Perspective Shape from Shading for Wide-FOV Near-Lighting Endoscopes

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Abstract. Near-Lighting Endoscopes are self-illuminated cameras often used in minimal invasive surgery. Since they have a wide field of view, their images are affected by high radial distortion (RD) and reduced resolution in the periphery of the image. Perspective Shape From Shading has been used for reconstruction but suffers from the problem of resolution and high RD when endoscopes are used. We propose in this paper two improvements to the state of the art methods for PSFS in Near-Lighting Endoscopes. The first contribution is the introduction of the RD model directly in PSFS equations and the second contribution is the compensation of the reduced resolution of the image in its periphery, due to wide FOV. Tests performed in real objects and in a knee bone show that by modeling these two effects our method highly enhances the accuracy of the estimation.

Keywords: Shape from Shading, Perspective, Near Point Lightning, Radial Distortion, Endoscopy.

1 Introduction

The use of endoscopes in surgery is becoming more and more common. They provide the surgeon visual access to zones of the human body that are difficult to reach, assisting in minimal invasive procedures. However, usually the images of bones and organs are partial and illuminated directly by the endoscope probe, whose interpretation is not an easy task.

Shape from shading (SFS) has been lately used in this scenario, in order to provide the surgeon shape reconstructions of bones and organs. Since the light source is incorporated in the endoscope probe, the general orthographic shape from shading model is, however, not adequate to this case. Instead, the perspective shape from shading (PSFS) model is more appropriate. Furthermore, endoscopes are vision systems with wide field of view (FOV) and thus presenting high RD. The existing SFS methods correct the RD in a previous step, by computing an undistorted image. While this step presents no problems for images with small distortion, it is a big source of error for images with medium to high, hence for endoscopes.

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In this paper we propose two modifications to the general formulation of the PSFS problem using near-lighting endoscopes. The first contribution is the modelling of the RD directly in the shape from shading reflectance equations. The new reflectance equations allow us to use non interpolated data (original image) in the estimation and so reduce the estimation error. The second contribution is to compensate the effect of reduced resolution in the periphery of the image, a problem that arises for wide FOV cameras.

1.1 Related Work

Shape from shading has been introduced to computer vision since the early works by authors like [1], [2]. The major part of papers are focused on Lambertian surfaces with orthographic projection and distant light sources ([1],[3]), however some authors have been considering more complex and realistic environments like non-Lambertian surfaces, perspective projection ([4], [2]). There are some relevant works for near-lightning and taking into account $1/r^2$ attenuation factor (fall-off law of isotropic point sources). Namely [5] and [4] have considered the particular case of the endoscope. In the former case they assume that the light source is coincident with the projection center and in the latter, they assume two sources of light very close (and symmetric) to the camera center of projection.

2 Perspective Shape from Shading for a Near Point Light Source

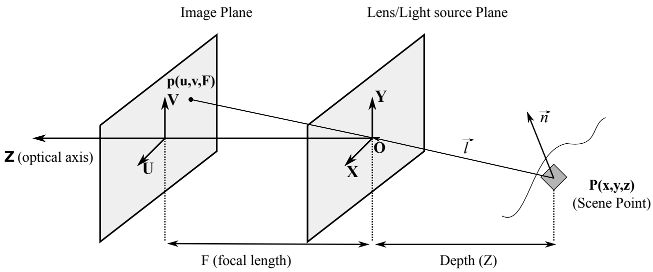

Fig. 1. Perspective projection model for a near light source located at the projection center **O**. The camera plane **XYZ** is centred at **O**.

Due to the light source position on the tip of the endoscope, we consider a perspective projection and formulate the shape from shading problem for a near point light source located at the projection center, as seen in (1). Assuming a Lambertian reflectance of the surface and the inverse square distance fall-off for the light intensity, the scene radiance can be recovered by:

$$R = I_0 \rho \, \frac{(\hat{\boldsymbol{n}} \, . \, \hat{\boldsymbol{l}})}{r^2} \tag{1}$$