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Line-Based Multi-Label Energy Optimization for Fisheye Image Rectification and Calibration

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As the basic step for higher level tasks, such as structure from motion, visual navigation and SLAM, automatic rectification and calibration for metric information from fisheye images are the work which has been under active research in recent years. The efforts have led to a remarkable improvements in this field. These techniques are either based on 2D or 3D calibration patterns [4] with prior knowledge or the line features manually selected from fisheye image. In fact, there is a trend that a variety of features on the fisheye image plane are taken into account and this pose an additional challenge for automatic calibration of omni-directional camera.

In this paper, we describe an easy implemented approach for fisheye image rectification and propose a framework for automatic calibration of fisheye camera by using the line constrain information. Inspired by the approach proposed in [1, 2, 3], we develop an algorithm to automatic merge and select long circular arcs using the Multi-Label Energy Optimization (MLEO) method. Our approach differs from previous work in two aspects. Firstly, our approach uses a general form of energy optimization algorithm to detect the circular arcs on fisheye image. Secondly, we employ a simplified line constrained fisheye image rectification algorithm on perspective image plane and derive a method that can automatically select three properly arranged circular arcs for fisheye image calibration. The biggest difference is that our circular arc selection algorithm not only consider the relationship between lines in fisheye image plane but also the line relations in perspective plane. Meanwhile the synthetic method is developed to deal with the situations lacking line information, which make the robust intrinsic parameters estimation possible.

For circular arc detection process, we define the energy function as

$$
\begin{aligned}
E(f,\hat{\theta}_c) &= E_{data}(f,\hat{\theta}_c)+E_{smooth}(f,\hat{\theta}_c)+E_{label}(f;\hat{\theta}_c)\\
&= \sum_{i=1}^{N(f)}\sum_{k=1}^{M_i}\left(s_i^k-\hat{r}_i\right)^2+\sum_{i=1}^{N(f)}\sum_{j=1}^{N(f)}\left|\hat{r}_i-\hat{r}_j\right|\\
&\quad+\sum_{i=1}^{N(f)}\sum_{j=1}^{N(f)}\left\|\hat{\mathbf{c}}_i-\hat{\mathbf{c}}_j\right\|^2+\sum_{i=1}^{N(f)}\delta_L^i\eta\frac{1}{M_i^2},
\end{aligned}
\tag{1}
$$

where the optimized parameters consist of the joint labelling f and the parameters $\hat{\theta}_c=\{\hat{r}_i,\hat{\mathbf{c}}_i\}_{i=1}^{N(f)}$ of the set of $N(f)$ clustered circular arcs $\hat{\mathcal{W}}=\{\hat{\omega}_i\}_{i=1}^{N(f)}$, M_i represents the number of points within the i-th clustered circular arc $\hat{\omega}_i$, and η is the coefficient used to augment the penalty cost of the label.

At the second stage, automatic selection of the three arcs is needed for intrinsic parameters estimation. We define the MLEO function as

$$
\begin{aligned}
E_s\left(f,\hat{\theta}_s\right) &= \sum_{c=1}^{4}\sum_{\hat{\omega}_i\in\mathcal{G}_m}\left(\ln\gamma(\hat{r}_i-\bar{r}_c)^2+\ln\beta\,(\hat{\kappa}_i-\bar{\kappa}_c)^2\right)\\
&\quad+\sum_{m=1}^{4}\sum_{n=1}^{4}\lambda\left|\bar{r}_m-\bar{r}_n\right|,
\end{aligned}
\tag{2}
$$

where the optimized parameters consist of the joint labelling f and the parameters $\hat{\theta}_s=\{\bar{r}_c,\bar{\kappa}_c\}_{c=1}^{4}$, $\bar{r}_c$ and $\bar{\kappa}_c$ represent the optimized radius with respect to the fisheye image plane Π_F and the slope value with respect to the perspective plane Π_P of the c-th clustered group, $\hat{r}_i$ and $\hat{\kappa}_i$ denote the radius and slope of the candidate circular arc $\hat{\omega}_i$ on the planes Π_F and Π_P, respectively, and the coefficients γ, β and λ are used for regulating the weights of three terms in the MLEO method. This equation guarantees the distribution of the selected arcs in different direction on the fisheye image, which is necessary for intrinsic parameters estimation.

We use the line constrains on perspective plane to rectify the fisheye image. The problem of removing distortion can be defined as

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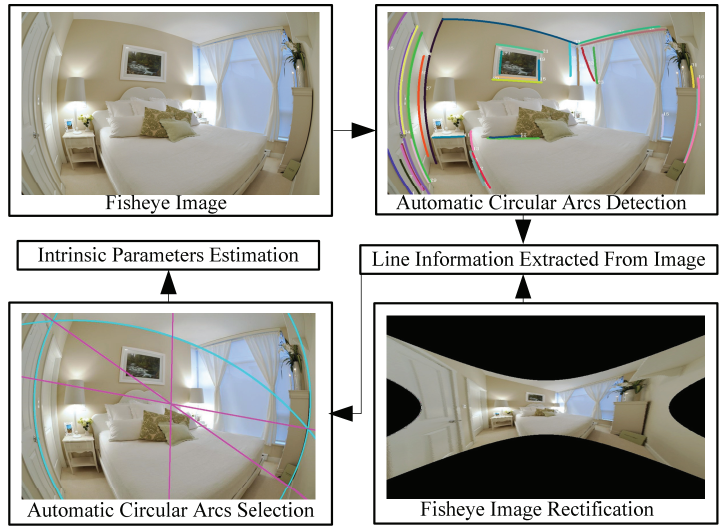

Figure 1: General framework for fisheye image rectification and calibration.

$$
E(d,R)=\sum_{i=1}^{N}\sum_{k=1}^{M_i}w_i\left|d(\mathbf{p}_k,\mathbf{l}_i)\right|^2=\sum_{i=1}^{N}\sum_{k=1}^{M_i}w_i\left|\frac{a_iu_k+b_iv_k+c_i}{\sqrt{a_i^2+b_i^2}}\right|^2,
\tag{3}
$$

where $d(\mathbf{p}_k,\mathbf{l}_i)$ is the deviation of a point $\mathbf{p}_k=(u_k,v_k)$ in the circular arc ω_i with respective to the line $\mathbf{l}_i=(a_i,b_i,c_i)$ in the perspective space, and w_i is the weight factor of the line $\mathbf{l}_i$ in proportion to its length. The parameter R which represents the hidden distortion variable can be estimated as a global minimum:

$$
\hat{R}=\arg\min E\left(d_i,R\right).
\tag{4}
$$

Once the optimized parameter $\hat{R}$ is obtained using Levenberg-Marquardt (LM) method, the fisheye image is rectified.

In order to provide a complete rectification and calibration framework as Figure 1, we estimate the intrinsic parameters by the algorithm proposed by [1] from the selected circular arcs. Implementation of our method is tested on various situations. Our conclusion is that the proposed framework can automatically detect and cluster the circular arc on the fisheye image. The fisheye image could be rectified and the intrinsic parameters can be estimated automatically using line information. For the situations lacking line information, our synthetic method makes it a useful model to consider when dealing with severe distortion.

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[2] A. Delong, A. Osokin, H. N. Isack, and Y. Boykov. Fast approximate energy minimization with label costs. *International Journal of Computer Vision*, 96(1):1–27, 2012.

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[4] L. P. Morales. *Omnidirectional multi-view systems: calibration, features and 3D information*. PhD thesis, Departamento de Informtica e Ingeniera de Sistemas Escuela de Ingeniera y Arquitectura Universidad de Zaragoza, Spain, 2011.