Backgrounds for This Project

1. Omnidirectional camera calibration

Camera calibration is a basic task in machine vision. The goal of camera calibration is to get camera parameters, including internal parameters such as focal length and optical centers as well as external parameters which determine the location and pose between multiple cameras.

Omnidirectional cameras are extensively used because of its large field of view, which means more information about a scene can be attend, by introducing large distortion, especially near the boundary of images. Omnidirectional cameras consist several types of cameras, such as fish-eye cameras and catadioptric cameras. Here are two examples of them:

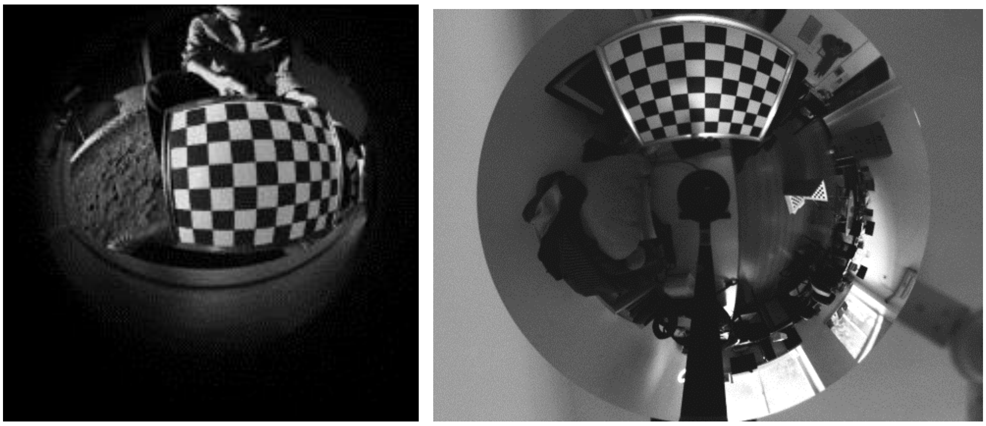

Fig 1 Images of fish-eye cameras (left) and catadioptric cameras (right)

Catadioptric cameras can be further divided into hyperbolic, parabolic and elliptical cameras, all have different imaging processes, making omnidirectional camera calibration a complex task. Fortunately, there is a unified sphere model [1] proposed by C'Mei which can be used to present fish-eye and all catadioptric cameras, even including perspective camera. It introduces a parameter ξ to control the types of cameras. For instance, $\xi > 1$ is for fish-eye cameras, $\xi < 1$ is for catadioptric cameras. By making use of the unified sphere model, one can use the same code to work with all omnidirectional cameras.

A description of C'Mei model is given below:

Given a 3D point X_w in world coordinate, first transform it to camera coordinate.

$$\mathbf{X}_c = \mathbf{R}\mathbf{X}_\mathbf{w} + \mathbf{T}$$

Next, map X_c to sphere.

$$\mathbf{X}_\mathrm{s} = \frac{\mathbf{X_c}}{||\mathbf{X_c}||} = (X_s, Y_s, Z_s)$$

Then transform $\mathbf{X}_\mathrm{s}$ to a new reference frame centered at $O_q = (0,0,-\xi)$

$$\mathrm{x} = \left(\frac{X_s}{Z_s + \xi}, \frac{Y_s}{Z_s + \xi}, 1\right)$$

Next, add lens distortion

$$\tilde{x} = x + \tilde{d}$$

Finally, with an intrinsic matrix $\mathbf{K}$, the pixel location of this 3D point is

$$\mathrm{p} = \mathbf{K}\tilde{\mathrm{x}}$$

Note ξ is also a parameter for calibration. The unified sphere model is given in Fig 2.

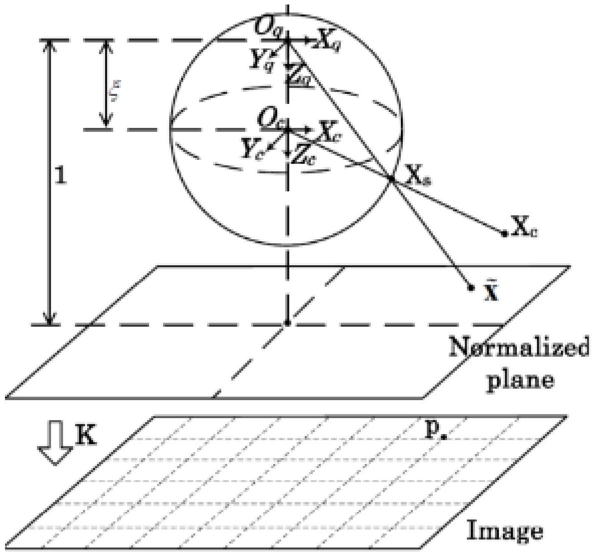

Fig 2. The unified sphere model

2. Stereo rectification of omnidirectional camera

To get 3D from one pair of stereo images, one should rectify them by camera parameters from calibration. The rectification method is also related with camera model. So the rectification should be also implemented.

The conventional rectification result is a perspective image so that horizontal lines in 3D space are horizontal on image, which restrict stereo matching on a single line. See Fig 3.

Fig 3. One fish-eye image (left), its perspective rectified image (center), 4 times scaled perspective rectified image (right)

It can be observed that perspective rectified image lost some boundary scene. One can scale the size of image to contain more scene. However, it becomes more difficulty when field of view is larger, when field of view is larger than 180, it is even impossible. The right figure of Fig 3 increase the image plane by 4 times, but still can preserve all details.

To deal with this, [2] propose a longitude-latitude mapping to rectify images. The main idea is that if one project 3D points on sphere, then horizontal lines in 3D space locate on latitude lines on sphere. So one can map the points on sphere to rectified image by their longitude and latitude, so that each pixel on rectified image represents one longitude-latitude pair. See Fig 4. Note that every points on sphere have longitude-latitude pair, the longitude-latitude mapping rectification supports 360° of field of view.

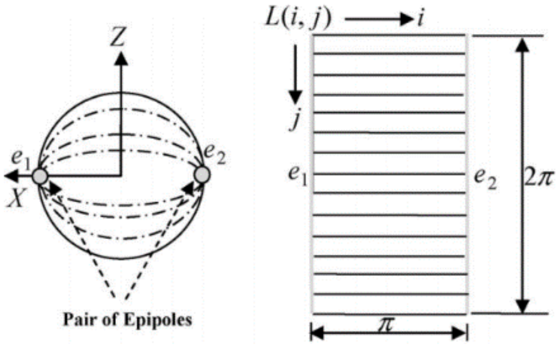

Fig 4. Explanation of longitude-latitude mapping

An example of longitude-latitude rectification for stereo images is given in Fig 5. Be aware that horizontal lines are mapped to latitude lines so that stereo matching can still be applied on single line, although it looks strange.

A new pair of fish-eye images and their disparity map is given in Fig 6.

Fig 5. A pair of rectified images by longitude-latitude mapping

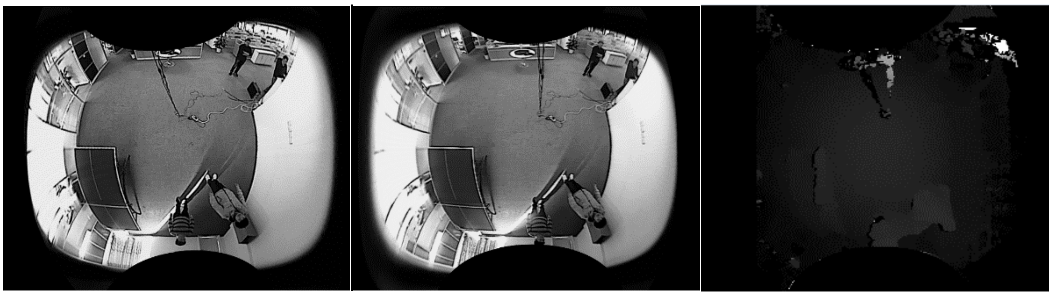

Fig 6. A pair of stereo rectified images and the disparity map

Reference:

[1] Mei C, Rives P. Single view point omnidirectional camera calibration from planar grids[C]//Robotics and Automation, 2007 IEEE International Conference on. IEEE, 2007: 3945-3950.

[2] Li S. Binocular spherical stereo[J]. Intelligent Transportation Systems, IEEE Transactions on, 2008, 9(4): 589-600.

[3] http://homepages.laas.fr/cmei/index.php/Toolbox

[4] https://sites.google.com/site/scarabotix/ocamcalib-toolbox

[5] http://apps.jcns.fz-juelich.de/doku/sc/lmfit

[6] Gong X, Lai B, Xiang Z. AL 0 sparse analysis prior for blind poissonian image deconvolution [J]. Optics express, 2014, 22(4): 3860-3865.
[7] Rufli M, Scaramuzza D, Siegwart R. Automatic detection of checkerboards on blurred and distorted images[C]//Intelligent Robots and Systems, 2008. IROS 2008. IEEE/RSJ International Conference on. IEEE, 2008: 3121-3126.