Comparison of Two Panoramic Sensor Models for Precise 3D Measurements

Shunping Ji, Yun Shi, Zhongchao Shi, Anmin Bao, Junli Li, Xiuxiao Yuan, Yulin Duan, and Ryosuke Shibasaki

Abstract

In this paper, the system errors produced by the most widely used ideal panoramic camera model for a close-range multi-camera rig are indicated and analytically modeled according to a rigorous panoramic camera model, and a comprehensive comparison between the two models is given. First, the 3D localization errors of the ideal model are analyzed that shows the correlations with the object-image distance and the viewing angles. Second, the epipolar errors are analyzed and are observed to exhibit changes with the rotation angles and z-coordinates of the image points. Finally, tests are carried out in space resection, epipolar constraints, and bundle adjustment with different sensor models. The outdoor tests with small object-image distance (several meters) show the difference between the two models is notably slight. In contrast, the indoor tests with larger object-image distance (more than 15 m) show the rigorous model produces 2 cm better measurement accuracy than the ideal.

Introduction

In many research studies and applications in recent years (Li *et al.*, 2004; Anguelov *et al.*, 2010), the close-range panoramic camera has been employed in place of a traditional plane camera because it features full panoramic information in a single image and a simple structure: one projection center and one projection sphere or cylinder. However, compared with a plane camera, larger geometric distortions exist in a panoramic camera or in a fish-eye camera even with a much smaller field of view, which may result in poor imaging quality. From a manufacturing perspective, there are three main methods used to overcome the large distortions. One method employs a dioptric multi-camera rig system, which reduces and shares the deformation equally over several separate and fixed fish-eye lenses. Further image stitching is required to form an entire panoramic image, which causes the main drawback of this structure that the projection radius should be fixed for a best stitching effect. The Ladybug® system is an example of this case (Sato *et al.*, 2004; Sato and Yokoya, 2010; Ladybug, 2013). The other method uses a linear-array-based camera, which can obtain seamless panoramic images with a vertical and turntable axis, such as the EYESCAN camera system (Schneider and Maas, 2006; Amiri and Gruen, 2010). This structure is not suitable for high-speed platforms, and static or low-speed platforms are preferred (Geyer and Kostas, 2001). A catadioptric system is the third type of panoramic camera composed of several lenses and parabolic mirrors (Geyer and Kostas, 2001; Barreto and Araujo, 2005). This paper concentrates on the multi-camera rig system with spherical projection.

The basic projective geometry of a panoramic camera is still represented by the ideal pinhole model, which describes the co-linearity that 3D object points, corresponding image points in the sphere, and the panoramic center are in a line (see Figure 1a). Kaess and Dellaert used a multi-camera rig for simultaneous localization and mapping (SLAM) with the pinhole spherical sensor model (Kaess and Dellaert, 2010). Paya *et al.* (2010) concentrated on the global description of each omni-directional image. Gutierrez *et al.* (2011) concentrated on the rotation and scale invariance of descriptor patches with a spherical camera model. Spherical perspective transformation functions and stereo-homographies based on the pinhole model are also covered by Mei *et al.* (2008). In Silpa-Anan and Hartley (2005) the fundamental matrix of the pinhole model is used as a geometric constraint between two views. The pinhole model for spherical imaging used in these articles (also referred to in this paper as the ideal panoramic camera model) is adopted under the assumption that the camera contains a unique spherical center as in Figure 1a. In fact, a multi-camera rig system does not contain an entire sphere but consists of several separate lenses with different projection centers and focal lengths (see Figure 1b). This internal structure may introduce additional system errors if the ideal panoramic camera model is applied.

Shunping Ji is with the School of Remote Sensing and Information Engineering, Wuhan University, 129 Luoyu Road, Wuhan, 430079, China; and the Center for Spatial Information Science, University of Tokyo, 5-1-5 Kashiwanoha, Kashiwa, Chiba, 277-8568, Japan.

Yun Shi is with Key Laboratory of Agri-informatics, Ministry of Agriculture / Institute of Agricultural Resources and Regional Planning, Chinese Academy of Agricultural Sciences, 12 Southern Street of Zhongguanchun, Haidian, Beijing, 10008, China; and the Center for Spatial Information Science, University of Tokyo, 5-1-5 Kashiwanoha, Kashiwa, Chiba, 277-8568, Japan.(shiyun@caas.cn).

Zhongchao Shi is with the Department of Restoration Ecology and Built Environment, Faculty of Environmental Studies, Tokyo City University, 3-3-1 Ushikubo-nishi, Tuzuki-ku, Yokohama, Kanagawa, 224-8551, Japan.

Anmin Bao and Junli Li are with the Xinjiang Institute of Ecology and Geography, Chinese Academy of Sciences, 818 Beijing South Road, Urumqi, 830011, China.

Xiuxiao Yuan is with the School of Remote Sensing and Information Engineering, Wuhan University, 129 Luoyu Road,Wuhan, 430079, China.

Yulin Duan and Ryosuke Shibasaki are with the Center for Spatial Information Science, University of Tokyo, 5-1-5 Kashiwanoha, Kashiwa, Chiba, 277-8568, Japan.

Photogrammetric Engineering & Remote Sensing
Vol. 80, No. 3, March 2014, pp. 229–238.
0099-1112/14/8003–229

doi: 10.14358/PERS.80.3.229