Journal of King Saud University – Engineering Sciences (2015) 27, 108–113

King Saud University

Journal of King Saud University – Engineering Sciences

www.ksu.edu.sa
www.sciencedirect.com

ORIGINAL ARTICLE

# A solution for exterior and relative orientation in photogrammetry, a genetic evolution approach

**Elgasim Elamin Elnima** *

*Ribat National University, Khartoum, Sudan*

Received 8 January 2013; accepted 12 May 2013
Available online 22 May 2013

**KEYWORDS**
Exterior orientation;
Photogrammetry;
Genetic;
Ground Control

**Abstract** Space resection is a technique that is commonly used to determine the exterior orientation parameters associated with one image or many images based on known Ground Control Points (GCPs). The term "exterior orientation" of an image refers to its position and orientation related to an exterior coordinate system. Several methods can be applied to determine the parameters of the orientation of one, two or more photos. Several methods have also been developed for the orientation of single photo. They are based on some characteristics of imaged objects. Chen and Shibasaki (1998), Cooper and Robson (1996), Dewitt (1996).

In this paper, we present a solution for the determination of the exterior orientation parameters (space resection) based on genetic evolution algorithms. This optimization model for space resection can be implemented with or without redundancy and requires no linearization. The proposed model is simple and converges to the global optimal solution.


## 1. Introduction

The exterior orientation aims to define the position and rotation of the camera at the instant of exposure. In photogrammetry, three fundamental conditions are frequently used to compute the exterior orientation parameters. These conditions are known as collinearity, coplanarity and coangularity conditions. All the solutions based on the conditions mentioned so far, use point coordinates as input data.

Several methods can be applied to determine the parameters of the orientation of single photo.

If we consider the orientation of a single image, the topological and geometrical characteristics of the imaged scene are used with the measurements in the image to determine the orientation parameters. These characteristics are considered as scene constraints (e.g. perpendicularity, parallelism, co-planarity). The relationship between camera space and object space is given by the perspective projection model of the camera.

The method presented in this paper implements genetic evolution algorithms for determining exterior orientation parameters in aerial and terrestrial photogrammetry. Good results are achieved which are comparable to the well-known methods.

* Mobile: +249 919391971.
E-mail address: Elgasim@gmail.com.
Peer review under responsibility of King Saud University.

ELSEVIER Production and hosting by Elsevier

http://dx.doi.org/10.1016/j.jksues.2013.05.004
1018-3639 

## 2. Related research

This section is a brief review of the research pertinent to our work. Liu et al. (1990) solved for the camera rotation first and then the camera translation which works for both point and line data. They considered three camera rotation angles as obtained from a nominal orientation by small perturbations, e.g., 0°. Based on this assumption, their algorithm only works if the three camera Euler rotation angles are less than 30°. Kumar and Hanson (1989) solved for the rotation and translation simultaneously by adapting an iterative technique. The initial estimates for translation and rotation are required to make the nonlinear algorithm converge. They reported that the initial rotation estimates for some data sets must be within 40° for all the three Euler angles representing the rotation. Taylor et al. (1991) estimated both the camera positions and the structure of the scene from multiple images. Based on a random initial estimate of rotation, the translation and model parameters are computed as initial inputs for the subsequent model-to-image fitting procedure. If the disparity between predicted edges and the observed edges is smaller than some preset threshold, the minimum is accepted as a feasible estimate.

Other Solutions for Exterior Orientation are presented by:

Chen and Shibasaki (1998), determination of camera's orientation parameters based on line features;
Grussenmeyer and Al Khalil (2002), solutions for exterior orientation in photogrammetry: a review;
Seedahmed (2006), direct retrieval of exterior orientation parameters using a 2-D projective transformation;
Smith and Park (2000), absolute and exterior orientation using linear features;
Wang (1992), a rigorous photogrammetric adjustment algorithm based on co-angularity condition;
Zeng et al. (1992), a general solution of a closed-form space resection.

## 3. Collinearity conditions

The collinearity condition expresses the basic relationship in which an object point and its image lies on a straight line passing through the perspective center (Fig. 1):

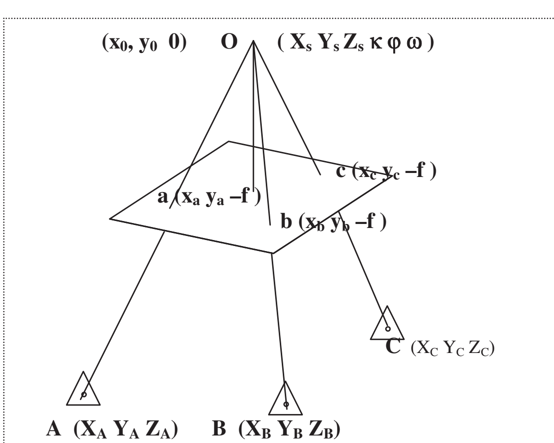


**Figure 1** Collinearity conditions.

$$\begin{pmatrix} x - x_0 \\ y - y_0 \\ -f \end{pmatrix} = \lambda \mathbf{R} \begin{pmatrix} X - Xs \\ Y - Ys \\ Z - Zs \end{pmatrix} \quad \text{or} \quad \mathbf{a} = k\mathbf{R}A \tag{1}$$

- $A$ is the vector from the perspective center to the point expressed in the object space coordinate system,
- **a** is the corresponding vector expressed in the camera space coordinate system ($f$ is the principal distance of the camera, $x_0$ and $y_0$ are the coordinates of the principal point),
- $X$, $Y$, $Z$ are the coordinates of the object-point and $Xs$, $Ys$, $Zs$ are the coordinates of the perspective center,
- **R** is the rotation matrix and $\lambda$ is the scale factor.

This collinearity equation contains the coordinates of the object point as well as the exterior orientation and the interior orientation parameters. The image coordinates of each point are considered as observations.

Expanding Eq. (1), we get:

$$\left.\begin{aligned} x_a - x_o &= \lambda[r_{11}(X_A - X_o] + r_{12}(Y_n - Y_o) + r_{13}(Z_A - Z_o)] \\ y_a - x_o &= \lambda[r_{21}(X_A - X_o] + r_{22}(Y_n - Y_o) + r_{23}(Z_A - Z_o)] \\ -f &= \lambda[r_{31}(X_A - X_o] + r_{32}(Y_A - Y_o) + r_{33}(Z_A - Z_o)] \end{aligned}\right\} \tag{2}$$

By dividing and rearranging of Eq. (2), we have

$$\left.\begin{aligned} X_a - x_o &= \frac{-f[r_{11}(X_A - X_o] + r_{12}(Y_n - Y_o) + r_13(ZA - Z_o)]}{[r_{31}(X_A - X_o] + r_{32}(Y_A - Y_o) + r_{33}(Z_A - Z_o)]} \\ y_a - x_o &= \frac{-f[r_{21}(X_A - X_o] + r_{22}(Y_n - Y_o) + r_{23}(Z_A - Z_o)]}{[r_{31}(X_A - X_o] + r_{32}(Y_A - Y_o) + r_{33}(Z_A - Z_o)]} \end{aligned}\right\} \tag{3}$$

Rotation matrix:

$$R = \begin{bmatrix} \cos\phi\cos\kappa & \cos\varpi\sin\kappa + \sin\varpi\sin\phi\cos\kappa & \sin\varpi\sin\kappa - \cos\varpi\sin\phi\cos\kappa \\ -\cos\phi\sin\kappa & \cos\varpi\cos\kappa - \sin\varpi\sin\phi\sin\kappa & \sin\varpi\cos\kappa + \cos\varpi\sin\phi\sin\kappa \\ \sin\phi & -\sin\varpi\cos\phi & \cos\varpi\cos\phi \end{bmatrix}$$

The collinearity equations can be rearranged to give the object space coordinates $X$ and $Y$ as follows:

$$\left.\begin{aligned} X &= Xs + (Z - Zs)\frac{r_{11}(x - x_o) + r_{12}(y - y_o) - r_{13} * f}{r_{31}(x - x_o) + r_{32}(y - y_o) - r_{33} * f} \\ Y &= Y_s + (Z - Z_s)\frac{r_{21}(x - x_o) + r_{22}(y - y_o) - r_{23} * f}{r_{31}(x - x_o) + r_{32}(y - y_o) - r_{33} * f} \end{aligned}\right\} \tag{4}$$

If the inner and outer orientation are both known, and points are measured in a pair of overlapping photographs, we obtain the following equations:

$$\left.\begin{aligned} X &= X_{s1} + (Z - Z_{s1}) * K1 \\ Y &= Y_{s1} + (Z - Z_{s1}) * K2 \\ X &= X_{s2} + (Z - Z_{s2}) * K3 \\ Y &= Y_{s2} + (Z - Z_{s2}) * K4 \end{aligned}\right\} \tag{5}$$

where:

$$\begin{aligned} K1 &= \frac{r_{11}(x - x_o) + r_{12}(y - y_o) - r_{13} * f}{r_{31}(x - x_o) + r_{32}(y - y_o) - r_{33} * f} \\ K2 &= \frac{r_{21}(x - x_o) + r_{22}(y - y_o) - r_{23} * f}{r_{31}(x - x_o) + r_{32}(y - y_o) - r_{33} * f} \end{aligned} \tag{6}$$

$K1$ and $K2$ are for the first photo station,
$K3$ and $K4$ are identical parameters for the second photo station.

The solution of the above Eq. (5) will give the object space coordinates for the measured pair of overlapping photographs.

## 4. Determination of EO elements using genetic evolution technique (Genetic algorithms)

Genetic algorithms were developed by John Holland at the University of Michigan in the early 1970's, Holland (1975). Genetic algorithms are theoretically and empirically proven to provide robust search in complex spaces, Goldberg (1989). Genetic algorithms are stochastic search methods that mimic natural biological evolution. Genetic algorithms operate on a population (a group of individuals) of potential solutions applying the principle of survival of the fittest to generate improved estimations to a solution. At each generation, a new set of approximations is created by the process of selecting individuals according to their level of fitness and breeding them together using genetic operators inspired by natural genetics. This process leads to the evolution of better populations than the previous populations, Eiben et al. (1999).

Fitness function is the measure of the quality of an individual. The fitness function should be designed to provide assessment of the performance of an individual in the current population.

In selection the individuals producing offspring are chosen. The selection step is preceded by the fitness assignment which is based on the objective value. This fitness is used for the actual selection process.

There are many types of selection methods used in genetic algorithms. A decision about the method of selection to be applied is one of the most important decisions to be made.

Selection is responsible for the speed of evolution and is often cited as the main reason in cases where premature convergence halts the success of a genetic algorithm.

*Crossover:* This is a version of artificial mating. Individuals with high fitness should have high probability of mating. Crossover represents a way of moving through the space of possible solutions based on the information gained from the existing solutions.

*Mutation:* Mutation represents innovation. Mutation is important for boosting the search; some of evolutionary algorithms rely on this operator as the only form of search. Many researchers have argued that GAs should be modeled more closely to natural genetics, Luke (1998), and many of them have already done so. The method implemented in this paper followed the same tradition and developed a breeding method which more closely simulates natural mating.

To determine the six elements of exterior orientation (EO) using collinearity condition: six EO Parameters ($Xs$ $Ys$ $Zs$ $\omega$ $\varphi$ $\kappa$) for each photo.

The algorithm consists of the following steps:

1. Calculate approximate estimations for the six elements.
2. Compute 2D conformal coordinate transformation parameters using two control points (whose coordinates are known in both photo coordinate system and the Object control coordinate system). Then compute Kappa, $Xs$, $Ys$ and $Zs$.
3. Compute lower and upper bounds for the 6 elements of exterior orientation. The bounds can be computed as a percentage (i.e., 5%).
4. Initialize the genetic evolution solutions by a random process to fall within the bounds.
5. The evaluation function of the genetic algorithm returns the fit value for each set of EO, which is the RMSE of the control points (2D).
6. Apply the genetic evolution algorithm for the set of solutions.
7. The genetic evolution algorithm would converge to the solution for 6 elements of exterior orientation (Single Photo).
8. The exterior orientation elements computed for the two photos are used as initial estimate for a solution that combine the two photos and produce the relative orientation parameters.
9. Compute lower and upper bounds for the 12 elements of exterior orientation related to the solutions from the two photos. The bounds can be computed as a percentage (i.e., 5%) or any other criteria that restrict the search area.
10. Initialize the genetic evolution solutions by a random process. The solutions are within the bounds computed above.
11. The evaluation function of the genetic algorithm returns the fit value for each set of EO, which is computed as the RMSE of the control points (3D).
12. Relative orientation parameters (12 parameters) would be used to compute object space coordinates from a pair of photos.

Any suitable initial estimates for the parameters can work but good estimates would lead to quick convergence. For more information about estimation of EO parameters, see Dewitt (1996). Programs for the test of this technique were developed with Matlab software, version 7.12.0.635(R2011a).

The algorithm is available if required.

## 5. Tests and results

This section describes a series of experiments that had been carried out in order to evaluate the proposed algorithm. The test data is the same test data used by Elhadi et al. (2008).

The focal length of the camera is $f$ = 152.77.

A set of tests was applied with different number of control points, ranging from 8 to 3 control points. The first test (test-1) incorporates eight control points from which the 12 parameters of orientation were calculated, the other points not used as control point are used as check points. All points are recalculated from the derived parameters of orientation and the root mean square error (RMSE) was computed for the control points and for the check points. The same procedure was repeated for the rest of tests.

Results are shown for this series of tests, from Test-1 to Test-6.

The results of Test-1 (8 control points) show an RMSE ($X$ = 0.45, $Y$ = 0.22, $Z$ = 0.98) compared to ($X$ = 0.82, $Y$ = 1.11, $Z$ = 2.94) achieved by Eiben et al. (1999), for eight control points.

Elhadi used the same above mentioned configuration set for his tests.

The first test (Test-1) is shown in detail, but other tests are presented in a summarized form. The RMSE (in meters) is shown for control points and check points.

Table 1 and Table 2 show the ground coordinates and the two photographs coordinates respectively. All ground coordinates are in meters, and all angles are in radians.

The distribution of the points is shown in the following figure (Fig. 2).

Test-1: control points = 8 {2 5 6 10 11 15 16 17}:

Left Photo(1)

Approximate values:

$H$ = 7307.83 m, kappa = −2.51761 rad, $Xs$ = 51348.31 m, $Ys$ = 49118.90 m.

Exterior orientation parameters:

| $X_S$ (m) | $Y_S$ (m) | $Z_S$ (m) | $\omega$ (rad) | $\psi$ (rad) | $\kappa$ (rad) |
|---|---|---|---|---|---|
| 51323.54 | 49105.36 | 7319.58 | 0.00251 | −0.00269 | −2.51598 |

Right Photo(2)

Approximate values:

$H$ = 7349.73 m, kappa = −2.52788 rad, $Xs$ = 48434.40 m, $Ys$ = 46894.51 m.

Exterior orientation parameters:

| $X_S$ (m) | $Y_S$ (m) | $Z_S$ (m) | $\omega$ (rad) | $\psi$ (rad) | $\kappa$ (rad) |
|---|---|---|---|---|---|
| 48387.92 | 46856.45 | 7319.40 | 0.00319 | −0.00720 | −2.52409 |

Two photo model (Exterior orientation parameters):

| Photo | $X_S$ (m) | $Y_S$ (m) | $Z_S$ (m) | $\omega$ (rad) | $\psi$ (rad) | $\kappa$ (rad) |
|---|---|---|---|---|---|---|
| Left | 51323.45 | 49105.28 | 7319.14 | 0.00250 | −0.00270 | −2.51599 |
| Right | 48385.82 | 46851.86 | 7318.30 | 0.00382 | −0.00754 | −2.52394 |

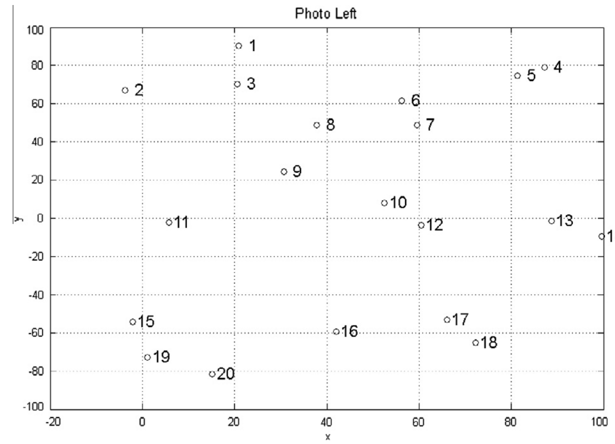


**Figure 2** Position of points on the left photo.

Test-2: Control Points = 7: {2 5 10 11 15 16 17}.

| | | | |
|---|---|---|---|
| Control Points (RMSE $n$ = 7): | 0.222 | 0.239 | 0.526 |
| Check Points (RMSE $n$ = 13): | 0.571 | 0.322 | 0.864 |

Test-3: Control Points = 6: {2 5 10 11 15 17}.

| | | | |
|---|---|---|---|
| Control Points (RMSE $n$ = 6): | 0.173 | 0.252 | 0.394 |
| Check Points (RMSE $n$ = 14): | 0.479 | 0.287 | 0.846 |

Control Points:

| Point | $X$(m) | $Y$(m) | $Z$(m) | $\Delta X$(m) | $\Delta Y$(m) | $\Delta Z$(m) |
|---|---|---|---|---|---|---|
| 2 | 53104.090 | 46945.660 | 949.760 | −0.101 | 0.171 | −0.186 |
| 5 | 50411.550 | 44620.420 | 943.100 | −0.407 | −0.460 | −0.546 |
| 6 | 50941.390 | 45676.680 | 958.000 | 0.357 | 0.236 | 0.461 |
| 10 | 49788.660 | 47604.710 | 1064.580 | 0.049 | 0.236 | 0.615 |
| 11 | 51091.620 | 49058.470 | 944.930 | −0.204 | −0.018 | 0.212 |
| 15 | 50093.510 | 50998.890 | 973.830 | 0.232 | 0.342 | −0.383 |
| 16 | 48458.340 | 50110.920 | 918.240 | −0.142 | −0.285 | 0.020 |
| 17 | 47746.580 | 49305.930 | 817.640 | 0.193 | −0.026 | −0.116 |
| **Control Points** (RMSE n = 8): | | | | 0.256 | 0.281 | 0.402 |

Check Points:

| Point | X(m) | Y(m) | Z(m) | ΔX(m) | ΔY(m) | ΔZ(m) |
|---|---|---|---|---|---|---|
| 1 | 52802.600 | 45639.630 | 1085.890 | −0.447 | 0.364 | −0.141 |
| 3 | 52360.220 | 46244.480 | 950.650 | −0.064 | −0.244 | 0.552 |
| 4 | 50313.590 | 44279.510 | 879.260 | 0.232 | −0.258 | −0.638 |
| 7 | 50518.970 | 46025.280 | 946.400 | 0.059 | 0.014 | 0.567 |
| 8 | 51254.820 | 46531.960 | 907.810 | 0.497 | −0.002 | 0.190 |
| 9 | 50896.880 | 47543.960 | 917.370 | −0.161 | −0.286 | −1.771 |
| 12 | 49251.940 | 47800.800 | 1074.740 | 0.818 | −0.288 | 0.346 |
| 13 | 48323.100 | 47011.390 | 964.110 | 0.116 | 0.104 | 0.975 |
| 14 | 47746.590 | 47016.200 | 941.400 | 0.856 | 0.043 | 1.506 |
| 18 | 47237.370 | 49573.260 | 831.480 | 0.328 | −0.267 | 0.293 |
| 19 | 49510.460 | 51574.210 | 895.600 | 0.194 | −0.036 | −1.457 |
| 20 | 48804.710 | 51540.330 | 880.000 | 0.331 | 0.012 | −0.879 |
| Check Points (RMSE $n$ = 12): | | | | 0.448 | 0.215 | 0.979 |

**Table 1** Ground coordinates in meters.

| Point | $X$(m) | $Y$(m) | $Z$(m) |
|---|---|---|---|
| 1 | 52802.60 | 45639.63 | 1085.89 |
| 2 | 53104.09 | 46945.66 | 949.76 |
| 3 | 52360.22 | 46244.48 | 950.65 |
| 4 | 50313.59 | 44279.51 | 879.26 |
| 5 | 50411.55 | 44620.42 | 943.10 |
| 6 | 50941.39 | 45676.68 | 958.00 |
| 7 | 50518.97 | 46025.28 | 946.40 |
| 8 | 51254.82 | 46531.96 | 907.81 |
| 9 | 50896.88 | 47543.96 | 917.37 |
| 10 | 49788.66 | 47604.71 | 1064.58 |
| 11 | 51091.62 | 49058.47 | 944.93 |
| 12 | 49251.94 | 47800.80 | 1074.74 |
| 13 | 48323.10 | 47011.39 | 964.11 |
| 14 | 47746.59 | 47016.20 | 941.40 |
| 15 | 50093.51 | 50998.89 | 973.83 |
| 16 | 48458.34 | 50110.92 | 918.24 |
| 17 | 47746.58 | 49305.93 | 817.64 |
| 18 | 47237.37 | 49573.26 | 831.48 |
| 19 | 49510.46 | 51574.21 | 895.60 |
| 20 | 48804.71 | 51540.33 | 880.00 |

**Table 2** Photograph coordinates.

| | Left photo | | Right photo | |
|---|---|---|---|---|
| Point | $x$ | $y$ | $x$ | $Y$ |
| 1 | 20.930 | 90.192 | −69.454 | 86.330 |
| 2 | −3.730 | 67.062 | −91.779 | 63.162 |
| 3 | 20.605 | 70.314 | −67.728 | 66.635 |
| 4 | 87.206 | 79.012 | −0.668 | 76.006 |
| 5 | 81.377 | 74.530 | −7.309 | 71.444 |
| 6 | 56.293 | 61.537 | −32.357 | 58.242 |
| 7 | 59.524 | 48.706 | −28.887 | 45.497 |
| 8 | 37.821 | 48.873 | −49.901 | 45.484 |
| 9 | 30.651 | 24.330 | −56.933 | 20.971 |
| 10 | 52.476 | 7.839 | −37.240 | 4.641 |
| 11 | 5.724 | −2.273 | −81.858 | −5.736 |
| 12 | 60.405 | −3.720 | −29.413 | −6.828 |
| 13 | 88.696 | −1.363 | 0.281 | −4.199 |
| 14 | 99.552 | −9.547 | 11.474 | −12.277 |
| 15 | −2.144 | −54.212 | −89.673 | −57.535 |
| 16 | 41.975 | −59.471 | −45.088 | −62.489 |
| 17 | 66.016 | −53.037 | −19.864 | −55.873 |
| 18 | 72.211 | −65.297 | −13.789 | −68.088 |
| 19 | 1.122 | −72.743 | −85.213 | −75.945 |
| 20 | 15.161 | −81.747 | −71.017 | −84.845 |

Test-4: Control Points = 5: {2 4 10 14 20}.

| | | | |
|---|---|---|---|
| Control Points (RMSE $n$ = 5): | 0.167 | 0.226 | 0.394 |
| Check Points (RMSE $n$ = 15): | 0.414 | 0.262 | 0.808 |

Test-5: Control Points = 4: {2 4 18 19}.

| | | | |
|---|---|---|---|
| Control Points (RMSE $n$ = 4): | 0.195 | 0.201 | 0.107 |
| Check Points (RMSE $n$ = 16): | 0.431 | 0.269 | 1.176 |

Test-6: Control Points = 3: {4 11 17}.

| | | | |
|---|---|---|---|
| Control Points (RMSE $n$ = 3): | 0.044 | 0.083 | 0.013 |
| Check Points (RMSE $n$ = 17): | 0.578 | 0.465 | 1.601 |

## 6. Analysis of results

The test results are summarized in the following table:

The results of Test-1 (8 control points) show an RMSE ($X$ = 0.45, $Y$ = 0.22, $Z$ = 0.98) compared to ($X$ = 0.82, $Y$ = 1.11, $Z$ = 2.94) achieved by Eiben et al. (1999), for the same eight control points. Elhadi used the same configuration of points for the above mentioned test. It is clear that the technique discussed in this paper achieved better results.

Table 3, shows that all RMSE values for the six tests are within 0.091 from their mean value for the $X$ and $Y$ coordinates. The $Z$ coordinate RMSE value for test-6 (3 control points) is the largest discrepancy (0.555) from the mean (1.046), all other sets show discrepancy of less than 0.238 from the mean.

A very small number of control points may lead to lower accuracy mainly in height. Also, good distribution of the control points would lead to better estimates.

In general, the estimated exterior parameters, using the proposed method, are within the accuracy requirements for topographic maps.

## 7. Conclusion

In this paper, a genetic evolution method to determine the camera exterior orientation parameters has been presented.

We can notice the actual tendency in photogrammetry toward single view modelling. Given that the determination of camera intrinsic and exterior parameters constitute the first

**Table 3** Summary of RMSE errors. The bold values are the summary value for each column(mean).

| | | RMSE | | | | RMSE – (mean of RMSE) | | | |
|---|---|---|---|---|---|---|---|---|---|
| Test# | #Points | $X$ | $Y$ | $Z$ | $P_{xy}$ | Xd | Yd | Zd | $P_{xy}d$ |
| 1 | 8 | 0.448 | 0.215 | 0.979 | 0.497 | −0.039 | −0.088 | −0.067 | −0.078 |
| 2 | 7 | 0.571 | 0.322 | 0.864 | 0.656 | 0.084 | 0.019 | −0.182 | 0.080 |
| 3 | 6 | 0.479 | 0.287 | 0.846 | 0.558 | −0.008 | −0.016 | −0.200 | −0.017 |
| 4 | 5 | 0.414 | 0.262 | 0.808 | 0.490 | −0.073 | −0.041 | −0.238 | −0.085 |
| 5 | 4 | 0.431 | 0.269 | 1.176 | 0.508 | −0.056 | −0.034 | 0.130 | −0.067 |
| 6 | 3 | 0.578 | 0.465 | 1.601 | 0.742 | 0.091 | 0.162 | 0.555 | 0.167 |
| | **Mean** | **0.487** | **0.303** | **1.046** | **0.575** | | | | |

step of the modeling procedure, the solutions based on projective geometry aspects can be very useful in this context.

The recovered camera exterior parameters, using the proposed method, can satisfy the accuracy requirements for qualified topographic maps in various civilian applications.

Other solutions using ground control features from existing databases as orthoimages, DTM interpretation operations or 3D wireframe models of buildings can be investigated to enhance the determination of the parameters of the exterior orientation.

The proposed method can be adopted to strip and block adjustment easily.

## References

Chen, T., Shibasaki, R.S., 1998. Determination of camera's orientation parameters based on line features. International Archives of Photogrammetry and Remote Sensing 32 (5), 23–28.

Cooper, M.A.R., Robson, S., 1996. Theory of close range photogrammetry. In: Atkinson, K.B. (Ed.), . In: Chapter 2 in Close range photogrammetry and Machine vision., vol. 371. Whittles Publishing, University College London, pp. 9–51.

Dewitt, B.A., 1996. Initial approximations for the three-dimensional conformal coordinate transformation. Photogrammetric Engineering & Remote Sensing 62 (1), 79–83.

Eiben, E., Hinterding, R., Michalewicz, Z., 1999. Parameter control in evolutionary algorithms. IEEE, Transations on Evolutionary Computation 3 (2), 124–141.

Elhadi, E.M., Guangdao, Hu., Zomrawi, N., 2008. The Solution of Collinearity Condition Equations With 6-Terms via 10-Terms. Journal of Modern Mathematics and Statistics 2 (2), 55–58.

Goldberg, D.E., 1989. Genetic Algorithms in Search, Optimization, and Machine Learning, Reading Mass. Addison-Wesley.

Grussenmeyer, P., Al Khalil, O., 2002. Solutions for exterior orientation in photogrammetry: a review. The Photogrammetric Record 17, 615–634. http://dx.doi.org/10.1111/0031-868X.00210.

Holland, J.H., 1975. Adaptation in Natural and Artificial Systems. The University of Michigan Press, Ann Arbor.

Kumar, R., Hanson, A.R., 1989. Robust estimation of camera location and orientation from noisy data having outliers. Proc. Workshop on Interpretation of 3D Scenes, 52–60.

Liu, Y., Huang, T.S., Faugeras, O.D., 1990. Determination of camera location from 2-D to 3-D line and point correspondences. IEEE Transactions on Pattern Analysis and Machine Intelligence 12 (1), 28–37.

Luke, S., 1998. Modification point depth and genome growth in genetic programming. Evolutionary Computation 11 (1), 67–106.

Seedahmed, G.H., 2006. Direct retrieval of exterior orientation parameters using a 2-D projective transformation. Photogrammetric Record 21 (115), 211–231.

Smith, M.J., Park, D.W.G., 2000. Absolute and exterior orientation using linear features. International Archives of Photogrammetry and Remote Sensing 33 (B3), 850–857.

Taylor, C.J., Kriegman, D.J., Anandan, P., 1991. Structure and motion in two dimensions from multiple images: A least squares approach. In: IEEE Workshop on Visual Motion. IEEE Computer Society Press, Princeton, New Jersey, pp. 242–248.

Wang, Y., 1992. A rigorous photogrammetric adjustment algorithm based on co-angularity condition. International Archives of Photogrammetry and Remote Sensing 29 (5), 195–202.

Zeng, Z., Wang, X., 1992. A general solution of a closed- form space resection. PE&RS. Zitoza, New York, vol. 58, no. 3, pp. 327–338.