Panoramic Video Stabilization Algorithm Based on Spherical Transformation

Chen Ke*, Li Yan-li, Zhou Zhong, Wu Wei

State Key Laboratory of Virtual Reality Technology and Systems, Beijing 100191, China

School of Computer Science and Engineering, Beihang University, Beijing 100191, China

Abstract

The acquisition of panoramic videos usually suffers from undesirable jitters due to deviations and rotations of the cameras. According to the characteristics of spherical panorama, an algorithm aimed to stabilize panoramic videos is proposed in this paper. For each frame, the algorithm estimates the Euler angle of the panoramic camera. With the mapping between spherical panorama and sphere, it then projects each panoramic frame onto a spherical surface, transforms them with the Euler angles of the camera and gets the corrected frames. The sequence of the corrected frames constitutes a stabilized video. The experimental results show that the algorithm corrects the jitters and improves the stability of panoramic video.

Keywords: Panoramic Video; Euler Angle; Spherical Mapping; Video Stabilization

1 Introduction

During the capture of panoramic videos, the undesirable motion of the panoramic camera for handshaking or platform movement often causes image jitters, which degrade the quality of the captured video. The purpose of video stabilization is to remove unwanted motions from the image sequence and to correct the jitters of the video. Existing solutions to video stabilization can be classified into three major types, which are the mechanical, the optical and the digital.

The mechanical stabilization methods stabilize image sequences by employing motion sensors such as gyros, angular sensors or other inertia devices to detect the camera movement for compensation. M. Oshima [1] used a gyro-sensor and a servo to keep images stabilized. Optical stabilization methods apply optical devices such as lens and prisms which move opposite to the shaking of the camera. Koichi Sato [2] controlled the angles of a fluid prism with the output of two angular velocity sensors to stabilize images. Both the mechanical stabilization and the optical stabilization are hardware dependent. The devices used by them are often expensive and lack of portability.

The digital stabilization algorithms remove unwanted motion effects and generate compensated image sequences by digital image processing techniques without any mechanical or optical devices such as gyros or prisms. Erturk S [3] and Rong Hu [4] estimated the global motions based on feature matching and compensated the global motions to remove the jitters. Shi Yan [5] proposed a video stabilization algorithm by evaluating the compensate parameters based on

* Corresponding author.
Email addresses: chenke@vrlab.buaa.edu.cn(Chen Ke)

feature tracking. Homer H. Chen [6] calculated the global motions for stabilization by estimating the motion vector of blocks. Xu Lidong [7] used circular block motion search to obtain the local motion vectors of each frame and determine the global motion parameters for jitter correction by these vectors. Hung-Chang Chang [8] calculated the optical flows between successive frames and estimated the camera motion parameters for video compensation.

The approaches discussed above are applied for the stabilization for traditional prospective cameras. They usually stabilize videos at the cost of losing image information. In this paper, we propose a stabilization algorithm for panoramic videos captured by a panoramic camera which involves multi-CCD (Charge Coupled Device) sensors. The panoramic videos can be stitched with image mosaicing algorithms [9], [10]. Unlike the videos captured by traditional prospective cameras, the spherical panoramic videos cover 360°*180° view of the scene. Therefore, jitters of the panoramic camera often lead to some deviations and rotations of frames. With the characteristics of the spherical panorama, the proposed algorithm aims to stabilize panoramic videos without loss of information. Spherical panoramic frames can be projected onto a sphere. With the mapping between a spherical panoramic frame and a sphere, the proposed algorithm projects each frame onto a sphere and transforms it according to the Euler angle of the panoramic camera, which is estimated by the pose of each CCD sensor. After spherical transformation, the jitters of the video are removed and the stabilized videos still cover 360°*180° view of the scene. Therefore, the proposed algorithm stabilizes spherical panoramic videos without loss of information.

The rest of this paper is organized as follows. Section 2 covers the estimation of the Euler angle of the panoramic camera from the angles of the CCD sensors. Section 3 discusses the stabilization of the panoramic video based on the estimated Euler angle. In Section 4, we describe the proposed stabilization algorithm. We present our experimental results in Section 5 and make a conclusion in Section 6.

2 Camera Angles Estimation

The estimation of Euler angle for a panoramic camera is a key to panoramic video stabilization. As the panoramic camera consists of several CCD sensors, we first estimate the Euler angle of each CCD sensor and then calculate the angle of the camera by the angles of all the CCD sensors.

2.1 Angle estimation for CCD sensor

First, the aperture camera model [11] is applied to each CCD sensor of the panoramic camera. In this prospective model, a point X in the world coordinate system is projected to a point p in the particular video frame i by the projection equation

$$p = K[\,R_i \mid t_i\,]\,X \qquad (1)$$

where $X = (x,y,z,1)^T$ is a 3D point in the world coordinate. $p = (u,v,1)^T$ is a 2D pixel location in the single input frame from a CCD sensor. K is the intrinsic matrix of the sensor, R_i is the rotation matrix and t_i is the translation vector of i-th frame. The intrinsic matrix K of each sensor can be calibrated by the method proposed by Z. Zhang [11].

The rotation matrix R_i is factorized as

$$R_i = \begin{bmatrix} \cos\alpha_i \cos\beta_i & \cos\alpha_i \cos\beta_i \sin\gamma_i - \sin\alpha_i \cos\gamma_i & \cos\alpha_i \sin\beta_i \cos\gamma_i + \sin\alpha_i \sin\gamma_i \\ \sin\alpha_i \cos\beta_i & \sin\alpha_i \sin\beta_i \sin\gamma_i + \cos\alpha_i \cos\gamma_i & \sin\alpha_i \sin\beta_i \cos\gamma_i - \cos\alpha_i \sin\gamma_i \\ -\sin\beta_i & \cos\beta_i \sin\gamma_i & \cos\beta_i \cos\gamma_i \end{bmatrix} \quad (2)$$

where $(\alpha_i, \beta_i, \gamma_i)$ is the Euler angle of the sensor on roll, pitch and yaw. R_i and t_i could be estimated with the Structure-From-Motion (SFM) algorithm [12], [13]. In reference to the initial pose of the CCD sensor, the sensor's Euler angles related to each frame can be obtained through the generic sparse bundle adjustment [14].

2.2 Angle estimation for panoramic camera

As presented in Section 2.1, the Euler angle of a CCD sensor can be estimated for each frame. Actually, the panoramic camera usually consists of several CCD sensors. As for a multi-CCD camera, the Euler angle of a CCD sensor is not exactly the Euler angle of the camera. As is shown in Fig. 1, σ_j denotes the Euler angle of the *j*-th CCD sensor and δ is the Euler angle of the panoramic camera. To improve accuracy, we estimate δ by the Euler angles of all the sensors rather than a single one. Therefore, δ is calculated through

$$\delta = \frac{1}{n} \sum_{j=1}^{n} \sigma_j \quad (3)$$

where n is the number of CCD sensors on a panoramic camera. The proposed algorithm chooses the average of the Euler angles of all the sensors as the angle of the panoramic camera to reduce error.

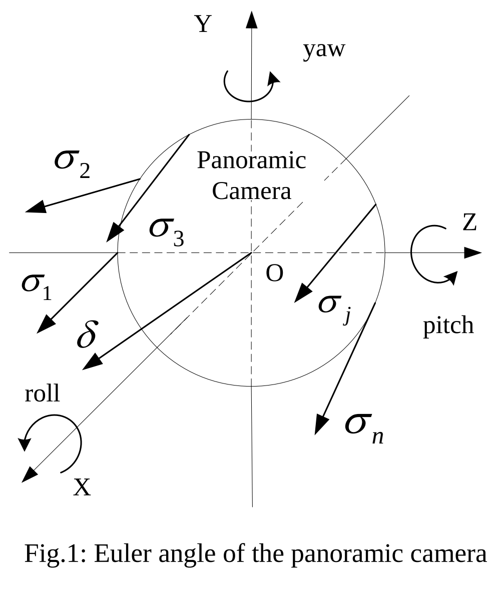


Fig.1: Euler angle of the panoramic camera

3 Panoramic Video Stabilization

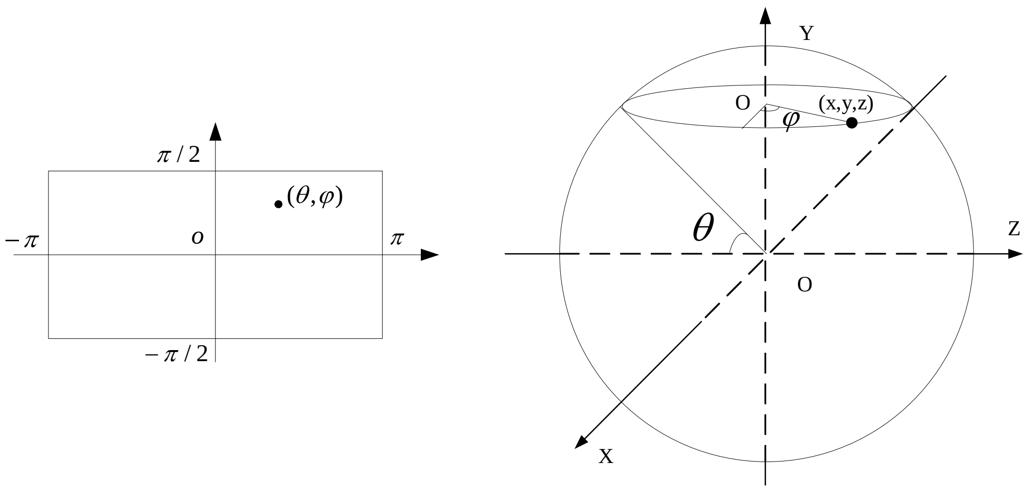
In this section, we describe the stabilization algorithm for the panoramic video. Each frame of the video is projected onto a sphere. According the Euler angle estimated in the previous section, the panoramic frames are transformed on the sphere and the stabilized frames are generated.

3.1 Spherical projection

The proposed algorithm processes each frame of panoramic video on a sphere to correct video jitters. Before spherical transformations, each panoramic frame is mapped onto a sphere. As shown in Fig. 2(a), a pixel of a spherical panoramic frame is denoted by latitude θ and longitude φ. θ ranges from $-\pi/2$ to $\pi/2$ and φ ranges from $-\pi$ to π. In Fig. 2(b), (x,y,z) denotes a pixel of a sphere and the projection between a panoramic frame and a sphere can be factorized with

$$\begin{cases} x = r\cos\theta\cos\varphi \\ y = r\sin\theta \\ z = r\cos\theta\sin\varphi \\ r = w/2\pi \end{cases} \tag{4}$$

where r indicates the radius of the sphere and w indicates the width of the panoramic frame.



(a) Panoramic frame (b) Sphere

Fig.2: The mapping between a panoramic frame and a sphere

Through Eq. (4), the re-projection from (x,y,z) to (θ,φ) can be obtained as

$$\theta = \begin{cases} \arctan\sqrt{\dfrac{y^2}{x^2+z^2}}(y \ge 0) \\ -\arctan\sqrt{\dfrac{y^2}{x^2+z^2}}(y < 0) \end{cases} \quad \varphi = \begin{cases} \arctan\dfrac{z}{x}(z \ge 0, x > 0) \\ \pi + \arctan\dfrac{z}{x}(z \ge 0, x < 0) \\ \arctan\dfrac{z}{x} - \pi(z < 0, x < 0) \\ \arctan\dfrac{z}{x}(z < 0, x > 0) \end{cases} \tag{5}$$

3.2 Stabilization based on spherical mapping

The proposed algorithm projects each panoramic frame onto a sphere and stabilizes panoramic video with the Euler angle δ. Each frame is associated with an Euler angle of the panoramic camera. The angles are estimated by the method discussed in section 2. As is shown in Fig. 3, (x',y',z') denotes a pixel of the jittered frame and (x,y,z) denotes the corresponding pixel of the corrected frame. α, β and γ denote the values of δ on roll, pitch and yaw respectively. Through the spherical geometry, the relationship between (x',y',z') and (x,y,z) can be described as

$$\begin{cases} \alpha = arctan\dfrac{y'}{z'} - arctan\dfrac{y}{z} \\ \beta = arctan\dfrac{y'}{x'} - arctan\dfrac{y}{x} \\ \gamma = arctan\dfrac{z'}{x'} - arctan\dfrac{z}{x} \\ x^2 + y^2 + z^2 = r^2 \end{cases} \tag{6}$$

According to Eq. (6), given (x',y',z') of the jittered frame, the proposed algorithm computes (x,y,z) of the stabilized frame. Actually, this group of equations has two resolutions and therefore (x,y,z) of the stabilized frame is ambiguous. (x_1,y_1,z_1) and (x_2,y_2,z_2) denote the resolutions of Eq. (6). Consequently, (x_1,y_1,z_1) and (x_2,y_2,z_2) are symmetric to the origin. The Euler distances from (x_1,y_1,z_1) and (x_2,y_2,z_2) to (x',y',z') can be measured as

$$\begin{cases} dist(x_1,y_1,z_1) = \sqrt{(x_1 - x')^2 + (y_1 - y')^2 + (z_1 - z')^2} \\ dist(x_2,y_2,z_2) = \sqrt{(x_2 - x')^2 + (y_2 - y')^2 + (z_2 - z')^2} \end{cases} \tag{7}$$

Each frame of panoramic video is associated with the current Euler angle of the camera. For the capture frequency is above 15 fps in many cases, the values of δ on roll, pitch and yaw range all range from $-\pi/2$ to $\pi/2$. Accordingly, the proposed algorithm selects the point which is nearer to (x',y',z') from the above 2 points as the value of (x,y,z) in the stabilized frame.

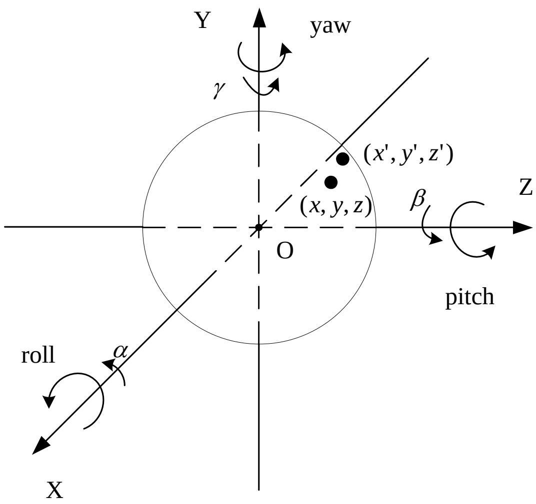


Fig.3: Panoramic frame stabilization on sphere

4 Stabilization Algorithm

The proposed algorithm stabilizes panoramic video on a sphere according to the Euler angle of the panoramic camera. Each panoramic video frame is related to an Euler angle which is estimated by the Euler angles of all the CCD sensors on the panoramic camera. With the mapping between a spherical panorama and a sphere, a panoramic frame could be projected onto a sphere. The proposed algorithm projects each panoramic frame onto a spherical surface, transforms it with the related Euler angle and gets a corrected frame. Consequently, the sequence of the corrected frames constitutes the stabilized video. The algorithm to stabilize a jittered panoramic video is summarized as follows.

Step 1 According to Eq. (3), for each frame of the panoramic video, compute the Euler angle δ of the panoramic camera by the CCD sensors' Euler angles estimated through SFM.

Step 2 Project each panoramic frame onto a sphere through Eq. (4). A point (θ,φ) of the frame is mapped into a point (x,y,z) of the sphere.

Step 3 In terms of the related Euler angle δ, stabilize the frame on the sphere through spherical transformations according to Eq. (6) and choose the corrected pixels of the stabilized frame using Eq. (7).

Step 4 According to Eq. (5), reproject the point (x,y,z) of the sphere to the point (θ,φ) of the panoramic frame and thus generate the corrected frame. Jump to step 2 to stabilize the next frame.

5 Experimental Results

In this section, the experimental results of the proposed stabilization algorithm applied to real panoramic video are presented. In the experiment, images (1231×192) are captured by a panoramic camera with a frame rate of 15 fps . As is shown in Fig. 4, the panoramic camera consists of six CCD sensors and outputs 360-degree panoramic videos. The stabilization was performed on a personal computer (Pentium4 2.4 GHz).

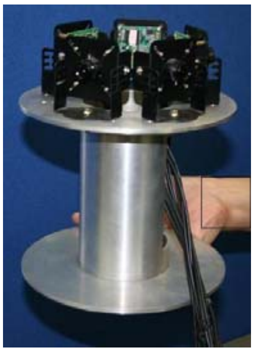
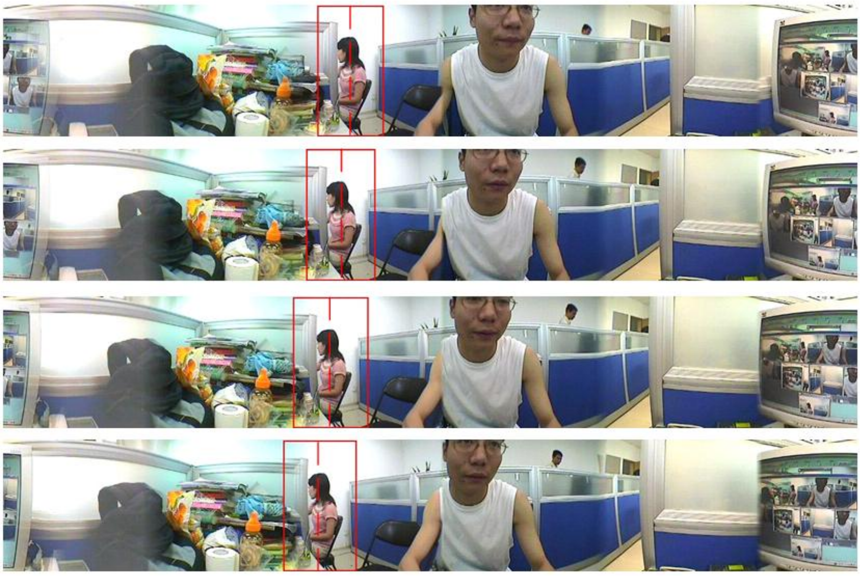


Fig.4: The panoramic camera with six CCD sensors

Under the limitation of the panoramic camera, we only applied the proposed algorithm to correct video jitters on yaw. Fig. 5(a) shows the initial panoramic frame, which corresponds to the initial Euler angle. Fig. 5(b) shows the 10th, 20th, 30th and 40th frames of the jittered panoramic video. In Fig. 5(b), the midline of the rectangle shows the position of the person in the frames. The change of the location of the midline means the jitter of the panoramic video on yaw. After the stabilization by the proposed algorithm, the original video was stabilized as shown in Fig. 5(c). Fig. 5(c) shows the 10th, 20th, 30th and 40th frames of the corrected panoramic video, corresponding to the frames in Fig. 5(b). In Fig. 5(c), the locations of the midlines are stable.

(a) The initial panoramic frame



(b) Frames of the jittered panoramic video

(c) Frames of the stabilized panoramic video

Fig.5: Frames of the jittered and the stabilized panoramic video

In the experiment, we use MSE (Mean Square Error) to evaluate the performance of the proposed stabilization algorithm. For each panoramic frame, the MSE is calculated by computing the correlative value using

$$MSE(I_k, I_t) = \frac{1}{w \times h} \sum_{x=1}^{w} \sum_{y=1}^{h} \left[I_k(x,y) - I_t(x,y) \right]^2 \tag{8}$$

where $I_k(x,y)$ is the gray value of the pixel at (x,y) in frame k, $I_t(x,y)$ is the gray value of the pixel at (x,y) in the reference frame, w and h are the width and height of the frame respectively. MSE reflects the stability and the vibration of the video. The lower the MSE, the more stable the video. With the initial frame as the reference frame, we compute the *MSE* of the original panoramic video and the *MSE'* of the stabilized video for the proposed algorithm. As the Fig. 6 shows, the *MSE'* of the stabilized video is lower than the *MSE* of the original video.

For the chromatic aberration between the six CCD sensors of the panoramic camera, we estimate the theoretical performance of the proposed algorithm. The theoretical MSE_0 is estimated as

$$MSE_0 = MSE' - \frac{1}{6}\sum_{i=0}^{5} MSE_{i,(i+1)\%6} \tag{9}$$

where *MSE'* is the mean square error of the stabilized panoramic video and $MSE_{i,(i+1)\%6}$ is the mean square error of the overlapped part of images captured by two adjacent sensors. According to Eq. (9), the estimated MSE_0 is shown in Fig. 6. From the distance between the theoretical effect and the practical effect, we conclude that the performance of the proposed algorithm could be improved by the qualities of the CCD sensors of the panoramic camera.

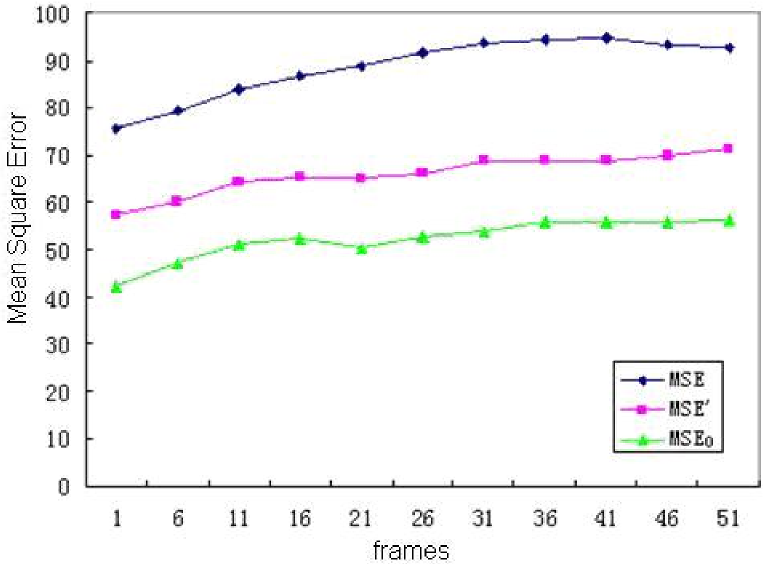


Fig.6: The mean square error of the original and the stabilized video

6 Conclusions

In this paper, we proposed a stabilization algorithm for panoramic video. As panoramic cameras usually consist of several CCD sensors, for each panoramic frame, the proposed algorithm calculates the Euler angle of the panoramic camera by the Euler angles of CCD sensors which are estimated through SFM. With the mapping between spherical panorama and sphere, each frame of panoramic video can be projected onto a sphere. Through spherical transformation, the proposed algorithm transforms each panoramic frame on the sphere according to the related Euler angle of the camera. The experimental results show that the proposed algorithm can correct the jitters caused by deviations or rotations of the panoramic camera and stabilize panoramic videos.

Acknowledgement

This work is supported by the National High Technology Development 863 Program of China under Grant No. 2006AA01Z331 and the National Natural Science Foundation of China under Grant No. 60603084.

References

[1] M. Oshima, T. Hayashi, S. Fujioka, T. Inaji, et al. VHS camcorder with electronic image stabilizer. IEEE Transactions on Consumer Electronics, 1989, 35(4): 749–758.

[2] Koichi Sato, Shigeki Ishizuka, Akira Nikami, and Mitsuru Sato. Control techniques for optical image stabilizing system. IEEE Transactions on Consumer Electronics, 1993, 39(3): 461-466.

[3] Erturk S. Image Sequence stabilization based on kalman filtering of frame positions. Electronic Letters. 2001, 137(20): 1217-1219.

[4] Rong Hu, Rongjie Shi, I-fan Shen, Wenbin Chen. Video stabilization using scale-invariant features. In: Proc. of 11th Information Visualization, Zurich, 2007, pp. 871-877.

[5] Shi Yan, Gao Xinbo. A Video Stabilization Algorithm Based on Feature Tracking. ACTA PHOTONICA SINICA, 2005,34(7):1108-1112.

[6] Homer H. Chen, Chia-Kai Liang, Yu-Chun Peng, Hung-An Chang. Integration of digital stabilizer with video codec for digital video cameras. IEEE Transactions on Circuits and Systems for Video Technology, 2007, 17(7): 801-813.

[7] Xu Lidong, Lin Xinggang. Global motion estimation for video stabilization. Journal of Tsinghua University, 2007, 47(1): 92-95.

[8] Hung-Chang Chang, Shang-Hong Lai, Kuang-Rong Lu. A robust and efficient video stabilization algorithm. In: Proc. of 5th ICME, Taipei, 2004, Vol. 1, pp. 29-32.

[9] Xian-Yong Fang, Zhigeng Pan, Gaoqi He, Li Li. A New Method of Feature Based Image Mosaic. Int. J. Image Graphics, 2006, 6(3): 497-510.

[10] Xian-Yong Fang, Mingmin Zhang, Zhigeng Pan, Peng Wang. A New Method of Manifold Mosaic for Large Displacement Images. J. Comput. Sci. Technol, 2006, 21(2): 218-223.

[11] Z. Zhang. A flexible new technique for camera calibration. IEEE Transactions on Pattern Analysis and Machine Intelligence,1999,22(11):1330-1334.

[12] Richard Hartley, Andrew Zisserman. Multiple View Geometry in Computer Vision. Second edition, Cambridge University Press.UK.2003.

[13] Pollefeys M., Van Gool L., Vergauwen M., et al. Visual Modeling with a Hand-Held Camera, International Journal of Computer Vision, 2004,59(3) :207-232.

[14] Manolis Lourakis, Antonis Argyros. sba: A Generic Sparse Bundle Adjustment C/C++ Package Based on the Levenberg-Marquardt Algorithm. http://www.ics.forth.gr/~lourakis/sba/.