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Cross-ratio invariant based line scan camera geometric calibration with static linear data

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ABSTRACT

A flexible new technique is proposed to calibrate the geometric model of a line scan camera. In this technique, the calibration pattern comprises two orthogonal planes; on each plane two groups of parallel feature lines are drawn. A single linear view of this pattern is captured by the line scan camera requiring calibration. Consequently, points crossed by the view plane and parallel lines are projected on the camera sensor. Then, two problems are addressed. Firstly, with the properties of cross-ratio, the corresponding spatial point coordinates are obtained. Secondly, using the point correspondences and line scan camera model, eight camera parameters are solved via two steps. Lens distortion is not taken into consideration. Compared with classical techniques, this newly proposed technique is easy to use and flexible.

1. Introduction

Line scan cameras are widely used in the fields of vehicle-borne 3D scene reconstruction and space-borne remote sensing areas [1,2]. With the advantages of high sample rate and high space resolution, they are replacing frame cameras in many applications.

Camera calibration is a crucial step before photogrammetric measurement or stereo vision computing. There have been several matured methods about frame camera calibration such as Tsai's [3] and Zhang's [4] methods. Tsai proposed a versatile two-step calibration method which can deal with single or multi images of a planar or 3D metric calibration pattern by using the property of radial alignment constrain (RAC). Zhang proposed a flexible calibration technique for desktop vision system (DVS) by using a printed planar calibration pattern. In his proposal, the metric planar pattern should be captured by the camera from at least three different orientations. Tsai's and Zhang's calibration methods have advanced computer vision and close range photogrammetry one important step to the real world applications. However, little attention is drawn to the subject of line scan camera calibration compared with frame cameras. Up to now, line scan camera calibration without professional instruments is still a tough job because a single captured line provides too little geometric information to establish point-to-point correspondences in the general case. By now, several papers have focused on the subject of line scan camera calibration. Horaud et al. [5] proposed a multiline calibration method to calibrate the camera parameters with the line image of a purposively designed 2D calibration pattern. Four coplanar lines with known equations in the pattern's coordinate system are drawn on the calibration pattern. The first three are mutually parallel, and the fourth makes an angle with the direction of these three. Therefore when the line scan camera captures a line image of the pattern, intersections of the view plane and feature lines are projected on the linear sensor. With the properties of cross-ratio, an invariant of 1D central projection [6], correspondences between these intersections and image points are established to solve the camera parameters. In this proposal, it is necessary to move the calibration pattern in the Y and/or Z directions with known increments. Luna et al. [7] proposed a similar method based on feature lines. A special 3D calibration pattern comprising two parallel planes is designed and thus relative movement between the line scan camera and the calibration pattern in [5] is avoided when the calibration pattern and the camera sensor are parallel. Different from the calibration methods based on static imaging in [5,7], Hui et al. [8] proposed a calibration method by fixing the line scan camera to a programmable linear stage. The camera scans a 3D calibration pattern along an arbitrary direction with the help of a linear stage. A sequence of captured lines is arranged in an image form and thus feature points on the calibration pattern are recognized easily. Compared with [5,7] in which only a single linear data is used, calibration methods using 2D scan images can provide higher precisions. However, in close-range photogrammetry moving platforms like the linear stage are not affordable and convenient for many low-cost line scan cameras.

In this paper, a new technique combining the advantages of [5] and [7] is proposed to calibrate a line scan camera from the image(s) of a

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metric pattern. A single catch calibration can be performed with good accuracy. Compared with the classical techniques which require relative movement or quasi-coplanarity between the sensor and the calibration pattern, the newly proposed technique improves the flexibility of the calibration process.

The remainder of this paper is organized as follows: Section 2 derives the line scan camera imaging model and lists the pending parameters for calibration. In Section 3, a general scheme of the two-step calibration procedure is explained. We start with an approximate solution, followed by nonlinear optimization. Section 4 details the calibration results. Both computer simulation and real data are used to test the proposed method. Finally, in Section 5, conclusions of this paper are summarized.

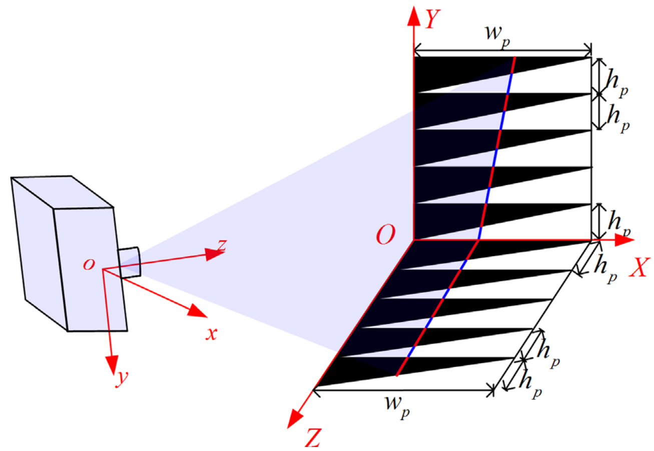

Fig. 1. A general view of static imaging for a line scan camera.

2. Line scan camera imaging model

In order to describe the projective relationship between image points and space points, central projection is adopted as a good approximation of the real camera imaging model. The imaging via line scan cameras can be comprehended as a special case of frame cameras. In this regard, central projection is satisfied only along one direction. Without considerations of lens distortion, the line scan camera model may be represented by

$$\begin{cases} 0 = r_{11}X + r_{12}Y + r_{13}Z + t_1 \\ y = f_y \frac{r_{21}X + r_{22}Y + r_{23}Z + t_2}{r_{31}X + r_{32}Y + r_{33}Z + t_3} + y_0 \end{cases} . \quad (1)$$

In Eq. (1), eight independent camera parameters are available. The value y_0 and f_y are referred to intrinsic parameters, which are stable parameters as long as line scan camera is configured. Focal length is represented by f_y and y_0 is the offset of the principal point. $r_{ij}(i, j = 1 \cdots 3)$ are elements of the rotation matrix parameterized by a vector of 3 parameters, denoted by $[r_1, r_2, r_3]^T$, which is a vector parallel to the rotation axis and whose magnitude is equal to the rotation angle. The rotation matrix and $[r_1, r_2, r_3]^T$ are related by the Rodrigues formula [9]. $[r_1, r_2, r_3]^T$ and $[t_1, t_2, t_3]^T$ means the rotation and translation vector from the world coordinate system to the camera coordinate system.

In general, Eq. (1) indicates that a space point (X, Y and Z) is projected on point y along the linear sensor. Actually, only the space points on the view plane can be imaged and the first part of Eq. (1) is the view plane equation in the world coordinate system. The second part of Eq. (1) describes the 1-D projective relationship between image points on the linear sensor and spatial points on the view plane.

3. A two-step calibration method

Compared with frame camera calibration, an inherent difficulty of line scan camera calibration is the establishment of correspondences between space points and image points. A single line image provides too little information to recognize feature points on the calibration pattern. In this paper, a purposively designed calibration pattern makes it possible to get corresponding space points and image points. Different from the calibration pattern in [7], our pattern comprises two orthogonal planes; on each plane ten black triangles are drawn to form similar feature lines in [5] (See Fig. 1). The equations of these feature lines are known in the pattern's coordinate system. To get more robust and stable calibration results, more triangles can be drawn on the pattern.

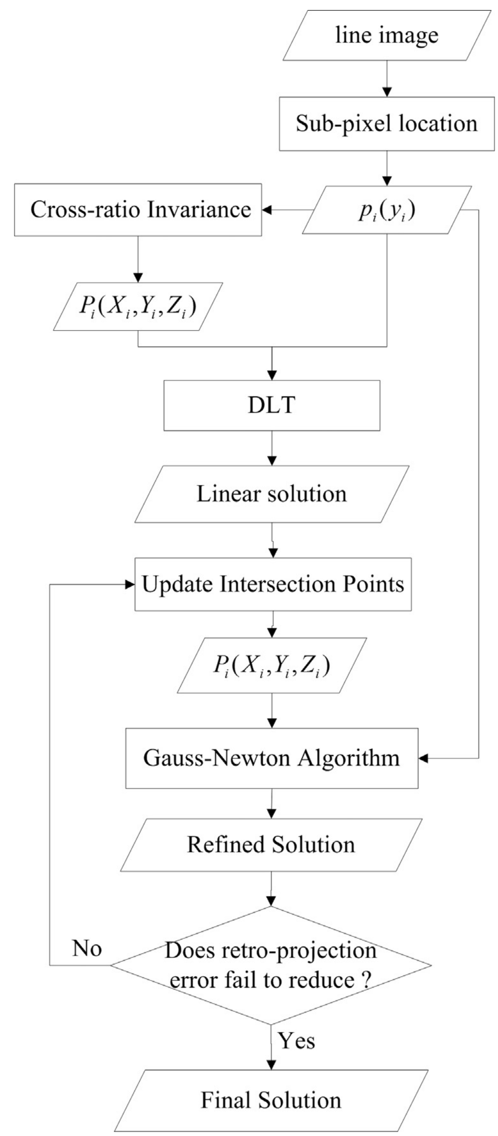

Fig. 2. The flow chart of our proposal.

The proposed calibration method consists of the following:

(1) From the line captured by a line scan camera and the geometry of the pattern, we are able to obtain the coordinates (X_i, Y_i and Z_i) of the points (P_i) corresponding to the straight lines of the pattern.

(2) With the P_i points and their corresponding values in the captured line, by means of a traditional two-step method, the intrinsic and extrinsic line-scan parameters are obtained.