ECE5554 Computer Vision Midterm - Project Update

Towards Keratoconic Image Generation

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1 Introduction to keratoconus

Keratoconus is a non-inflammatory degenerative eye condition where the cornea of the eye undergoes irregular thinning and gradual bulging till the cornea becomes conical.[1] This causes visual distortion such as multiple images, ghosting, astigmatism. Patients suffering from keratoconus often find it hard to detect objects. For example, consider the two images in Fig.1. The one on the left is the normal vision and the one on the right shows what the moon appears to a person with keratoconus. Prior computer vision has been applied extensively towards accurate detection, diagnosis and correction of keratoconus.

Figure 1: Left: Normal image of moon. Right: Blurred, shifted and copies as seen by patient

2 Problem Statement

The broad goal of this research project is to generate keratoconic images using existing models of the human eye. This would help us create a sort-of encoder and decoder which would create keratoconic images and possibly correct them and recreate the original image.

3 Literature Review

Mathematical models to represent the cornea's mechanical and optical properties is an area of research that helps refractive surgerys, corneal transplant (keratoplasty), intrastromal ring implant, implants of intraocular lens (IOL) etc. The keratoconic cornea changes shape under intraocular pressure because of localized corneal tissue loss. This makes the cornea conical and affects refractive power considerably. A topology map of the cornea along with a mathematical model of the eye can be used to generate keratoconic images for a particular person. Generally, a cornea suffering from keratoconus is conical at the center. In some cases, this might be shifted. To model such changes in the cornea, we need to investigate models of the eye with parameters for cornea thickness. We might make simplifying assumptions about the cases, for example, to begin with, we consider the case with conical at the center of the cornea and not the other cases. Comparing this with a normal cornea, we can have a set of parameters that can be tweaked to get the correct image.

1. **Finite element method** is used to model elasticity and rigidity of the cornea [2]. This paper did not check for optical properties and conducted experiments in vivo

2. **Iteratively re-weighted bi-cubic spline method** for topographic representation of cornea [3]. This paper conducted studies on two real eye samples, one with regular astigmatism and the other which had refractive surgery to correct the defects. This method is more accurate and stable than the general quadratic function of higher order Taylor polynomial methods to describe the topography of the cornea

   General quadratic function is used to make intraocular lens [3]

   Higher order Taylor polynomials used to describe data from videotopograher [3]

3. Anderson's model of the cornea is a **detailed 3-D finite element method-based model** that can model disease or injury such as keratoconic eyes [4]. This is the older method based on shell theory which is no longer used. Modern method is ray tracing.

4. **Zernicke polynomials** to simulate cornea [5, 6]

5. Building models from **Shack-Hartmann wavefront device output** [7, 8]

3.1 How to select an optical model

Atchison et. al. [9] suggest starting from the simplest model that is adequate for our application, one that might be functionally accurate but anatomically inaccurate. To that end, we can start by modeling only the cornea, a single refracting surface or reduced eyes.

Notes : Hysteresis is ocular resistance due to the combined effect of the parameters such as corneal thickness, ocular rigidity, and viscoelastic properties. [10]. Statistical modelling of light intensity distribution to classify between normal and keratoconic eyes [11]

4 Next steps

In order to define an implementation for generating images with visual aberrations, I can see two paths.

Path 1 : The first step would be to pass a normal image through a "lens" filter. By a lens filter I mean, this filter would model the image created on the retina by a normal cornea. This can be obtained using a geometric transformation of the image using the OpenCV API. The second step would be to replace this lens filter with a matrix representation of a Zernicke polynomial [5]. A Zernicke surface which models the conic shape of the cornea in a keratoconus patient will give us a certain image on the retina that can be integrated into the retina model in OpenCV. Overview of process is shown in Fig.2.

Path 2: In order to simulate the actual human vision of a particular subject, it is necessary to obtain a topographical map from Shack-Hartmann wavefront device. This device measures human eye aberrations accurately and is used to detect astigmatism, cataracts, kerataconus, among others. The output of this device is an image of bright points. I will then convert this image into a point spread function (PSF) that will show the distribution of light energy based on the wavefront. From [8], we can use the vision-realistic rendering algorithm to generate keratoconic images as shown in Fig.3.

References

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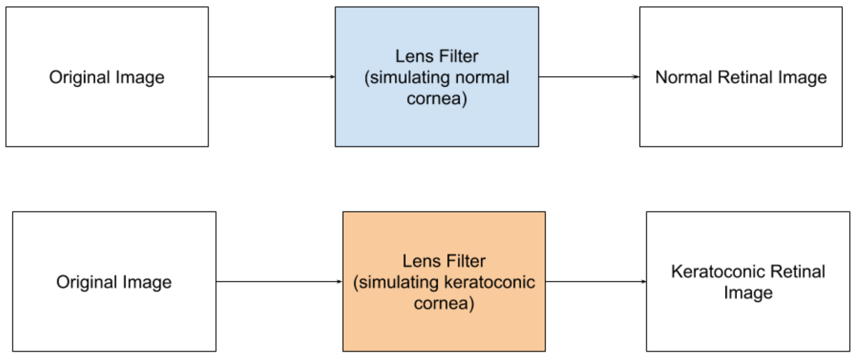

Figure 2: Workflow

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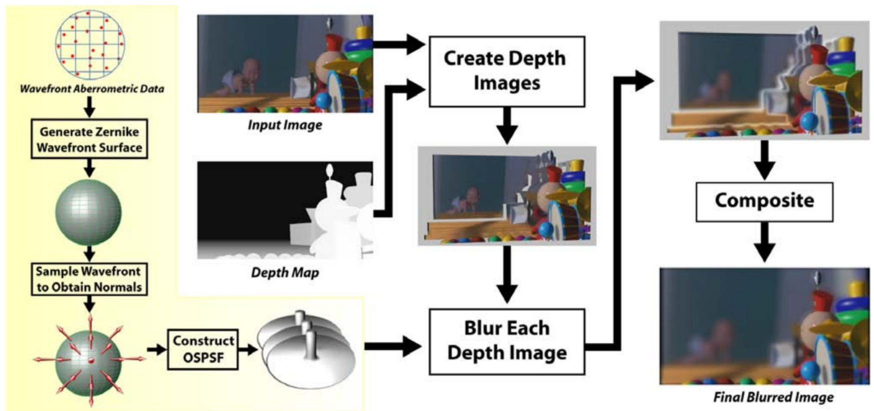

Figure 2: Overview of the vision-realistic rendering algorithm.

Figure 3: Overview of vision-realistic algorithm [8]

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