past and are fitful for making maps without ground control points. However images cannot be obtained until the spacecraft returns to the surface of the earth. With the development of the charge coupled device (CCD) technology digital space-borne stereo mapping cameras based on CCD sensors are predominant as images can be obtained instantly for further processing and analysis. Most mapping satellites nowadays such as ALOS, SPOT-5, and GeoEye use linear CCD sensors in the payloads and obtain images in the way of dynamic photographing [2].

Linear optical pushroom imaging mode for high resolution optical satellites. According to the three points collinear principle, a rigorous geometric model can be constructed as follow.

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{\mathrm{WGS84}} = \begin{bmatrix} X_s \\ Y_s \\ Z_s \end{bmatrix}_{\mathrm{WGS84}} + m\boldsymbol{R}_{\mathrm{J2000}}^{\mathrm{WGS84}} \boldsymbol{R}_{\mathrm{star}}^{\mathrm{J2000}} (\boldsymbol{R}_{\mathrm{body}}^{\mathrm{star}} \boldsymbol{R}_{\mathrm{cam}}^{\mathrm{body}}) \begin{bmatrix} x - x_0 - \Delta x \\ y - y_0 - \Delta y \\ -f \end{bmatrix} \tag{1}$$

In the formula: $(X\ Y\ Z)\frac{T}{WGS84}$ is the point coordinates of a photographic point in WGS84 coordinate system; $(X_s\ Y_s\ Z_s)\frac{T}{WGS84}$ is the position vector of satellite in coordinate system when imaging; m is the imaging scale; R_{cam}^{body} is the transformation matrix determined by the camera's installation angle in the body coordinate system; R_{body}^{star} is the transformation matrix determined by the attitude measurement's installation angle in the body coordinate system; R_{star}^{J2000} is the transformation matrix obtained from the position equipment(such as star sensor or gyroscope) between attitude measurement coordinate system and J2000 coordinate system; R_{J2000}^{WGS84} is the transformation matrix between WGS84 coordinate system and J2000 coordinate system; (x, y) is the imaging point coordinates; (x_0, y_0, f) is elements of interior orientation; (Δx, Δy) is the distortion of the camera.

In the process of designing surveying and mapping camera, effective design measures can be taken to control the errors according to the influce models of various errors on the geometric accuracy of imaging.

2. ANALYSIS OF SPACE-BORNE STEREO MAPPING CAMERA'S WORKING PRINCIPLE

Generally space-borne stereo mapping camera can be classified as one-line-array stereo mapping camera, two-line-array camera and three-line-array stereo mapping camera. Three-line-array stereo mapping camera can reconstruct exterior orientation elements from images and demands less attitude stability of the satellite. As a result three-line-array stereo mapping camera is more likely to realize photogrammetric survey without ground control points. But three-line-array make the satellite bulky and the structure of the camera become more complex, the difficulty of technical realization of the camera and the satellite is increased. So with the progress of camera and satellite technology, two-line-array has been gradually applied to the application of mapping without ground control points [3].

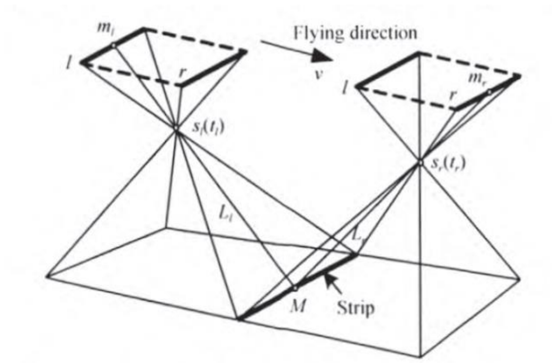

Fig.1 Diagrammatic sketch of stereo mapping principle for two-line-array CCD camera

The diagrammatic sketch of stereo mapping principle for double-linear-array CCD camera is shown as fig.1. The two cameras push and scan the same target at different angles at different times, obtaining a pair of stereo images.

3. DESIGN TECHNOLOGY OF HIGH PRESISION SPACE BORNE MAPPING CAMERA

Two-line-array system consists of two independent linear array CCD push-broom cameras with specific intersection angles. The cameras are mounted on the satellite through a common bracket. When the satellite flies, any ground point in the imaging area has two different viewing angles images overlap each other, forward-view image and backward-view image. The two images were used to measure the ground elevation. Back-view camera is usually set at a smaller angle to the subastral point and can be approximated to the orthographic effect, so it can be used to generate high-resolution orthophoto images on the ground. The influence of surveying and mapping is processed by photogrammetry, and the relative distance between the position of the target to the satellite is calculated and the height of the target terrain can be calculated with the high precision orbit measurement data and the high precision time data.

3.1 DESIGN TECHNOLOGY OF HIGH STABILITY OF ELEMENTS OF INTERIOR ORIENTATION FOR MAPPING CAMERA

In order to achieve high-precision stereoscopic mapping, the lens of the mapping camera requires excellent imaging quality and stable elements interior orientation. Combined with the composition and principle of space optical remote sensing camera, there are generally ways to achieve as follow:

1) Using the reflective quasi-telecentric optical system to improve the lens MTF, reduce the distortion and suppress lens stray light can effectively improve the lens imaging quality;
2) Increase the stiffness of the lens, control the gravity deformation of the lens in the stage of ground mounting and adjusting, and ensure the result of ground calibration is consistent with that of orbit;
3) Using low expansion structural materials and high precision temperature control technology to achieve good temperature stability. At present, the glass ceramics, resin based carbon fiber materials and ceramic based carbon fiber composites have been applied to the cameras with high geometric stability requirements.

3.2 HIGH PRECESION GEOMETRIC CALIBRATION TECHNIQUE FOR MAPPING CAMERA

High precision geometric calibration of surveying and mapping camera is the key factor to ensure high precision positioning of mapping satellites. Therefore, it is necessary to calibrate the geometric elements of the two-line-array mapping camera by using the collimator and the high precision two-dimensional rotating platform, and the geometric elements include the elements of interior orientation, the distortion of the lens, the intersection angle between the forward and backward cameras, and the parallaxes of the CCD line. For the scale of l:10000 scale mapping, the calibration accuracy of the main point position of the surveying camera is better than 0.1 pixel, the calibration precision of the principal distance is better than 20 μ m, and the calibration accuracy of the camera intersection angle is better than 0.2 ".

For large scale and high-precision mapping camera systems, the influence of gravity on the calibration of internal orientation elements can’t be ignored. The average value of the results achieved by reverse the camera can reduce the influence of gravity. Therefore, in the design process of the elements of interior orientation test table, the feasibility of the overall reversal test of the camera should be considered, and the optical axis direction between the camera and the star camera should be considered, and the position of the collimators should be designed reasonably, so as to ensure the efficient and accurate measurement of the geometric elements.

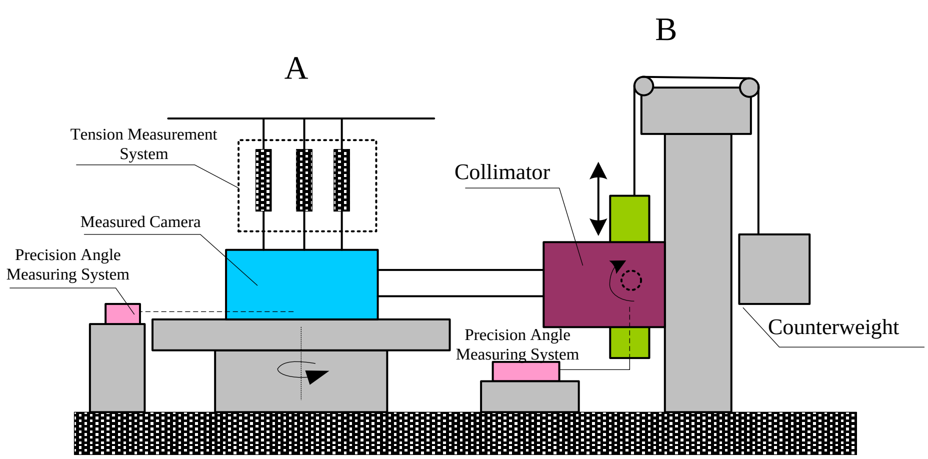

Fig.2 Diagram of the elements of interior orientation test with gravity compensation

In addition, most of the surveying and mapping satellites can use the ground high-resolution geometric calibration field for on-orbit image geometric calibration and high-level imaging product accuracy verification [5-6]. After the satellite was launched, the system error can be calibrated according to the ground control point information of the image. Then the attitude optimal calculation is carried out by using the star sensor, the original data of the gyroscope and the star map data to realize the high precision measurement of the satellite attitude. The coordinates of 18 field control points were measured on the ground by the ZY-3 satellite. The precision is better than 0.1m and the precision of image point measurement is better than 0.5 pixels. Using 4 control points, the high precision digital orthophoto image is generated, and the other 14 control points are used as checkpoints to obtain the calibration value of the elements of exterior orientation of the satellite, so that we can evaluate the plane precision and the elevation precision of the satellite by using ground control point. The test results show that the positioning accuracy of the satellite without control points is 25m, and the plane and elevation accuracy of the control points are better than 2.28m and 1.6m [7].

3.3 HIGH PRECISION TIME SYNCHRONIZATION DESIGN AND CALIBRATION TECHNIQUE

When the high precision surveying camera is on orbit and CCD linear array pushbroom imaging, the error of several milliseconds of the camera imaging time and the satellite time may produce several meters of positioning error, thus reducing the positioning accuracy of the surveying and mapping image. In order to meet the high time precision requirements of the mapping task, the high precision time synchronization design must be considered in the design of the surveying camera system and the high precision test must be carried out in the test stage, so that we can Ensure strict synchronization between camera and satellite time in the push-broom imaging[8].

As shown in fig3, the satellite uses the GPS receiver as the reference clock source to provide high precision hardware second pulse signal. By utilizing the whole-second characteristic of GPS signal, the receiver can produce a second pulse signal with an accuracy of 1 microsecond at every whole-second moment of normal operation. At the same time, the GPS time of the second pulse is also broadcasted through the bus. When the camera enters the imaging mode, each information source related to the mapping task, including the mapping camera, star sensor, and the gyroscope, takes the GPS second pulse signal as the time benchmark, generates their respective high precision time standard, and finally ensures the precise synchronization between the time standard of the relevant information and the time of the GPS (the synchronization precision is better than 20μs. The imaging time of each line can be accurately calculated by the mapping camera and marked in the auxiliary data of the corresponding image line.

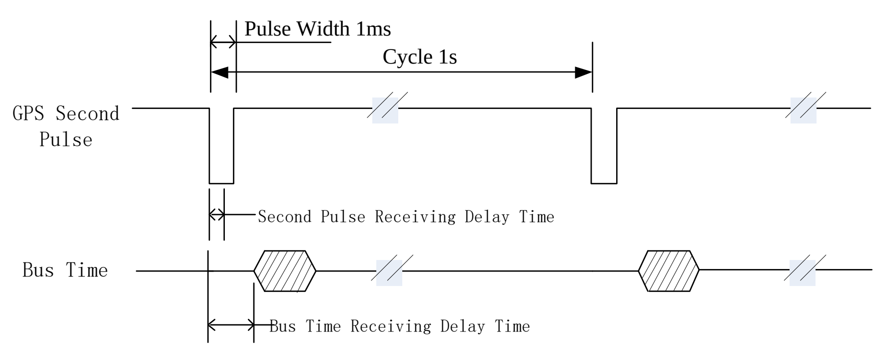

Fig.3 diagram of time calibration relationship for space-borne mapping camera

4 CONCLUDING

As the main payload of high precision mapping satellite, the performance and stability of satellite-borne mapping camera directly affect the precision of satellite mapping. According to the requirement of high geometric precision and stability of Surveying and mapping, the target analysis focus on the requirement of geometric elements must be carried out. The joint error analysis with satellite must be carried out, the configuration of the system must be optimized and multi-source data must be properly collocated and used correctly. It can not only improve the precision of the maping, but also reduce the difficulty of the satellite. Therefore, it is necessary to construct the quantitative analysis and evaluation model of the overall image chain geometric accuracy and the joint error correction method of multiple data sources for the construction of a business system with large scale, high reliability and high processing precision.

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