SELF-CALIBRATED DIRECT GEO-REFERENCING OF AIRBORNE PUSHBROOM HYPERSPECTRAL IMAGES

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ABSTRACT

The basic idea of direct geo-referencing (DG) was realized and refined in this paper by introducing 19 additional parameters for self-calibration of airborne pushbroom hyperspectral images with in-flight GPS/IMU data. It is demonstrated that the proposed self-calibrated DG approach significantly rectify the geometric distortions caused by misalignments in GPS/IMU, aircraft vibration, interior parameters of the sensor's optical system, and variations in pixel ground resolution and topography.

Index Terms— Direct georeferencing, self-calibration, pushbroom scanner, hyperspectral image, remote sensing

1. INTRODUCTION

In comparison with satellite-based sensors, airborne hyperspectral imager has the advantages in high spectral resolution and mobility in image acquisition [1]. It could provide abundant wealth of spectral variations of the ground surface within tiny spectral bandwidth. Such detailed spectral information makes accurate image interpretation and classification possible for agriculture management, resource investigation, disaster assessment, atmosphere science, and military uses, etc. Thus, airborne hyperspectral sensing has gained increasing attention for its potential in sustainable development in resource related applications.

The airborne Intelligent Spectral Imaging System (ISIS) scanner, which scans ground features in 240 bands in spectral range between 435~945 nm, was manufactured in 2004 by the Instrument Technology Research Center (ITRC) of the National Applied Research Laboratories (NARL) and partially supported by the National Chung Hsing University (NCHU) in Taiwan. The ISIS scanner and the Inertia Measurement Unit (IMU) device, as shown in Fig. 1, are equipped on a T-AS platform in a Britten-Norman BN-2A Islander aircraft in mission flights. A Novatel Global Positioning Systems (GPS) receiver antenna was precisely mounted vertically above the scanner on top of the BN-2A aircraft with the offset components carefully determined by intersection using two Trimble 603 total stations [2]. Meanwhile, an IGI AeroControl CCNS4 was also installed on board for aerial navigation and management on recording the time of exposure for GPS control with a Leica MC500 GPS receiver. During the scanning mission a Leica SR530 GPS receiver located at a fixed ground base station operates at the same *epochs*, which can be set as 0.1-0.5sec, as that of the on-board Leica MC500 receiver. The system also incorporates an Applanix POS AV510, which integrates and synchronizes the measurements from both GPS and IMU devices for capturing in-flight position and attitude data in order to interpolate the exterior orientation parameters of the exposure center of every scan line by Differential GPS (DGPS) technique.

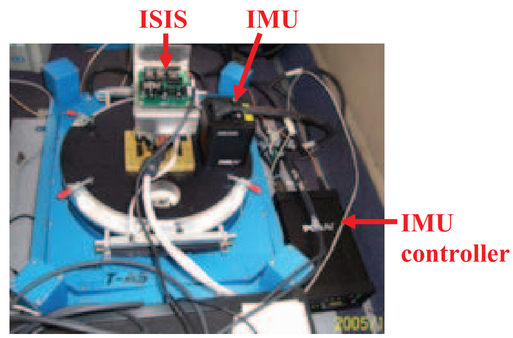

Fig. 1. The integrated airborne ISIS hyperspectral scanner

2. METHODOLOGY

Direct geo-referencing (DG) technique with the use of GPS/IMU was rapidly developed in recent decade in photogrammetric field and is nowadays standard [3]. As shown in Fig. 2, the DG approach for orthoimage production using line scanner imagery usually implements three-dimensional conformal transformations among the coordinate systems defined by the imaging sensor, GPS antenna, IMU, and object space, respectively based on the collinearity concept [3-7]:

$$V_{O-P}^{Obj} = V_{O-S}^{\Pr j} + s_G \cdot R_{O-S}^{Obj} \cdot V_{S-p}^{\Pr j} \quad (1)$$

where V_{O-P}^{Obj} is the vector of target point to origin in object space, V_{O-S}^{Obj} is the vector of center of sensor to origin in object space, s_G is the scale factor from image frame to object space, R_{O-S}^{Obj} is the rotating matrix between image frame and object space, and $V_{S-p}^{\Pr j}$ is vector of center of sensor to point p in image frame.

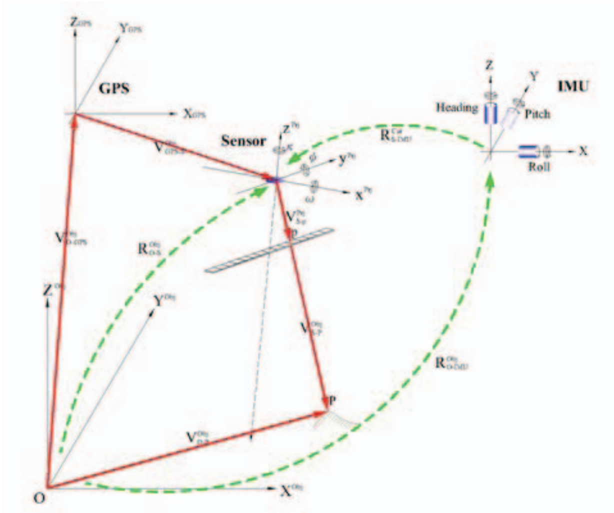

Fig. 2. Concept of DG-based orthoimage production using pushbroom scanner image.

However, there exist several factors which influence the geometry of the raw data and limit the overall accuracy in DG-based orthoimage production [4][8]. These factors include the interior and exterior orientation parameters of the sensor's optical system, boresight misalignment angles between the IMU sensor and ISIS scanner, drifts in lever-arm offsets between the GPS receiver and ISIS scanner, scaling factors of the stabilized platform that reduce the vibration of the aircraft in the flight, and the topography of the earth surface. Hence, many quality control procedures were applied by refining the mathematical model with high redundancy and reliability of the indirect method like the aerial triangulation [3][5].

This research develops a self-calibrated DG approach for rectifying airborne pushbroom hyperspectral images with GPS/IMU data. In addition to conventional DG approach [4], the proposed self-calibrated DG approach adopts 19 additional parameters for correcting the geometric distortions caused by errors in GPS receiver lever-arm offsets (X_{la}^{Car} , Y_{la}^{Car} , H_{la}^{Car}), misalignments in IMU boresight angles ($\delta\omega$, $\delta\phi$, $\delta\kappa$), scaling factors of the on-board T-AS platform (S_{ω} , S_{ϕ} , S_{κ}), variation of the sensor's CCD size in column direction (δc), and interior orientation parameters of the sensor's optical system including offsets of principal point (x_o , y_o), focal length (*f*) and radial and de-centering lens distortions (K_0 , K_1 , K_2 , K_3 , P_1 , P_2) [9]. These parameters were determined in a least squares solution of the linearized observation equations formed by using a series of well-distributed ground control points (GCPs) and digital elevation model (DEM) data describing the topographic surface. Bilinear interpolation technique was thereby applied for radiometric resampling of the rectified images during the process of georeferencing.

3. EXPERIMENTS

As shown in Fig. 3, a strip of raw ISIS images with 2250 lines x 1150 pixels in 1.16m ground resolution covering the north bank of Tachia river in Waipu District, Taichung, Taiwan was used in the experiment. Thirty eight GCPs, whose ground coordinates were surveyed by using GPS-Real Time Kinematic (GPS-RTK) approach, along with the POS GPS/IMU data for each scan line and 20m DEM data were used to solve for the 19 additional parameters by least squares method.

Fig. 4 shows the rectified ISIS images in 1.0m ground resolution by the proposed approach. The residuals of GCPs after applying the proposed self-calibrated DG approach and the conventional DG approach without calibration are shown in Fig. 5 and Fig. 6, respectively. In comparison with the conventional DG approach, the root-mean-squared error (RMSE) of the GCPs is significantly reduced from 24.11m to 3.21m by applying the proposed self-calibrated DG approach as show in Table 1.

Fig. 3. Raw ISIS images in 1.16m ground resolution (2250 lines x 1150 pixels; Red: λ_{182}=869.9nm, Green: λ_{94}=654.6nm, Blue: λ_{52}=551.9nm).

Fig. 4. Self-calibrated DG rectified ISIS images in 1.0m ground resolution (2998 lines x 3133 pixels).

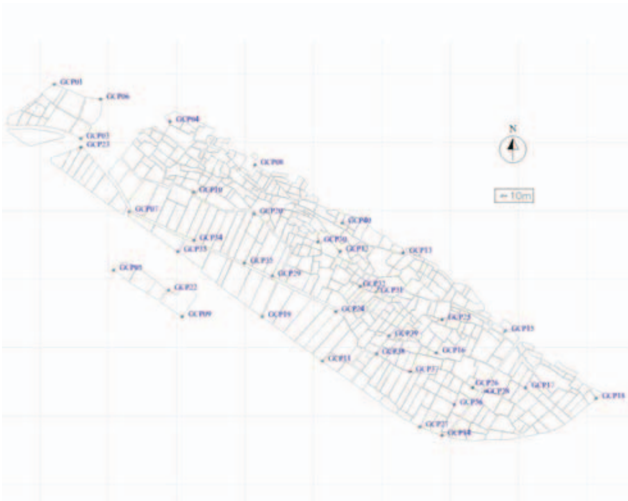

Fig. 5. Residuals of GCPs after applying the proposed self-calibrated DG approach ($RMSE_X$=2.31m, $RMSE_Y$=2.06m, $RMSE_H$=0.84m, RMSE=3.21m).

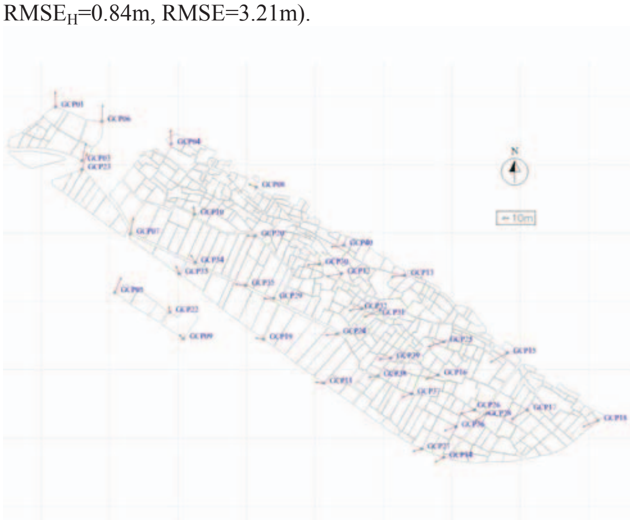

Fig. 6. Residuals of GCPs after applying the conventional DG approach without calibration ($RMSE_X$=18.89m, $RMSE_Y$=14.86m, $RMSE_H$=1.98m, RMSE=24.11m).

Table 1. Quality of self-calibrated DG vs conventional DG in ISIS image rectification

DG approach	$RMSE_X$	$RMSE_Y$	$RMSE_H$	RMSE
Conventional	18.89m	14.86m	1.98m	24.11m
Self-calibrated	2.31m	2.06m	0.84m	3.21m

4. CONCLUSIONS

The GPS/IMU data recorded on board Applanix POS AV510 provides a rough solution to the conventional DG approach, which assumes the post-processed position and orientation data of each scan line are correct with sufficient accuracy. However, there exist several factors which affect the geometry of the raw images and limit the accuracy of the DG-based orthoimage production. The basic idea of DG was refined in this research by introducing 19 additional parameters for self-calibration of the airborne pushbroom ISIS hyperspectral images. The experimental results showed that the proposed self-calibrated DG approach is feasible and significantly reduce the geometric distortions caused by misalignments in GPS/IMU, aircraft vibration, variations in CCD resolution, interior parameters of the scanner's optical system, and topographic variations.

5. ACKNOWLEDGEMENT

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