Projection onto a Slanted Cylindrical Surface by Use of a Curved Mirror and Scheimpflug Optics

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ABSTRACT

This paper proposes an optical system that has an angle with respect to the optical axis of the projection lens and projects a high-definition image on a cylindrical surface while maintaining the brightness of the projection lens. This projection component has one extra conjugate point between object and projected surface. A curved mirror is placed at the extra conjugate point to modify the cylindrical surface to plane. This mirror is arranged to maintain Scheimpflug condition with a projected surface to project clear image when the optical component has the angle against projected surface.

1 Introduction

In a general projection optical system, in order to increase the depth on the projection surface, the depth can be increased by reducing the aperture diameter size. When the projection surface is a spherical surface or cylindrical surface, the change in the minimum circle of confusion becomes very large, and even if it is within the depth at the center, the corner image is outside the depth.

Various method have been proposed to obtain a wide depth. A spherical mirror is placed into the optical path between the projection lens and the screen [1]. Also, a focus tunable lens by electronic control is used to extend the depth of focus [2-3]. On the other hand, computational imaging which is using phase mask is used to extend the depth of field [4-5]. Furthermore, a lens array or mirror array is placed between the projection lens and the projected surface to modify the projected image [6-7]. Scheimpflug condition is used for imaging at field of corneal imaging [8]

In this paper, we propose the optical setup that enables to get clear projected image on the cylindrical surface which has the angle against the axis of projection lens by using Scheimpflug condition.

2 Optical simulation

2.1 Focus depth on a cylindrical or a spherical projected surface

It is shown in Fig.1 that an image of circle of confusion when projected onto a cylindrical surface. In a general optical system, an object has flat surface and perpendicular against the optical axis. In that case a focusing point is also perpendicular against the optical axis and the depth of focus is defined in front and rear depth of focus. When a projected surface has the 3D shape such cylindrical and spherical, the corner area of the projected surface becomes out of depth of focus. To shift the focus point on the projected surface, the curved mirror is put at initial image point. It is possible to change the initial image to curved shape to fit the shape of the projected surface. It is shown in Fig.2. However, when the projected screen doesn't put perpendicular against the axis of optical component, the corner on projected surface has the out of focus and becomes low contrast image. And the reflection condition for initial image is shown in Fig.3 when the component has Scheimpflug condition.

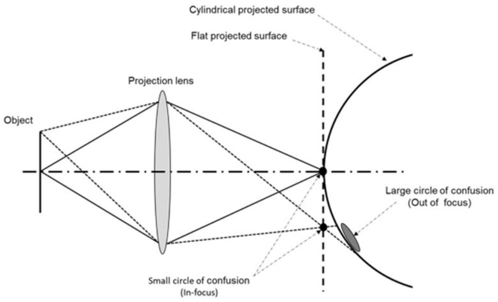


Fig.1 Difference of a circle of confusion on a cylindrical surface

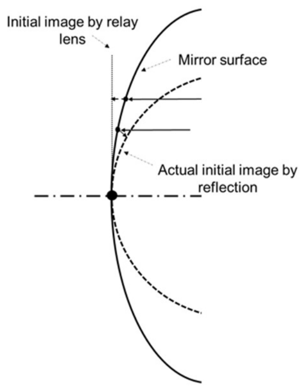


Fig.2 Initial image shifting by reflection

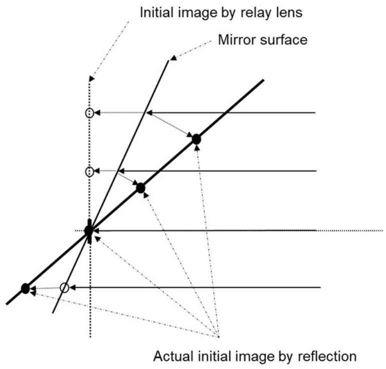


Fig.3 Initial image rotation by mirror reflection

2.2 Optical simulation setup

The optical setup for simulation is shown in Fig.4. The component consists of object chart, relay lens, beam splitter, mirror, projection lens and projected screen. The mirror at initial image point and the projected screen is possible to rotate to make the angle against the optical axis of the projection lens.

The relay lens has 1x magnification and projected lens has 2x magnification. The object size for horizontal x is x= ±4mm width and vertical y is y= ±4mm, is set. The radius of the projected surface R is R= 25mm and the mirror radius r is r=50mm.

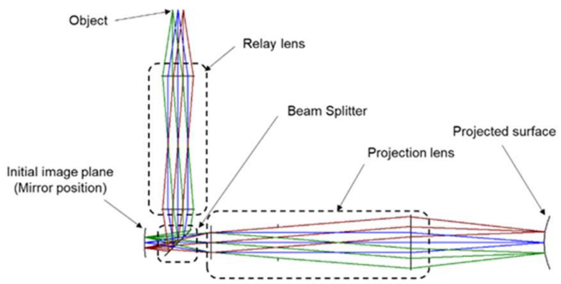


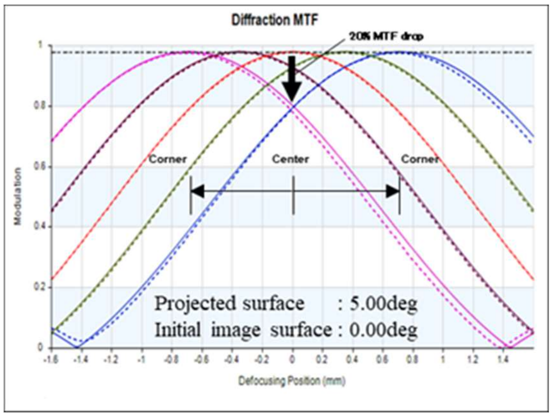
Fig.4 Optical component for simulation

2.3 MTF calculation by optical design software

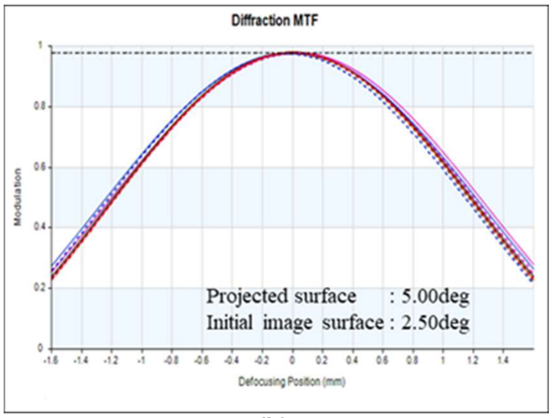
It is used the Code-V optical design software for simulation. It is put 5.00deg angle for the projected plane and 0.00deg for the initial image positon mirror. The simulation result is shown in Fig.5 (a). It is calculated for 4lp/mm resolution at the projected surface. The result shows drop of MTF for the corner image. The defocus positon 0 is the paraxial focal point and center image has over 95% MTF, but corner has around 80%. The peak of MTF curve for cornea has 0.7mm shift to forward and backward. That means the best resolution plane doesn't fit against the projected surface due to rotation. Then the mirror at initial image surface is rotated 2.5deg to fit the rotated projected surface. The result of simulation is shown in Fig.5 (b). The peak of each object height is overlapped at the point of paraxial focal point. It means the rotation angle of the projected surface and the mirror angle is fit under Scheimpflug condition. It is also calculated when the projected surface has 10deg and mirror has 2.5deg. The result is shown in Fig 6 (a), (b)

The suitable mirror angle for each angle of projected surface is calculated. It is shown in Fig.7.

When the axis of the optical component has an angle with respect to the projection surface, it is possible to obtain a clear image on the projection surface by determining the optimum angle of the mirror at the initial position.

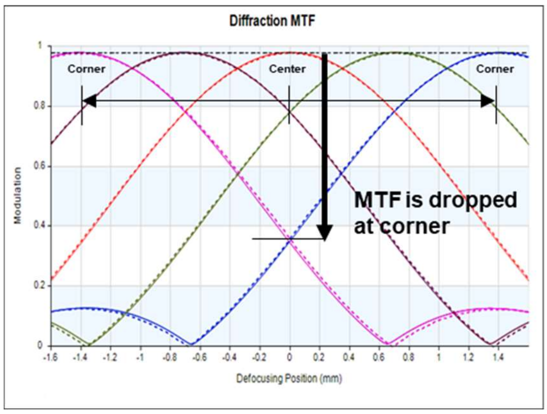


(a)

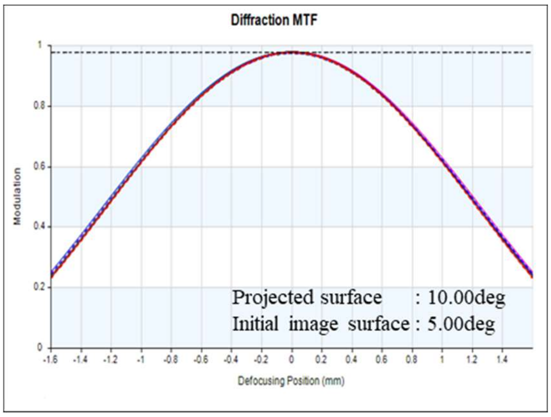


(b)

Fig.5 MTF simulation results in projection on 5.00-degrees slanted surface by use of (a) 0.00-degrees and (b) 2.5-degrees rotated mirror.



(a)



(b)

Fig.6 MTF simulation results in projection on 10.00-degrees slanted surface by use of (a) 0.00-degrees and (b) 5.0-degrees rotated mirror.

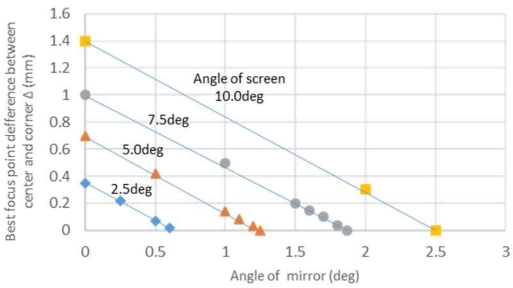


Fig.7 Best focus difference of the projected image between the centre and a corner

3 Experiment

The set up for optical experiment is shown in Fig.8. The projected surface and the mirror at primary position is possible to rotate. The projected image is captured by CMOS camera. The test system is placed 25mm radius cylindrical object as projected surface. The object is USAF test chart and it's possible to shift both horizontal and vertical on the object plane to cover whole projectable area.

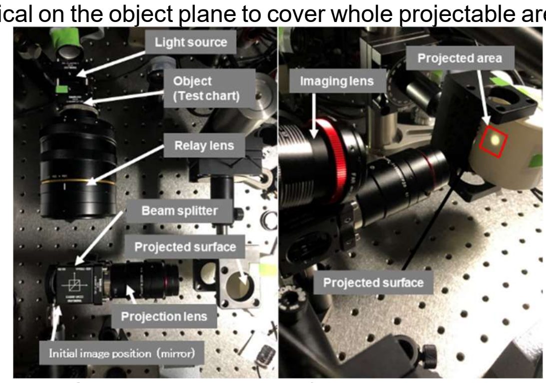
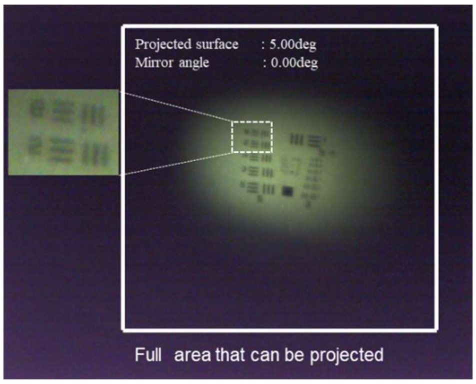
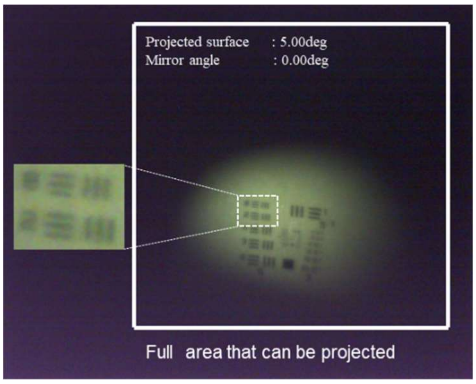


Fig. 8 Optical components for the experiments

At first, the projected plane is set at 5.00deg and mirror is set at 0.00deg to evaluate the image without Scheimpflug condition. The projected surface has cylindrical shape and R=25mm radius, and the mirror has cylindrical shape and radius is r=50mm. The projected image of the resolution test chart at the center on the projected surface is shown in Fig.9 (a). And also the corner of the vertical direction is shown in Fig.9 (b). When both projected image is compared, the chart image at the corner has a little blur, because the angle of the initial image is not fit against the angle of the projected surface.



(a)



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(b)

Fig. 9 Captured image (a) at the center and (b) at a corner by use of 0.0-degrees rotated mirror.

Then the angle of the initial image rotates to 2.5deg, in that case the mirror has 1.25deg, to fit the angle of projected surface as Scheimpflug condition. The image quality of the resolution test chart that is shown in Fig.10 becomes better so that the number on the chart is visible.

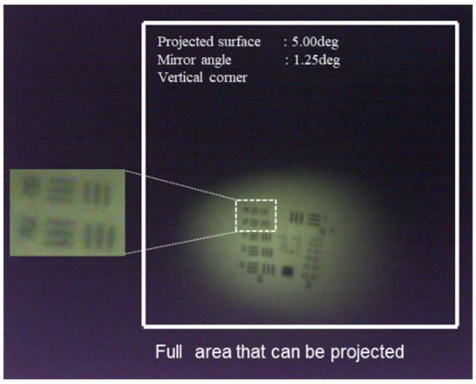

Fig. 10 Captured image at a corner by use of 1.25-degrees rotated mirror.

4 Results

The relative brightness data for the center chart is shown in Fig.11 (a). And also, the data at the corner that has no angle adjustment of the mirror is shown in Fig.11 (b). The result at center has three low peak point and two high point to explain the black and white line. However the corner doesn't have clear three low point.

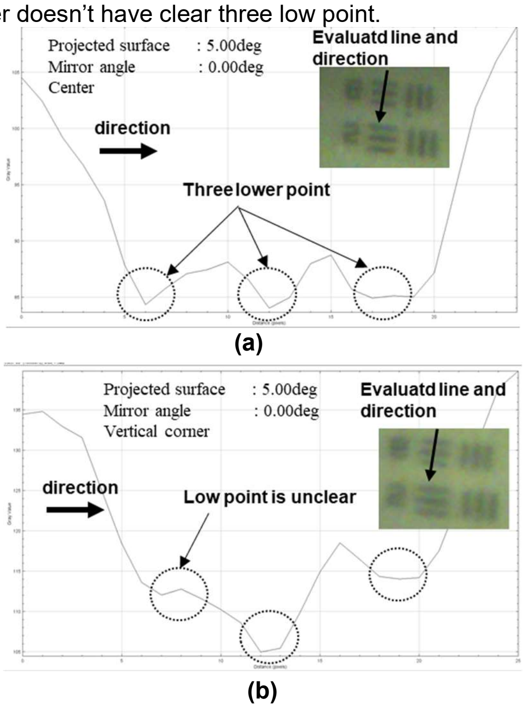

Fig. 11 Relative brightness (a) at the center and (b) at a corner by use of 0.0-degrees rotated mirror.

The relative brightness at the corner when the mirror is rotated is shown in Fig.12. The low point is seen again. The result is explain that the contrast becomes better by Scheimpflug condition.

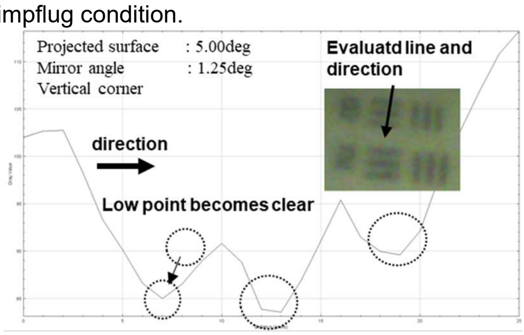

Fig. 12 Relative brightness at a corner by use of 1.25-degrees rotated mirror.

5 Discussion

When projecting on a surface that is cylindrical and angled with respect to the axis of the projection lens, place a cylindrical mirror at the initial image point and rotate the mirror to match the projection angle as Scheimpflug condition, and a clear image will be obtained. In this paper, the simulation is done that the optical component has 2x magnification. When the magnification of projection becomes larger, the angle ratio between initial image and projected surface becomes larger. In this case, the angle adjustment of the mirror will be more sensitive.

6 Conclusion

By using the Scheimpflug condition, we have succeeded in designing an optical component in which the axis of the projection lens is tilted with respect to the projection plane. Furthermore, by arranging a cylindrical mirror on the primary imaging surface, this optical system can be used even under condition where the projection surface has 3D shape such as a cylindrical surface or a spherical surface.

From the simulation result, it is found that the optimum image can be obtained by rotating the mirror at an angle of 1/4 of the angle of projected surface respect to the optical axis. This is the result from this condition. It depends on the magnification of projection.

The MTF simulation result that the condition of the adjusted angle has the same image plane. And when the experiment result is compared with the simulation, the captured image becomes better when the mirror is adjusted suitable angle respect to the projected surface.

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