CHAIRE DE RECHERCHE INDUSTRIELLE
DU CRSNG EN CONCEPTION OPTIQUE

NSERC INDUSTRIAL RESEARCH CHAIR
IN OPTICAL DESIGN

Historic Perspective and Modern Optical Design of Panoramic Lenses

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Historic Perspective and Modern Optical Design of Panoramic Lenses

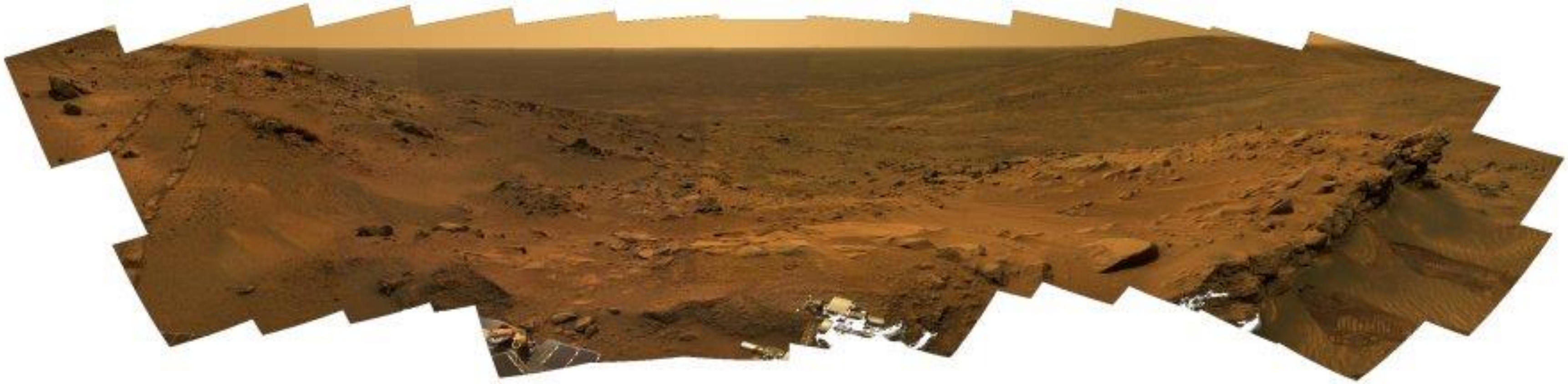
- *A Historical Perspective on Understanding Panoramic Imagery*

- *Modern Panoramic Imager*

- *Optical Design Challenges*
  - *Distortion management*
  - *Raytracing (EP, RI, Polarisation)*
  - *Tolerances*
  - *Testing*

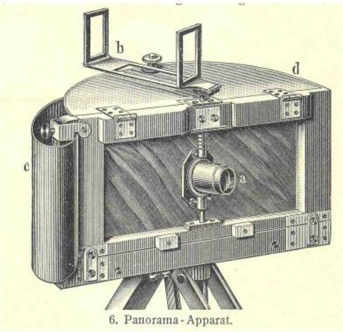
A Historical Perspective on Understanding Panoramic Imagery

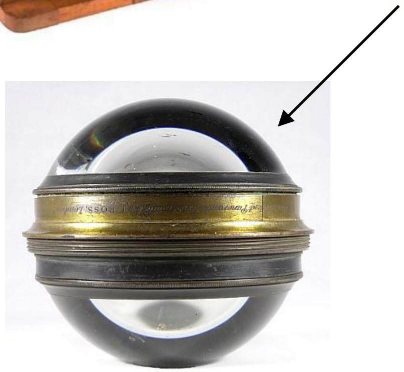
Panoramic imagery has been arround almost as long as the photography. From the beginning photographers wanted to be able to show city scenes…



A Historical Perspective on Understanding Panoramic Imagery

- One of the first recorded (patents) for a panoramic camera was submitted by Joseph Puchberger in Austria in 1843 for a hand-cranked, 150° field of view, 8-inch focal length camera that exposed a relatively large Daguerreotype, up to 24 inches (610 mm) long.
- The earliest panoramic wide-angle lens ever produced, patented by Sutton (1859). It consists of two glass hemispheres in brass mounts, 80 mm in diameter.





A Historical Perspective on Understanding Panoramic Imagery

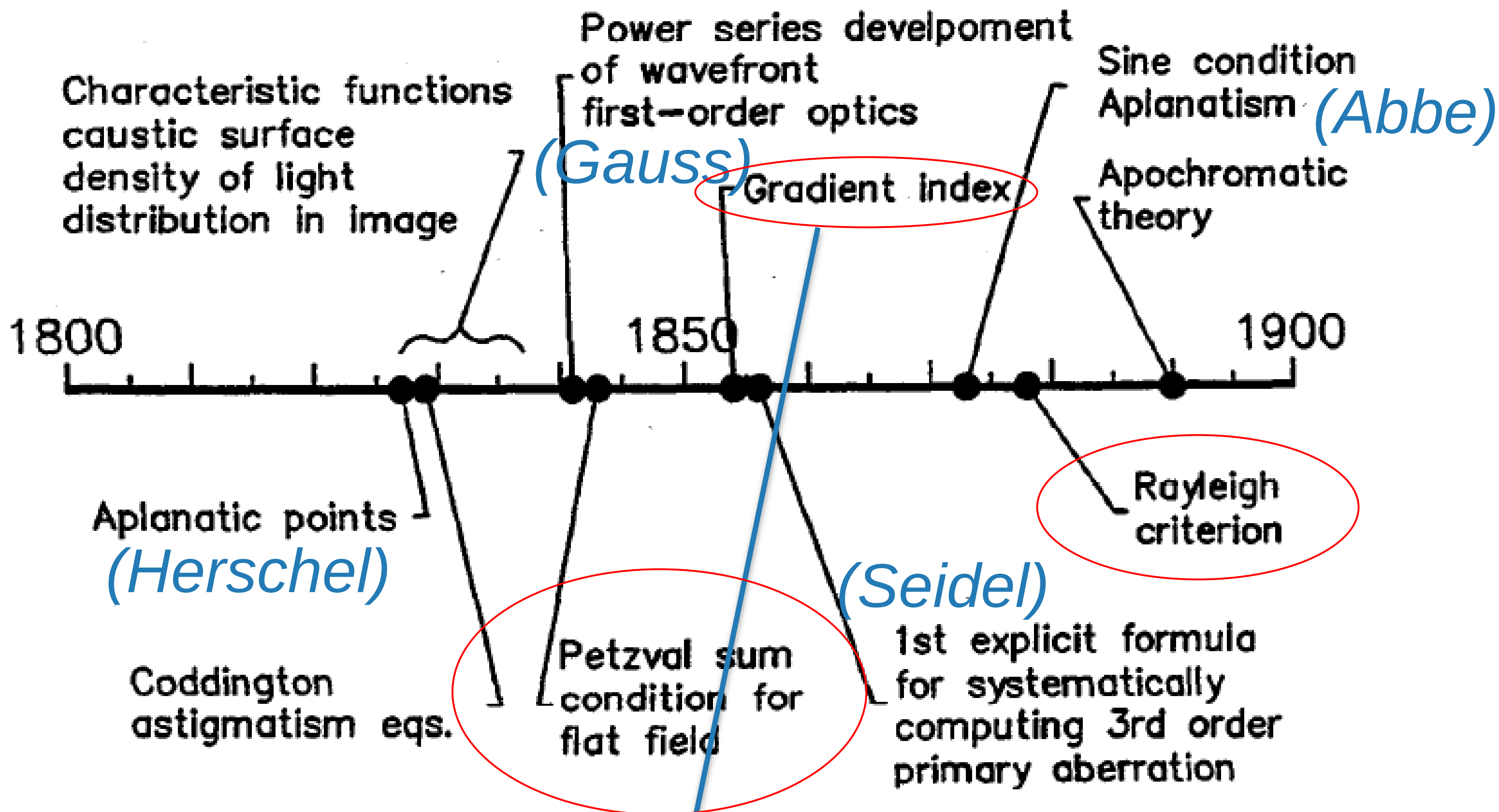


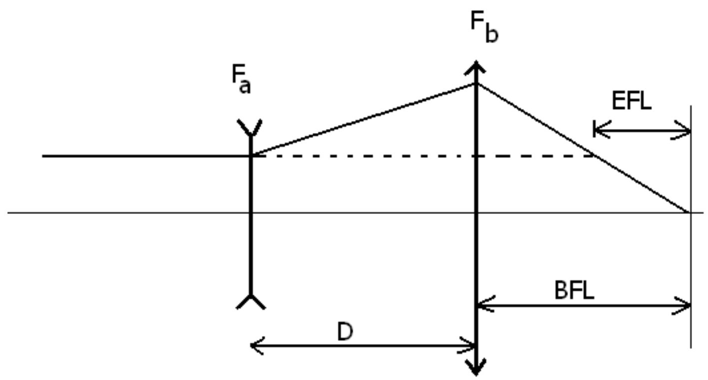
Figure 3: Major events and discoveries in the 19th century that contributed to the understanding of optical aberrations.

Maxwell fisheye lens

A Historical Perspective on Understanding Panoramic Imagery

From reversed telephoto to the modern panoramic lens

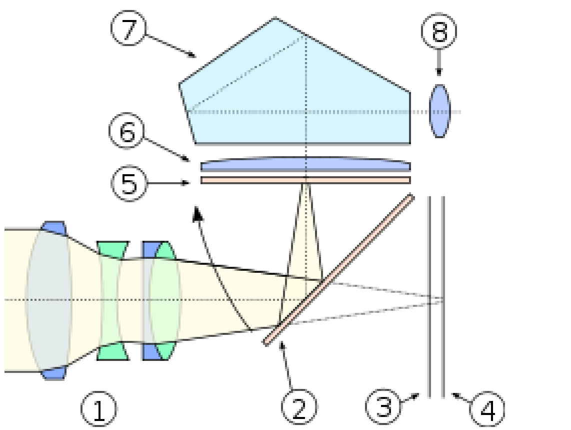
- Reversed telephoto → wide-angle lens



$$H = efl \tan(\theta) = f \tan(\theta)$$

$$F_a = \frac{D \cdot EFL}{EFL - BFL} \qquad F_b = \frac{-D \cdot BFL}{EFL - BFL - D}$$

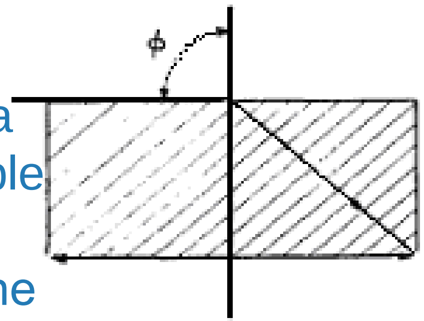
In the past, these types of lenses were very popular, since any lens used with a 35 mm camera (Reflex) had to have a back focal length of at least 35-40 mm to clear the rocking mirror on the camera.



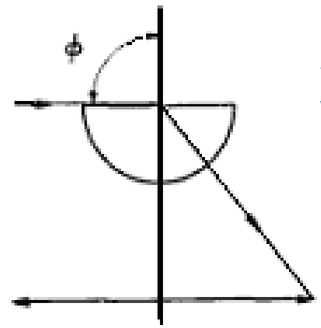
A Historical Perspective on Understanding Panoramic Imagery

Sky lens and fisheye

Water-filled pinhole camera that was capable of simulating a fish's view of the world (1911)



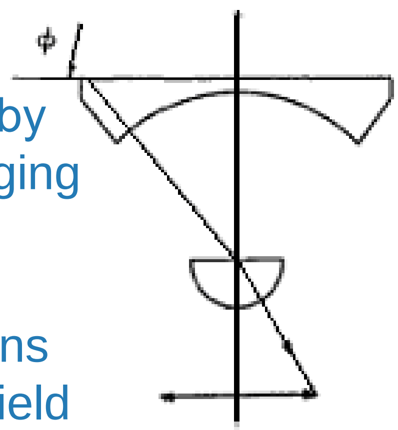
A



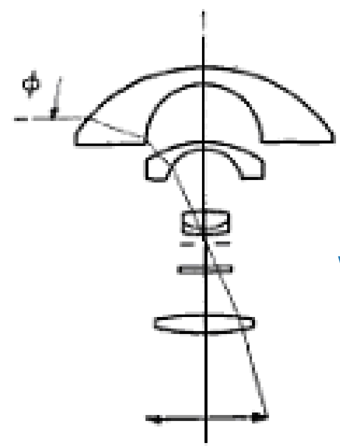
B

An hemispheric lens with a pupil at the centre of the curvature in place of the water

"Hill Sky lens" by adding a diverging meniscus lens before the hemispheric lens to reduce the field curvature (1924)



C



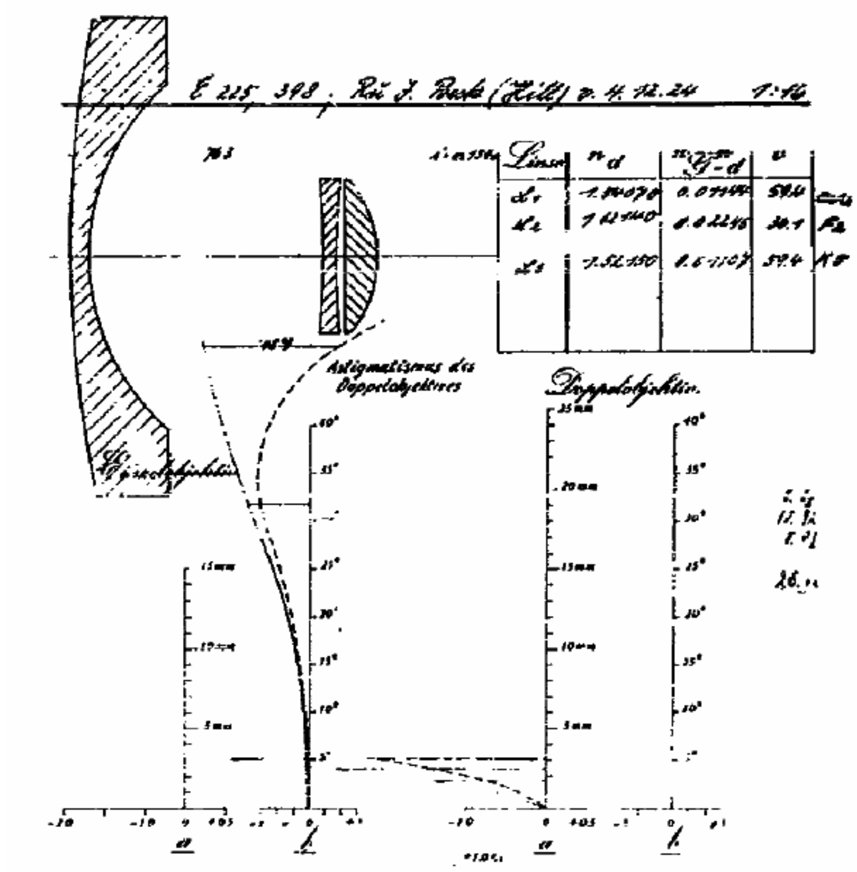
D

First prototype of the modern fisheye lenses which was patented by Schultz (1932) and Merté (1935).

A Historical Perspective on Understanding Panoramic Imagery

The father of all fisheye lenses was the famous "Sky lens" by Robin Hill and patented in 1924; this f/16 fisheye lens clutched out a 180˚ angle of view and was mounted on a special "Hill cloud camera" produced in London by Beck for metereological purposes. The lens is basically a stretched up triplet with the front lens shaped to achieve the desired angle of view, without taking care to the distorsion

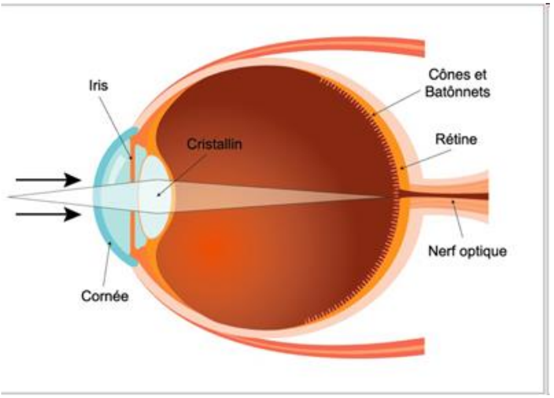
f/16 Sky lens - 180° fisheye
project by Robin Hill - 1924
produced by Beck - London



Modern Panoramic Lens

Foveated Imaging and Smart Distortion

Foveated imaging is an optical technique in which the image resolution, or amount of details, varies across the image.
In other word, the magnification change across the FOV (the distortion is seen as a design parameter).



Magnification In The Zone Of Interest

Fisheye

Panomorph

NATO Unclassified releasable to EOPs and PfP

Modern Panoramic Imager

Digital image can have virtually any distortion.

By reshaping the image before sampling, we can capture the image with magnification which varies across the FOV. We call this Selective Spatial Stretching.

Cylindrical anamorphism in Art

Modern Panoramic Imager

Controlled of the distortion (image footprint)

The field of view to image relation will be given now by a polynomial function

$$H = H(\theta) = a + b\theta + c\theta^2 + d\theta^3 + \ldots$$

By definition, 'a' is equal to zero (no dc value) and b is the effective focal length. However, the non zero value of 'c' and higher order terms will introduce a variation in the projection of the field of view in the image plane. We will use in this case the local focal length to express the variation of the magnification.

$$f(\theta) = \frac{\partial H}{\partial \theta} = b + c\theta + d\theta^2 + \ldots$$

From a geometrical optic point of view, as the objet and image distance is constant, the way to modify the magnification is to change the focal length.

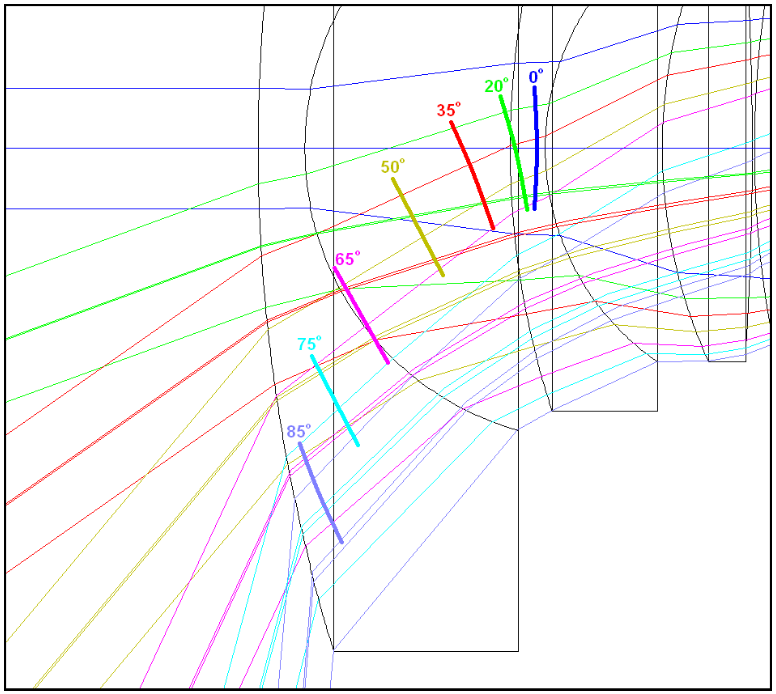
Optical Design Challenges

Almost every aspect concerning the design of modern panoramic lenses brings new challenges to optical designers. Examples of these include:

- Ray tracing programs having problems finding the entrance pupil which is moving through the field of view,
- Relative illumination
- Polarisation
- Surface optimisation due to distortion
- Tolerances (distortion)
- Particular setups required for their characterization

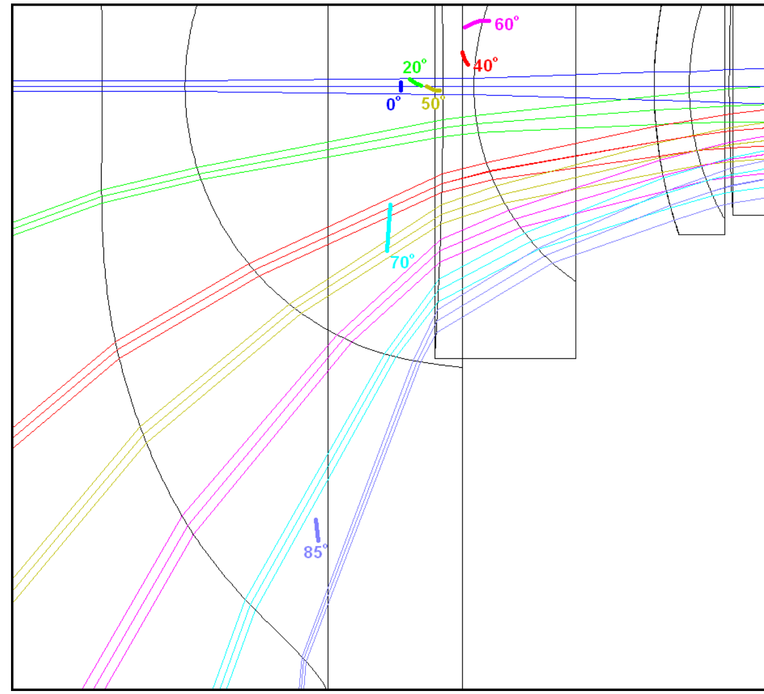
Optical Design Challenges

Ray tracing (Entrance pupil)



Fish-eye lens

With a spherical front surface, this displacement follows a curved line away from the optical axis

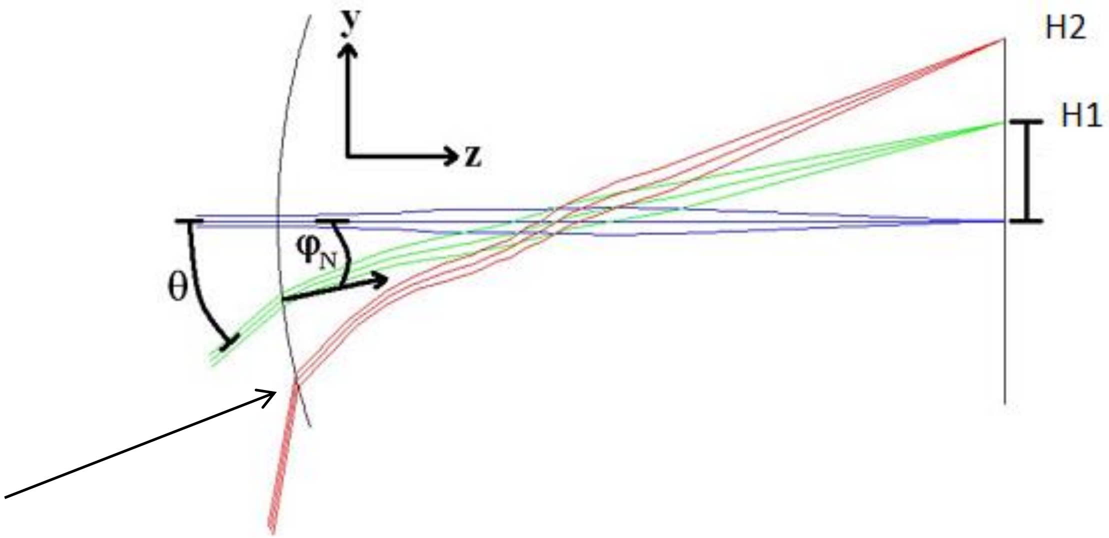


Panomorph lens

With an aspherical front surface, this displacement goes back and forth, following the front surface shape

Optical Design Challenges

Freeform Surface Optimisation



If H1 is good, we will optimize the surface to obtain H2, ideally without changing H1.

- Even asphere polynomial surface definition is not ideal!
  - Grid sag (spline)
  - Local optical surface representation as a sum of basis functions.

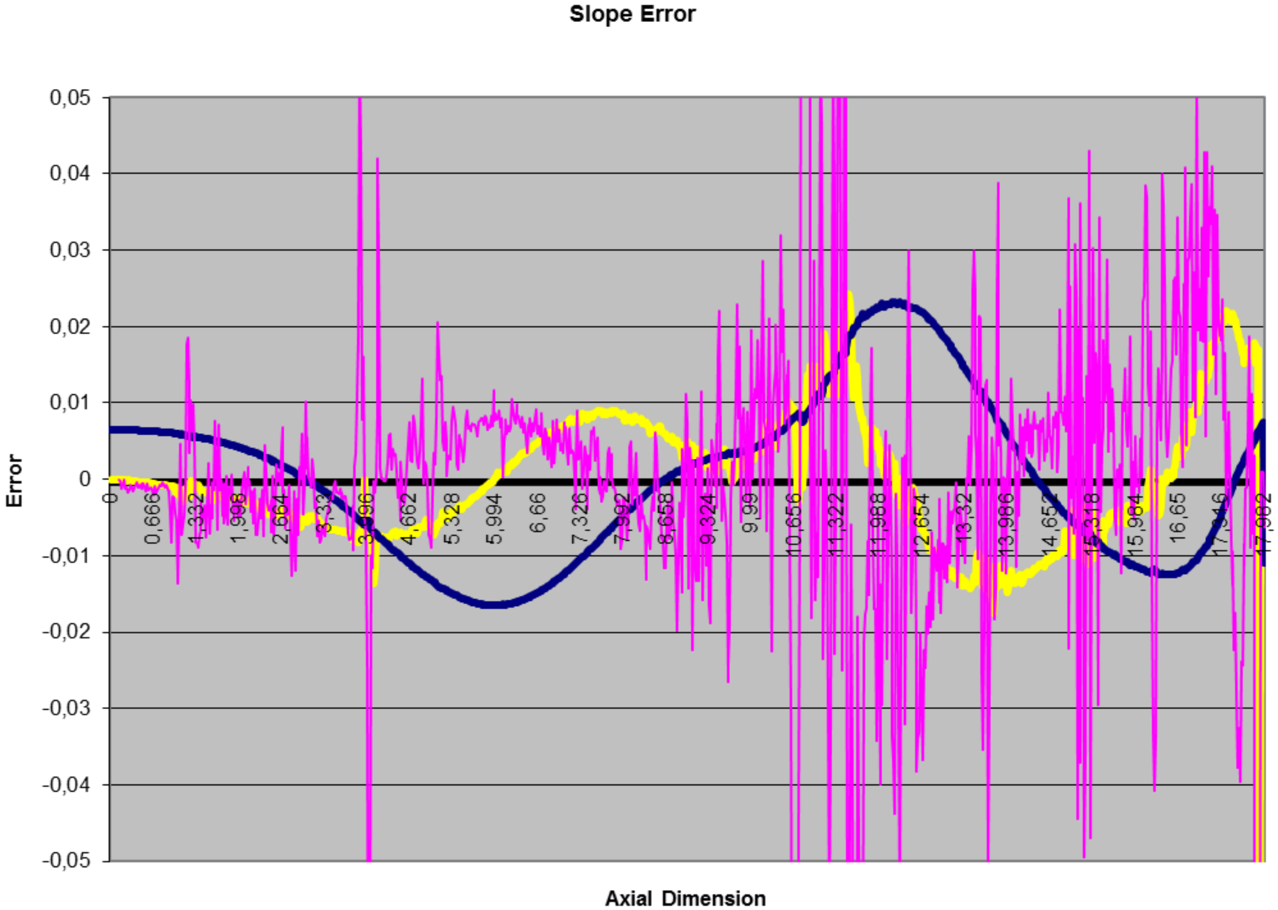
Optical Design Challenges

Tolerances: Impact of medium-low frequency on distortion.

Image local deformation?

Optical Design Challenges

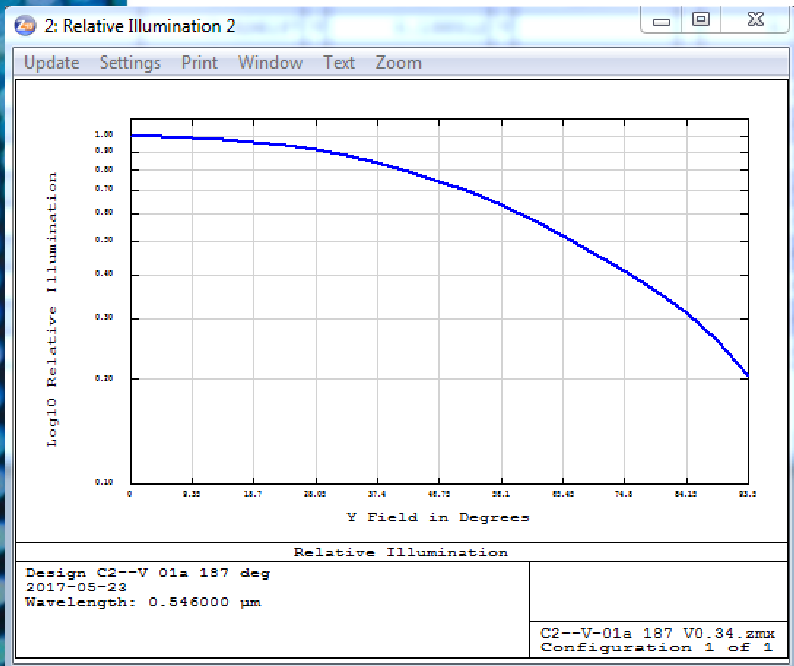
Tolerances: Impact of medium-low frequency on distortion.

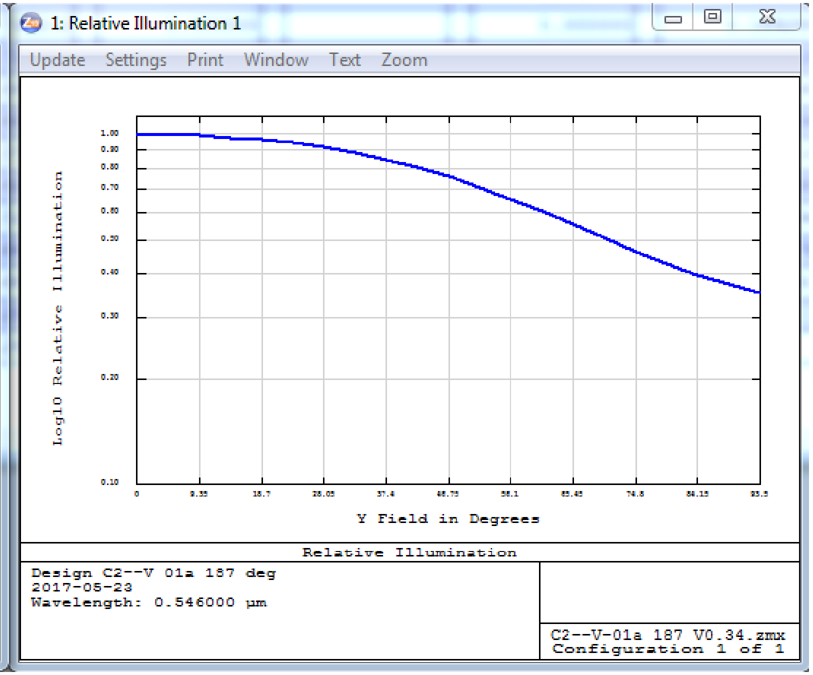


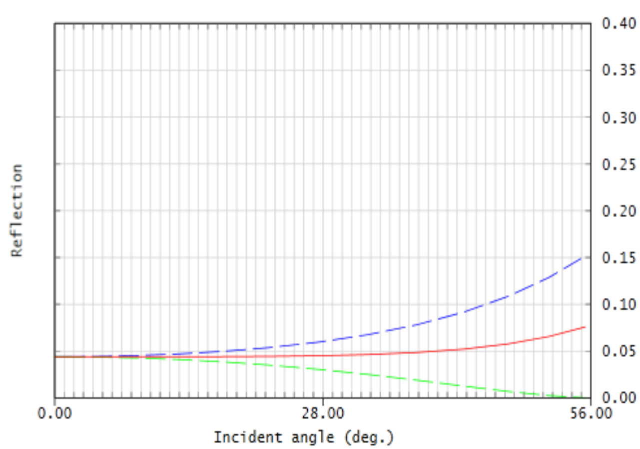
$$\Delta H \approx f(\theta)/[1+\tan^2(\varphi_N)] \times (n-1)[1+(\theta-\varphi_N)^2(n+1)/(2n)+\ldots] \times \partial Z_{\mathrm{error}}/\partial Y.$$

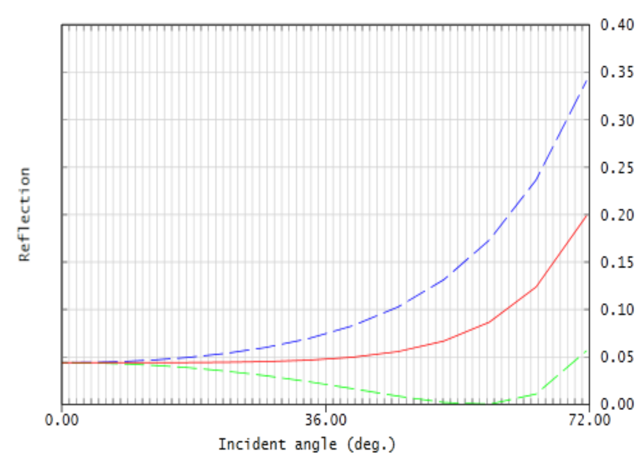
Optical Design Challenges

Relative Illumination and Polarisation



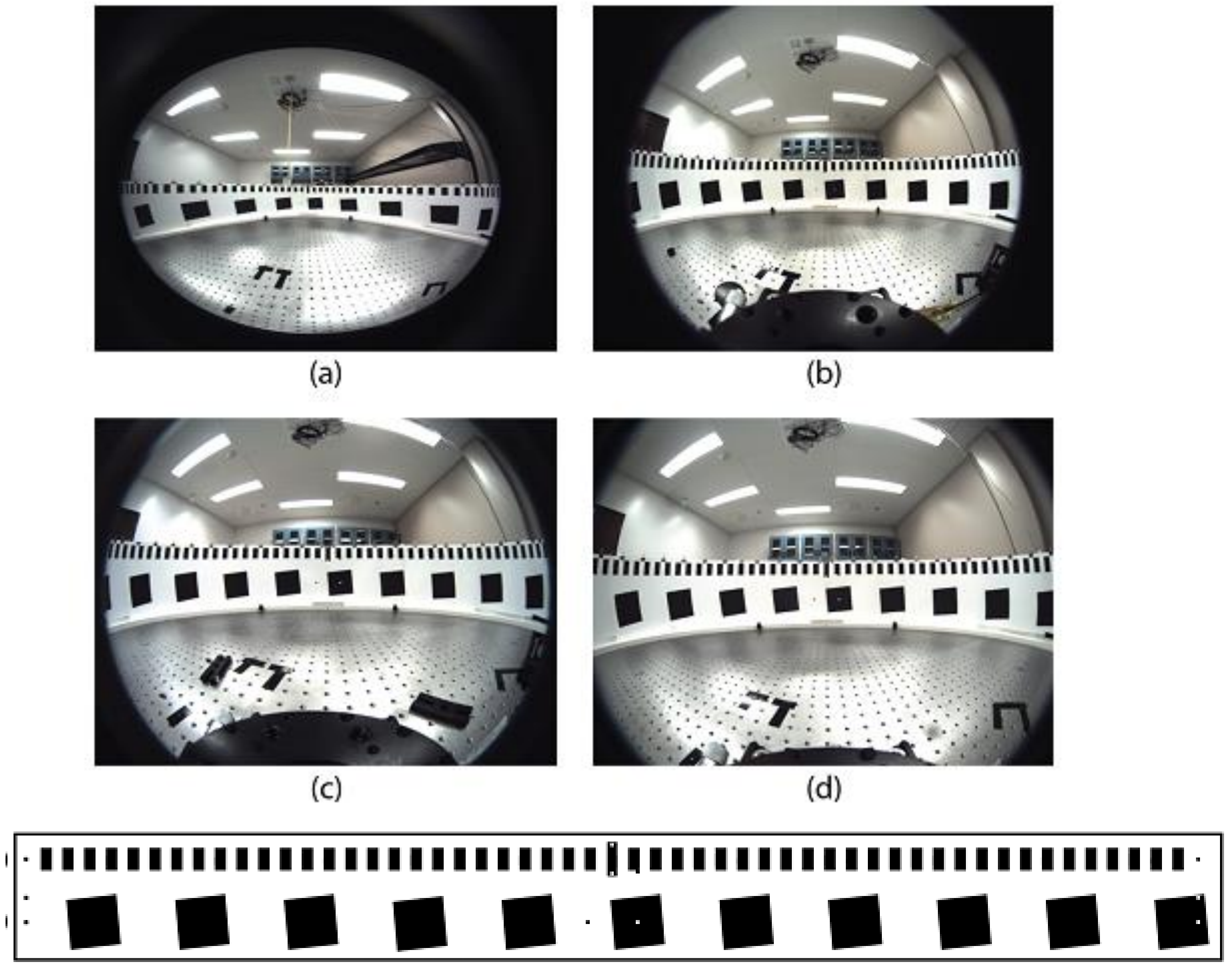






Optical Design Challenges

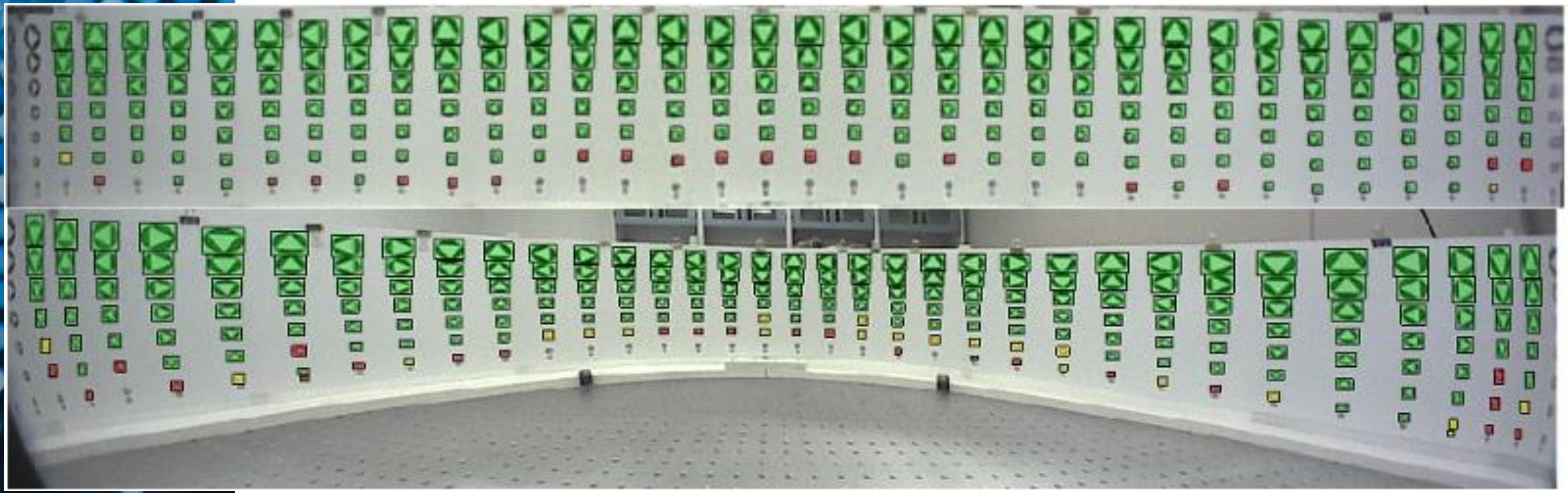
Testing (using target)



Anne-Sophie Poulin-Girard and Simon Thibault, "Optical testing of panoramic lenses", Opt. Eng. 51, 053603 (2012).

Optical Design Challenges

Testing: Rectification by software?



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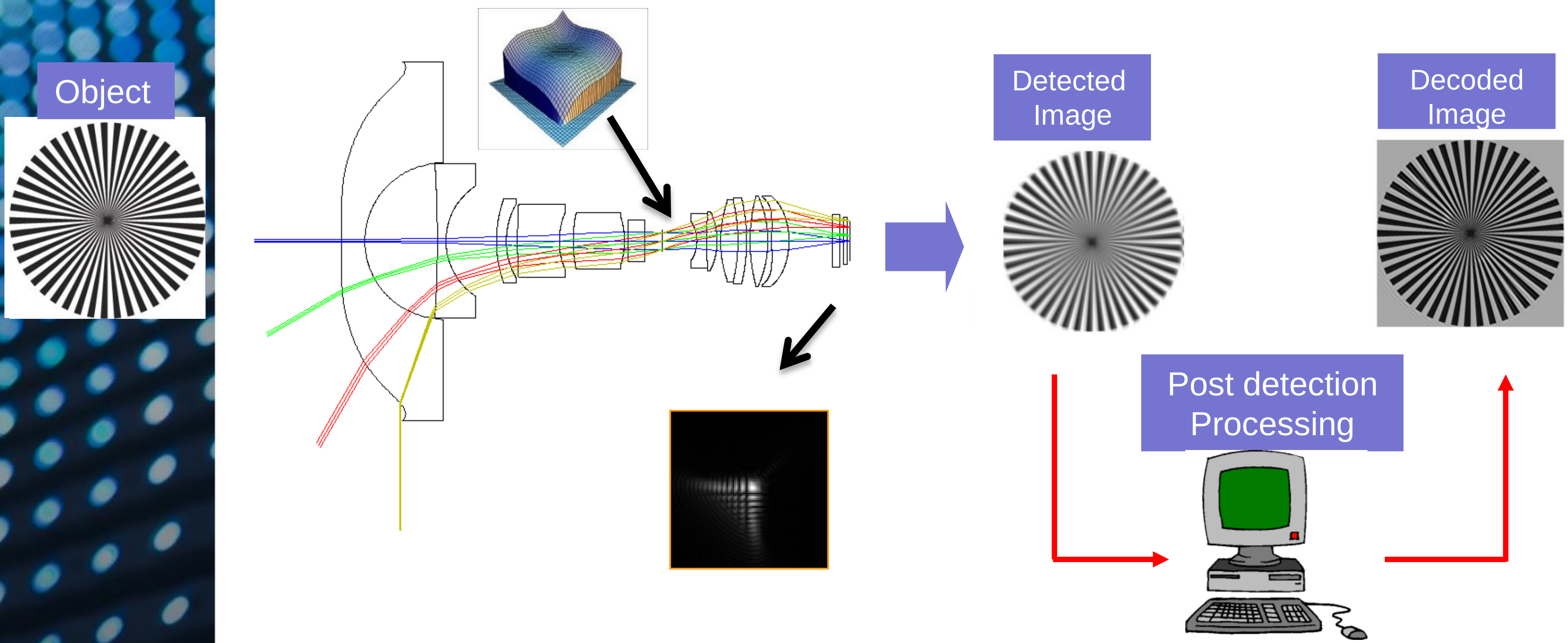
Computational Imaging:

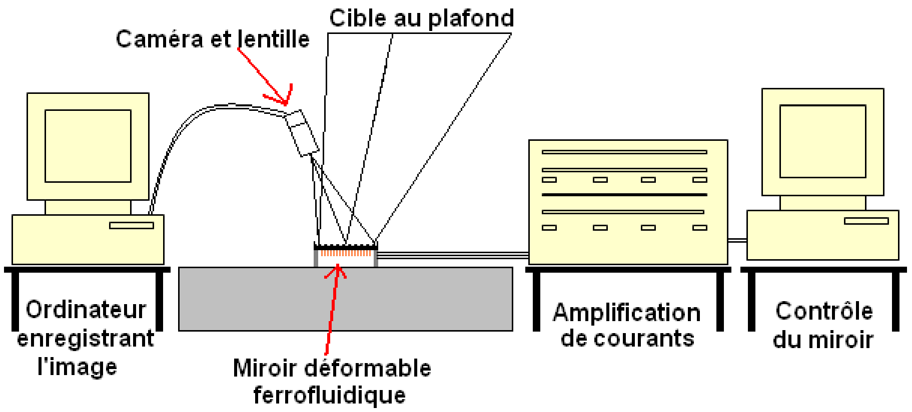
Integrated optical / digital system: joint design of optics and signal processing

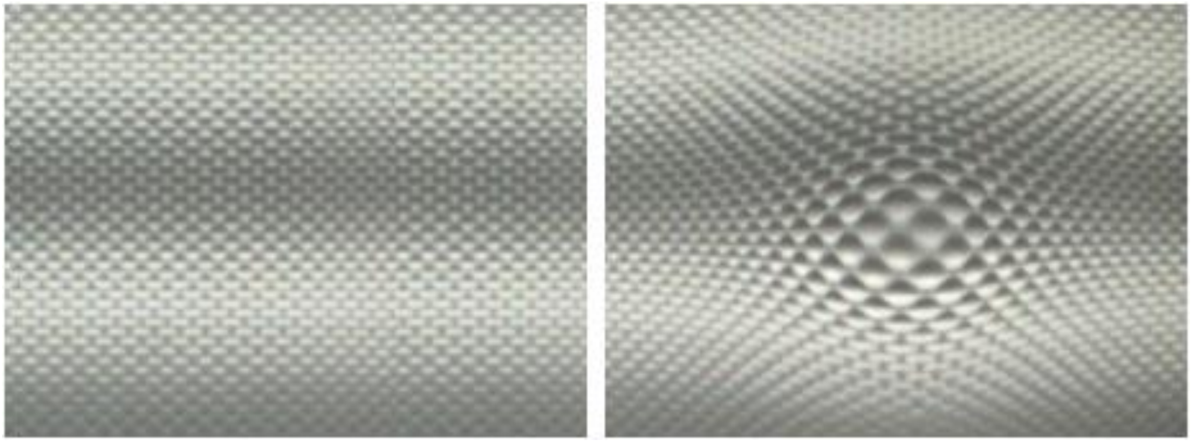


PSF invariant under aberrations

Martin Larivière-Bastien and Simon Thibault, "Limits of imaging-system simplification using cubic mask wavefront coding," Opt. Lett. 38, 3830-3833 (2013).

Active Imaging: *Locally magnifying imager*





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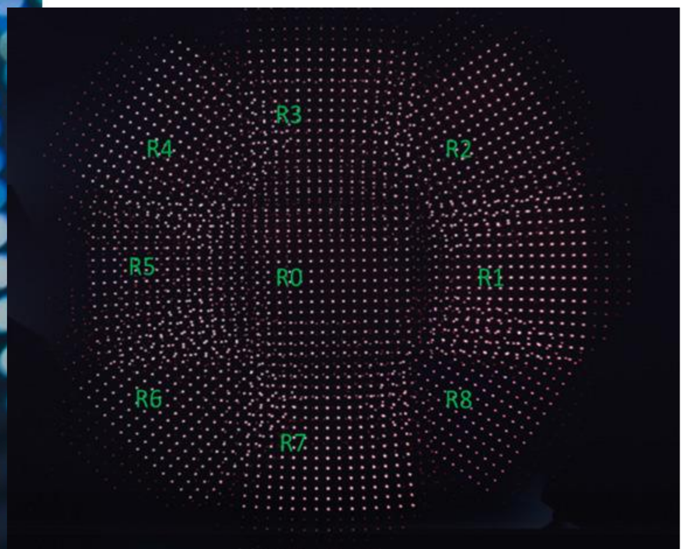
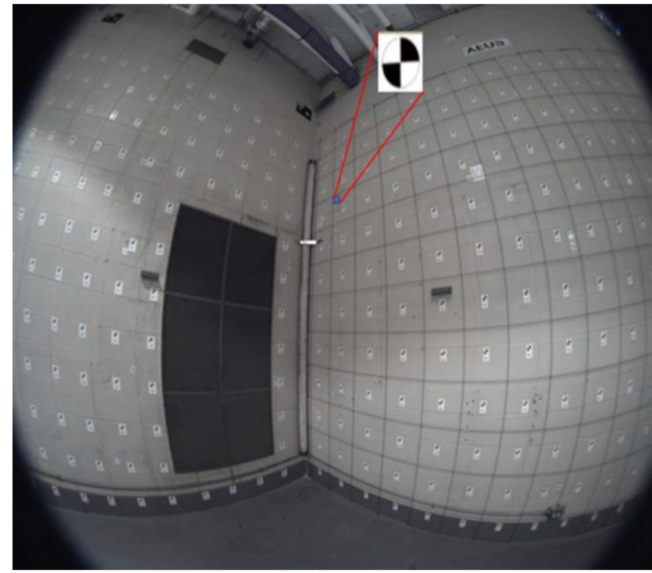
Panoramic Lens Calibration/Stereoscopic system





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- Aymen Arfaoui and Simon Thibault, "Fisheye lens calibration using virtual grid," Appl. Opt. 52, 2577-2583 (2013).
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- Poulin-Girard A, Thibault S, Laurendeau D; Study of the performance of stereoscopic panomorph systems calibrated with traditional pinhole model. Opt. Eng. 55(6):064107 (2016).

Today and Tomorrow

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