Camera Calibration for Endoscopical Fish-Eye Lenses for 3D Reconstruction

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CAMERA CALIBRATION FOR ENDOSCOPICAL FISH-EYE LENSES FOR 3D RECONSTRUCTION

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1. Introduction and problem description

3D reconstruction from endoscopic images, e.g. beneficial for the planning of a colon resection, requires the compensation of geometric distortions introduced by the lens system. Appropriate camera calibration is thus necessary. Commonly used calibration algorithms like the algorithm of Tsai [1] rely on the well-known pinhole camera model, extended by parametric terms for radial distortions.

The pinhole camera model describes the radial part of image formation by

\[ r(\theta) = f \tan \theta \]

where \( r \) is the distance from the principal point, \( f \) is the focal length and \( \theta \) is the angle between the incoming ray and the optical axis. A problem occurs when fish-eye lenses are used with angles \( \theta \) near to 90° where the tangent diverges.

2. Method

As an alternative, we have analyzed a more generic calibration algorithm published by Kannala and Brandt [2], which is based on more general projection equations.

Empirically, fish-eye lenses obey one of the following equations

\[
\begin{align*}
    r(\theta) &= 2f \tan(\theta / 2) \\
    r(\theta) &= 2f \sin(\theta / 2) \\
    r(\theta) &= f \theta \\
    r(\theta) &= f \sin(\theta)
\end{align*}
\]

which are known as the stereographic, equidistance, equisolid angle and orthogonal projection equations, respectively.

The camera model of Kannala and Brandt can describe all of the projection equations above – including the pinhole model – by expanding \( r \) in a Taylor series:

\[ r(\theta) = k_1 \theta + k_2 \theta^3 + k_3 \theta^5 + k_4 \theta^7 + \ldots \]

where the \( k_i \) are to be determined in the calibration process.

3. Experimental results

We acquired 23 images of a calibration pattern with an Olympus "CF H-180 AL" state of the art HDTV video endoscope. One of the calibration images can be seen on the left hand side of Fig. 1.

We carried out camera calibrations with both algorithms and performed geometric corrections. The result of this correction can be seen on the right hand side of Fig. 1.

Fig. 1. Geometric correction of a calibration pattern using Kannala and Brandt’s algorithm.

In the analysis, we found that the generic camera model of Kannala and Brandt exhibits consistently lower errors than the classical model.

4. Innovative contribution

Based on this accurate calibration, we were able to generate an accurate three dimensional model of a colon phantom based on strongly distorted images which were acquired with the before mentioned endoscope (see Fig. 2). The next step is extension of our algorithm, to work on images acquired during real colon examinations.

Fig. 2. Left: Geometrically corrected colon phantom (tube with overlaid texture) based on Kannala and Brandt’s camera model. Right: 3D reconstruction of the colon phantom.

References
