Design and calibration of an omni-RGB+D camera

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***Abstract*—In this paper, we present the design of a new camera combining both predator-like and prey-like vision features. This setup provides both a spherical RGB-view and a directional depth-view of the environment. The model and calibration of the full set-up are described. A few examples will be given to demonstrate the interest and the versatility of such camera for robotics and video surveillance at the oral presentation.**

***Keywords*—fisheye, dioptric, stereo vision, unified model.**

1. Introduction

The research of bio-inspiration is increasingly important along with the creation of autonomous robotics to replace the manned system [1]. The fabrication of the wide field of view (FoV) camera, work together with computer vision technique and integrated with the robotic system makes this research more effective. Nowadays, the camera is not only used for visualisation, but also maneuvering and analyzing the current state of the robot [2]. This paper will present the design and calibration of a new sensor composed of two fisheyes and a stereo-rig allowing both a 360° field-of-view and a directional depth-map of the scene in one-shot.

2. Hybrid Camera System

2.1. Omni-directional vision system

The omnidirectional vision can be achieved by using a single camera with special lens (dioptric) or a single camera with reflected mirror (catadioptric) also by combining several identical cameras (polydioptric) [3]. Fig. 1 shows the types of omnidirectional vision camera. Dioptric or fisheye camera has a better performance because it does not produce a blind area compare to catadioptric camera. The advantages of using two cameras are easy for synchronisation, low bandwidth, low power consumption and low cost.

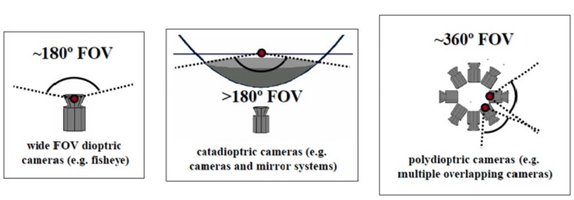

Fig. 1. The omnidirectional camera: types and characterization (From Youcef Mezouar: Omnidirectional vision: Application to visual servoing).

2.2. Stereo Vision - ZED Camera

The 3D information from a digital image can be estimated by using a stereo vision system. This depth information are estimated based on the two-view geometry technique to approximate the 3D structure of the scene. ZED is a stereo vision camera developed by Stereo Labs [4]. It has already been pre-calibrated by the factory.

3. Proposed System and Results

3.1. Unified Camera Model

The intrinsic parameters of two fisheyes are calculated before projecting the image on the unit sphere. Mei's projection model [5] has been used as a reference and its provides procedures to put the image on the unified model. The projection model is enhanced by incoporating it with the tangential and radial distortions. Let us consider a 3D point $\chi = (X, Y, Z)^T$ on the camera frame, and project it to the unit sphere with C_m as a center of sphere.

$$\chi_s = \frac{\chi}{\|\chi\|} = (X_s, Y_s, Z_s)^T. \tag{1}$$

Then the point χ_s mapped to the new reference frame with the new center C_p

$$(\chi_s)_{F_m} \rightarrow (\chi_s)_{F_p} = (X_s, Y_s, Z_s)^T. \tag{2}$$

Next, the point projected onto the normalised plane

$$m_u = (\frac{X_s}{Z_s + \xi}, \frac{Y_s}{Z_s + \xi}, 1)^T = \hbar X_s. \tag{3}$$

The models of distortion (tangential and radial) are added in the projection model.

$$x_c = x1 + k_1 r^2 + k_2 r^4 + k_5 r^6 + 2k_3 xy + k_4(r^2 + 2x^2), \tag{4}$$

$$y_c = y1 + k_1 r^2 + k_2 r^4 + k_5 r^6 + 2k_4 xy + k_3(r^2 + 2y^2), \tag{5}$$

where:

$$r = \sqrt{x^2 + y^2}, \tag{6}$$

and the sum of distortion is

$$m_d = m_u + D(m_u, V), \tag{7}$$

where V is the coefficient of distortion.

$$V = (k_1, k_2, k_3, k_4, k_5, k_6), \tag{8}$$

and finally, the point m_d is projected to the image plane using K, which is a generalized camera projection matrix.

The value f and η should be also generalized to the whole system (camera+lens).

$$p = Km_d = \begin{bmatrix} f_1\eta & f_1\eta\alpha & u_0 \\ 0 & f_2\eta & v_0 \\ 0 & 0 & 1 \end{bmatrix} m_d, \tag{9}$$

where the $[f_1, f_2]^T$ is the focal length, (u_0, v_0) is the principal point and α is the skew factor. Finally, by using the projection model, the point on the normalized camera plane can be lifted to the unit sphere by the following equation:

$$\hbar^{-1}(m_u) = \begin{bmatrix} \frac{\xi+\sqrt{1+(1-\xi^2)(x^2+y^2}}{x^2+y^2+1} x \\ \frac{\xi+\sqrt{1+(1-\xi^2)(x^2+y^2}}{x^2+y^2+1} y \\ \frac{\xi+\sqrt{1+(1-\xi^2)(x^2+y^2}}{x^2+y^2+1} - \xi \end{bmatrix}. \tag{10}$$

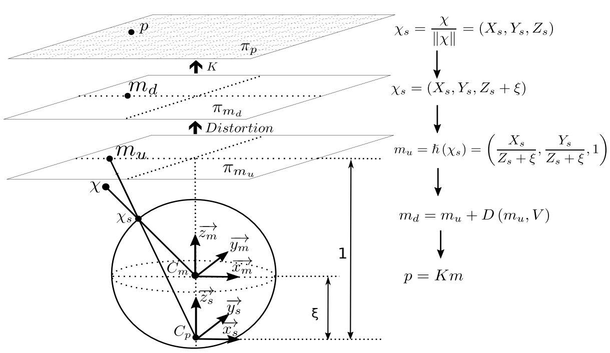

Fig. 2. Mei projection model from 3D world to 2D image. This figure is the courtesy of Christopher Mei [5].

3.2. Omni-Vision Camera Rig Setup

Our proposed system is a combination of two fisheyes and stereo vision camera. The two fisheye cameras with FoV of 185° are fixed back to back. Thus, they cover the whole scene at once. A depth camera, namely ZED Camera is placed at 90° to the right fisheye camera, allowing the system to observe the frontal view at higher resolution, with the depth information for each pixel of the image. Fig. 3 shows the proposed omni-vision camera rig. The calibration of each camera for intrinsic parameters is done using Omnidirectional Calibration Toolbox as described in [5]. The extrinsic parameters (rotation and translation) of right fisheye camera with respect to the left fisheye camera is computed using a straightforward approach to match overlapping image features. The rig is placed in a sufficiently open space to acquire images simultaneously from the two fisheye cameras. The features are matched manually with raw images with lens distortion and the selected points are projected onto three dimensional space using the camera intrinsic parameters obtained from the calibration results. Rigid Transformation is estimated from a set of three dimensional points from each camera, thus rotation and translation are obtained as follows:

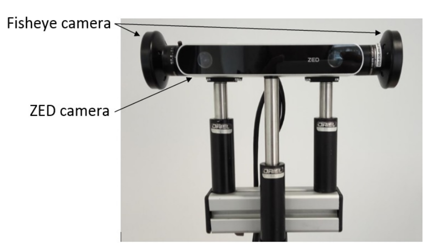

Fig. 3. Proposed omni-vision camera rig.

$$T = \begin{bmatrix} -1.0000 & -0.0047 & 0.0061 & 0.0004 \\ -0.0047 & 1.0000 & 0.0002 & 0.0011 \\ -0.0061 & 0.0002 & -1.0000 & 0.0505 \\ 0 & 0 & 0 & 1.0000 \end{bmatrix}. \tag{11}$$

The results show that the orientation of the right fisheye camera rotate about y-axis of 180°. Assuming that both cameras have the same optical center, the translation obtained is neglected and both images from left and right fisheye cameras are projected onto a unit sphere to obtain an Omni-vision of the scene as shown in fig. 4. The extrinsic parameters of the depth camera are obtained using a method described in [6]. The omni-vision system is considered as a single view vision system which provides a large scale SLAM. It provides the dense 3D reconstruction and texture mapping. Since the system has a prey and predator-like vision features, the system also provides sufficient information for target detection and tracking.

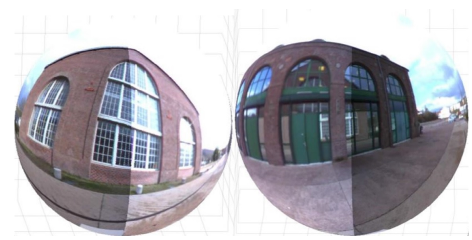

Fig. 4. Fisheye camera images projected and aligned onto the unit sphere

4. Conclusion

We have successfully combined the two hemispheric images to the unit sphere by matching points along the overlapping area. This research is in progress and we expect its great potential in a practical applications.

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