Dedicated testing setup for panoramic lenses

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ABSTRACT

Panoramic imaging is of growing importance in many applications around the world spurred by the development of digital imaging. Panoramic lens characteristics are unique and their careful characterization can be a challenge. For example, the price to pay for a large field of view in this type of lens is high distortion in the image. For vision applications like security or inspection, a precise knowledge of the distortion introduced by panoramic lenses is essential to produce natural unwrapped views to the operator. Of special concern is the image quality which must be uniformed over the entire field of view because all directions are equally important. In addition, two hemispheric images can also be stitched together to create a complete spherical image. For these reasons, we have developed a dedicated setup to study the distortion and the image quality produced by panoramic lenses. The test setup is made of a 75-cm radius cylindrical structure with targets placed on it. Using referenced equally-spaced targets, we obtained the radial image mapping curves for various azymuthal angles, allowing us to calculate the full-field resolution map. Also, transition targets were used to find field-dependent spatial frequency where the MTF is 50%. We tested four different panoramic lenses, two panomorph lenses and two fisheyes. For each lens, we discussed the experimental resolution and MTF curves and compared some of those results to theoretical design data.
Keywords: Panoramic lenses, distortion, resolution, MTF

1. INTRODUCTION

On account of their wide field of view (FOV), panoramic lenses are often used in digital imaging. Surveillance, reversing cameras, driver assistance systems for cars, ducts inspection and unmanned robotic exploration are just a few applications of panoramic lenses. The setbacks of a wide FOV are low object resolution, high barrel distortion in the image and sometimes a non-uniform illumination. It is therefore necessary to properly characterize the lens by obtaining image mapping and image quality charts.

Different methods to characterize lenses already exist. It is possible to measure radial image mapping using a 2D grid or a 3D chessboard pattern [1]. For measuring MTF, the Fourier transform of the line spread function (LSF) is often used [2] [3]. However, doing the same for panoramic lenses brings new challenges, so a setup dedicated to panoramic lenses for measuring both resolution and MTF was developed.

In this paper, section 2 presents a description of the experimental set up and draws up a list of tested lenses and their characteristics. Section 3 describes the procedure and shows experimental results for resolution and MTF measurements and includes a comparison with theoretical values.

2. CHARACTERIZING PANORAMIC LENSES

2.1 Description of the setup

Our setup, shown at figure 1, is inspired by the setup used by Kumler [4]. It is made of a clear plexiglass sheet enclosed in a circular grove of 75 cm interior radius and supported by 5 angle brackets. The grove is carved into a compressed PVC circular stage. The setup covers a field of view of 220° and is 9 inches high. It is fixed to the table with 5 L-shaped table clamps. Major advantages of having a cylindrical setup are the fact that the height of the camera does not impact the results as opposed to a hemispheric one and that all the targets are at the same distance to the front vertex of the lens unlike targets placed on a wall.

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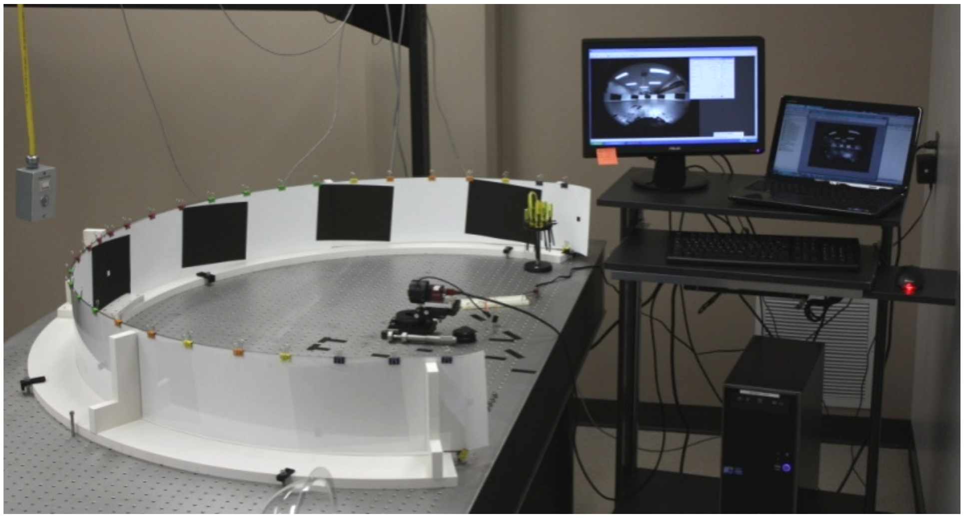
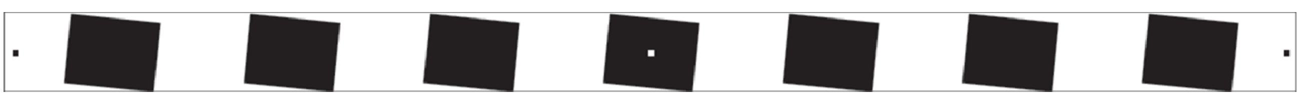


Figure 1. Experimental setup made of a 75-cm radius target holder. With cylindrical geometry, the height of the camera does not need precise position adjustments since measurements are height-independent.

The targets used to take measurements are illustrated in figure 2. Two types of targets were used, one for resolution measurements and one for radial MTF measurements. The resolution evaluation test pattern is a series of 2° wide black and white stripes. The central stripe is black. Five black stripes contain a white rectangle to mark specific angles (-80°, -60°, 0°, 60° and 80°). The second set of targets, used for radial MTF measurements, is a series of 16° wide rectangles with a 5.7° inclination, adequate angle for sfrmat2 (see section 3.2.1). It is important to make sure that the rectangles are large enough to have a sufficient number of pixels in the transition. The white square, identifying the center, is used for focusing and the black squares are positioning marks.

(a)



(b)

Figure 2. Targets used in the measurement of (a) resolution (b) radial MTF. Patterns were generated with Adobe Illustrator.

Proper distributed light sources are used to obtain a uniform luminosity over the entire FOV. In addition, the settings of the camera are chosen in order to have a white value between 0.90 and 0.99 normalized luminosity units in the center and to have a symmetric horizontal luminosity profile. Figure 3 shows the luminosity profile of the different lenses used with the radial MTF targets.

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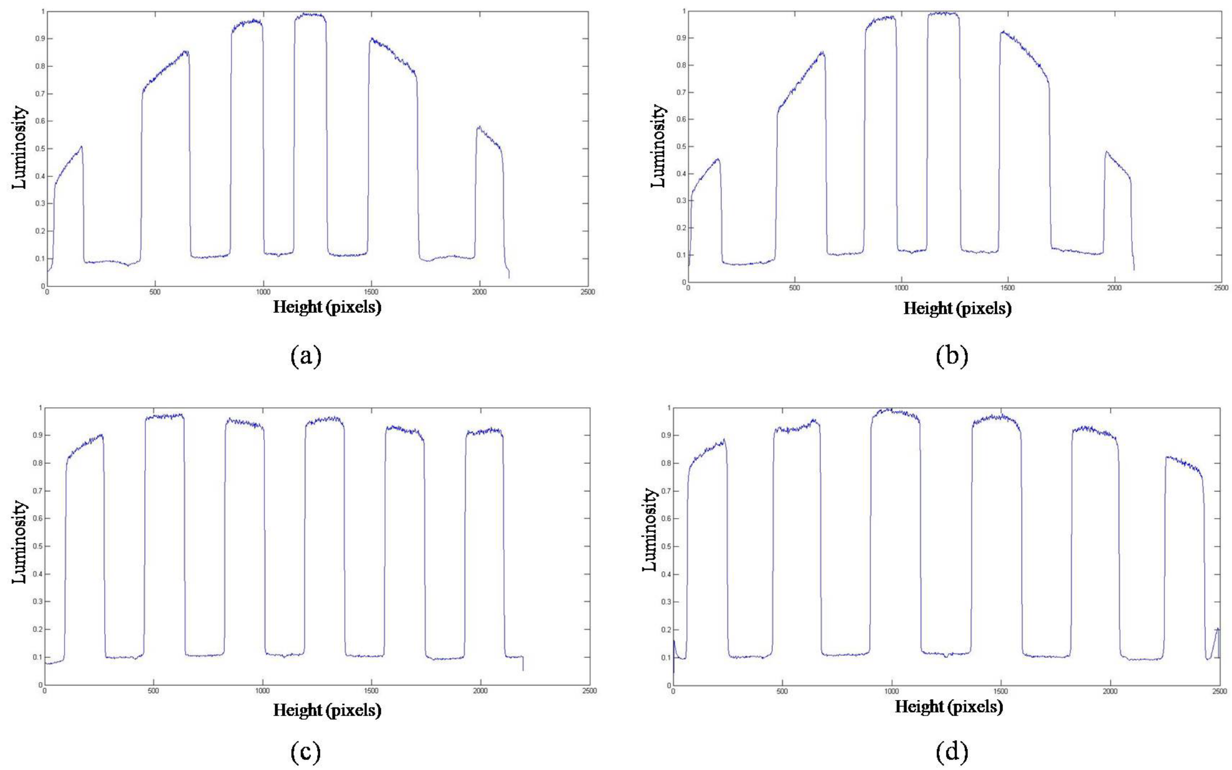

Figure 3. Luminosity profile for the (a) panomorph lens 1; (b) panomorph lens 2; (c) fisheye lens 3; and (d) fisheye lens 4. Camera settings and ambient lighting have been adjusted to have a white value in the center of the field of view (0°) between 0.90 and 0.99. The symmetry of the profile is also essential.

The camera used to make all the measurements is the AVT Guppy F-503. It has a 1/2.5 sensor with 5 megapixels (2592 × 1944) and a pixel pitch of 2.2 microns. It also has an infrared filter and a white balance feature. Images are saved in .tif format.

2.2 Tested lenses

Four lenses were tested for both resolution and radial MTF measurements. Table 1 lists their specifications. FOV, 0° focal length and F/# are the same order of magnitude for all tested lenses.

Table 1. Specifications of the four tested lenses

Number	Lens model	Type	Full FOV (°)	0° Focal length (mm)	F/#
1	Immervision IMV1-1/3	Panomorph (4:3)	182	0.9 (short axis) 1.15 (long axis)	F/1.9 (short axis) F/2.4 (long axis)
2					
3	Fujinon FE185C046HA1	Fisheye	185	1.4	F/1.4 to F/16
4	Sunex DSL219A	Fisheye	180	1.8	2

As the design data for lenses 1 and 2 were available from the manufacturer, it was possible to perform theoretical simulations and compare them with results to validate the setup and the procedure as it will be discussed in section 3.1.2. Lenses 1 and 2 are from the same model, but from different builds and were tested to look at the impact of fabrication errors and tolerancing [5].

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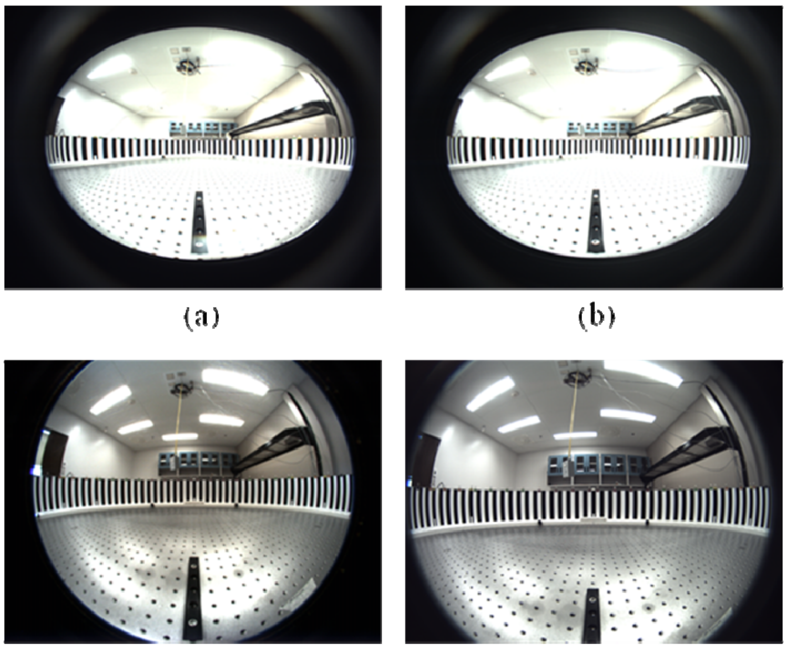
3. PROCEDURE AND EXPERIMENTAL RESULTS

3.1 Resolution measurements

3.1.1 Procedure for resolution

Figure 4 shows examples of pictures taken to calculate the resolution of the different lenses. Even if the pictures taken with lenses 1 and 2 are saturated, it does not compromise the quality of the resolution measurement.



(a) (b) (c) (d)

Figure 4. Pictures taken of the resolution pattern with (a) panomorph lens 1; (b) panomorph lens 2; (c) fisheye lens 3; and (d) fisheye lens 4. For resolution measurements, saturation does not compromise the quality of the results.

A Matlab code was developed to calculate the resolution over the full FOV. The user selects the central black stripe by clicking on it and the program extracts a 5×N matrix where N is the number of horizontal pixels in the original picture. It calculates the mean value of each column to have a final 1×N matrix that will be used to find the center of each stripe. The mean value of the 1×N matrix acts as a threshold that allows us to find the position of the center of each stripe in pixels. The position of a stripe is stated in relation to the position of the central stripe. The derivative of the relative target height in the image plane by the angle in the object plane gives the resolution, in pixels/°, as a function of the angle in the object plane.

3.1.2 Resolution experimental results

Resolution measurements for the four tested lenses are shown at figure 5.

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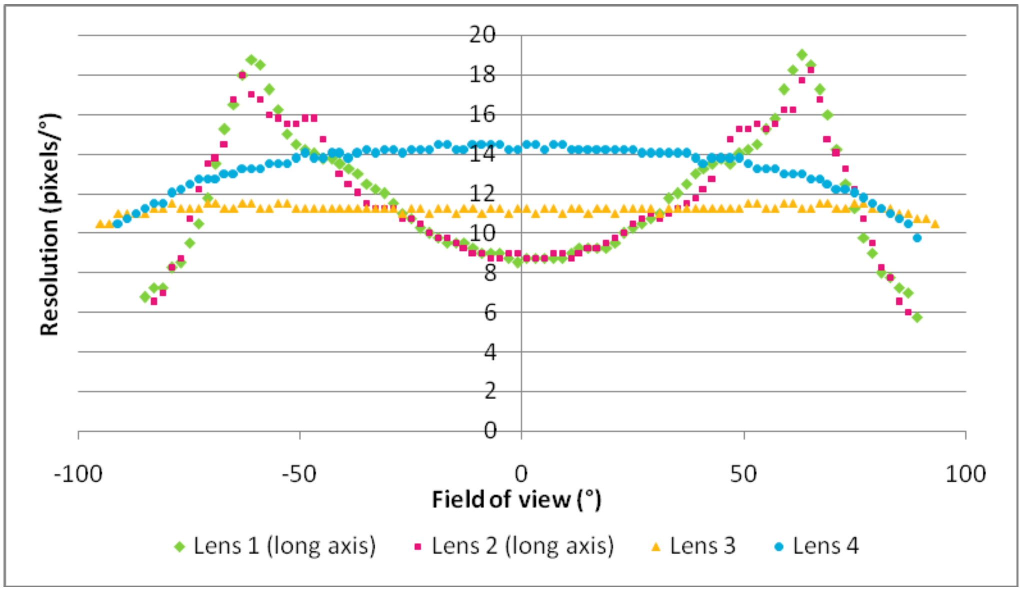

Figure 5. Experimental resolution for the four tested lenses. Panomorph lenses 1 and 2 show a significant variation of the resolution over the FOV with a maximum at ± 60°, unlike fisheye 3 and 4 which respectively have an almost constant resolution profile and a slowly decreasing one over the FOV.

All of the above resolution profiles are symmetric. Panomorph lenses 1 and 2, of the same model, have very similar resolution profiles as expected and show high-resolution areas around ±60°. Lens 3 has a very uniform resolution profile of 11 pixels/° for almost the entire FOV with a small decrease near the edges. Lens 4 has a resolution profile with a maximum at 0° and slowly decreasing when moving towards the edges. However, the variation of resolution is less important for lens 4 than for lenses 1 and 2.

As mentioned in section 2.2, it is possible to compare the theoretical resolution provided by Immervision to the experimental resolution for lenses 1 and 2 and the results are shown at figure 6.

Figure 6. Comparison between theoretical and experimental resolutions for panomorph lenses 1 and 2. Long and short axes were considered.

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From figure 6, note that there is a very good agreement between the simulation and the experimentation values for lenses 1 and 2. This confirms the validity of the method to measure resolution. Similar comparisons are impossible for lenses 3 and 4 since their original design files are not available.

Panoramic lenses are widely used in security applications and are often covered by a plastic dome for protection. By placing a 19-cm diameter PMMA dome in the setup at different positions in front of the camera and using lens 1, it was possible to conclude that the use of a protector dome does not bring any significant modification to the resolution profile for any position of the camera in the dome.

3.2 Radial MTF measurement

3.2.1 Procedure for the MTF

The MTF is an indicator of the image quality for a lens or for a system (camera and lens). Our technique gives MTF for a specific system. It simply requires replacing the resolution targets (fig.1a) by the radial MTF targets (fig.1b). No other modification to the setup is necessary. Important points to consider to measure the radial MTF are uniform luminosity, suitable setting of the white balance and a good focus.

A Matlab code was created to calculate the radial MTF. The user clicks on the white square in the center of the picture to indicate 0°. The program then finds the position of the transitions by using a threshold. Boxes of 41X41 pixels are made around the central position of the transition and the program sfrmat2 [6] is used to calculate the MTF. The spatial frequency where the MTF is 50% is used as an indicator of the image quality and can be calculated for some specific angles of the FOV. Even if the MTF measurement targets contain only 12 usable transitions, it is possible to rotate the camera using the front vertex of the lens as the center of rotation to calculate radial MTF for more angles.

3.2.2 MTF experimental results

For each lens, 5 pictures are needed to obtain sufficient data. Figure 7 shows the preliminary results for the spatial frequency where the MTF is 50% for different angles of the FOV for lenses 1 and 3.

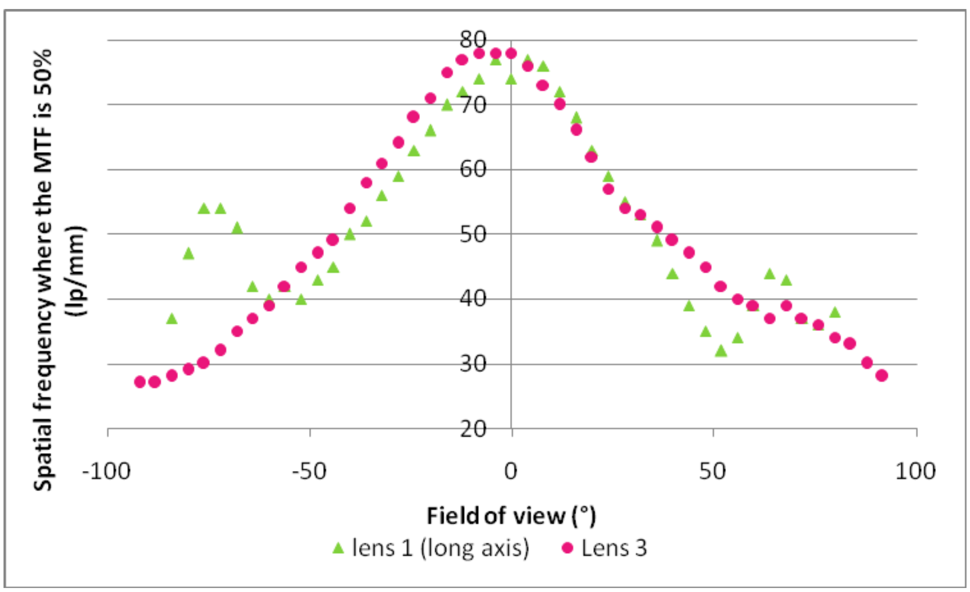

Figure 7. Spatial frequency where the MTF is 50% over the full field of view for lenses 1 and 3. This type of curve is an indicator of image quality. The curves were extracted from 5 different pictures for each lens.

From figure 7, it is seen that the profile of the spatial frequency where the MTF is 50% is very smooth and symmetric for lens 3. For lens 1, the profile is asymmetric and it could lead to believe that the method is inaccurate. However, similar results were obtained in an independent laboratory by doing the Fourier transform of the LSF with lens 1 (without camera).

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4. CONCLUSION

Properly characterizing panoramic lenses is an interesting challenge, mainly because the large angles they offer require new techniques and setups to effectively measure their attributes. In this paper, a versatile setup allowing the characterization of wide-angle lenses is demonstrated. As opposed to traditional methods of characterization, it is possible to measure both resolution and image quality by using two different types of targets with the same dedicated setup. The resolution curve and the 50%-MTF frequency curve were obtained for different panoramic lenses. When possible, the resolution results were compared to theoretical data and the good agreement allowed to assure the validity of the measurements made using this setup. For the MTF curves, preliminary results were presented, and here again, good concordance with previous measurements were achieved. Further work will focus on the elaboration of a single type of targets and a procedure to characterize resolution and image quality in panoramic lenses with a single picture.

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