FEATURE BASED IMAGE ORIENTATION AND OBJECT RECONSTRUCTION

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ABSTRACT:

Image orientation and object reconstruction tasks in photogrammetry are generally based on distinct points. However, in 3D object space besides points there are also lines (straight or curved) and surfaces (planar or curved), which are increasingly being available in digital data bases, and in 2D image space lines can be extracted, especially when automatic procedures of image analysis are used. These geometric features in object space and their projections into image space can be used for image orientation and object reconstruction.

In this paper a systematic overview concerning the use of points, lines and surfaces for photogrammetric orientation and object reconstruction tasks is given. It is shown, which tasks can be performed, and the respective minimum number of features needed for a solution is derived. Some remarks on degenerate configurations are given and the evaluation of precision using general geometric features is shown by means of simulated examples.

KEY WORDS: Image orientation, general geometric features, feature based photogrammetry.

1. INTRODUCTION

The transition from analytical to digital photogrammetry, which is one of the major topics in photogrammetric research, requires the modification and extension of the existing models and the development of completely new concepts. For the geometric tasks of photogrammetry this basically means that the photogrammetric observations in image space do not result from human measurements, but from automatic techniques of image analysis. In the traditional approach image orientation and object reconstruction tasks are more or less completely based on distinct points. However, geometric features in object space can also be straight or curved lines and planar or curved surfaces. (Note: the term lines refers to one-dimensional curves including both straight and curved continuous features, i.e. it is not restricted to straight lines). These features and their projection into image space can be used for image orientation and object reconstruction. Especially for digital techniques of image analysis this aspect is essential, because lines are easier to extract than point features by automatic procedures. Therefore a sound theory is necessary for dealing with general geometric features.

Research and practical work based on the correspondence of general geometric features, besides points, is being performed in computer vision and photogrammetry. Some references are given in the following, which represent important work done in this field.

Horizontal and vertical lines were used as control features for close range applications in Döhler (1975). Kager, Kraus (1976) described the mathematical model for plumb lines, straight lines, parallel and orthogonal lines and planes in a simultaneous adjustment of photogrammetric, geodetic and so-called fictitious observations. The concept of line to line correspondence in aerial photogrammetry was shown by Masry (1981) and Lugnani (1982). The rectification of SPOT imagery using points and edges as control was presented by Paderes et al. (1984). Space resection based on straight line correspondences was shown in Dhome et al. (1989), Liu et al. (1990) and Chen (1991). The formulation of the mathematical model for the solution of space resection and intersection using line features was given in Mulawa, Mikhail (1988); further work was published in Sayed, Mikhail (1990). Relative orientation of a sequence of images using correspondences of straight line features was treated e.g. in Yen, Huang (1983), Liu, Huang (1988a, 1988b), Spetsakis, Aloimonos (1990) and Weng et al. (1992). In these approaches the computation of the rotation and position parameters is separated and non-linear as well as linear algorithms are derived. In Kubik (1991) relative and absolute orientation using linear features was discussed. Finsterwalder (1991) presented algorithms and geometric explanations for the use of lines in space resection, rectification and absolute orientation. 3D to 3D matching of corresponding lines and surfaces was published by Faugeras, Hebert (1986), Kim, Aggarwal

(1987), Chen, Huang (1990) and Zhang, Faugeras (1991). The use of surface data (digital terrain models) as control information in block triangulation and absolute orientation was treated by Ebner, Strunz (1988) and Rosenholm, Torlegård (1988).

In this paper a systematic overview concerning the use of points, lines and surfaces for photogrammetric orientation and object reconstruction tasks is given. It is shown, which tasks can be performed, and the respective minimum number of features needed for a solution is derived. Some remarks on degenerate configurations are given and the evaluation of precision using general geometric features is shown by means of simulated examples.

2. MINIMUM CONFIGURATIONS

In the following first some basic considerations concerning the use of points, lines and surfaces for photogrammetric orientation and object reconstruction tasks are given, and then the minimum number of general geometric features needed for the solution is derived. It is assumed that the extraction of features and the precise determination of their locations in image space has already been accomplished and that the correspondences between these features are established, which in general are non-trivial problems. Furthermore, it is supposed that for the orientation tasks approximate values of the unknown parameters are available, so that linear models can be derived from the nonlinear models and the problem is solved iteratively. Linear algorithms as such are not discussed.

The general method for image orientation and object reconstruction is based on a bundle block adjustment, where the orientation parameters of multiple images and the coordinates of the object points are estimated simultaneously. Basic orientation tasks, which are implicitly comprised in multiple image orientation, can be classified into space resection (2D-3D), relative orientation (2D-2D), and absolute orientation (3D-3D). The mathematical model used in 2D-3D and 2D-2D orientation is based on perspective projection, which can be formulated by the collinearity equations, the underlying model of 3D-3D orientation is a spatial similarity transformation.

Lines in 2D image space can be described in several forms, e.g. parametric or implicit. If we assume a line to be represented by the image coordinates of a specific number of points, which uniquely define the line, then the collinearity equations can be used for points as well as for lines. In this paper only two types of algebraic lines are considered: straight lines and circular lines in object space, which in general correspond to straight lines or ellipses in image space. Basically the image lines can result from the

perspective projection of 3D lines or from occluding contours of 3D surfaces, the 3D positions of which depend on the exterior orientation of the images. However, these contours can not be used for 2D-2D correspondence. According to the specific orientation task the lines and surfaces can serve as "tie" features or as control features. This means that the spatial position and orientation of a particular feature is either unknown and has to be determined in the course of the orientation process or is given as control information in object space.

In the following for the basic orientation tasks the minimum number of corresponding features is derived, which is necessary to yield a solution. Degenerate configurations are not considered. An overview is given in Tab. 1 - 3, where n is the number of observation or condition equations and u is the number of unknowns.

2.1 Space resection (2D-3D)

Space resection involves the determination of the exterior orientation of a single image, and is described by 6 parameters.

Points in image space:
A point is defined by 2 coordinates in image space, which are given as observations, and 3 coordinates in object space, which are unknowns.
- *Point to point correspondence:*
If the corresponding feature in object space is a given point, its 3 object coordinates are known. Therefore, 3 image points and their corresponding object points are necessary to determine the exterior orientation parameters. The solution is based on fitting the bundle of rays to the corresponding object points.
- *Point to line correspondence:*
If the corresponding feature in object space is a given line, 2 conditions are imposed on the 3 unknown object coordinates. Consequently, 6 points in image space and their corresponding lines in object space are needed. The solution is based on fitting the bundle of rays to the corresponding line features in object space.

Lines in image space:
A straight line is uniquely defined by 2 parameters (observations) in image space and 4 parameters (unknowns) in object space. An ellipse is defined by 5 parameters (observations) in image space and in case the corresponding feature is a circle in object space it is described by 6 (unknown) parameters.
- *Line to line correspondence:*
Straight line: If the straight line is given in object space, its 4 line parameters are known. Therefore, 3 straight lines in image space and the correspon-

ding lines in object space are necessary to solve the exterior orientation. The solution is based on fitting a bundle of planes to the corresponding straight lines in object space.

Circular line: If the circular feature is given in object space, its 6 circle parameters are known. Consequently, 2 circular features are needed, including 4 redundant observations. The solution is based on fitting two cones to the corresponding circles in object space.

In case of an incomplete description of the features in image or object space a number of further configurations for the solution of space resection is possible. For instance, if in case of circular features only the respective planes of the circles in object space are given, then 3 circular features are needed. Some examples for partial control information are given in Tab. 1, where for each of the 2D features the configurations are grouped according to the number of observations for the corresponding features in 3D object space. Furthermore, minimum configurations based on a combined use of points and lines can be derived by similar considerations.

2.2 Relative orientation (2D-2D)

Relative orientation involves the determination of the relative position and attitude of at least two images. The number of unknowns to be determined is 5 for the relative orientation of two images (generally $6 \cdot i-7$ unknowns for i images) together with the parameters describing the corresponding features in model space. In the following generally 2 images and, if a solution is not possible, 3 images will be considered.

Points in image space:
- *Point to point correspondence:*
  A point is represented by 2 coordinates (observations) per image and 3 model coordinates (unknowns). 5 corresponding points in two images are needed in general to solve the relative orientation problem. The solution is based on the condition that the visual rays from the projection centres to the image points intersect in an identical point in 3D (model) space.

Lines in image space:
- *Line to line correspondence:*
  A straight line is defined by 2 parameters (observations) per image line and 4 parameters (unknowns) in model space. Therefore, the relative orientation of two images cannot be solved with corresponding straight line features. The reason is that the corresponding projecting planes always intersect in a straight line (except for parallel or identical planes); however, no redundant information, which is needed for the determination of the orientation parameters, results from this intersec-

tion. Consequently, at least 3 images and 6 corresponding straight line features in each of the images are necessary to simultaneously determine the relative orientation parameters of the images and the parameters describing the straight lines in 3D (model) space, including one redundant observation. The solution is based on the condition that the corresponding three projecting planes intersect in an identical line in model space.

A circular line feature is defined by 5 parameters (observations) per image ellipse and 6 parameters (unknowns) in model space. Consequently, 2 corresponding circular features projected in the 2 images are needed for a solution including 3 redundant observations. The solution is based on the condition, that the projecting cones consisting of the projection centres and the ellipses in image space intersect in an identical circular feature.

2.3 Absolute orientation (3D-3D)

Absolute orientation, i.e. the transformation from a 3D model coordinate system to a 3D reference system, is defined as a spatial similarity transformation by 7 unknown parameters (3 translations, 3 rotations and a scale factor).

- *Point to point correspondence:*
  3 corresponding points in the two systems are necessary to determine the 7 transformation parameters including 2 redundant observations.

- *Point to line correspondence:*
  4 points in one system and the corresponding lines in the other system are needed to solve the transformation including 1 redundant observation.

- *Point to surface correspondence:*
  7 points in one system and the corresponding surfaces in the other system are needed.

- *Line to line correspondence:*
  For straight line features 2 straight lines in each of the two systems are needed to solve the transformation including 1 redundant observation.

- *Line to surface correspondence:*
  For straight line features 4 straight lines and the corresponding planes are needed to solve the transformation including 1 redundant observation.

- *Surface to surface correspondence:*
  For planar surface features 4 planes in each of the two systems are needed to solve the problem including 5 redundant observations. 4 planes are needed, because in case of 3 corresponding planes all configurations are degenerate.

Space resection					
Corresponding features			Minimum configurations		
	2D	3D	$n = n_{2D} + n_{3D}$	u	$n \geq u$
0D	Point	Point	$2P + 3P$	$6 + 3P$	$P \geq 3$
		Line	$2P + 2P$		$P = L \geq 6$
		Surface	$2P + 1P$		-
1D	Straight line	Straight line	$2L_S + 4L_S$	$6 + 4L_S$	$L_S \geq 3$
			$2L_S + 3L_S$		$L_S \geq 6$
		Point/Plane	$2L_S + 2L_S$		-
			$2L_S + 1L_S$		-
	Ellipse	Circle	$5L_C + 6L_C$	$6 + 6L_C$	$L_C \geq 2$
			$5L_C + 5L_C$		$L_C \geq 2$
			$5L_C + 4L_C$		$L_C \geq 2$
		Plane	$5L_C + 3L_C$		$L_C \geq 3$
		Point	$5L_C + 2L_C$		$L_C \geq 6$
			$5L_C + 1L_C$		-

Tab. 1: Minimum configurations of space resection

Relative orientation					
Corresponding features			Minimum configurations		
	2D	2D	(3D)	$n = i \cdot n_{2D}$	u	$n \geq u$
0D	Point	Point	Point	$2 \cdot 2P$	$5 + 3P$	$P \geq 5$
				$3 \cdot 2P$	$11 + 3P$	$P \geq 4$
1D	Straight line	Straight line	Straight line	$2 \cdot 2L_S$	$5 + 4L_S$	-
				$3 \cdot 2L_S$	$11 + 4L_S$	$L_S \geq 6$
	Ellipse	Ellipse	Circle	$2 \cdot 5L_C$	$5 + 6L_C$	$L_C \geq 2$

Tab. 2: Minimum configurations of relative orientation

Absolute orientation					
Corresponding features			Minimum configurations		
	3D	3D	$n = n_{3D} + n_{3D}$	u	$n \geq u$
0D	Point	Point	$3P + 3P$	$7 + 3P$	$P \geq 3$
		Line	$3P + 2P$		$P = L \geq 4$
		Surface	$3P + 1P$		$P = S \geq 7$
1D	Straight line	Straight line	$4L_S + 4L_S$	$7 + 4L_S$	$L_S \geq 2$
		Plane	$4L_S + 2L_S$		$L_S = S_P \geq 4$
2D	Plane	Plane	$3S_P + 3S_P$	$7 + 3S_P$	$S_P \geq 4$

Tab. 3: Minimum configurations of absolute orientation

3. DEGENERATE CONFIGURATIONS AND SIMULATED EXAMPLES

3.1 Some remarks on degenerate configurations

Some degenerate cases, where a solution is not possible, are given in this chapter; however, a thorough investigation on the existence and uniqueness of the solutions is not presented. The examples refer to the use of straight lines in space resection and relative orientation.

In space resection using straight lines as control features the position of the projection centre can not be determined, if the lines are parallel or if they intersect in an identical point. In these cases the projection centre can be moved infinitely in the direction of the parallel lines or in the direction of the intersection point respectively, while the bundle of projecting rays or planes remains unchanged. These degeneracy applies to point to line correspondences as well as line to line correspondences. A differential uncertainty is given, if the orientation of the lines and the direction vectors of differential changes of the rotation parameters in object space are identical.

In relative orientation of three images using straight lines as tie features a degeneracy occurs, if the projection centres are collinear and at least one of the straight lines and the line connecting the projection centres are coplanar. In this case the three corresponding projecting planes are identical and the position and orientation of these straight lines cannot be determined. This case can be avoided by not using this kind of lines for the orientation. Another degenerate configuration occurs, if the projection centres again are collinear and the object lines are coplanar. This degeneracy, which can be explained by means of projective geometry, essentially restricts the application of the method in aerial triangulation.

3.2 Simulated examples

In order to study the effect of the location and orientation of linear features in basic orientation tasks simulated configurations were investigated by deriving the theoretical precision of the orientation parameters. However, only a few examples and some of the main results concerning space resection and relative orientation are given in this paper.

In space resection using straight lines as control features the resulting precision mainly depends on the spatial location and orientation of the lines in object space. A control point version was chosen, where 3 points are arranged regularly on a circle in a horizontal plane and the projection centre is located above the centre of the circle, which is the origin of the object coordinate system. The image coordinates

were assumed to be uncorrelated and equally precise, and the control points or lines to be error-free.

For point to line correspondences with horizontal control lines and a regular distribution of the points on the circle, the same precision of the orientation parameters as in the control point version can be achieved by a configuration, where the opposite straight lines are in pairs orthogonal and the directions are either radial or tangential. (Fig. 1). The simulations showed that for configurations with irregular orientation of the lines in space the resulting precision of the orientation parameters is slightly worse. If the configurations are approaching one of the degenerate cases as mentioned above (some are shown in Fig. 2), the precision deteriorates significantly.
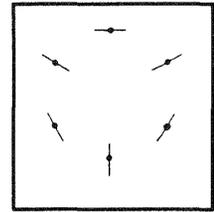
Fig. 1
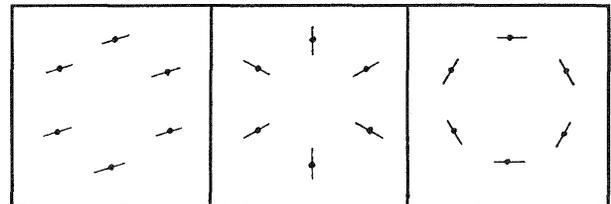
Fig. 2: Some degenerate configurations

In relative orientation the investigations on the use of straight lines confirmed the limited suitability of the method for aerial applications. This is due to the requirement that the straight lines have to be projected in at least three images, which is a severe restriction in case of standard overlap, and due to the singularity in case of collinear projection centres and coplanar object lines. The simulations showed that the precision deteriorates, when approaching these degenerate configurations, e.g. in case of approximately flat terrain the resulting precision is very low. For curved lines this situation is much more encouraging. It was shown that the relative orientation with two circular features is possible, however, only with moderate accuracy. In order to obtain comparable accuracy results as with a tie points version at least 4 or 5 lines are needed.

4. CONCLUSIONS

In this paper an overview on the use of general geometric features for orientation tasks was given and minimum configurations were derived. Furthermore, some degenerate configurations were mentioned and the results of some simulated examples were summarized.

An extension of the concept to more complex lines or surfaces is feasible and similar investigations can be performed. The use of general features in conjunction with line scanners is another possible field of

investigations.

Further research should be performed to derive a proper theory for dealing with general geometric features. This includes the extraction of features in image space, the matching of corresponding features in multiple images and image orientation and object reconstruction in 3-D space. The functional and the stochastic model for the rigorous treatment of these features should be developed including precision and reliability aspects on all levels of processing. This means that the uncertainty of the original observations as well as the precision and sensitivity of the intermediate results should be modelled and propagated through the whole evaluation process.

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