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Line detection in images showing significant lens distortion and application to distortion correction

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ABSTRACT

Lines are one of the basic primitives used by the perceptual system to analyze and interpret a scene. Therefore, line detection is a very important issue for the robustness and flexibility of Computer Vision systems. However, in the case of images showing a significant lens distortion, standard line detection methods fail because lines are not straight. In this paper we present a new technique to deal with this problem: we propose to extend the usual Hough representation by introducing a new parameter which corresponds to the lens distortion, in such a way that the search space is a three-dimensional space, which includes orientation, distance to the origin and also distortion. Using the collection of distorted lines which have been recovered, we are able to estimate the lens distortion, remove it and create a new distortion-free image by using a two-parameter lens distortion model. We present some experiments in a variety of images which show the ability of the proposed approach to extract lines in images showing a significant lens distortion.

1. Introduction

Most Computer Vision algorithms usually rely on the well-known pinhole camera model (see for instance Faugeras (1993) and Faugeras et al. (2001) or Tsai (1987)). This linear model assumes that the projection of 3D lines onto the camera plane are 2D lines. However, wide-angle lenses, especially most commercially available low-cost cameras, introduce a severe optical distortion that must be corrected to account for the foundations of the 3D to 2D projection.

The distortion is mainly due to the imperfection of the lens and the misalignment of the optical system. Among all possible distortions, lens radial distortion is considered the most important for low-cost cameras. It causes barrel distortion at short focal lengths as well as pincushion distortion at longer focal lengths.

The basic standard model for barrel and pincushion distortion correction (see for instance Brown (1971) and Hartley and Zisserman (2004) or McGlone (1980)) is the simple radial distortion model given by the expression

$$\begin{pmatrix} \hat{x}-x_c \\ \hat{y}-y_c \end{pmatrix} = L(r)\begin{pmatrix} x-x_c \\ y-y_c \end{pmatrix}, \quad (1)$$

where (x,y) is the original (distorted) point, $(\hat{x},\hat{y})$ is the corrected (undistorted) point, (x_c,y_c) is the center of the camera distortion model (the center of the image), $r=\sqrt{(x-x_c)^2+(y-y_c)^2}$ and $L(r)$ is the function which defines the shape of the distortion model. $L(r)$ can be approximated by a Taylor expansion as follows:

$$L(r) = k_0 + k_1r^2 + k_2r^4 + \cdots, \quad (2)$$

where the set $\mathbf{k}=(k_0,k_1,\ldots,k_{N_k})^T$ consists of the distortion parameters which must be estimated from image measurements, usually by means of nonlinear optimization techniques by imposing the requirement that 3D lines in the image must be projected onto 2D straight lines.

Two alternatives are possible to identify and select the visible straight lines in the scene: one (standard or *classical*) which uses human intervention (Alvarez et al., 2008; Brown, 1971; Devernay and Faugeras, 2001) and a more recent approach that identifies a minimum set of straight lines with no human intervention (Bukhari and Dailey, 2012). The classical approach, although more robust than the unsupervised techniques, becomes slow and inefficient when processing large sets of images, where an automatic method seems more adequate.

The objective of this work is twofold. On the one hand, we propose a new unsupervised approach to detect lines in images showing a significant lens radial distortion. The identification of those lines is performed through a three-dimensional Hough space which includes the radial distortion as a parameter. This approach

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is new in the sense that the lens distortion is embedded into the Hough space and, in this manner, a better estimation of actual straight lines is obtained. On the other hand, from the existing straight lines, we estimate the distortion and obtain the corresponding distortion-free image.

The organization of this paper is as follows: Section 2 summarizes the state of the art of radial distortion models, describing those requiring human intervention as well as the most recent approaches. Section 3 presents our adaptation of the Hough transform to detect the lines in the scene when the image shows a strong distortion. Section 4 deals with the application of the proposed method to a relevant problem in Computer Vision: the correction of lens distortion in images showing radial distortion. Section 5 explains the experimental setup and the evaluation of the proposal on several images showing significant radial distortion. Finally, some conclusions are drawn.

2. Related work

This section deals with some of the relevant literature regarding the radial distortion. Then, a revision of how these methods are applied to images is presented.

During the last decades, several methods for removing the radial distortion from images have been extensively researched. There exist mainly two widely accepted lens distortion models: the polynomial model and the division model.

The polynomial model (see Eq. (2)), has been widely applied because it provides an excellent trade-off between complexity and accuracy. The most applied polynomial model is the even-order polynomial model, which is coherent with the fact that the even distortion parameters are more relevant than the odd ones (see for instance Brown (1971)).

The complexity of the polynomial model is given by the number of terms of the Taylor expansion used to approximate $L(r)$. Some authors use a single parameter model (Devernay and Faugeras, 2001; Wang et al., 2009) which, as shown in Strand and Hayman (2005), provides similar results as the division model for the case of also using a single distortion parameter.

The one-parameter model, as Devernay and Faugeras (2001) reports, achieves an accuracy of about 0.1 pixels in image space using lenses exhibiting large distortion, when used for camera calibration (Faugeras and Toscani, 1987). However, Devernay and Faugeras (2001) also reports that for cases of significant radial distortion, such as fish-eye lenses or higher distortion lenses, the one-parameter model is not recommended.

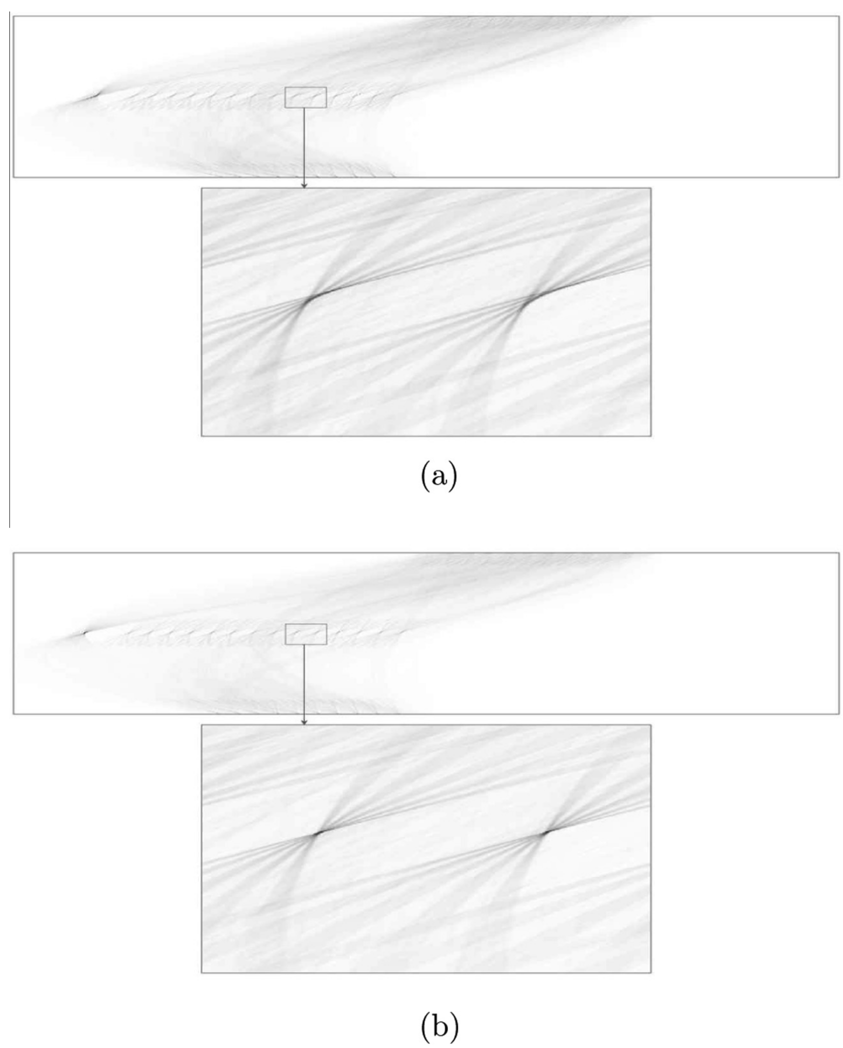

Fig. 1. General view and zoom of the distribution of the votes within the Hough space for the pattern in Fig. 3: (a) without considering the distortion parameter; (b) using the distortion value for which the maximum is reached. The horizontal direction represents the distance to the origin and the vertical direction represents the orientation of the lines.