# Chapter 3

Geometric model of Scheimpflug Imaging

### Introduction

TO DO: State the motivation and assumptions.

TO DO: Preview of what is coming in the following sections.

TO DO: State the novelty of this approach, and why needed to develop this model

### Relation between the direction cosines of the chief rays in the object and image side

Let be the direction cosine of the chief ray from a world point to the entrance pupil (ENP) in the object side, and let be the direction cosine of the chief ray emerging from the exit pupil (EXP) to the corresponding image point in the image side. If the angles between the chief ray and the optical axis at the object side and image side be and respectively, then the relation between the angles is given by the airy tangent condition [ref]:



Where, is the pupil magnification defined as the ratio between the paraxial exit pupil diameter to the paraxial entrance pupil diameter.

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| ***Figure 3.1*** *Schematic showing the chief ray from the object point to the image point when the optical axis is aligned with the z-axis of the reference frame.* |

If and are the zenith and azimuthal angles of the chief ray in the object side, and and the corresponding angles in the image side, the direction cosines are represented in the spherical coordinates as:



When the optical axis is aligned with the z-axis, then and . Substituting the expressions for from equation into equation we get:



By definition the chief ray (a meridional ray) is …. Therefore and the above relations reduces to:



Also, from



Simplifying further,



Therefore, the expressions for output direction cosines in terms of the input direction cosines and the pupil magnification is obtained as:



Since the chief ray emerging from the exit pupil spans the plane formed by the input chief ray and the optical axis, the chief ray in the image side may be represented as a linear combination of the input chief ray and the optical axis (represented in vector form) as follows:



Where, and are the weights and is direction cosine of the line representing the optical axis. when the optical axis is aligned with the z-axis (present case). The weight is readily obtained by comparing equations and :



Substituting the expression for into and comparing with we get the expression for :



We would like to derive the relationship between the input and output direction cosines of the chief ray for an arbitrary rotation of the optical axis centered about the ENP as shown in figure 3.2.

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| ***Figure 3.2*** *Schematic showing the chief ray from the object point to the image point when the optical axis is rotated about an arbitrary axis about the ENP.* |

Write appropriate text here.



Where

Write appropriate text here.



Letting and



By comparing the above equation with the expression for the weights and are obtained as:



Equation can then be written as:





Furthermore, using and , the general expression for the direction cosines of the chief ray in the image side in terms of the pupil magnification and direction cosines in the object side is:



Where

### Relation between object coordinate and image coordinate for arbitrary orientation of the lens and image plane

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| ***Figure 3.3*** *Schematic showing the chief ray from the object point to the image point when the optical axis is rotated about an arbitrary axis about the ENP.* |

Explain the different coordinate frames.

The exit pupil (EXP) is located at a distance from the entrance pupil (ENP) along the optical axis. The lens, and hence the optical axis, is tilted in the camera frame a rotation matrix . Therefore the location of the EXP in the camera frame is . The chief ray emerging from the exit pupil (EXP) with direction cosine vector is then represented by the parametric equation:



Where represents any point along the chief ray in the image side.



Multiplying equation by  :



