ISPRS Journal of Photogrammetry and Remote Sensing 135 (2018) 60–73

Contents lists available at ScienceDirect

ISPRS Journal of Photogrammetry and Remote Sensing

journal homepage: www.elsevier.com/locate/isprsjprs

Aerial photography flight quality assessment with GPS/INS and DEM data

Haitao Zhao [a,b], Bing Zhang [a,c,*], Jiali Shang [b], Jiangui Liu [b], Dong Li [a], Yanyan Chen [d], Zhengli Zuo [a], Zhengchao Chen [a]

[a] Institute of Remote Sensing and Digital Earth, Chinese Academy of Sciences, Beijing 100094, China
[b] Ottawa Research and Development Center, Agriculture and Agri-food Canada, Ottawa K1A OC6, Canada
[c] University of Chinese Academy of Sciences, Beijing 100049, China
[d] Peace Map Co., Ltd., Beijing 100142, China

ARTICLE INFO

Article history:
Received 13 May 2017
Received in revised form 18 October 2017
Accepted 26 October 2017

Keywords:
Aerial photography
Flight quality
Accuracy assessment
GPS/INS
DEM
Overlap
Crab angle
Tilt angle

ABSTRACT

The flight altitude, ground coverage, photo overlap, and other acquisition specifications of an aerial photography flight mission directly affect the quality and accuracy of the subsequent mapping tasks. To ensure smooth post-flight data processing and fulfill the pre-defined mapping accuracy, flight quality assessments should be carried out in time. This paper presents a novel and rigorous approach for flight quality evaluation of frame cameras with GPS/INS data and DEM, using geometric calculation rather than image analysis as in the conventional methods. This new approach is based mainly on the collinearity equations, in which the accuracy of a set of flight quality indicators is derived through a rigorous error propagation model and validated with scenario data. Theoretical analysis and practical flight test of an aerial photography mission using an UltraCamXp camera showed that the calculated photo overlap is accurate enough for flight quality assessment of 5 cm ground sample distance image, using the SRTMGL3 DEM and the POSAV510 GPS/INS data. An even better overlap accuracy could be achieved for coarser-resolution aerial photography. With this new approach, the flight quality evaluation can be conducted on site right after landing, providing accurate and timely information for decision making.

1. Introduction

Flight quality includes the quality of the flight trajectory, ground coverage, crab angle, tilt angle, photo overlap, etc. (GB/T15661, 2008; GB/T27920.1, 2011). Flight ground coverage, equipment/calibration requirements, flight altitude, flight time window, photo overlap and other acquisition specifications can directly affect the quality and accuracy of all subsequent mapping tasks (ASPRS, 2009). For vertical photography of a frame camera, the key flight quality indicators include sidelap, endlap, tilt angle, crab angle, etc. (Hong et al., 2013). In a flight mission, although pre-flight planning provides the first necessary step in designing proper camera exposure station to meet the overlap requirements using a DEM and the state-of-the-art flight planning systems, flight quality indicators such as overlap can still be severely affected during the actual flight due to air turbulence, flight deviation, exposure position deviation and drift effect, particularly in areas with steep and rugged topography due to large relief displacement. To meet the post-flight data processing requirements and fulfill the mapping accuracy, an effective, near-real-time on site post-flight quality assessment is desirable for screening out poor-quality flight lines and making timely correction flights before the end of the mission.

Conventionally, flight quality is evaluated manually through visual inspection of the printed images or digital images stored in a computer. Experience and skills are very important in the procedure. It is costly and time consuming due to laborious manual work and the need of well-trained experts. In more recent years, some flight quality indicators have been derived from tie points using an image matching approach applied on post-processed images (Chen et al., 2014; Duan and Zhao, 2010); however, image matching is a time consuming post processing procedure which needs to be conducted in the lab and is not precise enough to calculate the most important flight quality indicator, the true minimum overlap, when the tie points are located far away from the edge of the photos. A direct georeferencing concept using the

---

[*] Corresponding author at: Institute of Remote Sensing and Digital Earth, Chinese Academy of Sciences, Beijing 100094, China.
E-mail address: zb@radi.ac.cn (B. Zhang).

https://doi.org/10.1016/j.isprsjprs.2017.10.015
0924-2716/

GPS/INS system was proposed by Schwarz et al. (1993). Since then, GPS/INS (also called the INS/GPS, GNSS/IMU, GPS/IMU, POS, etc.) has been widely equipped on frame cameras, line scanning sensors, LiDAR, and SAR in airborne remote sensing (Hutton and Mostafa, 2005; Mostafa and Hutton, 2001; Yuan et al., 2009; Zhao et al., 2013b). With a GPS/INS, the position and orientation of the inertial measurement unit (IMU) in the global reference frame can be effectively determined (Zhao et al., 2014). The exterior orientation (EO) parameters derived from the GPS/INS has a high accuracy and even can be used for direct georeferencing of photos for certain mapping applications (Hutton and Mostafa, 2005); hence, it should be sufficient for flight quality assessment.

To calculate the ground coverage of photos and evaluate their overlap based on photogrammetric theory, a good quality DEM is needed. Fortunately, medium-resolution global DEM can be obtained freely from the Shuttle Radar Topographic Mission (SRTM) in 2001. Currently, the SRTM DEM dataset is one of the most complete and widely used DEM (Su and Guo, 2014). During the initial stage, 1 arc-second resolution data covering the USA and 3 arc-second resolution data for the globe were released, with un-filled gaps in high mountainous regions in Version-1 and Version-2. In 2013, the gap filled SRTMGL3 Version-3.0 was publicly released with a 3-arc-second resolution (90 m) for the globe (NASA-JPL, 2013). Afterwards, 1 arc-second SRTMGL1 Version-3.0 data product has been released gradually and is complete now. Although the SRTM dataset is very useful, it only covers the land areas between latitude 60° north and 56° south, about 80% of the Earth's total landmass. The Advanced Space borne Thermal Emission and Reflectance Radiometer Global Digital Elevation Model (ASTER GDEM) generated from the optical data collected by the ASTER instrument onboard the NASA's Terra satellite was released in 2009 (Version-1) and in 2011 (Version-2) (ASTER-GDEM, 2009; Tachikawa et al., 2011). This dataset is the only DEM that covers 99% of the Earth's landmass at a resolution of 30 m. However, the ASTER GDEM was found to contain significant anomalies and artifacts, which will affect its usefulness for certain user applications (ASTER-GDEM, 2009). Based on the SRTM DEM, ASTER GDEM, and other data sources, several improved DEM products have been generated, such as the CGIAR-CSI SRTM v4.1 (CGIAR-CSI, 2017), EarthEnv-DEM90 (Robinson et al., 2014), and High-quality seamless DEM processed by Yue et al. (2017). In addition to these global DEM datasets, many countries also have their own high accuracy DEM database created using either photogrammetry or Lidar technology. For example, China has built a 1:50,000 scale DEM for the entire country (NGCC, 2002). Other commercial global DEM data sources such as the NEXTMap World 10 ^{TM} (Intermap, 2017) and WorldDEM^{TM} (Airbus, 2017) are also useful alternatives for meeting the demand for high resolution DEMs. All these DEM datasets can be used for flight quality assessment when available.

Over the past two decades, technological development in sensors, software and computer processing capabilities have boosted the automation in photogrammetric mapping tremendously. Many tasks traditionally requiring well-trained experts can now be done by less-trained or less-experienced individuals with the aid of partially or fully automated tools and procedures (ASPRS, 2009). Flight quality assessment has also benefitted from the technology development. Using the widely available GPS/INS data and free DEM, we proposed a new quality evaluation method based on rigorous geometry calculations (Zhao et al., 2013a) and developed a Flight Evaluation System (FES) software package to conduct post-flight quality assurance quickly and accurately. The FES becomes a module in the commercial Flight Management System (FMS) FANS, which also consists of a Flight Planning System (FPS) and a Flight Control and Navigation System (FCNS) modules for flight planning and flight navigation respectively (FANS, 2017). This paper only documents the theoretical basis of the FES module and introduces its implementation. The performance of the software was tested using two datasets and the results were also reported.

2. Methodology of flight quality assessment

2.1. Procedures of flight quality assessment

Flight quality of an aerial photography mission can be evaluated using a set of indicators such as overlap (sidelap and endlap), tilt angle, crab angle, flight altitude and flight curve. The overlap is the most important indicator. If the overlap is too big, it will result in a small intersection angle which will impact the mapping accuracy of stereo-pair images. If the overlap is not sufficient, a gap between stereo-pair images or flight strips can occur. This is the most serious failure that may require a correction flight. In this study, the relationship of four-adjacent overlaps is presented in Fig. 1, the two sidelaps (left and right) and the two endlaps (forward and backward) with the flight direction as the reference direction. Because the overlap is interpreted in the image space, two key steps are needed to derive it. First, the ground coordinates of a photo's edge points need to be calculated. The ground coordinates of these edge points are then projected to the image space of the adjacent photos in order to generate the overlapping lines. From the overlapping lines in the image spaces, the overlap indicator can be calculated. Fig. 2 shows the procedures of the flight quality assessment proposed in this paper. Firstly, the exposure time, position and orientation can be retrieved from the GPS/INS data, and the four-adjacent relationship can then be determined for each photo. Secondly, with the EO data, camera parameters and DEM, the ground coverage of each photo is derived. The coverage of all photos belonging to the same flight line is merged to form the strip coverage. This step is needed because a given photo may intercept with several side-adjacent photos, and the sidelap can be easily calculated when the strip coverage is derived. The correspondent ground points of a photo's edge points are obtained through intersecting the photo's ground coverage with that of the adjacent photos or the flight strips. Once the ground points are determined, they are then transformed from the object space to the image spaces of adjacent photos in order to determine the overlaps. Some other indicators are calculated with the EO and DEM data directly. Finally, a statistic report of every photo and every strip is generated.

2.2. Fundamentals of the calculations

2.2.1. Calculation of photo ground coverages

The ground coordinates of a pixel in a photo can be calculated using the camera parameters, EO parameters and DEM with a transformed collinearity equations (Wang, 2007):

$$X = X_s + (Z - Z_s)\frac{a_1x + a_2y - a_3f}{c_1x + c_2y - c_3f}$$
$$Y = Y_s + (Z - Z_s)\frac{b_1x + b_2y - b_3f}{c_1x + c_2y - c_3f} \quad (1)$$

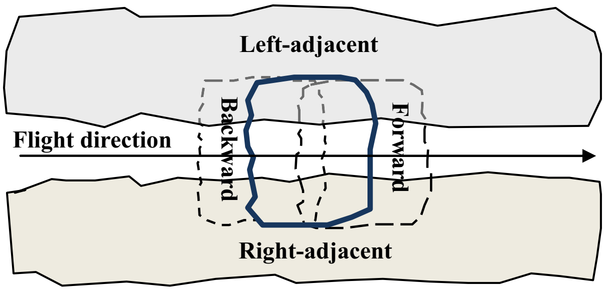

Fig. 1. The four-adjacent overlaps of a photo.