EPI Analysis of Fish-Eye Images

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Abstract. This paper proposes a method to get depth information from image sequences obtained from a moving fish-eye camera. The motion is assumed to be along the optical axis of the fish-eye camera. In this case, a point on a fish-eye image moves to radial direction. This is one of the epipolar constraints that are very effective to find corresponding points in an image sequences. Epipolar-plane image (EPI) is an image having epipolar constraint in a volume of accumulating an image sequence. The gradient of a curve on EPI has depth information of the corresponding measuring point. Measurement accuracy of the proposed method is examined over a wide-angle range.

1 Introduction

Wide-area sensing at one time is important for intelligent mobile systems such as mobile robots and intelligent cars. These systems often use wide-field cameras to sense surrounding environments while keeping them simple and cheap. One typical example of these is a visual support system for a driver. This has been developed using fish-eye cameras with large field of view to provide birds-eye view over a car to the driver [1,2].

In addition to visual support use, fish-eye cameras are used for taking 3D information. Stereo systems using two fish-eye cameras have been discussed about calibration and image rectification for stereo matching [3–5]. Stereo matching strategy of fish-eye images has been also discussed in a particular situation of actual forest environments [6].

Omnidirectional camera similarly has wide field, and is used for acquiring 3D structure of surrounding environments [7–10]. The wide-field feature is typically given by two ways; (i) swiveling a camera around the vertical axis [7,8], (ii) using a catadioptric system [9–12]. The first way is not suitable for 3D measurement from a mobile platform because the camera position changes before capturing entire omnidirectional images. Omnidirectional images captured from the second way include the camera lens at the image center. This implies that the installation position of an omnidirectional camera is limited to a particular area such as over a mobile system. In contrast to omnidirectional cameras, fish-eye cameras can capture a wide-field image at a time without an inclusion of the camera lens on the image. Consequently, this study focuses on a fish-eye camera to measure the 3D structure around an intelligent mobile system.
To obtain 3D information from image sequences of video data captured by a moving camera, there are two typical approaches [13]: (i) epipolar-plane image (EPI) analysis [14–17], (ii) factorization method [18]. The EPI analysis recovers depth information from known motion of a camera, in contrast to the factorization method estimating both of scene geometry and camera motion. It is usually difficult to extract stable feature points in an image sequence for the factorization method due to occlusion, noise, and complicated texture. In the EPI analysis, assumptions of camera motion such as constant speed and straight movement simplify the correspondence problem, and bring robustness of the matching between sequential images.

We focus on the EPI analysis instead of the factorization method because motion information of intelligent mobile systems is often available from odometry or other sensors. The EPI analysis using wide-field cameras has not been investigated except omnidirectional camera [16, 17].

In this paper, we propose a method to get depth information of static environment from fish-eye images based on the EPI analysis. The proposed method is on the assumption that an image sequence for the EPI analysis is captured from a fish-eye camera moving along the optical axis at a constant velocity. In this case, objects passing through the side of an intelligent mobile system can be seen for longer time by a fish-eye camera on the system than a pinhole camera of perspective projection. This leads to wide-area sensing of depth information of a static environment around the mobile system.

2 EPI Analysis of Fish-Eye Images for Depth Sensing

2.1 Fish-Eye Camera Model

Fish-eye lenses are designed to be radially symmetric, in particular, usually obeying one of the following projections [19]:

\[
\begin{align*}
    r &= 2f \tan(\theta/2) \quad \text{(stereographic projection),} \\
    r &= f \theta \quad \text{(equidistance projection),} \\
    r &= 2f \sin(\theta/2) \quad \text{(equisolid angle projection),} \\
    r &= f \sin \theta \quad \text{(orthogonal projection),}
\end{align*}
\]

where \( \theta \) is the angle between the optical axis and the incoming ray, \( r \) is the distance on the image plane between the image point and the focal one, and \( f \) is the focal length (Fig. 1).

Taylor expansion of these projection model can be expressed by the following equation:

\[
    r = k_1 \theta + k_3 \theta^3 + k_5 \theta^5 + k_7 \theta^7 + k_9 \theta^9 + \cdots,
\]

where parameters \( k_i \) (\( i = 1, 3, 5, \ldots \)) are appropriate constant values for fitting (5) into an actual projection almost obeying (1) – (4). The equidistance projection (2) is equivalent to the first-order approximation of (5), and is the most common model in these projections.