RELATIONAL MATCHING APPLIED TO AUTOMATIC EXTRACTION OF GROUND CONTROL IN DIGITAL IMAGES

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ABSTRACT

The aim of this paper is to test the use of relational matching in the automatic extraction of ground control (straight features). The identification of ground control on photographs or images is usually carried out by a human operator, who uses his natural skills to make interpretations. In Digital Photogrammetry, which uses techniques of digital image processing, the extraction of ground control can be automated using relational matching. This matching approach is commonly used in Computer Vision, but only recently has been applied by photogrammetrists. It has been recognized its great potential to automate several tasks in photogrammetry. The basic principles of the approach and an experiment based on simulated data are presented and discussed in this paper.

1. INTRODUCTION

Photogrammetric tasks, such as relative orientation of images, derivation of digital terrain models (DTM) and aerial triangulation can be automated by using the image matching technique. The matching method commonly used in these applications is the area based matching. The basic principle of this technique is the establishment of correspondences between patches of the overlapping images.

However, there are other tasks, also based on the correspondence principle, where the automation is very difficult to be implemented. One of these tasks is the automatic extraction of ground control. In such a case, the correspondence is performed between an image and a symbolic model describing the ground control. Several approaches have been proposed recently (Haala and Vosselman, 1992; Schickler, 1992; Hellwich and Faig, 1994). An approach to solve the problem of automatic extraction of ground control based on relational matching and a heuristic that uses the analytical relation between straight features of object space and its homologous in the image space is presented in this paper.

In the next section the basic principles of the approach are presented. The section 3 discusses an experiment based on simulated data.

2. THE MATCHING PROCEDURES

Relational matching is based on the correspondence between two relational structures. A relational structure is composed of primitives (in our case, straight features) and relations among the primitives.

Three steps can be identified in all relational matching approaches:

- transformation from raster space to entity space;
- transformation from entity space to relational space; and
- matching strategy.

2.1 Transformation from Raster Space to Entity Space

This transformation is performed by edge detection and vectorization. Gradient methods can be used to detect edges and Hough method to detect and vectorize straight features. Ground control (straight features) is supposed to be available in the entity space, i. e. , defined by two 3D points in the ends located at the straight feature or by one 3D point and one 3D normalised vector.

2.2 Transformation from Entity Space to Relational Space

Transformation from entity space to relational space is accomplished by using relational models, commonly referred to as relational descriptions in the Computer Vision literature. These structures are lists of relations. Let O_A be an object and **A** be the set of its parts. An N-ary relation over **A** is a subset of the Cartesian product $\mathbf{A}^N = \mathbf{A} \times \ldots \times \mathbf{A}$ (N times) (Shapiro and Haralick, 1987). In our approach, the relational description comprises four binary relations (subsets of the Cartesian product $\mathbf{A}^2 = \mathbf{A}\mathbf{x}\mathbf{A}$): parallelism, perpendicularism, connection and collinearity.

A more suitable type of relation, called star structure, can be used in the matching procedure. According to Cheng and Huang (1984), a star structure rooted at node *i* is node *i* itself plus all its links (binary components of star, i. e., r1, ..., rj) and neighbouring nodes (n1, ..., nj). Figure 1 illustrates this concept. This structure allows the definition of the matching between two homologous straight features. A star structure is defined to each straight feature that is named root. As already mentioned, a star structure is also a relation. Consequently, a star structure is defined similarly, but each of its components must contain the root straight feature. The relational description based on star structures is a list of these structures having the same root, which in our approach are based on parallelism, perpendicularism, connection and collinearity.

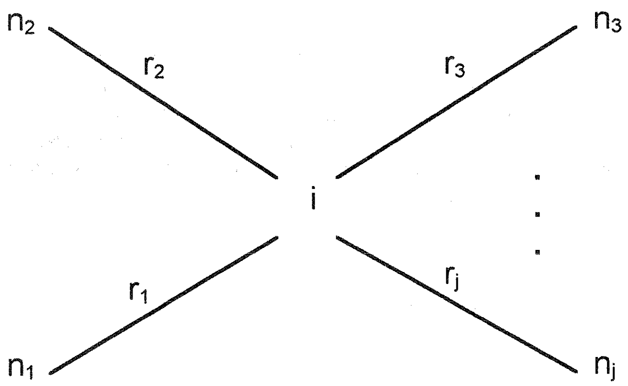

Figure 1 - Star structure.

Transformation from entity space to relational space is applied to straight features both in the image and object spaces. The relational descriptions of image and object straight features are constructed in the 2D-space. Although ground control is defined in the 3D-space, the object straight features are projected to the image space by collinearity equations. Approximated parameters of exterior orientation are required at the beginning of the matching process. Since the exterior orientation parameters are successively refined after the third correspondence, the ground controls are also successively re-projected to the image space by collinearity equations. Therefore, the relational description of re-projected image is continuously refined.

2.3 Matching Strategy

The matching strategy is performed in the search space (search tree). This space consists of nodes and arcs connecting nodes. Each node represents a possible assignment of one image straight feature to one object straight feature. The set of image straight features is called Unit and the set of object straight features is called Label. The latest set includes a special primitive named NULL, which is used to label an image straight features that have no correspondences in the object space. Each possible path from root node to some leaf node is a possible solution or a possible mapping. Then, the question is how to obtain the correct mapping. Each node of correct mapping must satisfy the following conditions: the uniqueness constraint, the rigidity constraint, a limit to normalised relational distance and, the self-diagnosis.

2.3.1 Uniqueness Constraint: If an image straight feature and an object straight feature are homologous, both straight features correspond to a unique phenomenon in the real world. In other words, each feature of the label set that was used in some correspondence is taken out of the search space in the following searches. This simple operation reduces the search space.

2.3.2 Rigidity Constraint: The rigidity constraint is based on a photogrammetric model relating straight features both in the image and object spaces. One photogrammetric model that relates image and object straight features is presented in Tommaselli and Tozzi (1993, 1996). In this model the observations are straight line parameters extracting in a vectorization process. The rigidity constraint is used in a paradigm called *matching while locating*. It was adapted from another similar paradigm called *recognising while locating* (Faugeras and Helbert, 1986). Given an image straight feature, the aim of this paradigm is to restrict the number of object straight features to be analysed in the matching process. In other words, the search space is drastically reduced.

2.3.3 Application of Normalised Relational Distance: The relational matching is applied at this step. The normalised relational distance is applied if the node of the search tree being analysed satisfies the uniqueness and the rigidity constraints. The normalised relational distance is a metric that measures the similarity between two relational descriptions and is defined in the range [0; 1]. In our case, they are constructed from unit and label sets and are based on star structures. In an ideal case, if the normalised relational distance is zero, the node being analysed is considered compatible. In practical applications, however, it will be necessary a threshold.

2.3.4 Self-diagnosis: Self-diagnosis is based on detection of gross errors. Due to the need of redundant data to apply least squares adjustment, only after the fourth correspondence it could be feasible the application of the self-diagnosis. An alternative would be to apply a recursive estimation method, e. g. Kalman filtering (Tommaselli & Tozzi, 1993, 1996). At this moment, only Chi-Squared test has been implemented.

3. RESULTS

The approach summarised in the previous sections was implemented in C language.

In order to illustrate the application of the method, an 1:10.000 aerial photograph was simulated. Random errors were introduced in the data. The spatial view of the simulated straight features are showed in figure 2.

The simulated data are listed in table 1. One image

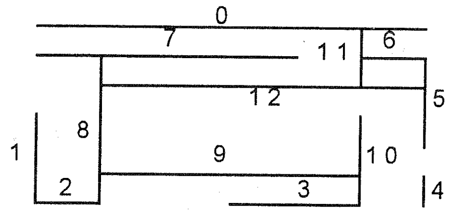

Figure 2 - Spatial view of the simulated straight features.

space straight feature is defined by angular (a) and linear (b) parameters. As already mentioned, random errors were introduced in these parameters. The standard deviations of a and b parameters are σ_a and σ_b, respectively. One object space straight feature is defined by a fixed point (X_1, Y_1, Z_1) and a normalised vector (Vx, Vy, Vz). The latest line of table 1 shows the elements of exterior orientation (κ, ϕ, ω, X_o, Y_o, Z_o) and the focal length used to simulate the image space straight features.

A summary of obtained results is presented in table 2. This table shows that all correspondences were found, which can be denoted by f= {(l_0, M_0), ..., (l_{12}, M_{12})}. As expected, the normalised relational distances (GDN) are zero. This is because the image and object space relational descriptions do not have any discrepancy. The

Table 1 - Simulated data.

No	Image Straight Features (I)				Object Straight Features (M)					
	a ($\times 10^{-6}$)	b (mm)	σ_a ($\times 10^{-9}$)	σ_b ($\times 10^{-9}$m)	X1 (m)	Y1 (m)	Z1 (m)	Vx	Vy	Vz
0*	-33	160.72	4	112	500	3500	100	1	0	0
1	-38	-160.74	17	225	500	2000	100	0	-1	0
2*	-40	-160.70	157	2921	500	500	100	1	0	0
3*	276	-160.71	39	224	2000	500	100	1	0	0
4	178	160.72	157	2920	3500	500	100	0	1	0
5	187	160.71	17	125	3500	1500	100	0	1	0
6*	-188	107.18	157	2923	3000	3000	100	1	0	0
7*	18	107.16	10	140	500	3000	100	1	0	0
8	-36	-107.13	6	116	1000	500	100	0	1	0
9*	105	-107.13	10	112	1000	1000	100	1	0	0
10	-230	107.11	17	225	3000	500	100	0	1	0
11	106	107.14	39	562	3000	2500	100	0	1	0
12*	-46	53.59	6	117	1000	2500	100	1	0	0

κ=0°; ϕ=0°; ω=0°; X_o=2000m; Y_o=2000m; Z_o=1500m; focal distance = 150mm

(*)image straight features represented by x=a*.y + b*, because of indeterminations in the representation y= a.x + b, when the feature is closely vertical.

Table 2 - Matching results.

Image Straight Features (I)			Object Straight Features (M)	GDN
Straight Features	Va($\times 10^{-6}$)	Vb($\times 10^{-3}$mm)		
l_0	-12	8	M_0	0
l_1	27	11	M_1	0
l_2	147	3	M_2	0
l_3	-169	10	M_3	0
l_4	-229	-22	M_4	0
l_5	-238	-8	M_5	0
l_6	168	-28	M_6	0
l_7	-38	-4	M_7	0
l_8	19	-10	M_8	0
l_9	-23	-1	M_9	0
l_{10}	185	27	M_{10}	0
l_{11}	-151	-2	M_{11}	0
l_{12}	47	-8	M_{12}	0

κ=-6"; ϕ=-15"; ω= 4"; X_o= 1999.891m; Y_o= 1999.835m; Z_o= 1499.961m

σ_κ = 6"; σ_ϕ = 9"; σ_ω = 9"; σ_{X_o} = 0.119m; σ_{Y_o} = 0.110m; σ_{Z_o} = 0.038m

$\sigma_o^2 = 1$; $\hat{\sigma}_o^2 = 0.808785$

elements of exterior orientation (κ, ϕ, ω, X_o, Y_o, Z_o), its standard deviations (σ_{κ}, σ_{ϕ}, σ_{ω}, σ_{X_o}, σ_{Y_o}, σ_{Z_o}) and estimated variance factor ($\hat{\sigma}_o^2$) are estimated in the process of rigidity constraint by least squares method. V_a and V_b are residuals of a and b , respectively, and σ_o^2 is the *a priori* variance factor.

A statistical test based on Chi-Squared distribution (χ^2) with 6 degrees of freedom and level of significance of 1% was applied to the obtained correspondences. This statistical test showed that σ_o^2 and $\hat{\sigma}_o^2$ were statistically equal. Then, the correspondences could be considered statistically correct.

4 CONCLUSION

This paper briefly presented the principles of matching method and preliminary experiment based on simulated data. As already mentioned, this method is based on relational paradigm and rigidity constraint. In addition, the method does not require points as ground control. Instead of points, only straight features are required.

Although only preliminary results are available, using simulated date, the method seems to be promising. In the future, other experiments will be performed with simulated and real data, which will allow more realistic conclusion.

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