Camera Calibration Toolbox for Generic Multiple Cameras

Qiang Fu[1], Quan Quan[1,2], Kai-Yuan Cai[1]

1. Department of Automatic Control, Beihang University, Beijing 100191, China

2. State Key Laboratory of Virtual Reality Technology and Systems, Beihang University, Beijing 100191, China

Emails: fq_buaa@asee.buaa.edu.cn (Qiang Fu); qq_buaa@buaa.edu.cn (Quan Quan); kycai@buaa.edu.cn (Kai-Yuan Cai).

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 [1]

$$r(\theta) = k_1\theta + k_2\theta^3 + k_3\theta^5 + k_4\theta^7 + k_5\theta^9 + \cdots . \tag{1}$$

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

$$\begin{pmatrix} x \\ y \end{pmatrix} = r(\theta) \begin{pmatrix} \cos\varphi \\ \sin\varphi \end{pmatrix} \tag{2}$$

Corresponding author: Qiang Fu. Email: fq_buaa@asee.buaa.edu.cn.

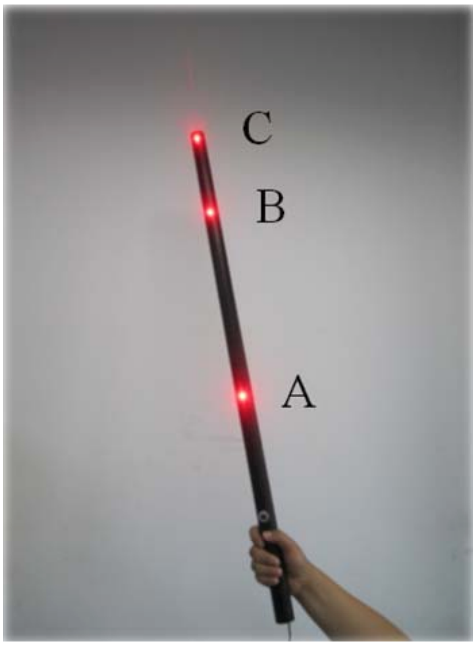

Fig. 1. One-dimensional calibration wand. The wand lengths between the three feature points A, B, C are known.

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

$$\begin{pmatrix} u \\ v \end{pmatrix} = \begin{bmatrix} m_u & 0 \\ 0 & m_v \end{bmatrix} \begin{pmatrix} x \\ y \end{pmatrix} + \begin{pmatrix} u_0 \\ v_0 \end{pmatrix} \tag{3}$$

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 9×1 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 3×3 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 3×1 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)

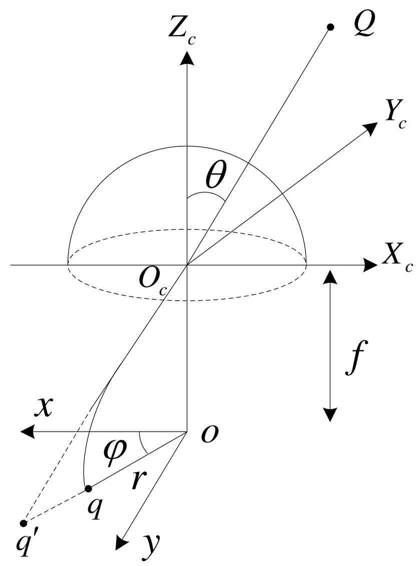

Fig. 2. Fish-eye camera model [1]. The 3D point Q is imaged at q by a fish-eye camera, while it would be q' by a pinhole camera.

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 ith camera, $(u_{b,i}, v_{b,i})$ is the image point of B in the ith camera and $(u_{c,i}, v_{c,i})$ is the image point of C in the ith 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.

		1	2	3	4	5	6	7	8	9	10	11
$u_{a,0}$ →	1	351	320	292	273	261	259	263	279	299	466	457
$v_{a,0}$ →	2	331	324	316	307	305	304	311	324	342	366	285
$u_{b,0}$ →	3	282	242	201	169	150	141	145	158	188	590	594
$v_{b,0}$ →	4	438	424	403	384	367	358	360	379	411	409	262
$u_{c,0}$ →	5	248	198	155	119	95	84	87	101	129	646	654
$v_{c,0}$ →	6	490	474	450	423	397	383	385	407	443	427	251
$u_{a,1}$ →	7	376	355	335	320	312	306	305	309	319	398	397
$v_{a,1}$ →	8	300	288	275	262	256	256	263	276	295	355	269
$u_{b,1}$ →	9	282	259	239	225	216	212	210	211	218	514	538
$v_{b,1}$ →	10	378	356	333	309	291	281	284	300	330	445	280
$u_{c,1}$ →	11	238	215	196	182	174	170	168	169	172	574	617
$v_{c,1}$ →	12	417	388	359	328	304	289	292	310	347	489	286

Fig. 3. The image coordinate matrix of stereo cameras. The matrix dimension is $12 \times n$.

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_2CAMS_DEMO or FISHEYE_3CAMS_DEMO.

References

[1] Kannala J., Brandt S.: 'A generic camera model and calibration method for conventional, wide-angle, and fish-eye lenses', IEEE Transactions on Pattern Analysis and Machine Intelligence, 2006, 28, (8), pp. 1335-1340.

[2] Fu Q., Quan Q., Cai K.-Y.: ‘A calibration method for fish-eye cameras using a wand under general motions’, submitted to IET Computer Vision, 2014.