Introduction

In Chapter 1 we will explore the necessary mathematics, in order to model and study imaging systems. We will start by going through the formal definitions of the Fourier Transform and its inverse, while considering its discrete counterpart, and some properties relevant to optical systems.

Chapter 2 will give us an anatomical description of the eye will help us identify the optical purpose of its components. This way we can better describe the biological context of the photoreceptor cells being counted. The Stiles-Crawford Effect, generated by the waveguide-like properties of the cone cells in the human eye, will be briefly described.

Chapter 3 is for discussing Optical Systems OS in general, their parts and how to model and study them through Fourier Theory. Specially, the study of the Fourier Transform in relation to the Point Spread Function (PFS).

Finally, Chapter 4 is for uncovering the results obtained from MATLAB simulations regarding the coronagraph. Specially the interaction between a phase vortex mask or fork hologram and the light that "passes" through the system. We as well point out the Rayleigh Criterion. This concept helps us find the closest distance between two point sources in order for them to be optically resolved. We will also cover the fact that it can be used as a huge increase on cone counting accuracy while decimating the costs of AO hardware.

Background

The French astronomer Bernard Lyot introduced the coronagraph in 1931, which he invented to observe the corona without having to wait for a solar eclipse; since then, coronagraphs have been used at many solar observatories. According to the Merriam-Webster definition, a coronagraph is an instrument that blocks out light emitted by the sun's actual surface so that the corona can be observed.

The applications of chronographs in telecommunications are very promising. With this kind of technology we can effectively eliminate relevant quantities of any unwelcome background noise, which in turn, facilitates the interpretation of images, sounds or any electrical signal.

Many types or coronagraphs exist, one of them takes advantage of the properties of optical vortex (OV) fields, so, we will referring to OV coronagraphs throughout the text. An optical vortex coronagraph uses a phase-mask in which the phase-shift varies azimuthally around the center. Several varieties of optical vortex coronagraphs exist, but we will be using the scalar optical vortex coronagraph. It is normally based on a phase ramp directly etched in a dielectric material, like fused silica, or created in a Liquid Crystal Display LCD.

In 2000, Swartzlander proposed a method that uses a different coronagraph than the one Lyot perfected. They used as a window the dark core of an optical vortex to examine a weak background signal hidden in the glare of a bright coherent source (Swartzlander 2000). The proposed method is intended to be used as an improvement to the Rayleigh resolution limit. A phase vortex helps us filter out the glare from one of the sources and see the other one more clearly. We can see a diagram of their imaging system in Fig. 1. Swartzlander reports that signal enhancements of at least 7 orders of magnitude may be achieved. This procedure was successful in obtaining optical images of an exosolar planet 25 light years away from Earth (Kalas, P. Graham, J. R et al. 2008).

The optical vortex coronagraph used by Swartzlander et al. was arranged in a Fourier transforming configuration, with the vortex lens placed in the focal plane of a telescope. The telescope had a circular aperture with no central obscuration, a so- called Lyot stop was placed in the exit pupil (where the entrance aperture is imaged) to prevent diffracted light from the star from reaching the detector. The vortex lens had a negligible effect on light from off-axis light sources, which transmitted through the Lyot stop.

Coronagraphs and the retina.

Today, medical researchers all over the world are very interested in counting photoreceptor cells in the retina. This information has great potential for screening and diagnosis of diseases that affect human vision (Mohammad et al.).

Many are trying to improve that cell counting method with the use of

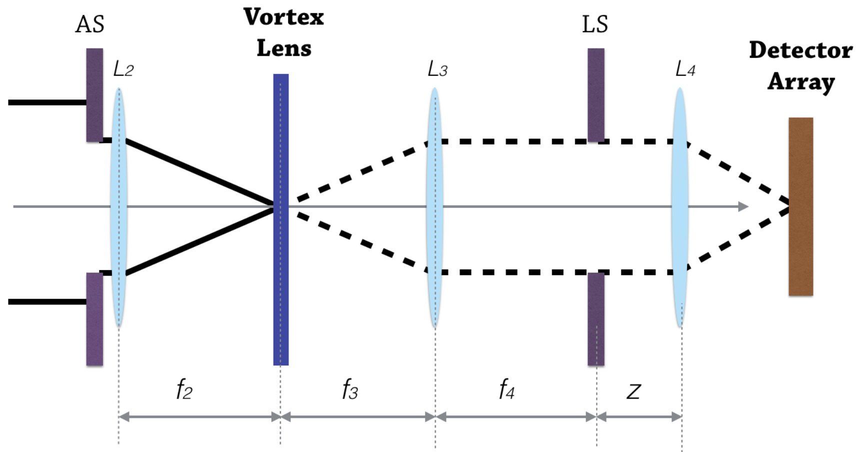

Figure 1: Swartlander's et al. coronagraph

systems based in Adaptive Optics. These systems are very expensive and somewhat restricted, as we will see later, but heavily utilized throughout the community (Kawano). For example, Choi et al. demonstrated in 2006 a clear correlation between functional vision loss and the extent to which cone density decreases as measured from AO retinal images of retinal dystrophies.(Choi et al.).

It is the opinion of some, that the most significant limitation to using flood-illuminated AO cameras is that on almost half of the healthy subjects accurate cone counting can't be performed (Feng et al.). Improving image acquisition and processing methods are clearly related to the increase in successfully obtaining images for which we can accurately identify cones. Particularly in older patients and in patients with retinal disease (Feng et al. "Repeatability of in vivo parafoveal cone density and spacing measurements."). Another limitaion of AO hardware is the difficulty of its propietary software. Fan Yi PhD from QUT, one of the leading experts in the field of Visual Optics, mentioned to us that some of the software used to control these AO cameras has a lot of room for improvement.

As we said, there is a huge interest in making noninvasive measurements of the human cone mosaic (Bidaut Garnier et al.), but the task of labeling each individual cone is unavoidable. As reported by Kenichi et al., a popular cam "AO detect TM" underestimates the cone packing density in the macula significantly. Thus, rendering manual counting necessary for maintaining any resemblance of accuracy (Kawano). Manual labeling is a time-consuming process, setting the motivation for the development of an automated method.

As a result, the clinical and research utility of adaptive optics remains limited by a lack of automated cone sampling and density representation methods. Further study is needed as it becomes necessary to identify sources of poor image quality, and to determine methods to improve the rate of successful imaging (Feng et al.).

We will be focusing on improving the performance of retinal cone counting systems that study the surface of the fovea. As part of this thesis, we were able to successfully simulate a cone detector system, that has the potential to improve accuracy, and with a fraction of the cost of AO sensors and mirrors. It also increased the natural Rayleigh Limit Criterion.