Huajian DENG, Hao WANG, Xiaoya HAN, Yang LIU, Zhonghe JIN, 2023. Camera calibration method for an infrared horizon sensor with a large field of view. *Frontiers of Information Technology & Electronic Engineering,* 24(1):141-153. https://doi.org/10.1631/FITEE.2200079

Camera calibration method for an infrared horizon sensor with a large field of view

Key words: Infrared horizon sensor; Ultra-field infrared camera; Camera calibration

Corresponding author: Hao WANG
E-mail: roger@zju.edu.cn
ORCID: https://orcid.org/0000-0002-0383-7258

Motivation

1. The low camera geometric accuracy is the main constraint to the precision improvement of the infrared horizon sensor with a large field of view (FOV).
2. The enormous FOV with a blind area in the center greatly limits the accuracy and feasibility of the traditional plane calibration board method.
3. The traditional collimator method has strict requirements on the experimental equipment to handle the camera's large FOV.
4. The severe distortion of the ultra-field cameras brings difficulties in the estimation of camera parameters.

Main idea

1. Multiple infrared targets were used to calibrate infrared cameras, and these targets can easily cover the infrared horizon sensor's super-large FOV at a low cost.
2. Compared with the traditional camera calibration method, the proposed method has lower requirements on experimental equipment, wider application, and higher accuracy.
3. By using multiple targets, enough data can be obtained in less experimental time, which means that higher accuracy can be achieved efficiently.
4. A three-step parameter estimation algorithm is proposed to avoid precisely measuring the positions of the camera and the control points.

Method

1. The infrared camera is mounted on the two-axis rotary table and points at the infrared targets. The two-axis rotary table drives the infrared camera to rotate to different angles, and the camera takes pictures of infrared targets at each pose.

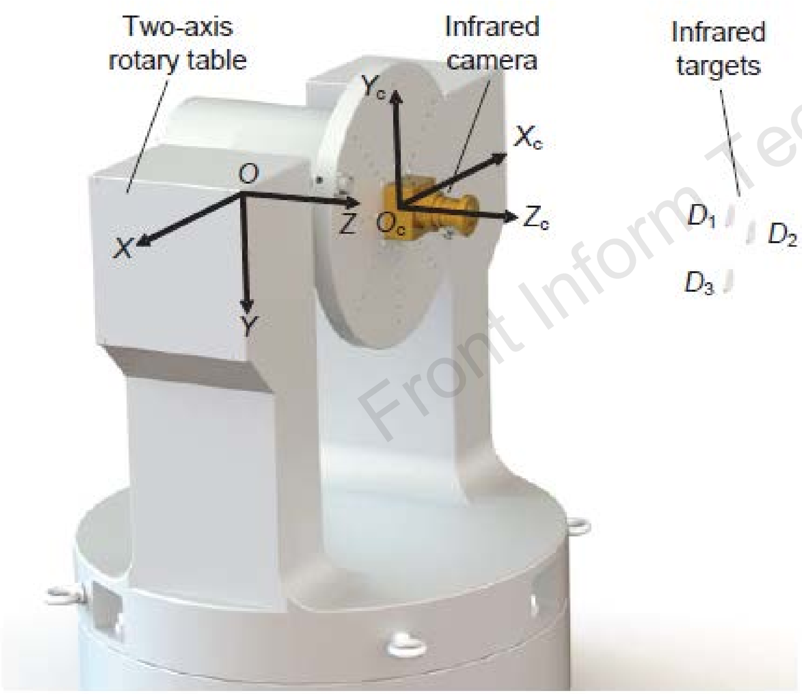

Fig. 6 The infrared camera calibration system

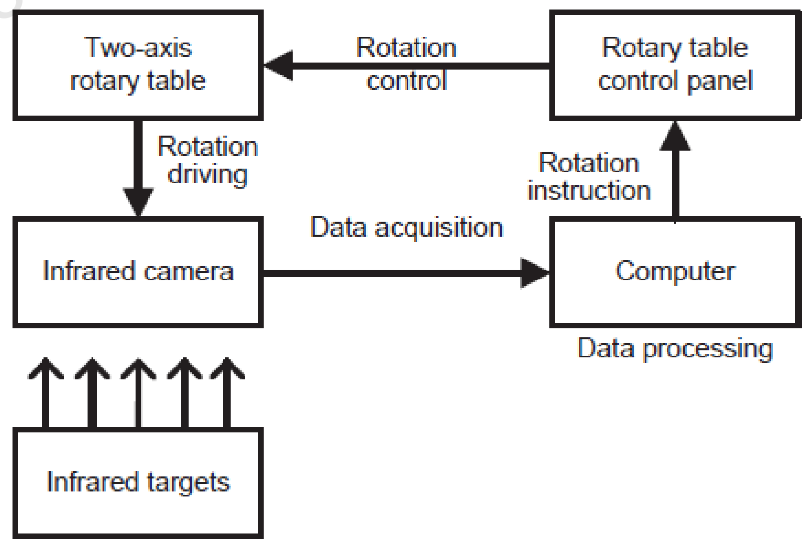

Fig. 4 Workflow of the infrared camera calibration system

Method (Cont’d)

2. Three infrared targets are used as control points. As the table rotates, these control points will be evenly distributed in the entire FOV. More data can be obtained in a shorter time by using multiple infrared targets. Control point positioning was achieved based on energy distribution.

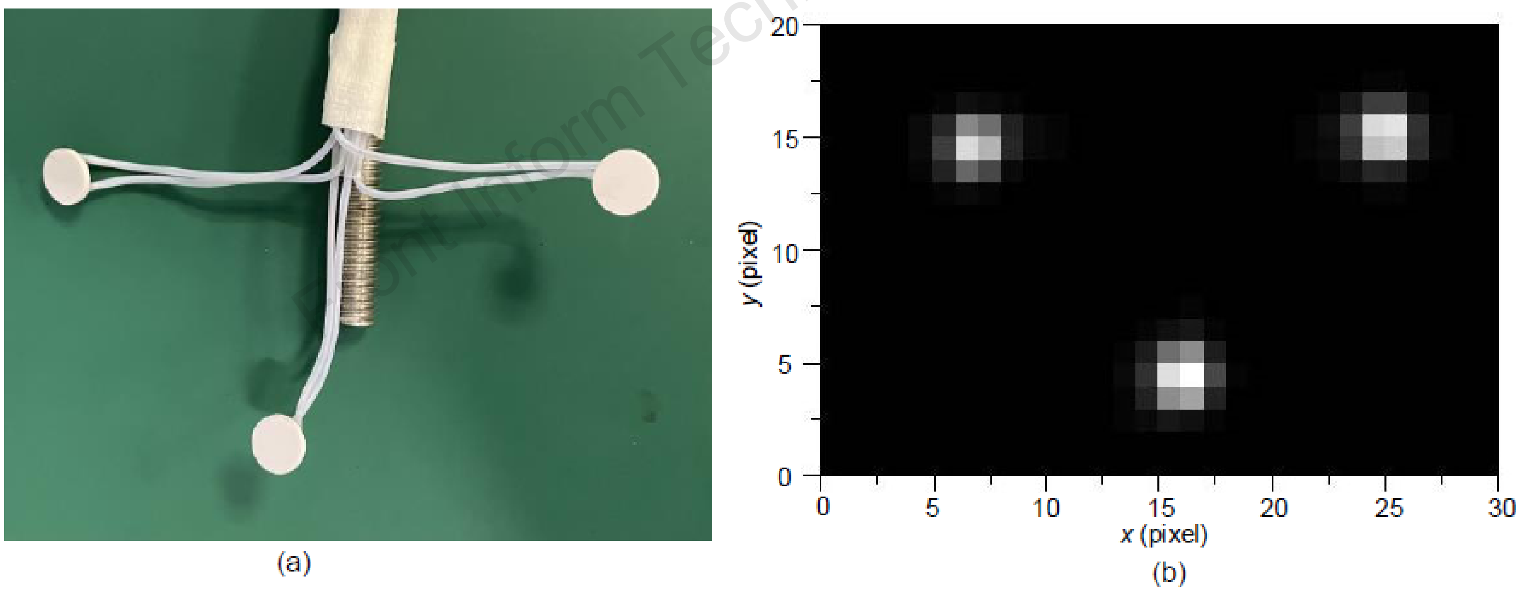

Fig. 5 Combination of three infrared targets with a diameter of 9 mm: (a) actual image; (b) infrared image

Method (Cont'd)

3. An integrated model of the infrared target imaging in the camera during the rotation is established. Parameters of the model can be estimated through a three-step estimation algorithm with high accuracy and robustness.

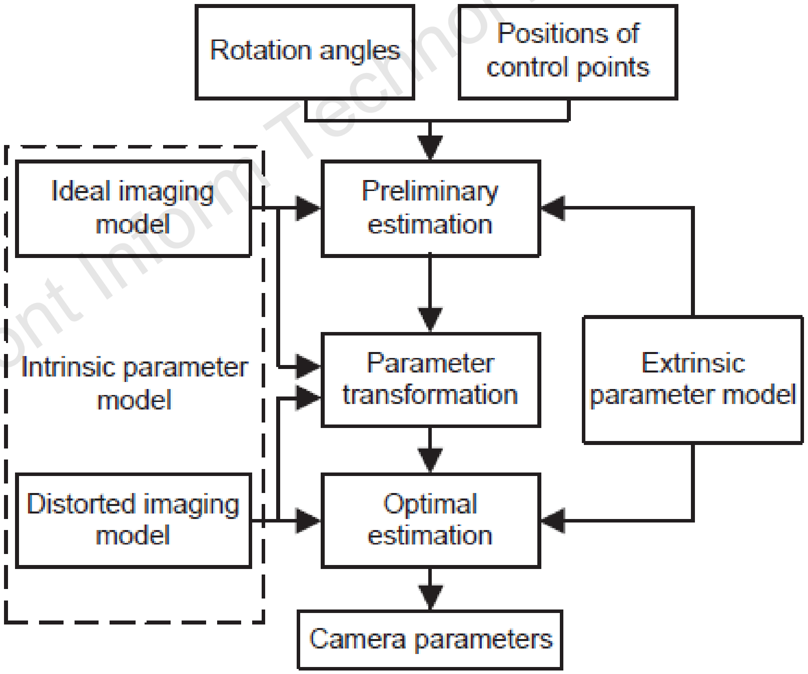

Fig. 7 Summary of the estimation algorithm

Major results

Simulation results

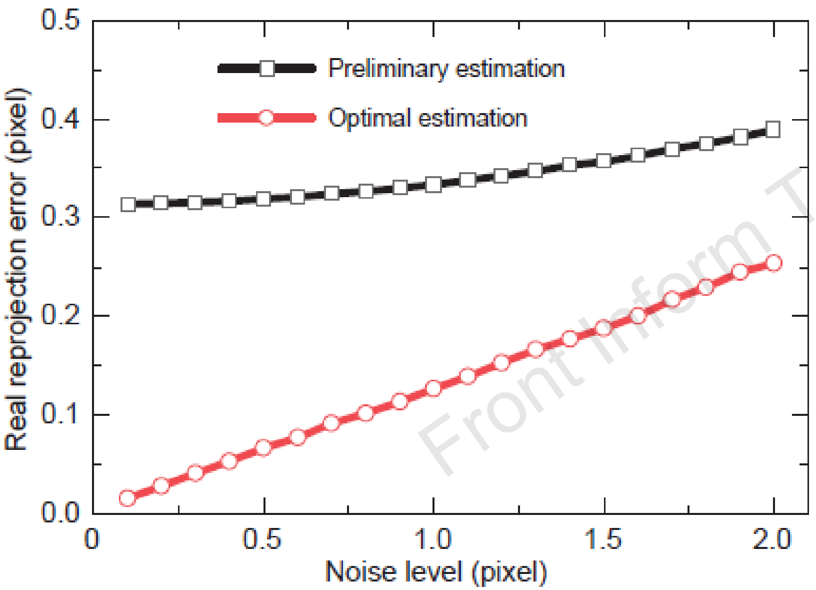

Fig. 8 Performance under different noise levels

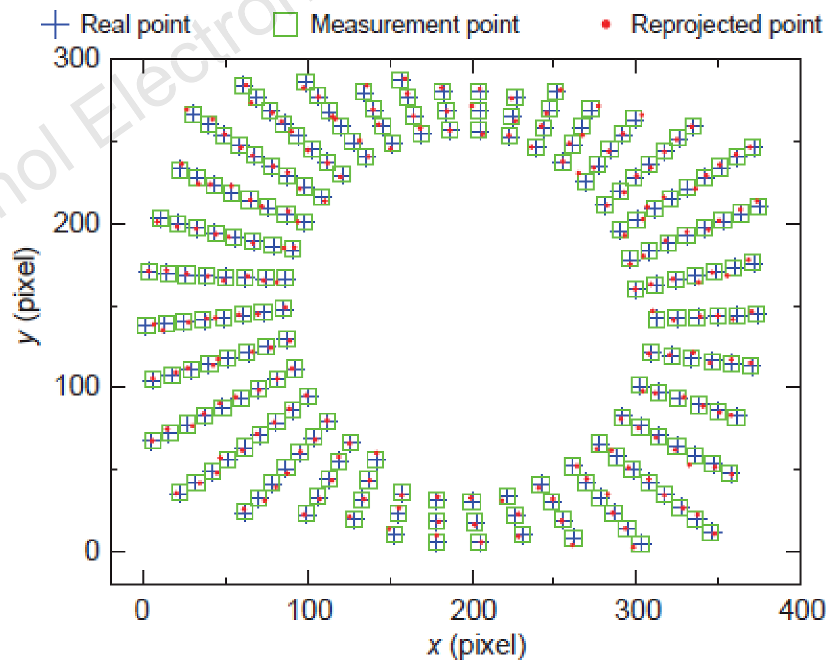

Fig. 9 Distribution of the real points, measurement points, and reprojected points

Major results (Cont'd)

Experimental results

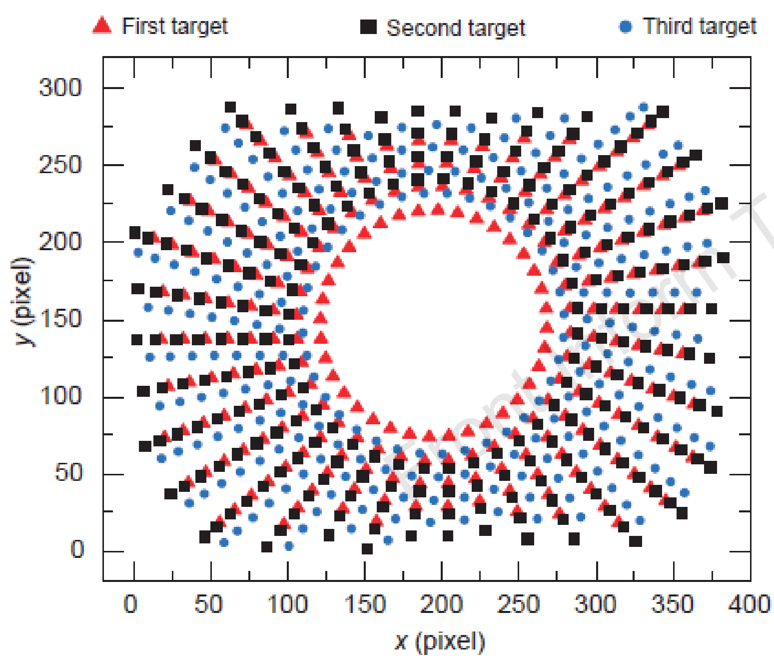

Fig. 11 Distribution of all control points obtained

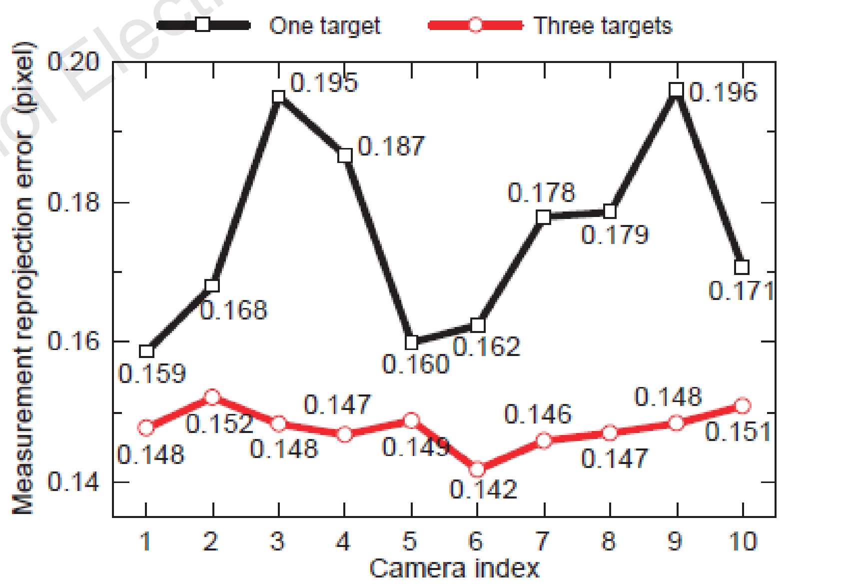

Fig. 13 Calibration experiments of 10 infrared horizon sensors

Major results (Cont'd)

Comparison of results

Table 6 Comparison of infrared camera calibration methods

Calibration methods	Camera resolution (pixel)	FOV	Calibration accuracy (pixel)
IPCB method(Chen et al., 2019)	384x288	175°(H)x127°(V)	0.275
IPCB method(Zhang et al., 2020a)	800x600	112°(H)x84°(V)	0.219
Proposed method with single target	384x288	162°(H)x120°(V)	0.175
Proposed method with three targets	384x288	162°(H)x120°(V)	0.148

IPCB: infrared plane calibration board; FOV: field of view; H: height; V: vertical

Conclusions

1. Experiments of 10 infrared horizon sensors show that the proposed method has high stability and accuracy.

2.The combination of three targets improves the calibration accuracy by 15% compared to a single target.

3.The camera calibration accuracy is improved by at least 30% compared to other existing methods.

Huajian DENG received his BS degree in College of Astronautics from Nanjing University of Aeronautics and Astronautics. He is now pursuing his PhD degree at Micro-Satellite Research Center, Zhejiang University. He is currently investigating optical sensor for attitude and orbit measurement of micro satellites.

Hao WANG received his PhD degree in precision instruments and machinery from Shanghai Jiao Tong University, Shanghai, China, in 2007. He is currently an associate professor at the Micro-Satellite Research Center, Zhejiang University. His current research interests include sensors and actuators for micro satellites attitude control systems. He is engaged in the research and development of several micro satellites.

Zhonghe JIN received his PhD degree in microelectronics and solid-electronics from Zhejiang University, Hangzhou, China, in 1998. He is currently a professor at the Micro-Satellite Research Center, Zhejiang University. His current research interests include micro satellites optical sensors, MEMS/NEMS technologies, and micro satellites attitude and orbit control systems. He is engaged in the research and development of several micro satellites.