Geometric analysis of mobile mapping images sequence

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Abstract: Spatially referenced mobile mapping (MM) images contain rich information of man-made objects , e.g. road centerlines, buildings, light poles, traffic signs ,billboards and line trees etc. Therefore, the applications in transportation, urban 3D reconstruction, utility management are implemented increasingly. It's a fundamental issue lies in MM image process that how to orient this image in the object space including interior orientation of camera and the exterior orientation of image. In this paper, the algorithm of automatic acquirement of DC (Digital Camera) parameters based on MM images is illustrated. And then, the mapping between image space and object space for MM images is described.

Keywords: Mobile mapping images sequence, DC parameters calibration, Vanishing point geometry, Constrain of straight lines bundle, Least square adjustment, Forward moving images along the optical axis, collinearity equation.

1. Introduction

How to acquire information from mobile mapping images is becoming a hot issue of photogrammetry and computer vision. This problem can be aided greatly if the camera is calibrated meaning that its intrinsic parameters and its position and orientation are known.

Vanishing points have proven to be employed as control points that are errorless and costless to calibrate Camera parameters. Caprile and Torre described a method to use vanishing points to recover intrinsic parameters [1]. Liebowitz *et al.* have developed a method to estimate intrinsic parameters by Cholesky decomposition [2] and to reconstruct scene geometry by using projective geometry methods; they do not explicitly compute the extrinsic parameters. Cipolla *et al* present a method [3] to compute both intrinsic and extrinsic parameters by using three orthogonal vanishing points and one reference point.

In this paper, we present a technique to automatically calibrate DC parameters. Vanishing point geometry is introduced here with the constrain of straight lines bundle. Vanishing point are employed as control points to control pose orientation only. Therefore, to calibrate DC parameters control points in object space should be involved. Here we acquire control points by automatic matching corresponding points between ortho-images and rectified MM images. Finally, an application is implemented with the mobile mapping image sequence.

2.The relationship of vanishing points and orientation parameters.

1) The decomposition of orientation parameters by three vanishing points.

According to the vanishing point geometry, orientation parameters can be decomposed by three vanishing points X_∞、Y_∞、Z_∞ employed Eqs 1,2.

$$f=\sqrt{-(x_{X_\infty}\cdot x_{Y_\infty}+y_{X_\infty}\cdot y_{Y_\infty})} \tag{1}$$

$$\left.\begin{aligned}\tan\varphi &= \sqrt{f^2+x_{Z_\infty}^2+y_{Z_\infty}^2}\Big/\sqrt{f^2+x_{X_\infty}^2+y_{X_\infty}^2}\\ \tan\omega &= f\Big/\sqrt{x_{Y_\infty}^2+y_{Y_\infty}^2}\\ \tan\kappa &= x_{Y_\infty}\big/y_{Y_\infty}\end{aligned}\right\} \tag{2}$$

2) Vanishing point is the functions of orientation parameters.

referring to the the vanishing point geometry , the relationship of vanishing point and DC orientation parameters is deduced.

$$
\left.\begin{aligned}
x_{X\infty} &= x_0 + f\cot\varphi\sec\omega\cos\kappa - f\tan\omega\sin\kappa \\
y_{X\infty} &= y_0 - f\cot\varphi\sec\omega\sin\kappa - f\tan\omega\cos\kappa \\
x_{Y\infty} &= x_0 + f\sec\omega\csc\omega\sin\kappa - f\tan\omega\sin\kappa \\
y_{Y\infty} &= y_0 + f\sec\omega\csc\omega\cos\kappa - f\tan\omega\cos\kappa \\
x_{Z\infty} &= x_0 - f\tan\varphi\sec\omega\cos\kappa - f\tan\omega\sin\kappa \\
y_{Z\infty} &= y_0 + f\tan\varphi\sec\omega\sin\kappa - f\tan\omega\cos\kappa
\end{aligned}\right\} \quad (3)
$$

3. The calibration of DC angular parameters

Vanishing point geometry is introduced here with the constrain of straight lines bundle to calibrate DC angular parameters. The algorithm can be described as below.

1) The determination of vanishing point.

Vanishing point is the intersection point of a set of straight lines which are parallel in object space. It means that each straight line such as line *ij* belong to this set must be passed through the vanishing point as showing in fig. 1. So Eqs. 4 is evolved.

$$d = (y_j - y_i)\frac{(x_V - x_i)}{s_{iV}} - (x_j - x_i)\frac{(y_V - y_i)}{s_{iV}} \qquad (4)$$

where, d is the distance of point j to line iV.

From Eqs. 4 a model of adjustment system of observations and parameters is deduced to determine vanishing point.

2) The calibration of DC angular parameters.

According to Eqs. 3 vanishing point coordinate in Eqs. 4 is replaced with interior and exterior orientation (angular) parameters. Then a model of adjustment system of observations and parameters combined with vanishing point geometry and the constrain of straight lines bundle is deduced to calibrate DC angular parameters while interior orientation parameters are fixed in the adjustment system.

4. MM images rectification and automatic matching corresponding points with ortho-images.

In this paper MM images are firstly rectified to leveled images using DC angular parameters calibrated in previous section. As Fig 2 illustrating, the process of rectification to leveled images is $\boldsymbol{p} \rightarrow \boldsymbol{p_0} \rightarrow \boldsymbol{P}$, origin point of the leveled image $\boldsymbol{P}$ is the projection point of the perspective center S in $\boldsymbol{P}$ as illustrated in Fig 2. Thereupon corresponding points are automatically matched between leveled images and ortho-images employed LSM approach As illustrated in Fig. 3.

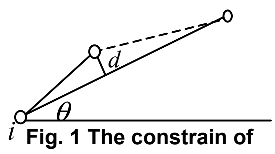

Fig. 1 The constrain of Straight lines bundle

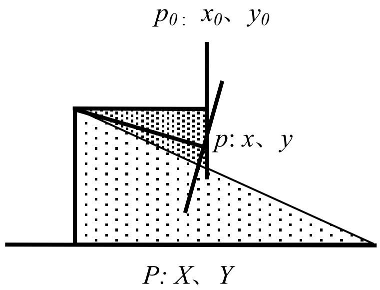

Fig. 2 The process of rectification

5. Automatic calibration of DC parameters.

In section 4, corresponding points between leveled images and ortho-images were automatically matched. The points in the ortho-images can be control points for our calibration of DC orientation parameters. However, because these control points are all in the road, i.e. they are coplanar, they can only determine partial DC angular parameters. As illustrated in section 2 and 3, Vanish points can be employed as conventional control points to control pose orientation of DC. Therefore, a hybrid model of adjustment system combined with vanishing point geometry , the constrain of straight lines bundle and photogrammetric collinearity equation is evolved as illustrated in Fig 4. DC orientation parameters is thereupon calibrated employed this hybrid model of adjustment system.

6. Results.

Two groups lines were firstly automatically extracted

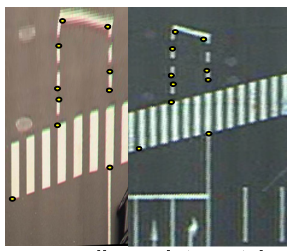

Fig. 3 corresponding points matched between and ortho-images and leveled images

from a single image. One group is plumb and the other is parallel to road centerlines in object space. Since there are only two groups lines extracted, the principle point cannot be determined. The center of the image is then chosen as the principle point.

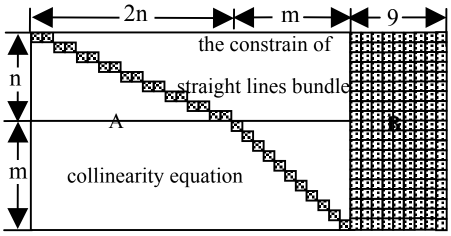

Fig. 4 A hybrid model of adjustment system to calibrate DC parameters

1) Images rectification and automatic matching corresponding points with ortho-images.

Based on two groups lines extracted from raw image, two vanishing point coordinates, focal length and three angular parameters are calculated (Result is showed in table 1.).The raw image is thereupon rectified to leveled imageemployed focal length and three angular parameters determined. As Fig. 3 illustrated, corresponding points are automatically matched between leveled image and ortho-image. As a result, there are 24 pairs corresponding points are matched out (Partial corresponding points matched are illustrated in Fig. 3).

Table 1 Calculated result: $x_{Y\infty}$, $y_{Y\infty}$, $x_{Z\infty}$, $y_{Z\infty}$ and f are in unit of pixel; φ, ω, κare in unit of radian.

f	φ	ω	κ
1235.7965	0.025	0.171	0.024
$x_{Y\infty}$	$y_{Y\infty}$	$x_{Z\infty}$	$y_{Z\infty}$
168.6919	7172.8667	-36.4768	-212.9257

2) Automatic calibration of DC parameters.

Based on the 24 pairs corresponding points matched above, the initial values of X_S、Y_S、Z_S are acquired and DC angular parameters relative to ground coordinate system are determined. The result is illustrated in Table 2.

Table 2 Initial values of X_S、Y_S、Z_S and three angular parameters: X_S、Y_S、Z_S are in unit of meter; φ_G, ω_G, κ_G are in unit of radian.

X_S	Y_S	Z_S	φ_G	ω_G	κ_G
-4759.07	-36343.68	4.84	4.40	-0.98	1.33

The precise values of DC parameters are acquired as Table 3 illustrated. Mean square errors are showed in Table 4 while the mean square error of unit weight is 0.783 pixel. The result is satisfying.

Table 3 Precise values of DC parameters

f	φ	ω	κ	X_s	Y_s	Z_s
1169.89	0.03	0.18	0.01	-4761.07	-36342.63	4.97

Table 4 The mean square errors of DC parameters

m_f	m_φ	m_ω	m_κ	m_{Xs}	m_{Ys}	m_{Zs}
1.493	0.001	0.002	0.002	0.085	0.079	0.219

7. **Conclusions.**

Here we presented an algorithm for automatic calibration of DC parameters. From the experimental results, we draw the following conclusions:

1) Vanishing point can be employed as control points that are errorless and costless to control pose orientation only; parallel lines should be used in stead of directly using vanishing points away from infinity.

2) For automatic matching corresponding points with ortho-images, MM images should be rectified to leveled images with calibrated DC angular parameters firstly. Afterward automatic matching of corresponding points is implemented. The result is satisfying.

3) To calibrate DC parameters, conventional control points should be involved since vanishing points are employed as control points to control pose orientation only. Control points can be automatically matched in the ortho-images. It is therefore proved that the method presented in this paper is effective and practical for the automatic Calibration of DC parameters.

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