ESTIMATING THE FLYING TRAJECTORY OF TILT UAV PHOTOGRAPHY FROM IMAGE SPACE TO OBJECT SPACE USING IMAGE FEATURES

Min-Lung Cheng[1], Toshiaki Satoh[2] and Masashi Matsuoka[1]
[1 2]Department of Architecture and Building Engineering, School of Environment and society,
Tokyo Institute of Technology
[1]4259-G3-2 Nagatsuta, Midori-ku, Yokohama, Kanagawa, 226-8502 Japan
[2]4259-J3-26 Nagatsuta, Midori-ku, Yokohama, Kanagawa, 226-8503 Japan
[1]Email: cheng.m.ab@m.titech.ac.jp
[2]Email: satoh.t.ad@m.titech.ac.jp
[1]Email: matsuoka.m.ab@m.titech.ac.jp

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Abstract: To analyze and visualize the environment, optical imagery is one of the great resources to acquire spatial information. In past years, two techniques have been well developed in processing the spatial data, namely photogrammetry and computer vision. No matter which method is adopted, three elements are defined, including the exterior orientation parameters of the camera, the photography, and the ground objects. As for exterior orientations, they can be measured by GPS/INS or estimated via spatial resection with ground control points. However, the optimized space resection may not be able to find the camera exterior orientations due to inappropriate initial values especially for off-nadir imagery. In order to overcome this obstacle, this study aims to utilize the relative translations in image space and transform them into object space by image features, such that initial exterior orientations can be approximated. The result indicates that incorrect matched features would lead to great error prorogation for a sequence of photography with the increased flying path. Hence, a few of ground control points are introduced to improve the accuracy and precision of the exterior orientation parameters. As a consequent, this research provides a novel perspective to approximate the initial camera exterior orientation parameters from image space to object space, and conquers one of the important difficulties toward oblique photography when performing the robust spatial data processing.

1. INTRODUCTION

Exterior orientation parameters (EOPs) is one of the indispensable elements to extract spatial information from optical imagery. There are currently two approaches in acquiring EOPs of the camera, including direct geo-referencing and ground control points (GCPs). The direct geo-referencing adopts GPS and INS to measure camera's orientations (Schwarz et al., 1993). On the other hand, a bottom-up method uses GCPs and collinearity condition to compute the optimized EOPs (Easa, 2010). As long as the EOPs of a sequence of imagery are available, it is able to extract spatial information from the dataset. For example, the stereoscopic viewing requires EOPs of each photo and image points to virtual three-dimensional (3D) scenes. In addition, the aerial triangulation (Schenk, 1996) demands such parameters and image points to build a completed model of the environment.

However, the conventional and robust means of utilizing GCPs and collinearity condition has been proven suitable for near-vertical imagery. When it comes to large-oblique and off-nadir photos, such an optimized procedure may lead to divergent light rays at the exposure station due to inappropriate initials. In order to retrieve EOPs of a series of photos, this paper firstly selects a few of near-vertical images and estimates their EOPs by available GCPs. Contrasting to single image space resection, the up-to-scale relative orientation parameters (ROPs) acquired via image features (Hartly and Zisserman, 2004) and can be used in approximating the EOPs of other photos based on images with known EOPs. Accordingly, this paper tries to address a linear solution to estimate the EOPs of the camera center instead of collinearity conditions requiring initial estimations. Moreover, a few of GCPs are capable of improving the accuracy and reliability of those parameters in the post-processing. As a consequence, the proposed strategy retrieves the EOPs and trajectory of a sequence of UAS photos without non-linear considerations.

2. MATERIALS AND METHODOLOGY

The experimental data in this paper consists of five off-nadir UAS photos taken in a series and a few of GCPs surveyed in WGS 84. However, they inherently lack the EOPs surveyed by GPS and IMU. An alternative image space resection based on barycentric coordinates (Li et al., 2015) solves the EOPs of candidate photos with adequate GCPs. For images containing insufficient GCPs, this study detects their normalized ROPs with a candidate photo as a stereopair. By introducing the base-height ration, those up-to-scale translation vectors are transformed into the object space. Therefore, the flying path can be solved via images with known EOPs and others with ROPs. Figure 1 illustrates an overview of a sequence of photography separating one type with EOPs and another without EOPs.

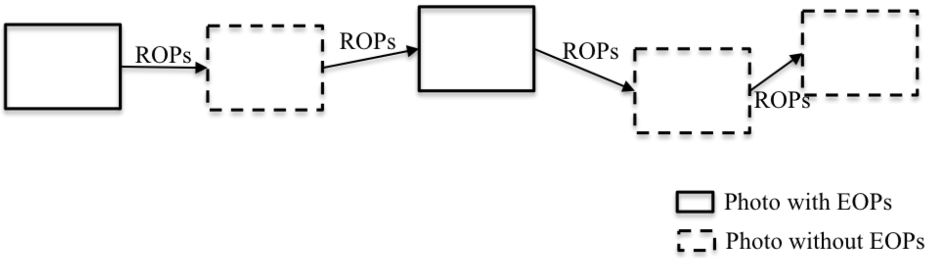
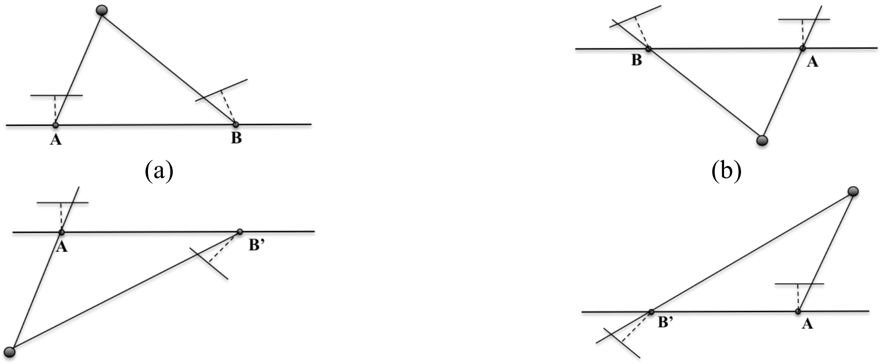


Figure 1. A series of overlapped imagery for flying trajectory simulation

2.1 Normalized Relative Orientation Parameters

Although an analytical relative orientation (Wolf and Dewitt, 2014) model is proposed using collinearity condition, it requires initial approximations to solve the results. Still, this means is difficult in dealing with large-oblique images by such robust processing. Therefore, this study alternatively utilizes conjugate image features of a stereomodel to estimate their ROPs in the image space (Hartly, 1992). In order to find keypoints in images, several algorithms such as scale-invariant feature transform (SIFT) (Lowe, 2004) and speed-up robust features (SURF) (Bay et al., 2008) are available. With detected image features, the two-side image matching (He and Habib, 2014) is to determine conjugate points normalized by a camera matrix.

Based on matched keypoints in a stereopair, the epipolar geometry estimates ROPs between two images. As illustrating in Figure 2, there are four feasible solutions describing the relationships among two cameras and image features. Within these solutions, Figure 2(a) is the possibility that image points are in front of two cameras by the co-planarity (Mikhail et al., 2001) model as Equation (1). In this foundation, p_l and p_r are conjugate image features; R_r^l is the rotation matrix of the stereomodel; (t_x, t_y, t_z) is an up-to-scale translation vector. Consequently, the desired ROPs are referring to the rotation matrix and the three translations.



(a) (b)

(c) (d)

Figure 2. Four solutions describing image features and two cameras (A and B)

$$p_l^T \begin{bmatrix} 0 & -t_z & t_y \\ t_z & 0 & -t_x \\ -t_y & t_x & 0 \end{bmatrix} R_r^l p_r = 0 \tag{1}$$

2.2 Denormalizing the Up-to-Scale Effect

The solved ROPs in the previous cannot be directly mapped into to object coordinates system due to the normalization. A conventional approach adopts field-surveyed GCPs to deal with the lost scale. Still, the scale varies through a whole large-tilt photo and it is tough to assign a unique value. In stead, this paper estimates the relative image scale by conjugate features of a stereopair and combines the base-height ration to approximate the scale factor. The procedure in Figure 3 describes the approaches to cope with the up-to-scale effect and acquire the scale factor indicating to the baseline.

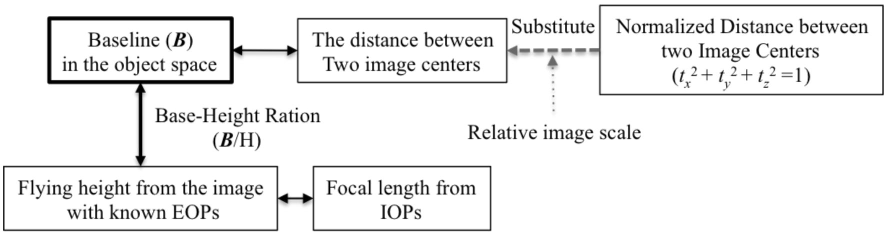


Figure 3. Using normalized translations and base-height ration for scale estimation

As long as the scale (**B**) is determined, it is able to remove the normalization of the translation vectors that $(\Delta T_x, \Delta T_y, \Delta T_z) = \boldsymbol{B}\,(t_x, t_y, t_z)$ and the three relative rotation angles $(\Delta\omega, \Delta\varphi, \Delta\kappa)$ can be derived from the rotation matrix (R_r^l) in Equation (1). For UAS photos without EOPs, the ROPs can be aid in estimating the parameters by connecting to an image with EOPs that $(X^R, Y^R, Z^R, \omega^R, \varphi^R, \kappa^R) = (X^L, Y^L, Z^L, \omega^L, \varphi^L, \kappa^L) + \Delta\,(T_x, T_y, T_z, \omega, \varphi, \kappa)$.

3. EXPERIMENTAL RESULTS AND ANALYSIS

As there are five test UAS photography (Figure 4) in this experiment, Figure 4(a) and (c) equips with absolute EOPs derived from GCPs in Table 1. For the remaining photos, this paper applies the proposed approaches to retrieve their EOPs. After acquiring the ROPs by the method, it is necessary to examine the reliability of the EOPs. Therefore, this study generates a few of virtual control points by photos with known EOPs beyond field-surveyed GCPs.

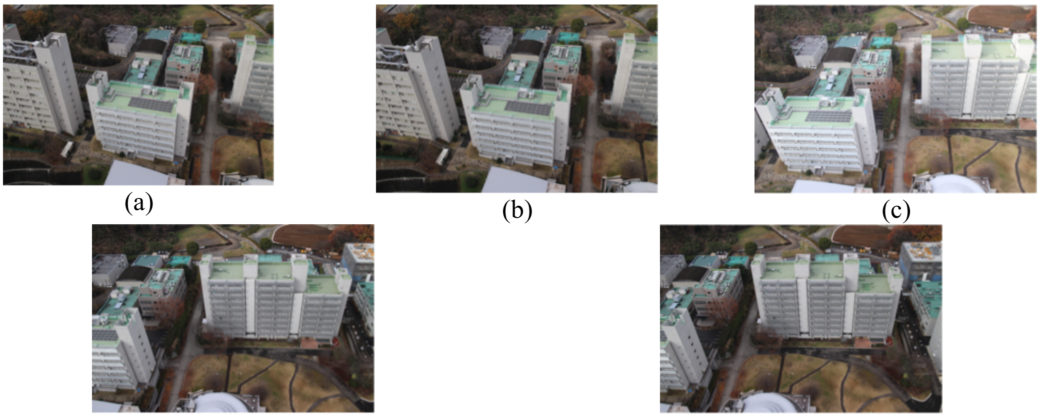

(a) (b) (c)
(d) (e)

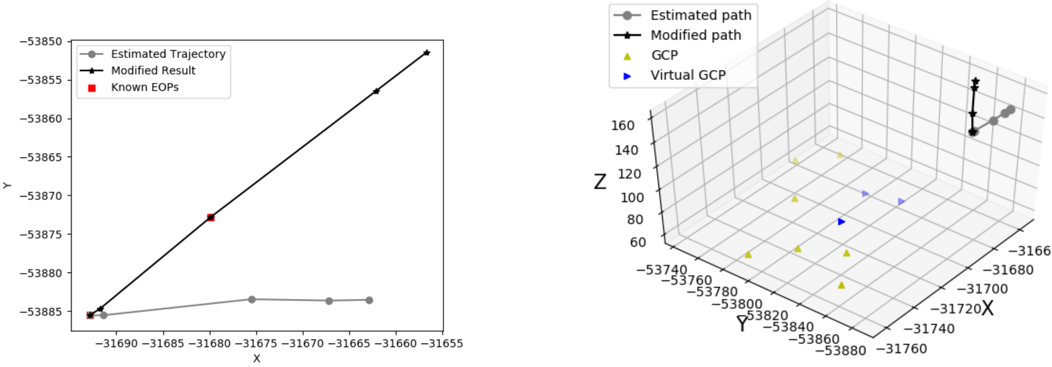
Figure 4. Experimental overlapped UAS photography
(UAS Photography Copyright 2014, Pasco Corporation, Japan)

Table 1. Exterior orientation parameters of the left photo

EOPs	X (m)	Y (m)	Z (m)	ω (rad)	φ (rad)	κ (rad)
(a)	-31692.838	-53885.550	158.596	0.591	0.698	0.731
(c)	-31679.915	-53872.871	157.456	0.704	0.615	0.526

The EOPs of the remaining three photos can then be reached by absolute EOPs and estimated ROPs. Although the absolute EOPs of Figure 4(c) are known, this result displays its approximations and compares their differences by positions. Figure 5(a) visualizes a planar estimated and improved flying trajectory to observe their discrepancies by adding GCPs. Besides, since the post-rectification requires well-distributed control points, Figure 5(b) displays not only the 3D side looking of the flying trajectory but also measured GCPs and virtual control points. With appropriate rotation angles omega, phi, and kappa from known EOPs and estimated ROPs, it is able to improve the whole system either by individual model or bundle adjustment.

Since the post-modification is an optimized approach that requires GCPs to distribute averagely through a whole photo, field-survey GCPs in this experiment are inadequate to cope with this obstacle. According to this consideration, this study places additional virtual controls aiming to strengthen the geometric network within photos. Three assistant points appear in Figure 5(b) as well to enhance the geometric control of an individual photo. Therefore, this study conquers the insufficiency of control points during the post data processing by the aid of virtual control points.



(a) (b)

Figure 5. Comparison of estimated and improved UAS flying path (a) visualization of planar positions (b) 3D side looking with GCPs

From the results, the errors become large as the flying trajectory extends. Several reasons cause this phenomenon that the first one is mismatched image features. Incorrect keypoints may affect the relative image scale and the estimated baseline as error propagation. The planar deformation of large-tilt photos is the second consideration affecting the results. In this experiment, the estimated Y-coordinates vary gently because main variations from up-to-scale ROPs indicate to X-directions. Accordingly, additional GCPs are required for post-correctness by using the results as initials and the robust image space resection.

4. CONCLUSIONS

This paper presents an alternative perspective, which is similar to aerial triangulation, to solve the EOPs for off-nadir photography using ROPs estimating by image features and the re-developed base-height ratio. A linear approach is helpful in dealing with such images contrasting to the conventional robust method, which required initial estimations. Although incorrect image keypoints may affect the results, a few of GCPs and generated assistant control points are aid in improving the EOPs with appropriate rotation angles omega, phi, and kappa in the post optimization. Consequently, it is able to retrieve the flying trajectory for a sequence of large-oblique UAS photos without initial approximations and iterative operations in a linear manner.

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