PHOTO ORIENTATION BY CONTROL PHOTOS

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Abstract: Photo orientations have been conducted either by conventional way where tie points and few control points are employed or by GPS/INS aided aerial triangulation. In this study, photos with known orientations, thus called control photos, are investigated for their functions in solving for the orientations of those photos that cover the very same area. The methodology developed includes both the nearly critical configuration and general roles when control photos are exclusively considered for reaching orientation solutions. In addition, the quality of the orientation obtained is also evaluated to conclude the applicability of control photos.

INTRODUCTION

Multi-temporal photos present extraordinary geometric and radiometric anomaly as compared to regular orientation solution where patterns of tie points and control points required can be designated or advised (Redweik *et al*., 2010). Due to time and environment variables, orientation task of photos taken in different years may face with difficult challenges in finding conjugate points and control data. To this end, the previous study (Hsiao and Jaw, 2012) already analyzed minimum solution for cases that control information rarely exist. What is mainly focused in this study is to further assess the orientation quality by sufficient measurements that include point features as well line features. In particular, the terminology of control photo, control ray and control interpretation plane that serve as the significant roles in this study were emphasized.

METHODOLOGY

Ideally, the perspective center, image point and the corresponding object point are collinear under perspective geometry. Due to the distortions resulting from camera lens, film and others, the ideal image point is eventually presented by so-called actual image point that somewhat violates the collinearity property. Therefore, the corrections accounting for the distortions that show in Equ.(1) must be placed.

$$
\begin{aligned}
x-\Delta x &= -f\,\frac{m_{11}(X_A-X_L)+m_{12}(Y_A-Y_L)+m_{13}(Z_A-Z_L)}{m_{31}(X_A-X_L)+m_{32}(Y_A-Y_L)+m_{33}(Z_A-Z_L)} \\
y-\Delta y &= -f\,\frac{m_{21}(X_A-X_L)+m_{22}(Y_A-Y_L)+m_{23}(Z_A-Z_L)}{m_{31}(X_A-X_L)+m_{32}(Y_A-Y_L)+m_{33}(Z_A-Z_L)}
\end{aligned}
\qquad \text{....(1)}
$$

$$
\begin{cases}
\Delta x = -x_o - \dfrac{\bar{x}}{\bar{z}}\Delta f + \bar{x}d^2K_1 + \bar{x}d^4K_2 + \bar{x}d^6K_3 + (2\bar{x}^2+d^2)p_1 + 2p_2\bar{x}\bar{y} + b_1\bar{x} + b_2\bar{y} \\
\Delta y = -y_o - \dfrac{\bar{y}}{\bar{z}}\Delta f + \bar{y}d^2K_1 + \bar{y}d^4K_2 + \bar{y}d^6K_3 + 2p_1\bar{x}\bar{y} + (2\bar{y}^2+d^2)p_2
\end{cases}
$$

Where (x,y) : image point coordinates;
f: principal distance; d:distance from image point to principal point;
(x_o,y_o): principal point offset;
$m_{11} \sim m_{33}$: elements of rotation matrix; (X_A,Y_A,Z_A): object point coordinates;
(X_L,Y_L,Z_L): exposure station coordinates; $K_1 \sim K_3$: coefficients of radial lens distortion;
p_1,p_2: coefficients of decentering lens distortion; b_1,b_2: coefficients of film/electronic sensors.

Control photos, as exclusively used and defined in this study, are those with known orientation parameters. A point measured in control photo would determine the ray passing perspective center and photo point, giving the trajectory of the object point, thus called "control ray". It comes no surprise that conjugate rays from control photos would intersect and provide 3-D object point coordinates. In addition, from the basic geometry where conjugate rays must intersect, it reveals the power of control rays in orienting those unknown photos (photos with unknown orientation parameters) when observing tie points that link control photos and unknown photos, as depicted in Figure 1.

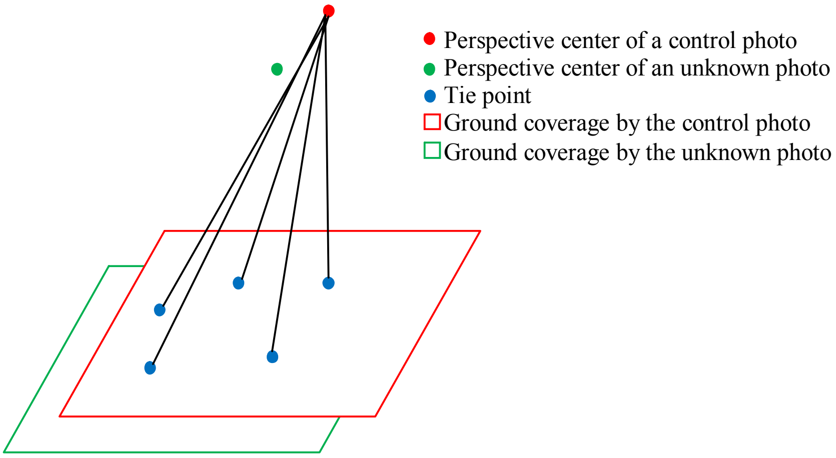


Figure1 Control photo and control rays

On the other hand, line features as presented both in image space and object space can be mathematically corresponded by again collinearity equations except that the object point needs to be formulized to lie on a 3-D line (Perng, 2005), as shown in Equ. (2). The remarkable characteristic for conjugate line features is that the line segment to line segment, instead of point to point, would allow, if provided with photo orientation parameters, a 3-D line feature intersected in the object space. The plane passing perspective center of control photo and a line segment in the photo is named "control interpretation plane", as illustrated in Figure 2.

$$x - \Delta x = -f\frac{m_{11}(p + z\times a - X_L) + m_{12}(q + z\times b - Y_L) + m_{13}(z - Z_L)}{m_{31}(p + z\times a - X_L) + m_{32}(q + z\times b - Y_L) + m_{33}(z - Z_L)}$$

$$y - \Delta y = -f\frac{m_{21}(p + z\times a - X_L) + m_{22}(q + z\times b - Y_A) + m_{23}(z - Z_L)}{m_{31}(p + z\times a - X_L) + m_{32}(q + z\times b - Y_L) + m_{33}(z - Z_L)} \quad ..(2)$$

$$\begin{cases} \Delta x = -x_o - \frac{\bar{x}}{\bar{z}}\Delta f + \bar{x}d^2K_1 + \bar{x}d^4K_2 + \bar{x}d^6K_3 + (2\bar{x}^2 + d^2)p_1 + 2p_2\bar{x}\bar{y} + b_1\bar{x} + b_2\bar{y} \\ \Delta y = -y_o - \frac{\bar{y}}{\bar{z}}\Delta f + \bar{y}d^2K_1 + \bar{y}d^4K_2 + \bar{y}d^6K_3 + 2p_1\bar{x}\bar{y} + (2\bar{y}^2 + d^2)p_2 \end{cases}$$

Where $\bar{x},\bar{y},\bar{z},x,y,x_0,y_0,f,m_{11}\sim m_{13},X_L,Y_L,Z_L,K_1\sim K_3,d,p_1,p_2,b_1,b_2$ are of the same definitions as in Equ. (1);

a,b,p,q : four parameters of 3-D straight line;

z : variables of 3-D straight line under four-parameter representation.

Similar to control rays, control interpretation planes would provide constraints towards orientation solution if conjugate line segments that appear both in control photos and unknown photos are to be collected.

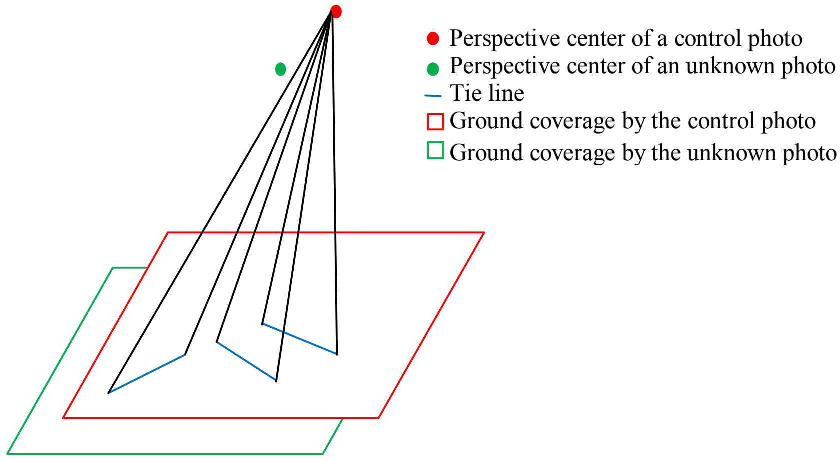


Figure 2: Control photo and control interpretation planes

EXPERIMENTS AND ANALYSES

To elaborate on the usefulness of control photos, control rays and control interpretation planes, an experiment was designed under the following scenario: modern photos with orientation parameters were served as control photos while historical photos without orientation information, overlapped with control photos, were the unknown photos to be oriented. In addition, a severe condition where neither control points nor control lines can be found due to overlap among photos and also the scene change or illuminating variation was imposed.

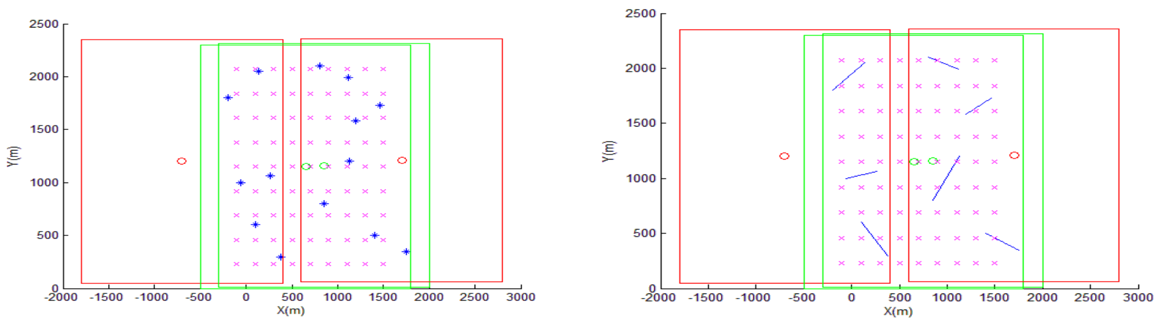
Two control photos (red rectangles indicate the ground coverage in Figure 3) and two unknown photos (green rectangles indicate the ground coverage in Figure 3) with certain overlap were simulated as in Table 1 for the orientation information and in Figure 3 for measurement layout. The blue stars represent tie points. The line features in Figure 3(b) were simply made by linking the pair of points that stayed nearby in Figure 3(a), aiming at demonstrating the orientation quality resulting from point features versus line features in a similar geometry.

To evaluate the orientation quality of control photos on the solution of unknown photos, the orientation of control photos and measurements were noised at three levels by the amount shown in the first column of Table 2. The pose error of 30 seconds approximately leads to positioning error of 0.2m on the ground. And the photo point measuring error of 0.01mm corresponds to 0.1m ground dislocalization for a single ray.

The crossings shown in Figure (3) are check points. The unknown photos upon solving orientations were to perform intersections on these locations for quality evaluations. The results in terms of RMSE (Root Mean Square Error) and theoretical precision (precisions of intersected point coordinates through adjustment) are given in Table 2

Table 1: Simulated true values of photos

Control photos	**Exterior orientation parameters**						**Flying height**
	X(m)	Y(m)	Z(m)	ω(°)	ψ(°)	κ(°)	1400m
C1	-700	1200	1300	0	0	0	**Focal length**
C2	1700	1210	1200	0	0	0	150mm
Unknown photos	**Exterior orientation parameters**						**Image scale**
	X(m)	Y(m)	Z(m)	ω(°)	ψ(°)	κ(°)	1/10000
U1	650	1150	1600	0	0	0	**Base-height ratio**
U2	850	1160	1650	0	0	0	0.25



(a) (b)

Figure 3: Measurement layout, (a) tie point and, (b) tie line distribution

Table 2: Positioning quality on check points

		Point features		Line features	
Orientation and measurement errors		RMSE (m)	Theoretical precision (m)	RMSE (m)	Theoretical precision (m)
Orientation (pose:±30 sec) Image point :±0.01mm	X	0.5597	0.5202	0.6565	1.3569
	Y	0.4249	0.4609	0.5075	1.4214
	Z	1.0783	1.0367	1.2052	2.4219
Orientation (position: ±0.2m) Image point:±0.01mm	X	0.5552	0.5386	0.8158	1.3716
	Y	0.4641	0.4699	0.7723	1.4403
	Z	1.0620	1.0446	3.5118	2.4347
Orientation (pose: ±30; position: ±0.2m) Image point:±0.01mm	X	0.6097	0.5498	1.1059	1.3844
	Y	0.5142	0.4903	1.3281	1.4611
	Z	1.0988	1.0594	3.7664	2.4563

As revealed in Table 2, one can conclude firstly that the control photos are capable of orienting unknown photos even without applicable control points or control lines. Secondly, the orientation and point measuring errors would rationally propagate to the solution of unknown photos and therefore realized in the quality of check points both validly in empirical accuracy and theoretical precisions. The control rays and control interpretation planes assist in solving the orientation parameters, they however present different levels of power. In general, point features outperform line feature in a similar geometry.

CONCLUSIONS

Control photos, photos with orientation parameters as stated, are not a new terminology for photogrammetric society. Yet when dealing with orienting multi-temporal photos where tie points and control data hardly fulfill traditional aerial triangulation requirement, the control rays and control interpretation planes are not just conceptual but actually so workable as identified in this study to lead to the solution . The question then is how flexible this type of task can be solved satisfying both the quality and efficiency, left as further work to be investigated.

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