Paper presented at the 22nd Asian Conference on Remote Sensing, 5 - 9 November 2001, Singapore.

A New Algorithm of Automatic Relative Orientation

[1]Zhang Guo [2]JIANG Wanshou [2]Li Deren

[1]School of Information Engineering in Remote Sensing, Wuhan University,

#129 Luoyu road, Wuhan, P.R. China

Tel: +86-27-87650980, Fax: 86-27-87863229, E-mail: guozhangchina@21cn.com

[2] LIESMARS, Wuhan University, P.R. China

KEY WORDS: automatic relative orientation, softassign, deterministic annealing

ABSTRACT: Automatic relative orientation is one of the key problems in photogrammetric processing. In past years, it has been deeply studied, but it is still worth studying, especially in close-range photogrammetry .In this paper, a new self-adaptive algorithm is put forward. It adopts softassign and deterministic annealing technology combined with coplanar equation to search homologous points in right image. Even in close-range photogrammetry when there are large parallaxes in the images, this New Algorithm can still work successfully. Other strategies such as pyramid are also taken into consideration.

1. INTRODUCTION

Relative orientation is a fundamental problem in photogrammetry. The relative orientation of two overlapping images describes the relative position and attitude do two images with respect to one another. It is a 5-parameter problem. Given these 5 parameters all imaging rays of conjugate features intersect, and these intersections from the model surface. After having completed the interior orientation for both images separately, the two image coordinate systems are explicitly known. Therefore, relative orientation is a non-semantic task, and arbitrary conjugate feature can be used for the computation if the orientation parameters. It must only be assured that enough features distributed across the complete model are used (Zhang, 1996).

Generally, automatic relative orientation should be fast, accurate, robust, and reliable. Listed in Table 1 are several traditional methods of relative orientation. In which, relative orientation are divided into three tasks: 1) Computing image pyramids for both images separately, 2) Approximately determining overlap and possible rotation and scale differences between the image on the highest level, 3) Extracting features, 4) Matching these features, 5) Determining coarse orientation parameters, 6) Proceeding with extraction, matching, and parameter determination through the pyramid from coarse to fine in order to increase the accuracy of the results, 7) Subpixel positioning of homologous points,8)Computation of relative orientation parameters.(Christian ,1997)

Among these steps, matching these features is the most important and the hardest. Cross correlation, line matching, relational matching or other feature based analysis technique is used in these methods to match these features. For the images photographed by RC10, RMK and other aerial cameras, these methods perform well. Small parallaxes are distributed in the image.

But in close range photogrammetry, images are photographed with cameras such as P31, UMK etc. There are large parallaxes in the images; the traditional methods may fail in such cases. Fortunately, global image matching technique has achieved great successfully. In fact, relative orientation can be regarded as a global matching problem. Firstly we can use gray correlation to find several peaks of correlation coefficient in the predicted searching area. And then determining the right homonymous points from the points of peak is a combination optimization problem.

There are many algorithms such as genetic algorithm, relaxation algorithm and Hopfield networks, which are usually used to solve combination optimization problem. Relaxation algorithm and Hopfield networks generate local minima and do not usually guarantee that correspondences are one-to-one. Genetic algorithm is time consuming. To overcome these problems, softassign and deterministic annealing technology with coplanar equation is put forward. This algorithm solely makes use of point location information, but it can supply an access to one-to-one correspondence and reject a fraction of points as outliers. In our study, softassign and deterministic annealing are adopted to solve the problem automatic relative orientation (Jiang W., 2001).

In order to be more efficient in locating the peaks point with less effort, several levels of pyramid images and the original for each patch can be used throughout the template matching processing.

Table 1.Methods to automatic relative orientation (Christian 1997)

Reference	Matching method	Area of application
Hannah (1989)	Cross correlation (left to right and right to left)	Aerial and close range imagery
Schenk et al. (1991)	Line matching followed by least-squares matching	Aerial imagery
Muller and Hahn (1992); Haala et al.(1993); Hahn and Kiefner (1994)	Feature based matching, checked by cross correlation	Aerial imagery
Tang and Heipke (1993,1996)	Feature based matching, checked by cross correlation	Aerial imagery
Deriche et al. (1994)	Cross correlation (left to right and right to left)	Close range imagery
Wang (1994,1995,1996)	Relational matching	Aerial and close range imagery
Cho(1995,1996)	Relational matching	Aerial imagery

2. THE NEW ALGORITHM

Firstly, we review coplanar equation with an eye toward integrating it with the softassign correspondence engine and deterministic annealing technology proposed by Gold et al (Gold, 1996a, 1998). Secondly, we develop the full-blown New Algorithm from the correspondence energy function based on the first step.

2.1 Establishment of the Energy Function with coplanar equation Combining Softassign and Deterministic Annealing Technology

When the searching areas are determined, we can select several points whose correlation coefficients are locally maximal as candidates of the left Interest points. And to determine homonymous points from the candidates becomes a combination optimization problem.

Now the problem is: Given two point-sets $\{L_i, i=1,2\ldots N\}$ and $\{R_a, a=1,2\ldots K\}$, where $\{L\}$ denotes the coordinate of interest points in the left image coordinate system and $\{R\}$ denotes the coordinate of candidate points in the right image coordinate system. L and R are related by a coplanar equation $\{j, k, j', w', k'\}$ (relative orientation of an independent image pair). The task is to find the correspondence in the two point-sets. We can define a correspondence matrix $\{m_{ai}\}$ between the two point-sets at first, such as following (Gold, 1996a, Haili, 2000):

$$m_{ai} = \begin{cases} 1 & if \quad \text{point } L_i \text{ corresponds to point } R_a \\ 0 & \text{otherwise} \end{cases}$$

To ensure one-to-one correspondence, each row and each column of M should sum to one. In the case of relative orientation, some candidates have no correspondence. We also put in an extra row and an extra column in M to take care of the outliers so that the row and column summation constraints still work. An example of the correspondence matrix is shown as following: Table 2. Points R_1, R_2 and R_4 correspond to L_1, L_2 and L_3 respectively, and the other points are outliers.

Table 2. An Example of Correspondence Matrix

m_{ai}	L_1	L_2	L_3	L_4	L_5	Outlier
R_1	1	0	0	0	0	0
R_2	0	1	0	0	0	0
R_3	0	0	0	1	0	0
Outlier	0	0	1	0	1	

The energy function with both the correspondence M and the coplanar equation (j, k, j', w', k') is the following:

$$E_{2D}(M, j, k, j', w', k') = \sum_{i=1}^{N} \sum_{a=1}^{K} m_{ai} \| F(l_i, r_a, j, k, j', w', k') \|^2 \qquad (1)$$

Where M always satisfies :

$$\sum_{a=1}^{K+1} m_{ai} = 1, \ for \forall_i \in \{1,2,...,N\}$$
$$\sum_{i=1}^{N+1} m_{ai} = 1, \ for \forall_a \in \{1,2,...,K\}$$
And $m_{ai} \in \{0,1\}$.

Now the major problem in finding good optimal solutions to the point matching objective (energy function in EQ.1) is to satisfy the two-way constraints, i.e. the row and column constraints on the correspondence matrix together with the constraints that the individual M be either zero or one. Firstly we use deterministic annealing (Gold, 1996a, 1998) methods to turn our discrete problem into a continuous one in order to reduce the chances of getting trapped in local minima. Deterministic annealing is closing related to simulated annealing except that all operations are deterministic. This method consists of minimizing a series of objective function indexed by a control parameter (temperature parameter). As the temperature is decreased the correspondence matrix approaches a permutation matrix (With binary outlier). An entropy term $T\sum_{ai} m_{ai} \log m_{ai}$ is added to the energy function to serve this purpose.

The major problem now is the point-matching objective subject to the usual two-way constraints on the matching matrix and the new constraint that the individual entries of M lie in the interval [0,1].

With the deterministic annealing technology, our two-way constraints are that: We are given a set of variables $\{Q_{ai}\}$ where $Q_{ai} \in R^1$. Then we associate a variable $m_{ai} \in \{0,1\}$ with each Q_{ai}, such that $\forall_i \sum_{a=1}^{K+1} m_{ai} = 1$ and $\forall_a \sum_{i=1}^{N+1} m_{ai} = 1$.

The aim is to find the matrix M that minimizes the following (Gold, 1996a):

$$E(M) = \sum_{i=1}^{N} \sum_{a=1}^{K} m_{ai} Q_{ai}$$

This is known as the assignment problem, a classic problem in combinatorial optimization (Papadimitriou, 1982). This problem usually has two good solutions: softmax and softassign. Softassign has clear advantages in accuracy, speed, parallelizabllity and algorithmic simplicity over softmax and a penalty term ($1.0/T \sum_{i=1}^{N}\sum_{a=1}^{K} m_{ai}$) in optimization problem with two-way constraints (Gold, 1996b).

Putting everything together, the final energy function that is actually minimized by our algorithmis as follows(Gold, 1996a, Haili, 2000):

$$E(M,d,t) = \sum_{i=1}^{N}\sum_{a=1}^{K} m_{ai} \| F(l_i, r_a, j, k, j', w', k') \|^2 + T\sum_{i=1}^{N}\sum_{a=1}^{K} m_{ai}\log m_{ai} - (1.0/T)\sum_{i=1}^{N}\sum_{a=1}^{K} m_{ai} \qquad (2)$$

Where $m_{ai} \in [0,1]$ satisfies:

$$\sum_{i=1}^{N+1} m_{ai} = 1, \ for\ a = 1,2,\dots,K,$$

And

$$\sum_{a=1}^{K+1} m_{ai} = 1, \ for\ \mathrm{i} = 1,2,\dots,N.$$

Let's briefly go through all the components of the energy function. The first term is just the error measure term .The second term is an $x\log x$ entropy barrier function with the temperature parameter T. The entropy barrier function ensures positivity of M. The third term with a parameter (1.0/T) is used to guard against null matches.

2.2 **Pseudocode for the Algorithm**

The pseudocode for the adaptive algorithm is as follows (using the variables and constants defined below) (Gold, 1996a, Haili, 2000)

Initialize j, k, j', w', k' T_0, M, L, R, N, K, T_r

Begin A: Do A until ($T>T_f$)

Begin B: Do B until d converges or of iteration $>I_0$

Begin C (update correspondence parameters by softassign):

$$Q_{ai} \leftarrow -\frac{\partial E(l_i, r_a, j, k, j', w', k')}{\partial m_{ai}} \qquad m_{ai} \leftarrow \exp(Q_{ai}/T)$$

Begin D Do D until $\hat{M}$ converges or of iteration > I_1

Update $\hat{M}$ by normalizing across all rows

$$\hat{m}_{ai}^{1} \leftarrow \hat{m}_{ai}^{0} \Big/ \sum_{i=1}^{N+1} \hat{m}_{ai}^{0}$$

Update $\hat{m}$ by normalizing across all columns

$$\hat{m}_{ai}^{0} \leftarrow \hat{m}_{ai}^{1} \Big/ \sum_{a=1}^{K+1} \hat{m}_{ai}^{1}$$

End D

End C

Begin E (Update pose parameters by coordinate descent)

Y=MR (calculate current correspondence points)(Pay attention to this)

Update (j, k, j', w', k') using Least squares for coplanar equation with Y and L

End E

End B

$T \leftarrow T * T_r$

End A

Variable and constant definition can be found as following:

L the coordinate of interest points in the left image coordinate system,

N number of interest points,

R the coordinate of candidate points in the right image coordinate system,

K number of candidate points,

T control parameter of the deterministic annealing method,

T_0 initial value of the control parameter *T,*

T_f minimum value of the control parameter *T,*

T_r rate at which the control parameter *T* decreases (annealing rate),

E (M, j, k, j', w', k') point matching objective function (EQ. (2)),

m_{ai} matching matrix variables,

Q_{ai} partial derivative of E (M, d, t) with respect to m_{ai},

I_0 Maximum of iterations allowed at each value of the control parameter *T*,

I_1 Maximum of iteration allowed row and column normalizations,

The criterion for convergence for step D is $\sum_{i=1}^{N}\sum_{a=1}^{K}|m_{ai}^0 - m_{ai}^1| < e_1$, and e_1 is a constant close to zero,

The criterion for convergence for step B is $\sum |\nabla d| < e_2$, and e_2 is also a constant close to zero.

3. EXPERIMENTS

The algorithm is tested on some close-range photographs. These photographs are 6000 pixels × 4500 pixels taken by a P31 metric camera. In this experiment, 3 points are found as candidates of every interest points. The New Algorithm is set up in the following manner. The T_0 is set so that it is slightly bigger than the largest square distance of all point pairs to allow all possible matching. T_r (annealing rate) is 0.93. T_f is half of the longer length of the film. The correspondence matrix M is set to zero, and the outliers row and column are endowed with a value proximate to zero, the 5 relative orientation parameters are zero. The alternating updating of correspondence M and transformation d is repeated for 5 times, which is usually sufficient for convergence after which the temperature (*T*) decreases with T_r. After $T<T_f$, the correspondence matrix got.

A clean-up heuristic is necessary because the algorithm does not always converge to a permutation matrix. In the test, a very simple heuristic is used. We just set the maximum element in each row to 1 and all others to 0. A correct one-to-one correspondence is got after this .

4. CONCLUSION

The relative orientation becomes much harder in close range photogrammetry. The New Algorithm performs quite well without the usage of correlation coefficient.

5. ACKNOWLEDGE

The National Natural Science Foundation of China has supported this paper. (Grand number: 40023004, 40001018)

6. REFERENCES

1) Christian Heipke 1997. Automation of interior, relative, and absolute orientation. ISPRS Journal of Photogrammetry & Remote Sensing 52 pp .1-19

2) Gold S. And Rangarajan A. 1996a A graduated assignment algorithm for graph matching. IEEE Trans. Patt. Anal. Mach. Intell. 18(4) pp.377-388,

3) Gold, S. and Rangarajan, A. 1996b. Softmax to softassign: neural network algorithms for combinatorial optimizations Journal of Artificial Neural Networks, in press

4) Gold S., Rangarajan A, Lu C. P., Pappu S, and Mjolsness E 1998 New algorithms for 2-D and 3-D point matching: pose estimation and correspondence. Pattern Recognition, 31(8) pp.1019-1031,

5) Haili Chui and Anand Rangarajan 2000 A new algorithm for non-rigid point matching, IEEE Conference on Computer Vision and Pattern Recognition (CVPR),

6) JIANG W. Zhang G. Li D. 2001. A Self-Adaptive Algorithm of Automatic Interior Orientation for Metric Images ISPRS, Vol.34, Part 2W2,"Dynamic and Multi-Dimensional GIS", Bangkok, May 23-25,2001,pp.141-144

7) Papadimitriou, C. and Rangarajan, K. 1982 Combinatorial Optimization Prentice-Hall, Inc. Englewwood Cliffd, NJ

8) Zhang Z., Zhang J. 1996. Digital Photography. Press of wtusm