Camera Calibration Toolbox for Generic Multiple Cameras

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I. INTRODUCTION

This is a camera calibration toolbox for generic multiple cameras. The toolbox can be used to calibrate: 1) two conventional cameras; 2) two fish-eye cameras; 3) two mixed cameras (e.g. a conventional camera and a fish-eye camera); 4) multiple cameras (each camera can be a conventional camera or a fish-eye camera). The calibration is based on viewing a freely-moving one-dimensional wand (see Fig. 1) that has three collinear feature points \( A, B, C \). The intrinsic and extrinsic parameters of two/multiple cameras are estimated from point correspondences between the calibration wand and calibration images simultaneously.

II. DESCRIPTION OF THE CALIBRATION PARAMETERS

A. Intrinsic parameters (generic camera model):

A generic camera model is proposed as follows \cite{1}

\[
r(\theta) = k_1\theta + k_2\theta^3 + k_3\theta^5 + k_4\theta^7 + k_5\theta^9 + \cdots .
\]

(1)

It is found that the first five terms can approximate different projection curves well. Therefore, in this toolbox we choose the model that contains only the five parameters \( kc = (k_1, k_2, k_3, k_4, k_5) \).

As shown in Fig. 2, a 3D point \( Q \) is imaged at \( q \) by a fish-eye camera, while it would be \( q' \) by a pinhole camera. Let \( O_c - X_cY_cZ_c \) denote the camera coordinate system and \( o - xy \) the image coordinate system (unit mm). We can obtain the image coordinates of \( q \) in \( o - xy \) by

\[
\begin{pmatrix}
  x \\
  y
\end{pmatrix}
= r(\theta)
\begin{pmatrix}
  \cos \phi \\
  \sin \phi
\end{pmatrix}
\]

(2)

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where \( r(\theta) \) is defined in (1), and \( \varphi \) is the angle between the radial direction and the \( x \)-axis. Then we can get the pixel coordinates \((u, v)\) from

\[
\begin{pmatrix}
  u \\
  v
\end{pmatrix} = \begin{bmatrix} m_u & 0 \\ 0 & m_v \end{bmatrix} \begin{pmatrix} x \\ y \end{pmatrix} + \begin{pmatrix} u_0 \\ v_0 \end{pmatrix}
\]

(3)

where \( cc = (u_0, v_0) \) is the principal point, and \( mc = (m_u, m_v) \) is the number of pixels per unit distance in horizontal and vertical directions, respectively. Thus, for each camera, the intrinsic parameters are \( p = (k_1, k_2, m_u, m_v, u_0, v_0, k_3, k_4, k_5)^T \in \mathbb{R}^9 \).

**Intrinsics:** a set of \( m \) \( 9 \times 1 \) vectors \( p_0, p_1, \cdots, p_{m-1} \) (assuming there are \( m \) cameras to be calibrated).

**B. Extrinsic parameters:**

Rotations: a set of \( m \) \( 3 \times 3 \) matrices \( Rc_0, Rc_1, \cdots, Rc_{m-1} \) (assuming there are \( m \) cameras to be calibrated, camera 0 is the ‘base’ camera).

Translations: a set of \( m \) \( 3 \times 1 \) vectors \( Tc_0, Tc_1, \cdots, Tc_{m-1} \) (assuming there are \( m \) cameras to be calibrated, camera 0 is the ‘base’ camera).

Note that \( RMS_{camera} \) gives root-mean-squared (RMS) reprojection error of camera 0, 1, \( \cdots, m-1 \) (beginning with camera 0).
Fig. 2. Fish-eye camera model [1]. The 3D point $Q$ is imaged at $q$ by a fish-eye camera, while it would be $q'$ by a pinhole camera.

III. INSTALLATION

Copy all the files into a directory and add it and its subfolders to your MATLABPATH. Matlab 2011b or higher version in Windows 32-bit system environment is required.

IV. USAGE

(i) Suppose that there are $m$ cameras to be calibrated and $n$ images of the wand are captured by each camera. Since there are three feature points $A, B, C$ projected on the image plane of each camera, we can reformulate the coordinates of image points as a $6m \times n$ matrix. Note that if a 3D point is not viewed by a camera, the coordinate then is $(0, 0)$.

Take $m = 2$ for example, the $12 \times n$ matrix is shown in Fig. 3, where $(u_{a,i}, v_{a,i})$ is the image point of $A$ in the $i$th camera, $(u_{b,i}, v_{b,i})$ is the image point of $B$ in the $i$th camera and $(u_{c,i}, v_{c,i})$ is the image point of $C$ in the $i$th camera ($i = 0, 1$). We can obtain the image coordinate matrix when $m > 2$ in a similar way.

(ii) Given the point correspondences between the calibration wand and calibration images, one may directly compute the camera parameters as follows. First fill in all the necessary information in calibconfig.m. Then run CALIBRATE with the correspondences as input. See HELP CALIBRATE for more information. Finally, the intrinsic and extrinsic parameters of the cameras to be calibrated are stored in Calib_Results.mat.
V. MAIN FUNCTIONS

CALIBCONFIG
Prior information about the cameras or the calibration wand must be given in file calibconfig.m.

CALIBRATE
Compute the optimal intrinsic and extrinsic parameters of two or more cameras. Each camera can be a fisheye camera or a conventional camera. The correspondences between the calibration wand and the calibration images are given as input. The estimated intrinsic and extrinsic parameters are saved into a mat-file.

BACKPROJECT
The backward camera model. After the calibration this function may be used to compute the directions of back-projected rays corresponding to given image points.

COMPUTERANDT

gives the correct combination of R and T if the essential matrix is known.

RANSAC_FIVE
RANSAC algorithm for the estimation of the essential matrix using the five point algorithm.

RECONSTRUCTION

gives the reconstructed 3D coordinate of a space point viewed by N cameras.

STEREO_CALIBRATION

gives the calibration results of stereo cameras’ internal and external parameters and error analysis.

VI. DEMO

Run function FISHEYE_2CAM DEMO or FISHEYE_3CAM DEMO.

REFERENCES