Passive Stereoscopic Panomorph System

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Abstract

In the last decade, wide-angle stereoscopic systems using fisheye lenses have been proposed but the compromise made to obtain a large field of view is low resolution and high distortion resulting in imprecise depth estimation of objects in a 3D scene. High and non-uniform distortion, especially in the azimuthal direction, is often considered as a weakness of panoramic lenses because it is sometimes difficult to compensate for by image processing.

The aim of this paper is to present an alternative to existing stereoscopic panoramic systems by taking advantage of non-uniform distortion and anamorphosis in Panomorph lenses. There are many challenges related to this project such as the calibration of the system and the creation of a 3D depth estimation algorithm that suits the resolution of the different areas in the images.

This paper presents different configurations of two Panomorph lenses within a stereoscopic device and a study of specific parameters to highlight their impact on the quality of 3D reconstruction of an object in a scene. Finally, an overview of future work is presented.

Keywords: Panomorph lens, stereoscopic system, 3D depth estimation, panoramic lens, wide-angle lens

1. INTRODUCTION

For many applications in the field of imaging, it is advisable to have a wide-field of view. In the last decade, various panoramic lenses and devices had been developed to answer that need. Foveated devices, built to mimic the human eye, usually exhibit a region of enhanced magnification around the optical axis, called the fovea, and a full field of view of about 155°. They can be created by using only information from some pixels of the sensor [1] or by using a SLM to correct aberrations of the wavefront locally [2]. Fovea can also be introduced within the design process of the lens or two lenses can be used in each foveated device, one with a large field of view and one with a small one, like in the Cog Project [3] and the humanoid head Karlsruhe [4]. Traditional fisheye lenses are another example of the commonly available panoramic lens. They have a field of view of 180° or more and uniform magnification over the entire field of view.

Having a wide field of view is also an interesting feature for stereoscopic systems for 3D reconstruction of objects in a scene. This goal can be achieved by various techniques, like the use of many traditional cameras [5] or of a traditional camera looking at two concentric mirrors with different curvatures [6]. We are focusing here on stereoscopic systems that use only two panoramic lenses because the growing number of panoramic lenses available on the market has led the designers to include them in their systems. Foveated stereoscopic systems show an area of enhanced magnification where the optical axis of both lenses meet but this reduces the common and total field of view of the system. Fisheye lenses are also widely used in stereoscopic systems [7] [8]. Their

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uniform magnification over the field of view is looked at as an advantage because it is easy to manage during the calibration process. For fisheye lenses, the angular position θ of an object and the height H of its image are linked by the focal length f as expressed at equation (1).

$$H = f\theta \tag{1}$$

Like other panoramic lenses, both foveated and fisheye lenses show high barrel distortion which is most of the time eliminated when used in stereoscopic systems. However, distortion can be controlled and planned during the design of the lens or device in order to take advantage of that phenomenon.

1.1 Panomorph lenses

Panomorph lenses are anamorphic panoramic lenses with controlled distortion. From this moment on, the expression *Panomorph lens* will refer to the Panomorph lens IMV1-1/3 from Immervision (also, Fujinon YF360A-2/SA2).

The Panomorph lens show a full field of view of 182° and an anamorphic ratio of 4:3 created by cylindrical elements in the design in order to use the maximum area of the rectangular light sensor. The focal length is 1.15 mm on the long axis and 0.9 mm on the short axis. A Panomorph lens also shows highly non-uniform magnification over the field of view with enhanced magnification areas located around ±60°. Therefore, the angular position θ of an object and the height H of its image are linked by the local focal length $f(\theta)$:

$$H = f(\theta)\ \theta \tag{2}$$

Fig. 1 shows theoretical local focal length (LFL) profiles for the short and the long axis of a Panomorph lens. Results were obtained with Zemax.

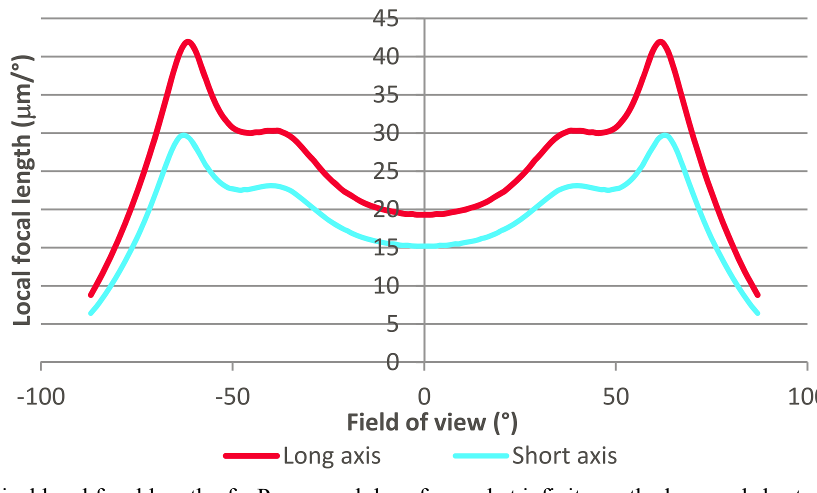

Fig. 1 Theoretical local focal length of a Panomorph lens focused at infinity on the long and short axis. Theoretical data was obtained with Zemax.

2. CONFIGURATIONS

As mentioned in section 1.1, Panomorph lenses show enhanced magnification areas around ±60°. In a stereoscopic Panomorph system, this feature allows the angle 2α between the optical axes of the lenses to be varied, as opposed to foveated stereoscopic devices, where the optical axes must converge towards a region of interest, or to fisheye lenses that just do not have enhanced magnification areas. In a stereoscopic Panomorph system, an object will most likely not be seen with the same magnification by both cameras. The accuracy of the 3D reconstruction of that object will rely on the weakest element, namely the camera that will show the smallest magnification.

Suppose a stereoscopic Panomorph system looking at an object plane containing the two optical axes and the long axis of each lens. As a rule, the angle α is positive if the optical axes converge and negative if they diverge. The system looks at an object at each position in the object plane described above. As mentioned previously, the object will have a different size on the sensor of each camera due to its distance from the system and to the variation of the magnification along the field of view. Fig. 2 shows the minimum image size of an object of a length of 10 mm for a stereoscopic system made of two fisheye lenses and three different configurations of a Panomorph stereoscopic system.

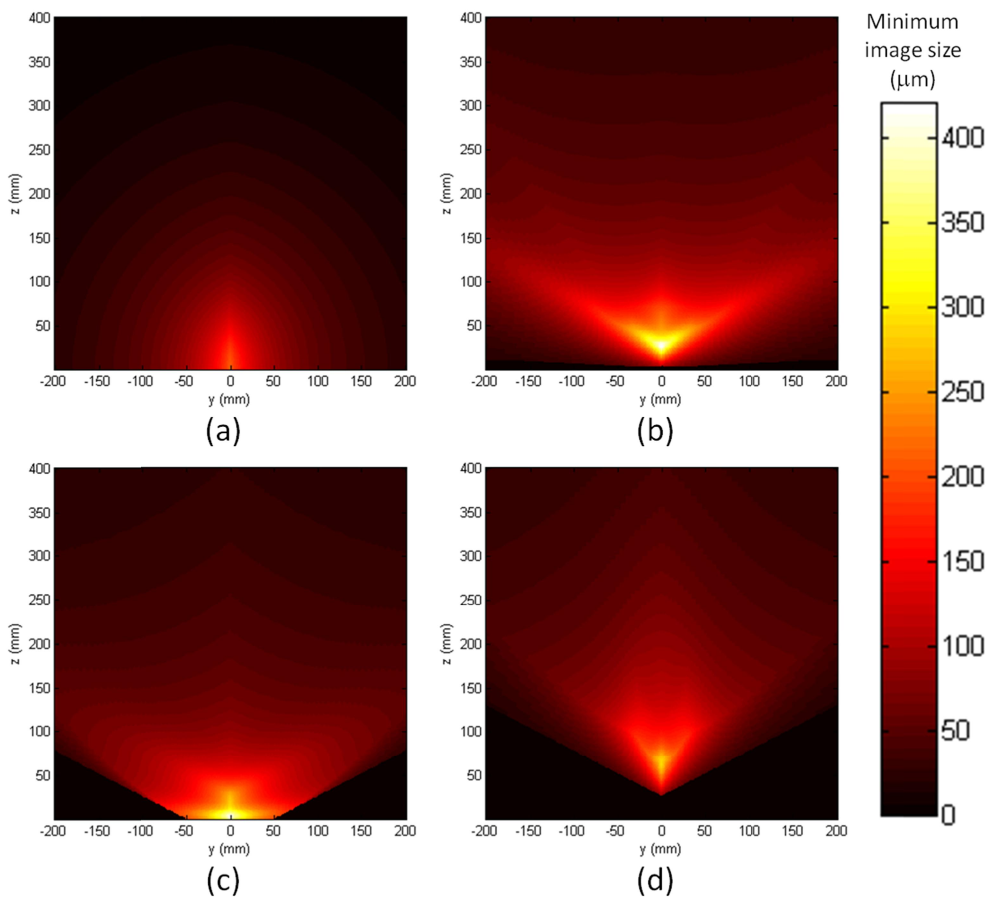

Fig. 2 Minimum size of the image of an object of 10 mm as seen by a stereoscopic system made of (a) two fisheye lenses, (b) two Panomorph lenses (α=0), (c) two Panomorph lenses with convergent optical axes (α=+15°) and (d) two Panomorph lenses with divergent optical axes (α=-25°). The baseline of all systems is 100 mm. (Color version available online)

As shown in Fig. 2, the minimum image size of an object of a length of 10 mm as seen by different Panomorph stereoscopic systems is larger than the same object seen by a stereoscopic system using fisheye lenses for almost every position of the common full field of view. This shows that Panomorph lenses are a very interesting choice in the design of a stereoscopic system compared to fisheye lenses.

3. SPECIFIC PARAMETERS AND THEIR IMPACT ON CALIBRATION

Calibration is a critical step in the 3D reconstruction of objects in a scene. Most of the time, the key to a good calibration of a panoramic camera is an accurate description of the distortion in the lens. Many radial distortion models had been developed to be included in existing calibration techniques. It has already been established that traditional calibration processes using the pinhole camera model are not well suited for panoramic lenses, even when distortion models are included. A more adequate calibration technique that uses spherical projection and angular objects coordinates has been recently presented by Kannala and Brandt [9]. Unfortunately, this technique does not take into account two critical parameters: the entrance pupil shift and the magnification as a function of depth.

3.1 Entrance pupil shift

Entrance pupil shift is a phenomenon that has been studied for a long time for the fisheye lenses [10]. Fig. 3 shows the behavior of the entrance pupil of a Panomorph lens for each object angle between 0° and 90°.

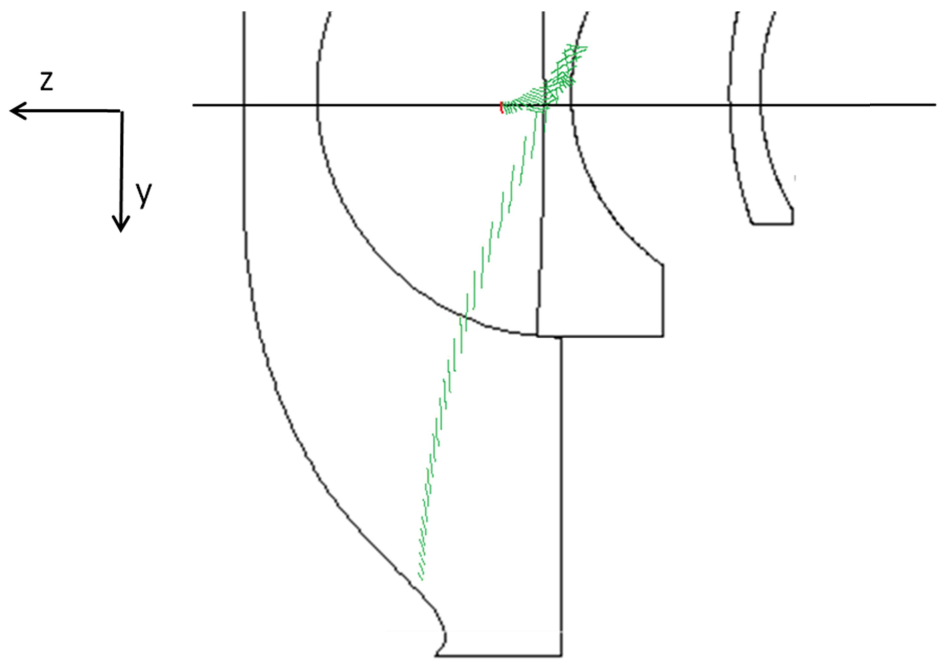

Fig. 3 Entrance pupil position of a Panomorph lens for each integer field between 0° and 90°

The entrance pupil undergoes an important shift as seen at Fig. 3. For example, at 85°, the entrance pupil presents a shift in the *y* direction of 14.4 mm. This important shift is incompatible with existing calibration techniques, using the pinhole camera model or spherical projection that uses a single on-axis view point. This behavior leads to an error in the image plane caused by the single view point approximation. Fig. 4 shows this error in microns that depend on the entrance pupil shift and the local focal length profile.

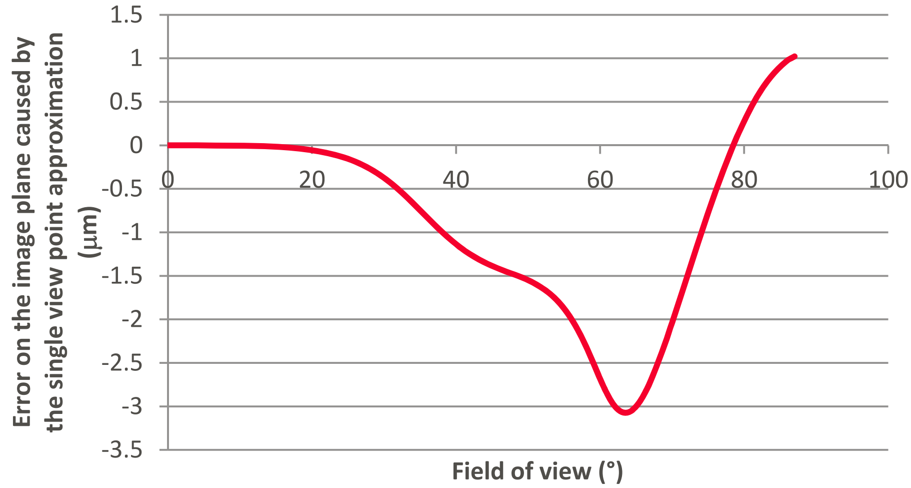

Fig. 4 Error on the image plane caused by the single view point approximation for the long axis of a Panomorph lens. This error depends on the entrance pupil shift and the local focal length profile of the lens.

3.2 Finite conjunction and magnification

The behavior of the local focal length for a Panomorph lens has already been looked at in section 1.1. But, to our best knowledge, no attention has been given to the behavior of the local focal length and the magnification in finite conjunction. We use a characterization set up to measure the experimental local focal length profiles shown in Fig. 5 for infinite conjunction (r=∞) and finite conjunction (r=4.1 cm) on the long axis of a Panomorph lens.

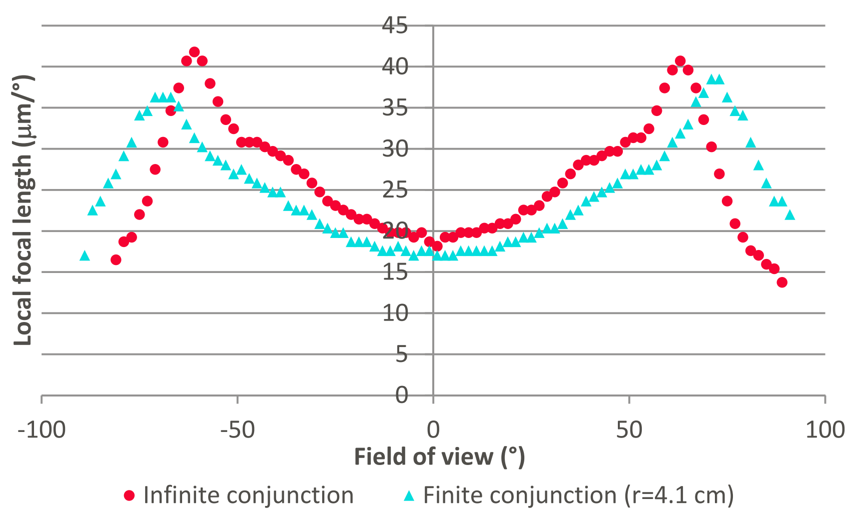

Fig. 5 Experimental local focal length profile on the long axis of a Panomorph lens and infinite and finite conjunction

By definition, we know that the focal length and the local focal length do not vary with object distance. It is then possible to calculate the magnification M over the field of view for an object distance of 4.1 cm.

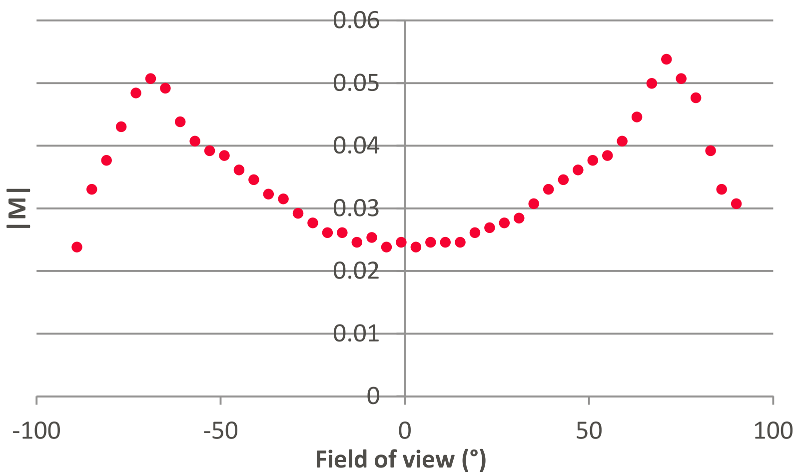

Fig. 6 Experimental absolute value of the magnification on the long axis of a Panomorph lens for an object distance of 4.1 cm

Even if the focal length of panoramic lenses is very short compared to more traditional lenses, there is for sure a critical object distance where infinite conjunction is not a suitable approximation and magnification should be considered.

4. FUTURE WORK

The calibration of a Panomorph stereoscopic system is a real challenge since it determines the accuracy of the 3D reconstruction of objects in a scene. An adequate calibration technique should include the influence of the entrance pupil shift as a variation of the extrinsic parameters with the position of the object. Looked to as a great advantage in a Panomorph stereoscopic system, distortion should not be eliminated but used to obtain more information in some regions of interest in the scene. It is then extremely important to preserve all the information contained in the enhanced magnification areas during the calibration process. Since Panomorph lenses exhibit high anamorphosis, the revolution symmetry in the image is not only broken by the manufacturing process but by the design of the lens itself. Managing azimuthal distortion with small corrections is not a suitable strategy for this specific type of lens. After all parameters are taken into account and the calibration process of the Panomorph stereoscopic system is completed, projection in the object space will be possible by traditional techniques. Since the magnification undergoes important variations along the field of view, the accuracy of the 3D depth estimation of objects in a scene will also vary with the position of an object. If this object is big enough, the accuracy will vary within the object itself and accuracy estimation as a function of the field of view will be essential.

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