Geometric Correction of PHI Hyperspectral Image without Ground Control Points

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\textbf{Abstract.} Geometric correction without ground control points (GCPs) is a very important topic. Conventional airborne photogrammetry is difficult to implement in areas where the installation of GCPs is not available. The technical of integrated GPS/INS systems providing the positioning and attitude of airborne systems is a potential solution in such areas. This paper first states the principle of geometric correction based on a combination of GPS and INS then the error of the geometric correction of Pushbroom Hyperspectral Imager (PHI) without GCP was analysed, then a flight test was carried out in an area of Damxung, Tibet. The experiment result showed that the error at straight track was small, generally less than 1 pixel, while the maximum error at cross track direction, was close to 2 pixels. The results show that geometric correction of PHI without GCP enables a variety of mapping products to be generated from airborne navigation and imagery data.

\textbf{Keywords:} Geometric Correction, PHI, GCP, Hyperspectral

1. Introduction
Comparing to satellite platform, airborne hyperspectral imager has advantage of high flexibility and mobility. Due to in-flight acquisition errors and instrumental errors of platform, the obtained data has obvious geometric distortion. The image data collected by airborne platform sensors has serious geometric distortion due to high frequency aircraft motion and topographic relief. Therefore, the images cannot be applied to mapping and other products directly. Geometric correction is an important processing to decrease or even eliminate the geometric distortion of remote sensing images in the photogrammetric mapping industry.

Two different strategies can be used in the geometric correction of remote sensor images, one is based on rigorous method and the other is based on non-parametric model\cite{1}. Rigorous model takes advantage from a photogrammetric approach of collinearity equations\cite{2}, while non-parametric model is another strategy which relates to different mathematical models, such as Polynomial Functions (PFs)\cite{3} and Rational Function Models (RFMs)\cite{4}.
The geometric correction of hyperspectral images has been investigated in recent years. Devereux developed an algorithm of matching delaunay triangles to cope with high frequency distortion [5]. Westin developed a model which was derived from collinearity equations, and RMS error tested using SPOT satellite imaging was lower than 1/2 pixel [2]. The obtainable accuracy of integrated sensor orientations in large scale topographic mapping was investigated [6]. geo-rectification of aerial photos was studied for different terrain types, and the residuals in x and y directions were compared [7]. Some research also focus on the correction of distortions arising from the curvature of the earth and the inevitable length distortion of the map projection in large area mapping [8].

Pushbroom Hyperspectral Imager (PHI), which was designed by Shanghai Institute of Technical Physics (SITP), is a type of airborne linear array push-broom hyperspectral sensor. Different to frame camera sensors, its projection is linear center projection, and it scans the ground vertically to the flight direction.

The investigation of geometric correction of aerial hyperspectral images without Ground Control Points (GCPs) is few, in particular for those provided by the PHI sensors. Geometric correction without GCPs is a very important topic in the photogrammetric mapping industry. The task of geometric correction of PHI includes the determination of the exterior orientation (EO) parameters of PHI at the acquisition time and the restitution of the scene from the image data. EO parameters can be measured directly by navigation sensors--DGPS/INS system (also called POS system), which is composed of DGPS (Difference Global Positioning System) and INS (Inertial Navigation System). The position and attitude of each image line measured during the PHI acquisition can be used to access three line elements and three angle elements of EO. Using this method, the geometric correction of PHI hyperspectral image can be implemented in reliable accuracy without or with few GCPs. The proposed method can not only speed up the mapping process, but also improve the efficiency of aerial photogrammetry.

EuroSDR addressed several phases to improve the reliability of direct georeferencing without GCPs [9]. An approach with 19 additional parameters was proposed for correction of geometric distortions caused by misalignments in GPS/IMU, aircraft vibration, variations in CCD resolution, interior parameters of the scanner’s optical system, and topographic relief [10]. Luan used the DGPS/INS data for direct georeferencing to MAMS and eliminated the geometric distortion of the MAMS images [11].

2. The approach of geometric correction based on DGPS/INS

2.1. Principle of DGPS

Normally, DGPS is composed of two parts. One part is base station, which was placed at the ground point with high accuracy. According to the observation areas, the number of base station can be one or more. Another part is airborne receiver, which is placed on the aircraft with the image sensor, simultaneously work with the base station. According to known precise coordinates of the base station, the distance correction of the base station and satellite is calculated, and the result can be corrected, therefor improving the positioning accuracy.

DGPS can be divided into two categories: pseudo range differential method and carrier phase differential method. Pseudo range differential method treats pseudo range as observation, the positioning accuracy can achieve meter-level, while carrier phase differential method can achieve centimeter-level. The latter one is widely applied in the field of aero photogrammetry with DGPS/INS and other fields requiring high precision. Carrier phase measurement, which is the observation of receiver k to the GPS satellite j at the time of receiver clock $T_k$, can be expressed as:

$$\phi_k^j(T_k) = \varphi_k^j(T_k) - \varphi_A(T_k)$$

(1)
Where $\varphi_k^j(T_k)$ is the phase value of carrier signal, which is observation of receiver $k$ to the GPS satellite $j$ at the time of receiver clock $T_k$, and $\varphi^j(T)$ is the phase value of signal broadcasting of GPS satellite $j$ at GPS time $T$.

2.2. INS attitude measurement principle

INS(Inertial Navigation System) or IMS(Inertial Measurement System) is a new navigation and positioning system developed in the early 20th century. The basic principle is that according to the laws of mechanics of the inertial space, using the data of the rotational angular velocity of the body, which is measured by the gyroscopes and accelerometer inertial element during movement and acceleration, providing the final relative position of the moving body, the speed and posture and other navigation parameters by the servo system to vertical tracking or rotation transformation of coordinate system in the integral calculation within a certain coordinate system. Gyro and accelerometer inertial components are referred to as the inertial measurement unit (Inertial Measurement Unit, IMU), which is the core component of the INS.

2.3. DGPS / INS combined posture measurement principle

Though INS can provides high accuracy navigation parameters independently without using outside information, the error of INS, specifically positioning error, will accumulate with time, and is not suitable for navigation independently in long time. GPS satellite navigation system has high positioning accuracy. However, GPS cannot provide carrier attitude parameters due to non-autonomous system. On the other hand, the GPS receiver on a moving vehicle is difficult to capture or track satellite signal stably, thus decreasing signal-to-noise ratio in dynamic environment and prone to cycle slips. GPS/INS takes advantages of the two systems and provides better performance in navigation.

Applying navigation and positioning of GPS/INS in PHI system, reliable geometric accuracy can be achieved by geometric correction with few GCPs or even without GCPs.

3. Experimental results and analysis

3.1. Study Area

An experiment is conducted to validate the proposed approach with PHI. The image was recorded by the PHI sensor, while position and attitude data were collected by POS/AV 510 in an area of Damxung, Tibet, China in August 2011.

With flight height of about 4000 meters, 2 long image strips were collected (the flight distance is about 20 km), each strip has about 4000 lines. The ground resolution is 4 meters, the frequency of line scanning is 50 lines/s, and the pixel number of each scanning line is 1028. The test area is a plateau in Tibet, the terrain elevation changes wildly, and the main features are snow-capped mountains, roads, grasslands, wetlands and a few houses.

3.2. Base Station

Considering the large coverage of the flight area, two GPS base stations were implemented to improve the accuracy of geometric correction.

3.3. DGPS / INS experimental results and analysis

The raw hyperspectral image (Figure 1) was not geo-referenced. The image orientation and the position information were extracted according to the sequence of images in the direction of flight. Geometric distortions also exist due to the irregular movement of the aircraft platform, airflow influence, terrain changing and other factors. In some cases the features in the image cannot be recognized due to severe distortions, making further process impossible.
Figure 1. The image without geometric correction

After geometric distortions correction using the data of DGPS/INS, the geometric distortion of the image (Figure 2) was almost eliminated. Each pixel has accurate coordinate in the reference coordinate system, real flight direction and accurate position can be measured on the image directly. The corrected image can be further processed for photogrammetric application.

Figure 2. The geometric corrected image

For geometric accuracy evaluation, some ground control points were measured. Experiment result showed that, the error in X-direction was less than 2 pixel, while in the Y direction the error was larger and up to 6 pixels, but both systematic, the reason may be refer to positioning deviation caused by un-calibration of eccentric angle and eccentric vector in the calibration field.

4. Conclusion
Geometric correction without GCPs is feasible for the correction of the PHI images with aid of DGPS/INS data. The result of the experimental test in Damxung, Tibet showed that it was a feasible solution in the area where ground control points were not available. The error of the corrected image was 2 pixels in the X direction, basically meet the accuracy requirement.

The result presented also revealed that the POS data was with strong systemic errors. The main error source came from the eccentric angle and eccentric vector caused by the un-coincidence of INS geometric center, sensor lens perspective center and the GPS antenna phase center. Due to the limitation of measurement means, the value of eccentric angle and eccentric vector were not obtained, which affected the final accuracy.

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