Extracting Image from Corneal Reflection

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***Abstract*—Just like a mirror, the cornea of human eye can reflect images of the surrounding. Corneal reflections can reveal surprisingly rich information about the subjects surroundings. This project implements algorithms that extracts corneal reflection from the eye and combines the images from the two corneas to form a panorama of the view. This panorama reveals exactly what the subject in the image is looking at. It has applications in several fields including security, computer graphics, eye image analysis, human affect studies and visual recognition.**

I. Introduction

The cornea of the eye and the camera viewing the eye form a catadioptric imaging system. The cornea, covering iris and pupil is protected by tear fluid and thus is a highly reflective surface. When placed in front of the eye, a high resolution camera is able to obtain distorted partial reflection of a person's current field of view. It could reveal subtle aspects of the physical environment such as where the person is, what the person is looking at and the structure of objects. There are many applications of this such as facial reconstruction and relighting, face recognition. One application of interest is reconstructing scene panorama. The wide angle view of the environment can be used to extract information about the location and circumstance of the subject when the image was taken and could be used for surveillance or identification purposes.

II. Related Work

A. *"Corneal Imaging System: Environment from Eyes"*

Nishino and Nayar [3] provide a detailed analysis of corneal imaging system including field of view, resolution and locus of viewpoints. They use a geometric model of cornea based on anatomical studies and estimated its location and orientation from a single image of the eye. Their work has been used before to recover coarse aspects of the physical environment such as ambient lighting conditions. Basically, the image from eye reflection can be flattened even if the eye is looking to the side. Through our project, we are looking towards using the extracted corneal images to reveal aspects of the subject's social environment instead.

B. *"Identifiable Images of Bystanders Extracted from Corneal Reflections"*

In their experiments, Jenkins and Kerr [5] took high resolution passport-style photographs of people while a group of bystanders stood behind the camera watching. The subjects eye were zoomed in on and faces of the bystanders were extracted. Their experiments revealed that the bystanders were not only visible but identifiable. This work has many application especially in crime scenes. The investigator could recover images of bystanders from the subject's eye and can further use facial recognition to identify hidden information. The authors however haven't provided any implementation for the image extraction. They used manually zoomed-in images to conduct the experiment whereas we are implementing the algorithm required to extract the reflection from the eyes.

C. *"Corneal Imaging Revisited: An Overview of Corneal Reflection Analysis and Applications"*

Nitschke et al.[2] describe corneal imaging techniques which uses the eye model of two intersecting spheres. They use the reflection in the user's eyes to calculate the relation between the camera and the monitor. The calibrated camera setup is then used to track a person's point of gaze. The algorithm uses a three-step approach. First the eye pose is estimated and a low resolution environment map is created and then registration of multiple maps and finally construction of high resolution image. Although this implementation was useful for our purpose we decided to build upon Starburst algorithm [1] since it aligned more with the scope of the project.

III. Contribution/Method

The method by which we extract the image from the corneal reflection in the eye of the subject in the picture is given in detail in this section. We made a contribution by developing a code based on the corneal reflection and localization of algorithm given [1]. Inside the eye, the corneal region is the brightest areas. But we cannot use a constant threshold since for different people and for different surroundings, the thresholds values that separate the corneal regions can vary. Thus, Adaptive thresholding technique is used to localize the corneal reflection. Also, since the cornea is a part of the eye, initially we crop the image to a certain size that contains the cornea and the Sclera of the eye. Thus, we decide a window size for the image and the center of the eye approximately and give that location of the eye. Then we use adaptive thresholding, where we calculate a new threshold each time there is a new input image in the code. Once we input an image, we start with a maximum value of threshold and convert the image into a binary image. The threshold is lowered in an iterative manner.

At each step where a new threshold is used and a new binary image is formed from the original image, we also calculate a ratio of the region that has the largest area and average area of the regions. Out of all the thresholds, we use decide upon the threshold that gives us the largest ratio. We then calculate the center and the radius of the image in the cornea using the largest area as our corneal reflection. In the code, we run a 'for' loop to reduce the threshold iteratively and at each step we calculate the areas and the center of the areas using the `connectedComponentsWithStats()` function. At each iteration, we also calculate the ratio of the areas and store it and compare the ratio with the previous step. As soon as the ratio from the current step becomes lower than the ratio from the previous step, we break the loop and the center of the maximum area recorded at that step becomes the center of the reflection. Thus, adaptive thresholding and localization are used to find the center and the area of the reflection in the eye. To determine the full extent of the corneal reflection, the paper [1] assumes that the intensity profile of the corneal reflection follows a bivariate Gaussian Distribution. Thus, we find a radius for the image that mimics the radius that is associated with the maximum decline for a Gaussian. For this, we use an initial radius = $\sqrt{area/pi}$ and then we converge the radius using Gradient Descent using the formula:

$$\frac{\int I(r+d, xc, yc, \theta) d\theta}{\int I(r-d, xc, yc, \theta) d\theta}$$

Once the radius converges such that the difference between the previous radius and the current radius is negligible, we calculate the final radius equal to 2.0*r. The authors in the paper indicate that they take the a circular region using the center (xc,yc) and the radius 2.0*r but for our purposes we use a square region with a width and a height of 5*r. In the code, we model the gradient descent formula using 'for' loop and integration. Our 'd' is 1 pixels and the theta varies from 0 to 360 degrees. In this manner, we refine the radius using gradient descent to get an optimal region from the photograph of the eye we initially input in the code.

Next, we use Gaussian filter to filter the image for noise reduction. We use a Gaussian filter of size 5 and a standard deviation of 2. Once, all the corneal reflections are extracted from the images by the same subject, we stitch these extractions together get a panorama view from selfies clicked by the subject. In code, this is done using the stich.sticher() function.

IV. Results

Experimental results verify the implementation under both indoor and outdoor lighting conditions. The input images were taken using a calibrated phone camera. Three different scenes were used for testing. The eye images contains corneal reflection from the environment. Next to them are the close view of the corneal limbus - cropped images followed by outside view towards the cornea.

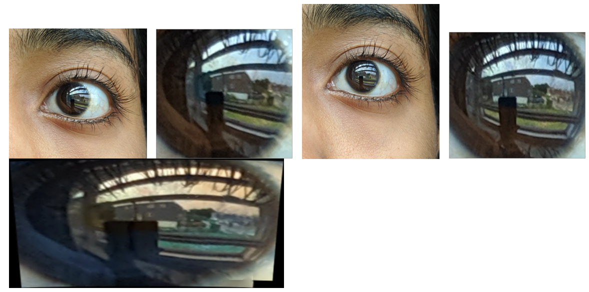

Fig. 1. Subject looking at the backyard

Fig. 2. Subject looking around the room

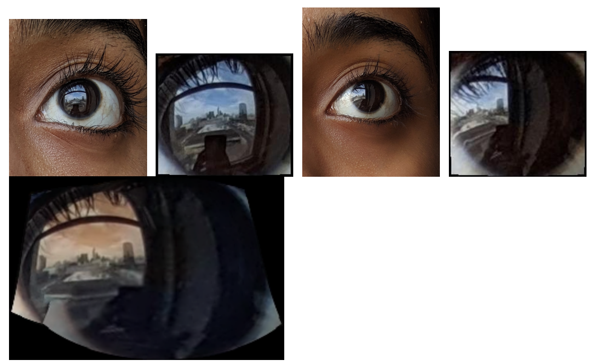

Fig. 3. Subject looking at the Philly skyline

References

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