Wavefront techniques for characterizing antique optical instruments

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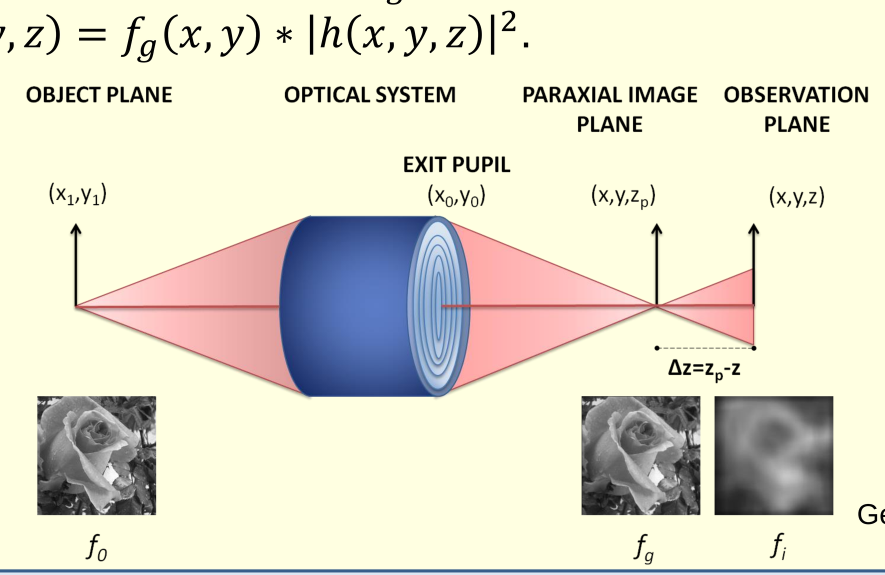
Summary

A non-contact technique for analyzing the image quality of antique optical instruments is proposed. We use a wavefront sensor, in particular a Shack–Hartmann device placed at the exit of the instrument in combination with a suitable illumination. So, using the experimental parameters provided by the Shack-Hartmann wavefront analyzer (Zernike polynomial coefficients) and our own software we are able to calculate the PSF of the instrument that we are studying, and then calculate the convolution within the PSF and the function that describes a paraxial image. In other words, without removing the instrument from the museum, we are able to see the images as they would have been seen in their time.

The Shack-Hartmann device can also be used for mesure the focal length of the instruments.

Theoretical background: Optical Systems and the PSF

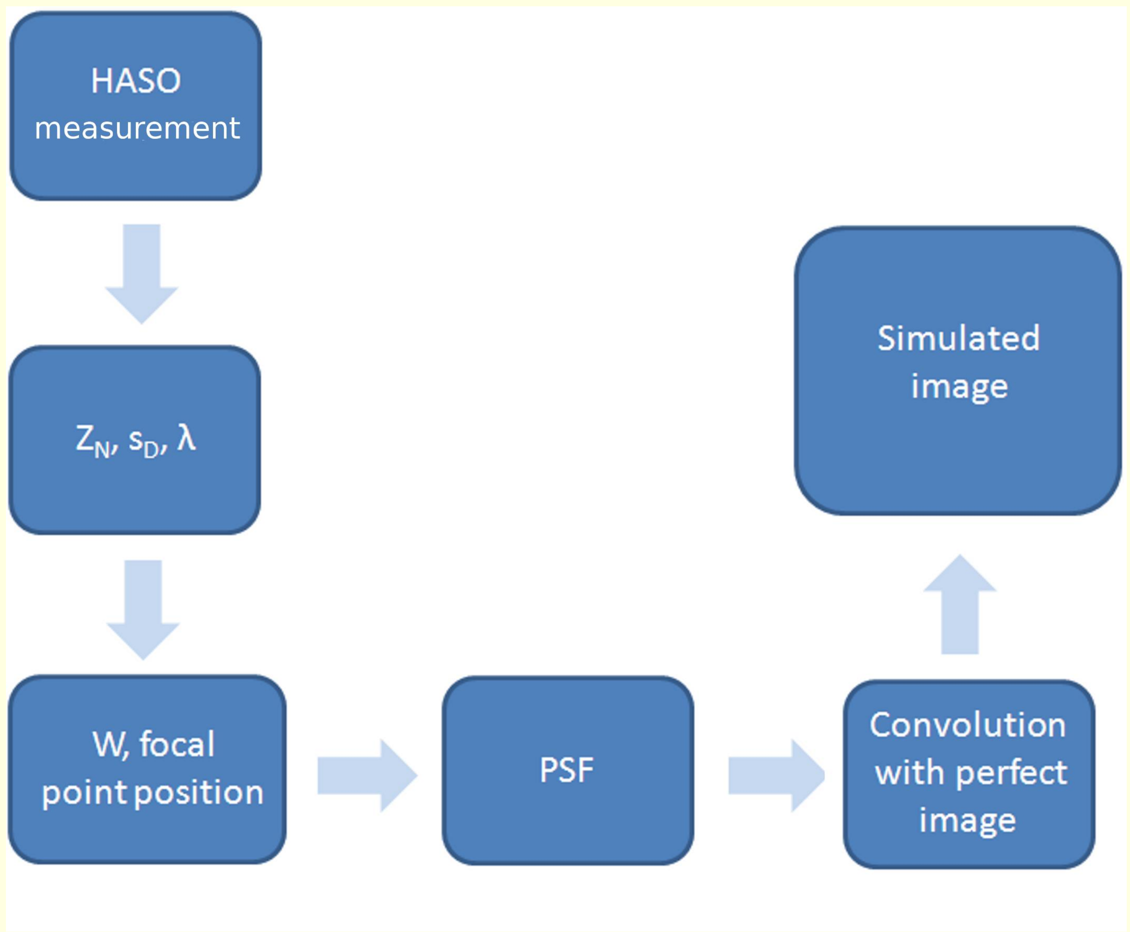
From the geometrical point of view, an optical instrument can be sketched by tracing rays through the surfaces that compose the system, using Snell's law. Moreover, a general imaging device can also be described as a black box consisting of two planes containing the entrance and exit pupils. For a linear and intensity invariant optical system, the intensity pattern in an observation plane at a distance *z* from the exit pupil can be described as a convolution of the geometrical image, $f_g(x,y)$, and the corresponding incoherent PSF, $|h(x,y,z)|^2$, i.e., $f_i(x,y,z) = f_g(x,y) * |h(x,y,z)|^2$.



Generalized (black box) optical system.

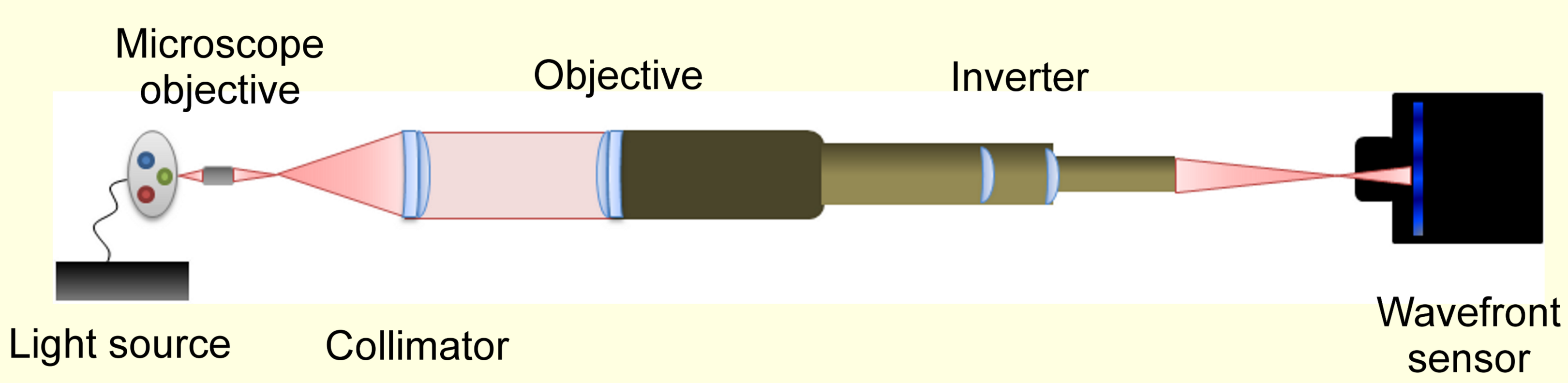
Computational implementation

Diagram of the experimental and computing procedure for obtaining the PSF of an old optical instrument with Shack-Hartmann device's experimental results, and the method for obtaining a simulated image as it'd seen through the antique optical instrument.

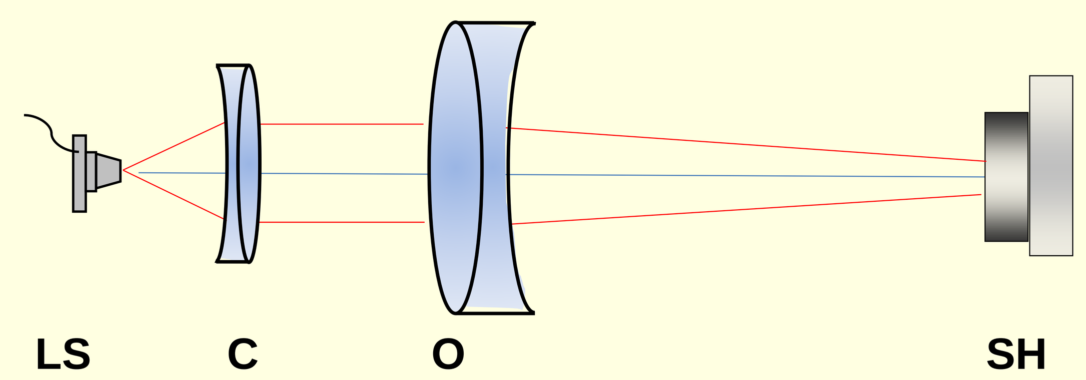


Experimental Measurements

An on-going study: Optical quality assessment and determination of geometrical parameters of antique optical instruments.

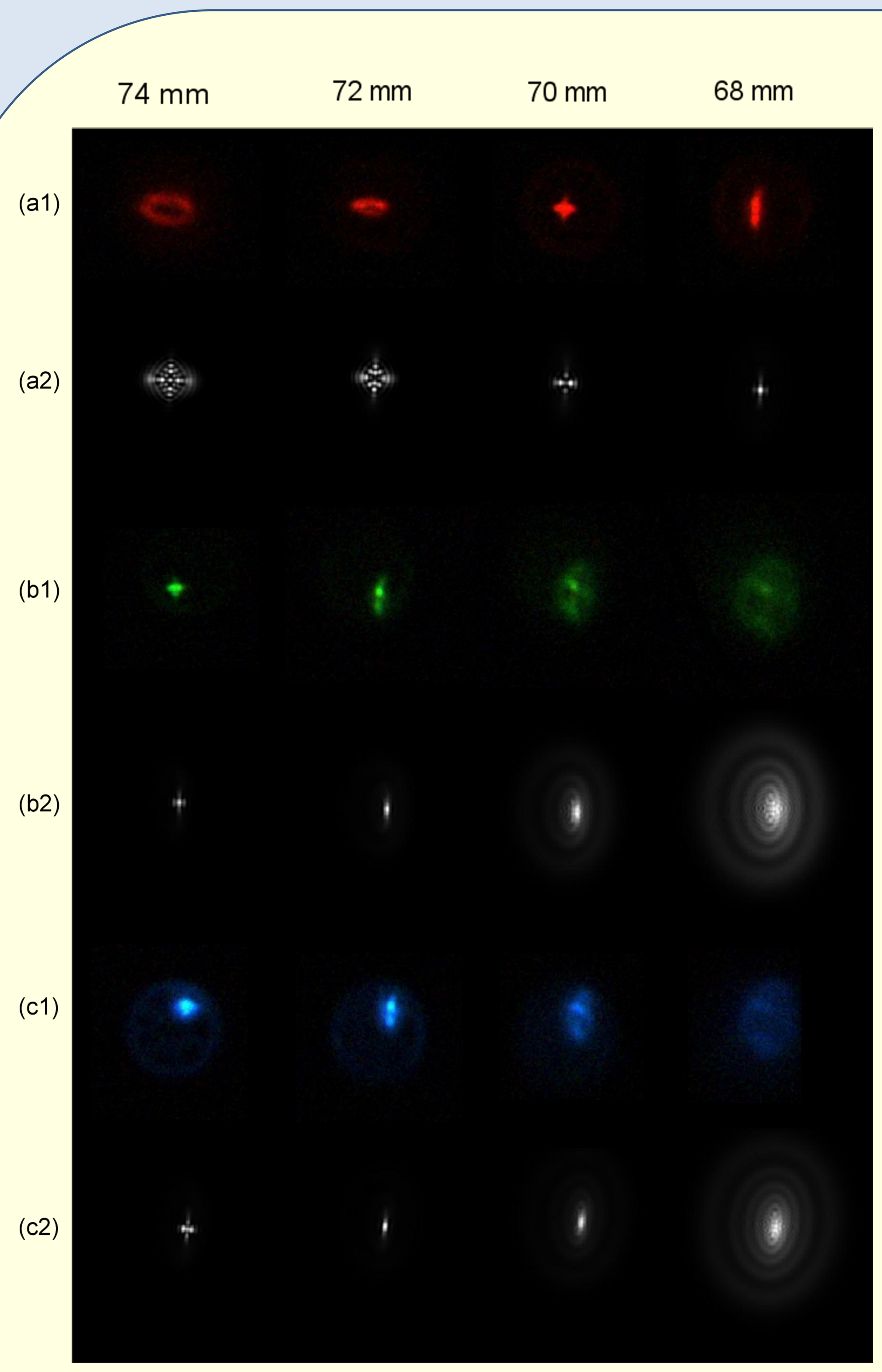


Experimental set-up for obtaining the Zernike polynomial coefficients of the aberrated wavefront by an antique optical instrument (terrestrial telescope) using a Shack-Hartmann wavefront sensor. We're going to use this method and configuration in the study of antique microscope objectives.



Experimental set-up for obtaining the focal distance of telescope's objectives with a very big aperture. From left to right: Light source (LS), Collimator (C), Objective (O) and Shack-Hartmann device (SH). Using this configuration we can determinate the focal length of the objective that we are studying and the refractive index of each lens that compose the objective.

Experimental results



At the left there are experimental (subindex 1) and simulated (subindex 2) PSFs for wavelengths (a) 621 nm, (b) 525 nm and (c) 470 nm at a different distances from the wavefront sensor. The size of each PSF is among 300 µm. Experimental PSFs were capturated using a CCD camera.

The object under test was an extensible terrestrial telescope manufactured by the British company T.T. & H. Ltd in 1916, comprising four extension brass tubes, which can be seen folded (a) and unfolded (b) down here.

(a)

(b)

(a)

(b)

(c)

Here the results of the application of our method can be seen: (a) Reference image, (b) real images seen through the antique telescope and (c) simulated images of parabolic antennas. We obtained the simulated ones convolving the PSF of the instrument with (a). Using this method we can see the images as they would have been seen in their time without removing the instrument from the museum.

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