Ghost images for optical systems with tilted object plane

Rania H. Abd EL-Maksoud*'**, Matthias Hillenbrand*, Stefan Sinzinger*

Fachgebiet Technische Optik, Technische Universität Ilmenau

*** Physics Department, Faculty of Science, Ain Shams University*

mailto: Rania.Abd-El-Maksoud@tu-ilmenau.de

Ghost images may cause contrast reduction and may veil parts of the nominal image. Performing ghost image analysis during the design stage is important to ensure the success of the system. We address the applicability of Scheimpflug principle for ghost image formation and we present a new criterion to identify problematic ghost images. Simulation example is provided.

1 Introduction

Ghost images are formed by light that is partially reflected by refractive surfaces. In imaging applications, ghost images may degrade the image quality as shown in Fig. 1 while in high power laser applications ghost images may damage the optical surfaces. In general, there are two approaches to model ghost images: a deterministic approach and a statistic approach. In a previous paper sequential ray tracing was used to model ghost images [1].

Scheimpflug condition describes the required nominal image plane tilt in order to have nominal focused image of a tilted object. There is little or no literature about modeling ghost images of a tilted object. In this paper, we present a methodology to model ghost images for optical systems with tilted object plane. In addition, we present a new criterion for problematic ghost images in tilted systems.

2 Theory

An optical system may be considered as a nominal and several ghost systems. Each system has its own parameters and therefore its own contribution to the image formation at the nominal Gaussian image plane. In a previous paper [1], paraxial sequential ray tracing was used to determine the ghost second-order properties and the aberration function.

***Fig. 1** Ghost images superimposed on the nominal image scene*

A tilted object produces a tilted image or a decentered image and a decentered object produces a decentered image. The image tilt angle ε' for tilted and deceneterd object is given by [2]

$$\tan\varepsilon' = \frac{Z'_o \tan\varepsilon}{Z_o + \left(y_o - y_o'\right)\tan\varepsilon} \tag{1}$$

Where, ε is the object tilt angle, y_o and y_o' are the decentrations of the object and image, respectively. Z_o and Z_o' are the longitudinal positions of the object and image centers, respectively. For each ghost system, same equation that is used to determine the nominal image tilt is used to determine the ghost image tilt but with the appropriate ghost layout parameters. Throughout this paper, the suffixes n and g are used to label nominal and ghost parameters, respectively.

A problematic ghost image is formed if there is an intersection between the ghost and nominal image planes as shown in Fig. 2. The criteria for focused ghost at the nominal image plane is

$$-a_{\det} \le y_{\text{int}} = \frac{\Delta Z}{\tan\varepsilon'_g} \le a_{\det} \tag{2}$$

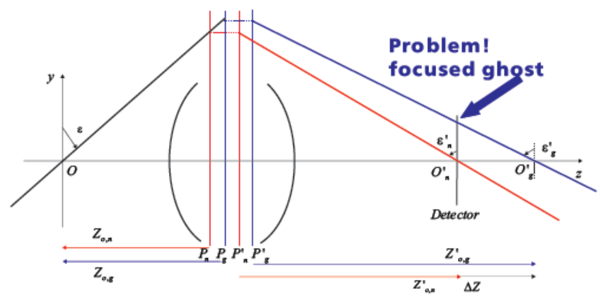
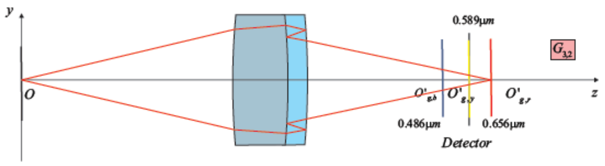


***Fig. 2** The formation of a focused ghost image at the nominal image plane.*

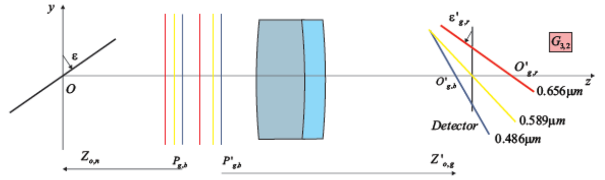
Where ΔZ is the distance from the detector to the center of the ghost image, $a_{\det}$ is the half size of the detector along the y axis, P and P' are the front and rear principle points, respectively.

3 Simulation example

A doublet lens from ZEMAX sample files [3] imaging an object at finite distance is considered. Three second-generation ghosts are possible. Sequential ray tracing is used to model the ghost system $G_{3,2}$ that is formed by reflections from the 2nd and 3rd surfaces. Second-order properties are given in tab. 1 while the ghost tilt angle and the locations of focused ghost images along at the detector plane as a function of wavelength and for $\varepsilon = -15^o$ are given in tab. 2. Fig. 4 shows the ghost image plane tilt angle as a function of wavelength for $\varepsilon = -8^o$. Fig. 5 shows the locations of the focused ghost image at the detector plane. The detector size will determine the number of focused ghost images.



(a)



(b)

Fig. 3 *Ghost image formation by a doublet lens for a) untilted object b) tilted object. The figure is not to scale.*

λ (μm)	d_g (mm)	d_g' (mm)	$z_{o,g}$ (mm)	$z_{o,g}'$ (mm)
0.486	-2.11	10.58	-97.94	112.15
0.589	-2.19	10.69	-97.86	113.9
0.656	-2.22	10.74	-97.82	114.71

Tab. 1 *Ghost second-order parameters for three wavelengths.*

λ (μm)	$\varepsilon_g'(^o)$	$y_{\text{int}}'(mm)$
0.486	17.06	-5.32
0.589	17.32	0
0.656	17.44	2.42

Tab. 2 *Ghost image plane tilt angle for three wavelengths* $(\varepsilon = -15^o)$.

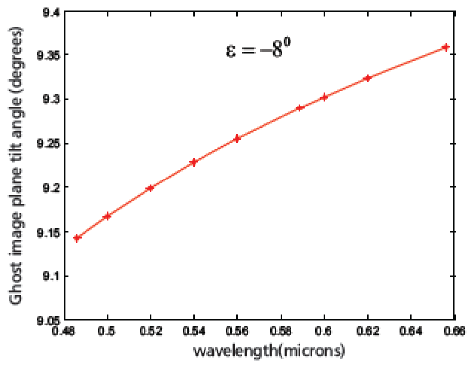


Fig. 4 *Ghost image plane tilt angle as a function of wavelength.*

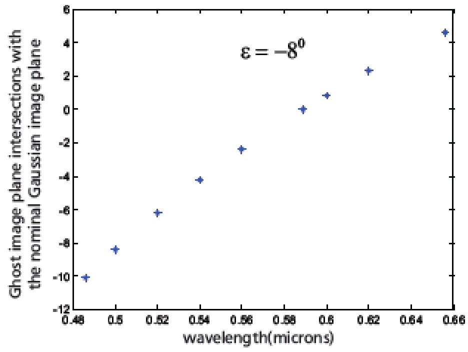


Fig. 5 *Locations of the ghost image plane intersections with the detector as a function of wavelength.*

Conclusion

In this paper we developed a methedology to analyze ghost images for tilted object. An expression for the ghost image plane tilt angle is presented and a new criterion for the formation of focused ghost images at the nominal image plane is presented. The simulation example shows the dispersion curve of the ghost image plane tilt angle and the possible locations of the focused ghost images at the nominal image plane.

Acknowledgement

The authors would like to thank the German Federal Ministry of Education and Research and the Thuringian Ministry for Education, Science, and Culture for the financial support through the projects “Kompetenzdreieck Optische Mikrosysteme-KD OptiMi” (FKZ: 16SV3700) and “Graduate Research School on Optical Microsystems Technology (FZK: PE 104-1-1).

4 References

[1] R. H. Abd El-Maksoud and J. Sasian, “Modeling and analyzing ghost images for incoherent optical systems,”Applied optics, Vol.50 (15): 2305-2315(2011).

[2] J.R. Rodgers, Aberrations of unobscured reflective optical systems, Ph.D dissertation (University of Arizona, 1983).

[3] ZEMAX optical design software, *http://www.radiantzemax.com/.*