The Design and Calibration of a Portable Panoramic Image Mapping System

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ABSTRACT: This paper proposes a Portable Panoramic Image Mapping System (PPIMS) for rapid acquisition of 3D spatial information, which is one kind of Portable Mobile Mapping System (PMMS). PPIMS is equipped with 6 circularly arranged cameras to capture panoramic images and a GPS receiver for positioning. The total weight of the platform, cameras and the GPS antenna is less than 2.5kg, so that it can be carried by a person for data collection. The motivation of this design is to develop a portable MMS for some difficult accessing areas by vehicles, such as a heavily damaged mountain village or a disaster landscape. This PPIMS is in fact a GPS assisted close-range photogrammetric system. The equipped GPS receiver should have the function of e(electronic)-GPS positioning, which is a VRS GPS navigation system provided by the National Land Survey and Mapping Center, Taiwan. Therefore, the platform position of each image can be determined. Under the condition of knowing the relative orientation of the camera set and the GPS antenna, the elements of exterior orientation of each captured image can be solved through a simple computation.

1. INTRODUCTION

With the development of geomatics, spatial information accessing is becoming more and more accurately and precisely. The INS/GPS integrated systems are useful because of its rapidly direct geo-referencing capability. However, Taiwan's geographical environment is crowded, and the rugged terrain is not suitable for mapping vehicle to collect the disaster information. Therefore, we propose a hand-held panoramic image mapping system with six SONY NEX-3 cameras which are loaded on a special platform with e-GPS antenna on the top of the platform. The e-GPS can provide instant position when the cameras taking photos and can reduce the ground control points significantly. The system is operated by hand-held to collect the spatial information. For this measurement manner, the less mobility and inconvenient data acquisition of MMS for disaster mapping are overcome. This paper will describe the theory of the computation. In order to know the relative orientation between the camera set and the GPS antenna, a system calibration is required before the system can be applied. This paper will also briefly describe the method of system calibration with an MMS calibration field.

2. SYSTEM ARCHITECTURES

We propose the portable panoramic mapping system which can be divided into three parts: platform system, image sensors and e-GPS positioning systems .And the most important thing is to integrate all the coordinates of each part.

2.1 platform system

Considering the image size of each camera can make overlap for panoramic, we design a hexagon platform and set up a white pock on each side for fixing the camera (fig2.1). All shutters are connected by six rods down to the bottom. There is a ring controlling the rods (fig2.2). The pole in the middle is for e-GPS .The size of the platform is about 40x 40x 35 cm . The total height is about 2.4 m (fig2.3).

Figure 2.1 The platform. Figure2.2 Shutter control. Figure 2.3 Total height.

2.2 camera sensor

Under the cost consideration in the portable mapping system, the camera should be light in weight and its image quality should be stable. In this research, Sony Nex-3 camera is chosen. It is about 300 grams. It is a single-lens digital camera and can provide a stable shooting quality (fig2.4).The sensor size is 23.4 x 15.6 mm, and the maximum resolution is 4592 x 3056.

Figure2.4 Camera with the platform.

2.3 e-GPS positioning systems

e-GPS(Electronic Global Positioning System) is a technology designed for mobile phones on internet and to deliver faster positioning(fig2.5). It is based on Virtual Reference Station (VRS), and the position is determined by network RTK connected to National Land Surveying and Mapping Center, Taiwan. From setting up the platform to the positioning of one station, it only takes five or six minutes. And the precision is centimeter-level. The following advantages of e-GPS are why we choose instead of GPS in PPIMS. (a)Instantaneity, (b)Replaced by mobile communication, (c)Improvement of RTK(Without base station, lower cost, and saving time.), (d)Continuously observe of VRS for base processing and network adjustment.

Figure 2.5 e-GPS with the platform.

3. System Operation

3.1 Camera Calibration

We established an inner calibration field for camera interior orientation parameter (IOP) calibration, and also confirmed the relative position between each camera (fig3.1). The analysis of IOPs, such as the focal length, the principle point, and the lens distortion, is the objective in this phase. The equations included to the bundle adjustment as follow:

(Yu-Hua LI , 2010)

$$\mathbf{x_a = x_p - c\frac{r_{11}(X_A-X_O)+r_{12}(Y_A-Y_O)+r_{13}(Z_A-Z_O)}{r_{31}(X_A-X_O)+r_{32}(Y_A-Y_O)+r_{33}(Z_A-Z_O)} + \Delta x} \tag{1}$$

$$\mathbf{y_a = y_p - c\frac{r_{21}(X_A-X_O)+r_{22}(Y_A-Y_O)+r_{23}(Z_A-Z_O)}{r_{31}(X_A-X_O)+r_{32}(Y_A-Y_O)+r_{33}(Z_A-Z_O)} + \Delta y} \tag{2}$$

Where

$\Delta x = x' + (K_1 r^2 + K_2 r^4 + K_3 r^6)x' + P_1\left(r^2 + 2x'^2\right) + 2P_2 xy + b_1 x + b_2 y$

$\Delta y = y' + (K_1 r^2 + K_2 r^4 + K_3 r^6)y' + P_1\left(r^2 + 2y'^2\right) + 2P_1 xy$

$x'=(x-x_p)$, $y'=(y-y_p)$, $r=\sqrt{x'^2 + y'^2}$

(x_p,y_p)：Principle Point

(x , y)：Image Point

K1,K2,K3：Radial Lens Distortion parameters

P1,P2：Decentric Lens Distortion parameters b1：Differential scaling between x & y

b2：Non-orthogonality between x & y axes

This research adapts the commercial software, Australis, to solve those parameters. (Cronk & Fraser, 2008)

Figure 3.1 inner calibration field.

3.2 PPIMS Calibration

For the system calibration, we have to connect the six cameras with the e-GPS. The most important thing is to unify all the coordinate systems to our body frame (phase center of e-GPS as original).Using the local level frame (center of calibration field as original)as transformer, integrated the camera frame(six cameras)and WGS-84(e-GPS) into the PPIMS coordinate(fig3.2). Since we don't use the INS, we lead the orientation of one camera instead of INS. Then we can get the orientation relation of PPIMS. Finally, we deduced the mathematical model for resolving the offset vector and orientation between the cameras and e-GPS. And the concept is based on the boresight and lever-arm calibration of MMS. (fig3.3)

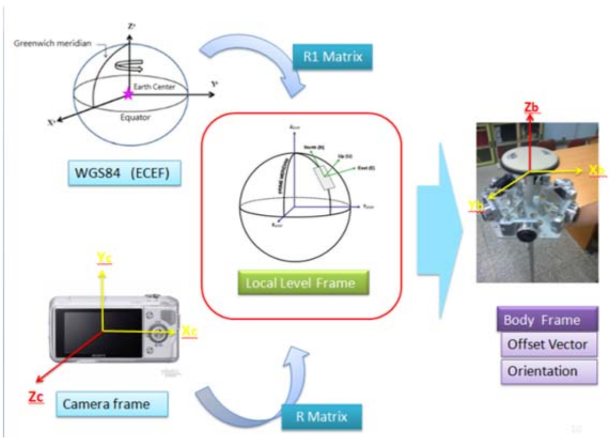


Figure 3.2 Coordinate integrated.

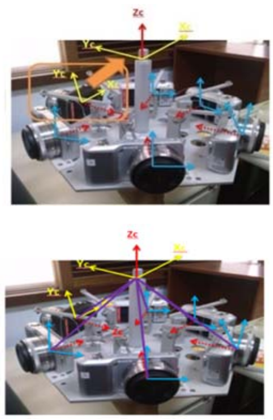
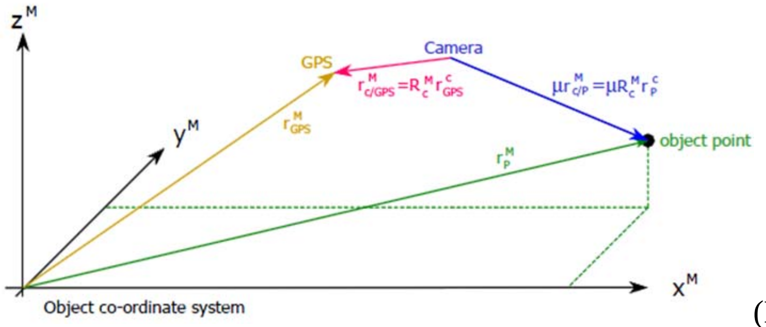


Figure 3.3 Lead the orientation of one camera instead of INS.

3.3 Exterior Orientation (EO)

We can get the relationship between cameras and e-GPS of PPIMS(fig3.4).

$$\mathbf{r}_{\mathbf{p}}^{\mathbf{M}} = \mathbf{r}_{\mathbf{GPS}}^{\mathbf{M}} - \mathbf{R}_{\mathbf{C}}^{\mathbf{M}} \mathbf{r}_{\mathbf{GPS}}^{\mathbf{C}} + \mu \mathbf{R}_{\mathbf{C}}^{\mathbf{M}} \mathbf{r}_{\mathbf{P}}^{\mathbf{C}} \qquad \mathbf{(3)}$$



(EI-Shiemy,1996)

Figure3.4 The relationship between cameras and e-GPS.

$\mathbf{r}^{\mathbf{M}}_{\mathbf{p}}$ = the position vector of an object in the chosen mapping frame

$\mathbf{r}^{\mathbf{M}}_{\mathbf{GPS}}$ = the position vector of GPS in the m frame

$\boldsymbol{\mu}$ = a scale factor which relates the image coordinates to the object coordinates

$\mathbf{R}^{\mathbf{M}}_{\mathbf{C}}$ = transformation matrix which rotates the camera frame into m frame

$\mathbf{r}^{\mathbf{C}}_{\mathbf{P}}$ = the vector of image coordinates given in the c frame

Based on the collinear formula of close-range photogrammery, we rearrange it:

$$\mathbf{r}^{\mathbf{c}}_{\mathbf{p}} = \boldsymbol{\mu}^{-1}[\mathbf{R}^{\mathbf{c}}_{\mathbf{M}}(\mathbf{r}^{\mathbf{M}}_{\mathbf{P}} - \mathbf{r}^{\mathbf{M}}_{\mathbf{GPS}}) + \mathbf{r}^{\mathbf{c}}_{\mathbf{GPS}}] \qquad \textbf{(4)}$$

We will get the new formula which is the observation of each object point:

$$x_p = -\mathbf{c}\frac{r_{11}(X_P - X_{GPS}) + r_{12}(Y_P - Y_{GPS}) + r_{13}(Z_P - Z_{GPS}) + x_{GPS}}{r_{31}(X_P - X_{GPS}) + r_{32}(Y_P - Y_{GPS}) + r_{33}(Z_P - Z_{GPS}) + z_{GPS}}$$

$$y_p = -\mathbf{c}\frac{r_{21}(X_P - X_{GPS}) + r_{22}(Y_P - Y_{GPS}) + r_{23}(Z_P - Z_{GPS}) + y_{GPS}}{r_{31}(X_P - X_{GPS}) + r_{32}(Y_P - Y_{GPS}) + r_{33}(Z_P - Z_{GPS}) + z_{GPS}} \qquad \textbf{(5)}$$

Due to the known condition by PPIMS calibration: offset vector($\mathrm{r}(x,y,z)^{\mathrm{c}}_{\mathrm{GPS}}$)、orientation($\mathrm{R}^{\mathrm{GPS}}_{\mathrm{c}}$) , then we can apply the aerial triangulation for resolving the EO ($\mathrm{R}^{\mathrm{C}}_{\mathrm{M}}$ 、$\mathrm{r}^{\mathrm{M}}_{\mathrm{C}}$) of PPIMS.

4. Experiment and Result

4.1Interior orientation parameters of camera

The camera calibration was implemented by Australis. Table4.1 shows SONY NEX-3 camera's calibration report .The result for estimated internal accuracy of referencing is under 0.2pixels for each camera.

METRIC CALIBRATION PARAMETERS

Resolution = 4592 x 3056 pixels

Pixel width = 0.0051mm, Pixel height = 0.0051mm

		VALUE	STANDARD ERROR
Principal distance	c =	15.8540mm	0.001mm
Principal point offset in x-image coordinate	xp =	-0.0688mm	0.001mm
Principal point offset in y-image coordinate	yp =	0.2443mm	0.000mm
3rd-order term of radial distortion correction	K1 =	2.50988e-004	1.3130e-006
5th-order term of radial distortion correction	K2 =	-1.32011e-006	2.0795e-008
7th-order term of radial distortion correction	K3 =	-9.81883e-010	1.0150e-010
Coefficient of decentering distortion	P1 =	7.3696e-005	9.186e-007
Coefficient of decentering distortion	P2 =	-5.1299e-005	6.941e-007

Measurement Accuracy Summary

Scale set? Yes

Estimated accuracy of 3D point coordinates (RMS 1-sigma level)

X	0.0338	units, or	1:69900
Y	0.0437	units, or	1:54100
Z	0.0445	units, or	1:53000
Overall	0.0407	units, or	1:58100

Estimated accuracy of image referencing 0.19 pixels (RMS 1-sigma level)

Quality of self-calibration (if applied) 1.0

Table4.1 IOPs calibration result.

4.2 The relative position and orientation

Table4.2 shows the relative distance between six cameras on each station. We can see the mean distance is about 17.4 centimeters. The standard error is about 2 millimeters.

And Table4.3 shows the result of relative orientation calibration. For each camera on different stations, the standard error σ of rotation angle is about 0.02 degrees. Based on the result, the positioning precision can attain 7 millimeters in the 20 meters.

Relative Distance	Six cameras Station1	Six cameras Station2	Six cameras Station3	Six cameras Station4	Six cameras Station5
Mean(mm)	174.79	175.26	174.40	174.33	174.02
STD(mm)	2.53	2.34	1.58	0.97	2.11

Table4.2 Relative distance between six cameras on each station.

Relative Orientation	Camera 1 For all station	Camera 2 For all station	Camera 3 For all station	Camera 4 For all station	Camera 5 For all station
ω (deg)σ_0	0.026	0.018	0.009	0.021	0.024
ϕ (deg)σ_0	0.017	0.020	0.020	0.014	0.019
κ (deg)σ_0	0.030	0.044	0.016	0.042	0.031

Table4.3 Relative orientation calibration.

5.CONCLUSIONS

This study is compared with the Mobile Mapping System, it overcomes the mapping vehicle limits in relief terrain, and improves mobility and reduces equipment costs. This system is expected to have significantly contribution of disaster information collection in Taiwan. And through a new calibration process to calculate the offset vector and orientation of PPIMS, we can gain the EOPs of the panoramic for geo-referencing in the future application.

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