PREPROCESSING AND IMAGE COORDINATES ENHANCEMENT IN ANALYTICAL FOTOGRAMMETRY

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Abstract

The paper aimed to present the main steps necessary to determine photo-coordinates and the process to correct them for systematic errors, such as radial distortion, refraction and earth curvature which is also known as image refinement. Image preprocessing is a technique which is used to enhance raw images received from aerial photo-cameras, placed on drones, airplanes, satellites or other aircrafts for various engineering applications with a good accuracy. Photogrammetric original data obtained are usually geometrically distorted due to the acquisition system and the movements of the platform. So, we inserted the diapositives into the measuring system (e.g. stereo-comparator or analytical plotter) and measured the fiducial marks in the machine coordinate system. Then, we compute the transformation parameters with a similarity or affine transformation. The transformation establishes a relationship between the measuring system and the fiducial coordinate system, and translates the fiducial system to the photo-coordinate system. Finally, we corrected photo-coordinates for radial distortion (by linearly interpolating with the values given in the calibration certificate) and other systematic errors.

Keywords*: Analytical photogrammetry, image processing, systematic errors.*

INTRODUCTION

Photogrammetry is the science of obtaining reliable information about objects and of measuring and interpreting this information.

The photo-coordinate system serves as the reference for expressing spatial positions and relations of the image space. It is a 3D cartesian system with the origin at the perspective centre.

Digital aerial cameras have only become available in about the last 15 years and have now replaced film cameras in many parts of the world. Their design must satisfy the need to produce high quality images and also provide a wide coverage of the terrain surface. Modern digital aerial cameras continue to be improved as new digital imaging technologies are developed.

MATERIALS AND METHODS

The coordinates and parallaxes of the midpoint M, which will become the origin of the coordinate system for the measured values, are calculated on the basis of the coordinates (x',y'') and the parallax (Δx'',Δy') of the reference indices as presented in Table 1.

Table 1. Calculation of Reduced Coordinates

Point	x' (mm)		y'' (mm)		x'' (mm)		y' (mm)	
number	x'	x' barred	y''	y'' barred	Δx''	Δx'' barred	Δy'	Δy' barred
1	392.605	-105.036	392.433	105.902	292.142	0.177	292.251	0.180
2	603.715	106.074	391.752	105.221	292.138	0.173	291.886	-0.185
3	602.674	105.033	180.629	-105.902	291.783	-0.182	291.889	-0.182
4	391.571	-106.070	181.311	-105.220	291.798	-0.167	292.257	0.186
M	497.641		286.531		291.965		292.071	
3172	499.602	1.961	205.127	-81.404	355.843	63.878	297.289	5.218
5022	479.156	-18.485	229.035	-57.496	355.582	63.617	297.604	5.533
22	478.194	-19.447	226.142	-60.389	355.428	63.463	297.626	5.555
5213	521.820	24.179	249.887	-36.644	354.971	63.006	297.048	4.977
217	531.936	34.295	230.615	-55.916	353.331	61.366	296.862	4.791
3173	563.317	65.676	199.377	-87.154	353.467	61.502	296.167	4.096
14	585.306	87.665	297.341	10.810	358.677	66.712	296.608	4.537
229	548.957	51.316	274.841	-11.690	357.390	65.425	296.747	4.676
5211	501.866	4.225	273.162	-13.369	354.991	63.026	297.223	5.152
13	477.058	-20.583	334.984	48.453	358.820	66.855	296.965	4.894
5234	558.006	60.365	323.908	37.377	362.578	70.613	296.747	4.676
1172	484.513	-13.128	391.328	104.797	365.410	73.445	296.275	4.204

Coordinates of the stereogram are calculated with the following formulas:

$$x' = \bar{x}' \qquad x'' = x' - \Delta x''$$

$$y' = \bar{y}'' + \Delta \bar{y}' \qquad y'' = \bar{y}''$$

So, we can see in Table 2 the gross image coordinates of the fiducial 4 marks and other 12points on a stereo-photo (Popescu, 2016).

Table 2. Gross image coordinates of the fiducial 4 marks and other 12 points on a stereo-photo

Point	Photogram F'		Photogram F''	
number	x' (mm)	y' (mm)	x'' (mm)	y'' (mm)
1	-105.036	106.082	-105.213	105.902
2	106.074	105.036	105.901	105.221
3	105.033	-106.084	105.215	-105.902
4	-106.070	-105.034	-105.903	-105.220
3172	1.961	-76.186	-61.917	-81.404
5022	-18.485	-51.963	-82.102	-57.496
22	-19.447	-54.834	-82.910	-60.389
5213	24.179	-31.667	-38.827	-36.644
217	34.295	-51.125	-27.071	-55.916
3173	65.676	-83.058	4.174	-87.154
14	87.665	15.347	20.953	10.810
229	51.316	-7.014	-14.109	-11.690
5211	4.225	-8.217	-58.801	-13.369
13	-20.583	53.347	-87.438	48.453
5234	60.365	42.053	-10.248	37.377
1172	-13.128	109.001	-86.573	104.797

The relationships used for the orientation, correction and reduction of coordinates measured at the main point are of the form:

$$x_i^c = a_0 + a_1 x_i^{'} + a_2 y_i^{'} + a_3 x_i^{'} y_i^{'}$$

$$x_i = x_i^c - x_P$$

$$y_i^c = b_0 + b_1 x_i^{'} + b_2 y_i^{'} + b_3 x_i^{'} y_i^{'}$$

$$y_i = y_i^c - y_P$$

Table 3. Correction equations for x (for photo F')

a1*10-2	a2*10-2	a3*10-4	l*10-2
-1.05036	1.06082	-1.11425	-1.06008
1.06074	1.05036	1.11416	1.06008
1.05033	-1.06084	-1.11423	1.06008
-1.06070	-1.05034	1.11410	-1.06008

Table 4. Correction equations for y(for photo F')

a1*10-2	a2*10-2	a3*10-4	l*10-2
-1.05036	1.06082	-1.11425	1.06008
1.06074	1.05036	1.11416	1.06008
1.05033	-1.06084	-1.11423	-1.06008
-1.06070	-1.05034	1.11410	-1.06008

Table 5.Calculation of transformed coordinates

Point	Measured coordinates		Corrected Coordinates	
number	x' (mm)	y' (mm)	x (mm)	y (mm)
3172	1.961	-76.186	2.344	-76.506
5022	-18.485	-51.963	-18.327	-52.292
22	-19.447	-54.834	-19.281	-55.181
5213	24.179	-31.667	24.447	-31.682
217	34.295	-51.125	34.718	-51.163
3173	65.676	-83.058	66.449	-83.041
14	87.665	15.347	87.939	15.828
229	51.316	-7.014	51.572	-6.793
5211	4.225	-8.217	4.280	-8.239
13	-20.583	53.347	-20.921	53.471
5234	60.365	42.053	60.372	42.500
1172	-13.128	109.001	-13.704	109.401

Table 6. Correction equations for x (for photo F'')

a1*10-2	a2*10-2	a3*10-4	l*10-2
-1.05213	1.05902	-1.11422	-1.06008
1.05901	1.05221	1.11430	1.06008
1.05215	-1.05902	-1.11425	1.06008
-1.05903	-1.05220	1.11431	-1.06008

Table 7. Correction equations for y (for photo F'')

a1*10-2	a2*10-2	a3*10-4	l*10-2
-1.05213	1.05902	-1.11422	1.06008
1.05901	1.05221	1.11430	1.06008
1.05215	-1.05902	-1.11425	-1.06008
-1.05903	-1.05220	1.11431	-1.06008

Table 8. Calculation of transformed coordinates

Point	Measured Coordinates		Corrected Coordinates	
number	x'' (mm)	y'' (mm)	x (mm)	y (mm)
3172	-61.917	-81.404	-61.872	-81.969
5022	-82.102	-57.496	-82.224	-58.024
22	-82.910	-60.389	-83.024	-60.933
5213	-38.827	-36.644	-38.863	-36.937
217	-27.071	-55.916	-26.993	-56.252
3173	4.174	-87.154	4.470	-87.517
14	20.953	10.810	21.005	10.914
229	-14.109	-11.690	-14.133	-11.794
5211	-58.801	-13.369	-59.004	-13.627
13	-87.438	48.453	-88.011	48.375
5234	-10.248	37.377	-10.421	37.493
1172	-86.573	104.797	-87.370	104.970

Correction for radial distortion causes off-axial points to be radially displaced. A positive distortion increases the lateral magnification while a negative distortion reduces it. Distortion values are determined during the process of camera calibration. They are usually listed in tabular form, either as a function of the radius or the angle at the perspective center. For aerial cameras the distortion values are very small. Hence, it suffices to linearly interpolate the distortion.

ri (mm)	20	40	60	80	100	120	140	148
Δri (μm)	3	6	2	0	-4	-8	2	9

$$\Delta r_i = a_1 r_i + a_2 r_i^3 + a_3 r_i^5 + a_4 r_i^7 + \ldots$$

Δr = movement in the plane between the real and corrected position of the point P in the object space;

$$r_P = \sqrt{x_P^2 + y_p^2}$$

$$c_x = -\frac{\Delta r}{r} x' \qquad c_y = -\frac{\Delta r}{r} y'$$

$$x_i = x_i' + c_{xi} \qquad y_i = y_i' + c_{yi}$$

c_x, c_y = corrections;
x_i, y_i = corrected coordinates;
The coefficients are determined by the minimum squares method.

A (8,4) A^T (4,8) l (8,1)

$N = A^T \times A$ N (4,4) N^{-1} (4,4)

$X = N^{-1} \times A^T \times l$ X (4,1)

a_1= … $*10^{-2}$
a_2= … $*10^{-5}$
a_3= … $*10^{-9}$
a_4= … $*10^{-13}$

In Table 9 are presented the equations of correction and in Tables 10 and 11 are presented the computing of corrected coordinates for both photos.

Table 9. Equations of correction

a1*10-2	a2*10-5	a3*10-9	a4*10-13	l*10-3
0.200	0.080	0.003	0.000	0.003
0.400	0.640	0.102	0.016	0.006
0.600	2.160	0.778	0.280	0.002
0.800	5.120	3.277	2.097	0.000
1.000	10.000	10.000	10.000	-0.004
1.200	17.280	24.883	35.832	-0.008
1.400	27.440	53.782	105.414	0.002
1.480	32.418	71.008	155.536	0.009

Table 10. Calculation of corrected coordinates (F')

Point	Initial Coordinates		Corections				Corrected Coordinate	
number	x' (mm)	y' (mm)	r (mm)	Δr (μm)	cx (μm)	cy (μm)	x (mm)	y (mm)
3172	2.344	-76.506	76.542	0.538	-0.016	0.538	2.344	-76.505
5022	-18.327	-52.292	55.411	4.110	1.359	3.879	-18.326	-52.288
22	-19.281	-55.181	58.453	3.776	1.246	3.565	-19.279	-55.178
5213	24.447	-31.682	40.018	4.751	-2.902	3.761	24.444	-31.678
217	34.718	-51.163	61.830	3.327	-1.868	2.753	34.716	-51.160
3173	66.449	-83.041	106.354	-6.218	3.885	-4.855	66.453	-83.046
14	87.939	15.828	89.353	-2.578	2.537	0.457	87.942	15.828
229	51.572	-6.793	52.017	4.403	-4.365	0.575	51.568	-6.793
5211	4.280	-8.239	9.284	1.590	-0.733	1.411	4.279	-8.238
13	-20.921	53.471	57.418	3.897	1.420	-3.629	-20.920	53.468
5234	60.372	42.500	73.831	1.139	-0.931	-0.656	60.371	42.499
1172	-13.704	109.401	110.256	-6.706	-0.834	6.654	-13.705	109.407

Table 11. Calculation of corrected coordinates (F")

Point	Initial Coordinates		Corections				Corrected Coordinates	
number	x" (mm)	y" (mm)	r (mm)	Δr (μm)	cx (μm)	cy (μm)	x (mm)	y (mm)
3172	-61.872	-81.969	102.699	-5.600	-3.374	-4.470	-61.876	-81.973
5022	-82.224	-58.024	100.636	-5.197	-4.246	-2.997	-82.229	-58.027
22	-83.024	-60.933	102.984	-5.653	-4.557	-3.345	-83.028	-60.936
5213	-38.863	-36.937	53.616	4.276	3.099	2.946	-38.860	-36.934
217	-26.993	-56.252	62.393	3.245	1.404	2.925	-26.992	-56.249
3173	4.470	-87.517	87.631	-2.148	0.110	-2.146	4.470	-87.519
14	21.005	10.914	23.671	3.648	-3.237	-1.682	21.002	10.912
229	-14.133	-11.794	18.408	2.983	2.290	1.911	-14.131	-11.792
5211	-59.004	-13.627	60.557	3.506	3.416	0.789	-59.001	-13.626
13	-88.011	48.375	100.429	-5.155	-4.518	2.483	-88.015	48.377
5234	-10.421	37.493	38.915	4.730	1.267	-4.557	-10.420	37.489
1172	-87.370	104.970	136.573	-1.253	-0.801	0.963	-87.371	104.971

This correction applies when the coordinate systems are used in the design plan; the displacement of the points is radial to the main point and is negative in the radial direction to it.
If we consider:

R = 6370000m;
$H_{of\ flight}$ = 2800 m;

$$r_P = \sqrt{x_P^2 + y_p^2}$$

$$\Delta r_i(mm) = \frac{H(m) * r_i^3(mm)}{2R(m) * c_k^2(mm)}$$

$$c_X = \frac{\Delta r_i}{r_i} x_i' \qquad \text{Then:} \qquad x_i = x_i' + c_x$$

$$c_y = \frac{\Delta r_i}{r_i} y_i' \qquad y_i = y_i' + c_y$$

Table 12. Calculation of corrected coordinates for F'

Point	Initial Coordinates		Curvature correction				Corrected Coordinates	
number	x' (mm)	y' (mm)	r (mm)	Δr (μm)	cx (μm)	cy (μm)	x (mm)	y (mm)
3172	2.344	-76.505	76.541	4.275	0.131	-4.273	2.344	-76.509
5022	-18.326	-52.288	55.407	1.621	-0.536	-1.530	-18.326	-52.290
22	-19.279	-55.178	58.449	1.903	-0.628	-1.797	-19.280	-55.179
5213	24.444	-31.678	40.013	0.611	0.373	-0.483	24.444	-31.679
217	34.716	-51.160	61.827	2.253	1.265	-1.864	34.717	-51.162
3173	66.453	-83.046	106.361	11.470	7.166	-8.956	66.460	-83.055
14	87.942	15.828	89.355	6.801	6.693	1.205	87.949	15.830
229	51.568	-6.793	52.013	1.341	1.330	-0.175	51.569	-6.793
5211	4.279	-8.238	9.283	0.008	0.004	-0.007	4.279	-8.238
13	-20.920	53.468	57.415	1.804	-0.657	1.680	-20.921	53.469
5234	60.371	42.499	73.830	3.836	3.137	2.208	60.374	42.502
1172	-13.705	109.407	110.262	12.779	-1.588	12.680	-13.706	109.420

Table 13. Calculation of corrected coordinates for F''

Point	Initial Coordinates		Curvature correction				Corrected Coordinates	
number	x'' (mm)	y'' (mm)	r (mm)	Δr (μm)	cx (μm)	cy (μm)	x (mm)	y (mm)
3172	-61.876	-81.973	102.704	10.327	-6.222	-8.243	-61.882	-81.981
5022	-82.229	-58.027	100.641	9.717	-7.939	-5.603	-82.236	-58.033
22	-83.028	-60.936	102.990	10.414	-8.395	-6.161	-83.037	-60.942
5213	-38.860	-36.934	53.612	1.469	-1.065	-1.012	-38.861	-36.935
217	-26.992	-56.249	62.390	2.315	-1.002	-2.087	-26.993	-56.251
3173	4.470	-87.519	87.633	6.415	0.327	-6.407	4.470	-87.525
14	21.002	10.912	23.667	0.126	0.112	0.058	21.002	10.912
229	-14.131	-11.792	18.405	0.059	-0.046	-0.038	-14.131	-11.793
5211	-59.001	-13.626	60.554	2.117	-2.062	-0.476	-59.003	-13.626
13	-88.015	48.377	100.434	9.657	-8.463	4.652	-88.023	48.382
5234	-10.420	37.489	38.910	0.562	-0.150	0.541	-10.420	37.489
1172	-87.371	104.971	136.574	24.284	-15.535	18.665	-87.386	104.990

RESULTS AND DISCUSSIONS

The photo-coordinate system serves as the reference for expressing spatial positions and relations of the image space. It is a 3-D cartesian system with the origin at the perspective center. depicts a diapositive with fiducial marks that define the fiducial center FC. During the calibration procedure, the offset between fiducial centre and principal point of autocollimation, PP, is determined, as well as the origin of the radial distortion, PS. The x, y coordinate plane is parallel to the photograph and the positive x–axis points toward the flight direction. Positions in the image space are expressed by point vectors. For example, point vector p defines the position of point P on the diapositive. Point vectors of positions on the diapositive (or negative) are also called image vectors.

CONCLUSIONS

A mono or stereo comparator is used to measure the image coordinates which form the basic input into the next adjustment. Precision of stereocomparators and mono comparators (e.g., Zeiss, Kern etc.) provide an accuracy at the level of1-2 μm. Analytical stereoplotters in comparator mode can also be used to measure the image coordinates providing 3-5μm accuracy. It is recommended to observe each point at least twice and to observe the fiducial marks. For example, for analytical aerotriangulation, it is also necessary to transfer points from one image to another when using a mono comparator. However, if the points are targeted on the ground, point transferring is not required.

In order to compensate for systematic errors such as lens distortion, atmospheric refraction and the digital camera scale bias and improve the collinearity equation model, distortion or additional parameters, (Δx_p, Δy_p), are introduced into the basic collinearity equations as (Ebadi, 2006):

$$x_i - x_o + \Delta x_p = -c\,\frac{m_{11}(X_i - X_O) + m_{12}(Y_i - Y_O) + m_{13}(Z_i - Z_O)}{m_{31}(X_i - X_O) + m_{32}(Y_i - Y_O) + m_{33}(Z_i - Z_O)}$$

$$y_i - y_o + \Delta y_p = -c\,k_y\,\frac{m_{21}(X_i - X_O) + m_{22}(Y_i - Y_O) + m_{23}(Z_i - Z_O)}{m_{31}(X_i - X_O) + m_{32}(Y_i - Y_O) + m_{33}(Z_i - Z_O)}$$

where (Δx_p, Δy_p), are functions of several unknown parameters and are estimated simultaneously with the other unknowns in the equations. A complete recovery of all parameters (exterior orientation, object space coordinates, interior orientation, and additional parameters) is possible under certain conditions without the need for additional ground control points. This approach is called a "self calibrating bundle block adjustment" and it is very used in many applications of analytical photogrammetry.

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