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Geometric calibration of Colour and Stereo Surface Imaging System of ESA's Trace Gas Orbiter

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Abstract

There are many geometric calibration methods for "standard" cameras. These methods, however, cannot be used for the calibration of telescopes with large focal lengths and complex off-axis optics. Moreover, specialized calibration methods for the telescopes are scarce in literature. We describe the calibration method that we developed for the Colour and Stereo Surface Imaging System (CaSSIS) telescope, on board of the ExoMars Trace Gas Orbiter (TGO). Although our method is described in the context of CaSSIS, with camera-specific experiments, it is general and can be applied to other telescopes. We further encourage re-use of the proposed method by making our calibration code and data available on-line.

Keywords: Geometric calibration; Optical distortion; Off-axis; Star field; CaSSIS; TGO; Telescope; Rational distortion model

1. Introduction

On March 15, 2016 Trace Gas Orbiter (TGO) was launched to Mars, as part of the European Space Agency's (ESA's) ExoMars project. Its aim is to find trace gases, which may be evidence of geological or biological activity on Mars. The Colour and Stereo Surface Imaging System (CaSSIS) is TGO's imaging system that provides visual context for sites identified as potential sources of trace gases. A brief specification of CaSSIS is provided in Table 1.

CaSSIS (Thomas et al., 2014, submitted for publication) is a multi-spectral push-frame camera with 4 rectangular color filters covering its sensor (Fig. 1). As the spacecraft is moving along the orbit, each part of a targeted area becomes visible, sequentially, in each filter. By acquiring and mosaicking multiple images ("framelets"), CaSSIS is able to reconstruct a large 4-colours image of the targeted area.

CaSSIS is also a stereo camera. It is capable of acquiring two images of a target area from two distinct points on the same orbit. While approaching the target area it acquires the first image, then it gets mechanically rotated and acquires the second image, while departing from the target area. By computing parallax from these two images, one

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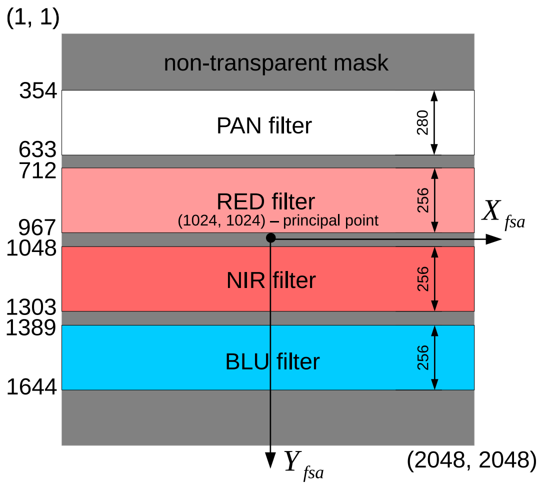

Quantity	Value
Optic	3-mirror plus fold mirror off-axis
Detector	Raytheon Osprey 2k CMOS hybrid
Filters	675, 485, 840, 985 nanometers
Focal length	880 millimeters
F#	6.52
Pixel size	10×10 micrometers
Detector area	2048×2048 (2048×1350 is used)
FOV	1.33×0.88 degree
Angle w.r.t nadir	10.0 ± 0.2 degree

Fig. 1. CaSSIS camera specification. The CaSSIS telescope is three-mirror anastigmat system (off-axis) with a fold mirror. The CaSSIS Filter Strip Assembly (FSA) comprises a Raytheon Osprey 2048×2048 hybrid CMOS detector with 4 colour filters mounted on it following the push-frame technique. Narrow dark bands between the filters reduce spectral cross-talk. The detector can acquire an un-smeared image along ground-track. The along-track dimension of the image is then built up and put together on ground. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

can reconstruct a Digital Elevation Model (DEM) of the target area.

To prepare scientific products, such as color images and DEMs from raw CaSSIS images, one needs geometric camera parameters, such as its focal length and a optical distortion model. While their nominal values are known from technical specification, their actual values might deviate from the nominal ones, due to imprecise manufacturing, mounting, or various changes during the spacecraft cruise and operation (due to structure dryout and zero gravity). Therefore, their actual values have to be measured in the controlled environment of the clean room and validated during the commissioning phase in flight. This is the main goal of geometric calibration.

There are many geometric calibration methods (Hartley and Zisserman, 2003; Zhengyou, 1999; Heikkila and Silven, 1997; Tsai, 1987) and tools[1,2,3] for "standard" cameras. However, these off-the-shelf tools cannot be used for the calibration of telescopes such as CaSSIS, for two reasons. Firstly, most of these tools require images of calibration targets, such as a checkerboard chart. For telescopes with a large focal length, however, such targets must be very large ($\approx$ km^2) and should be placed very far away from the telescope ($\approx$ 10 km), which is impractical. Secondly, telescopes often have off-axis optical designs with complex optical distortion, that cannot be handled by off-the-shelf tools. Therefore, there is a need for specialized calibration methods, which are unfortunately scarce in the literature.

In this paper we describe the calibration method that we developed for CaSSIS. Although our method is described in the context of CaSSIS, it is general and can be applied to other telescopes. We further encourage re-use of the proposed method by making our calibration code and data available on-line.[4]

We first discuss in Section 2 the related work, and describe in Section 3 the geometric camera model adopted in the paper. In Section 4 we explain the distortion model selection procedure based on lens simulation, in Section 5 we describe the on-ground calibration using images of a dotted calibration target captured through a collimator, and in Section 6 we describe the in-flight calibration using star field images. Finally, in Section 7 we show how refined geometric parameters improve the quality of map-projected CaSSIS images.

2. Related work

2.1. Optical distortion models

Off-the-shelf calibration tools typically assume a radial or a Brown-Conrady optical distortion model. The radial model (Hartley and Zisserman, 2003) is a simple 5 degrees-of-freedom (DOF) model, only accounting for radially symmetric distortion. Brown-Conrandy (Brown, 1966) is a more complex model with 7 DOF, that in addition to the radially symmetric component, accounts for tangential decentering. These models, however, cannot represent the complex distortion in a camera with off-axis

[1] MATLAB camera calibration tool, https://ch.mathworks.com/help/vision/ug/single-camera-calibrator-app.html, accessed 2017–05-23.

[2] OpenCV camera calibration tool, http://docs.opencv.org/2.4/doc/tutorials/calib3d/camera_calibration/camera_calibration.html, accessed 2017–05-23.

[3] Caltech camera calibration tool, http://www.vision.caltech.edu/bouguetj/calib_doc/, accessed 2017–05-23.

[4] https://github.com/eSpaceEPFL/CASSISgeometry.git.