Enabling Diverse Eye Anatomy Tracking

UCLA Samueli School of Engineering
SUMMER UNDERGRADUATE RESEARCH PROGRAM

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Background & Introduction

Eye tracking is a sensor technology that can detect a person's presence and follow what they are looking at in real-time.

- Need to capture the underlying distribution of data for reliable results
- Performance depends on how well the test data distribution is covered by the training set
- Data collection is expensive!

Solution: Render images from synthetic eye model!

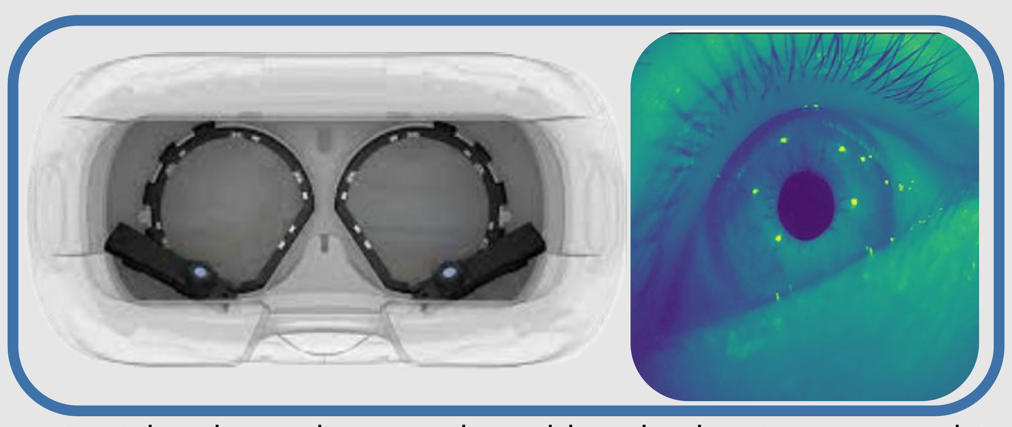

Fig 1. VR headset with eye-tracker add-on that has 1 camera and 2 infrared light sources per eye. The image on the left is typical data captured by eye tracker

Fig 2. Integration of our eye model with remeshed dense 3D head scan of subjects showing diverse human physiology (left and middle image). The image on the right shows previous model which is not anatomically accurate (Only the left eye was replaced with eye models)

Applications

- Assistive technologies for disabled individuals
- Neurological Disorder Diagnosis
- Surgical Robotics
- Medical Education

What can be improved?

Previous work doesn't use an anatomically accurate eye model creating a potential domain gap between real and synthetic data

Hypothesis: eye tracking is a function of eye anatomy and using a more anatomically correct/diverse eye model result in improved eye tracking performance.

Key Terms

- **Gaze estimation** is the process of identifying the line of sight for each eye of a human user at a single instant
- **Rendering** is the process of generating a photorealistic or non-photorealistic image from a 2D or 3D model by means of a computer program.
- **Iris**: The colored membrane around your **pupil**.
- **Cornea**: The clear front outer layer of your eye. It covers the iris.
- **Sclera**: The outer coat of the eyeball that forms the whites of your eyes.

Methods and Design

The eye model was created in Blender 3.6 (computer graphics software):

- model the cornea as a biconic surface for anatomical accuracy [2]
- Iris curvature depends on eye health, Iris can be flat or curved in our model [3]
- utilize dense 3D head scan of 10 subjects for diversity
- use physiological parameters reported in previous research
- models head-slippage by generating random jittering

Fig 3. Blender Logo

Biconic Surface Equation

$$z(x,y) = \frac{\frac{x^2}{R_x} + \frac{y^2}{R_y}}{1+\sqrt{1-\frac{(1+Q_y)y^2}{R_y^2}-\frac{(1+Q_x)x^2}{R_x^2}}}$$

for each meridian and rotation angle ϕ:

- R_x, R_y are principal radii of curvature
- Q_x, Q_y are asphericity values

corneal diameter: 11.79mm
anterior cornea measurements [2]
Rx: 7.63±0.29mm
Ry: 7.4±0.28mm
Qx: -0.46±0.14mm
Qy: -0.48±0.14mm

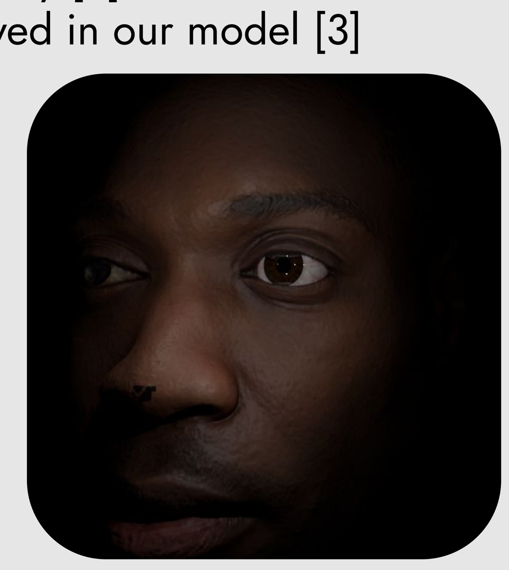

Fig 4. Image showing realistic lighting conditions for Virtual Reality data collection

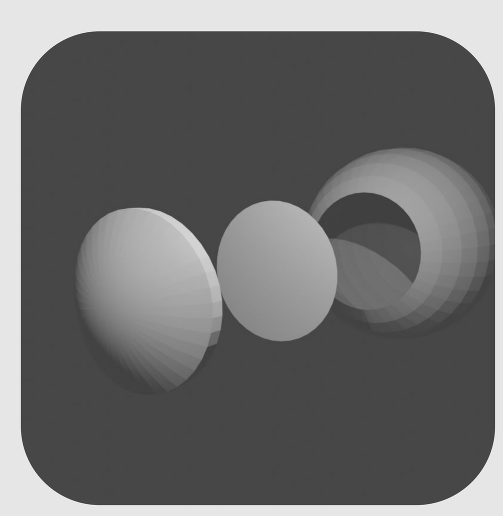

Fig 5. Deconstructed view of the mesh that makes up our eye model (cornea, iris, sclera from left to right)

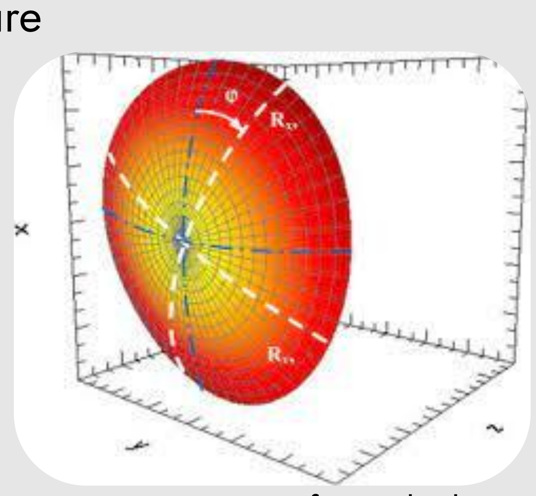

Fig 6. Biconic surface which is used to model the cornea

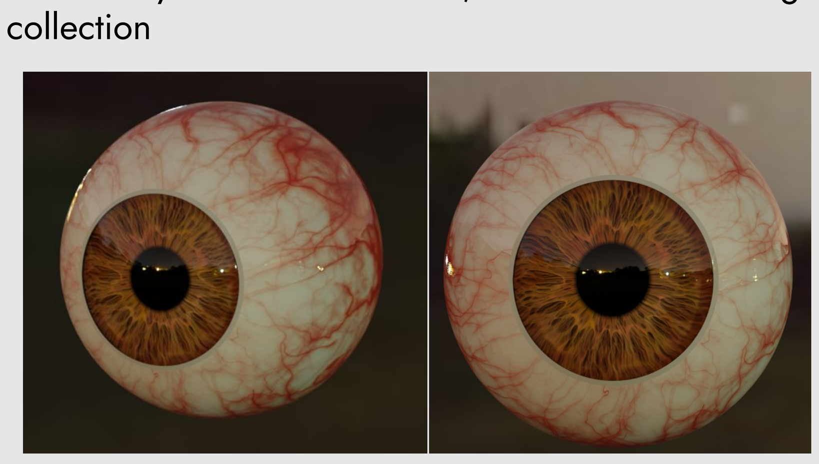

Fig 7. Rendered view of our standalone eye model (off-axis view on the left and on-axis view on the right)

Results & Discussion

Results

- Modeled the refractive caustics of the cornea
- Created geometrically accurate sclera and cornea
- Automated scene setup eye model creation using python scripting

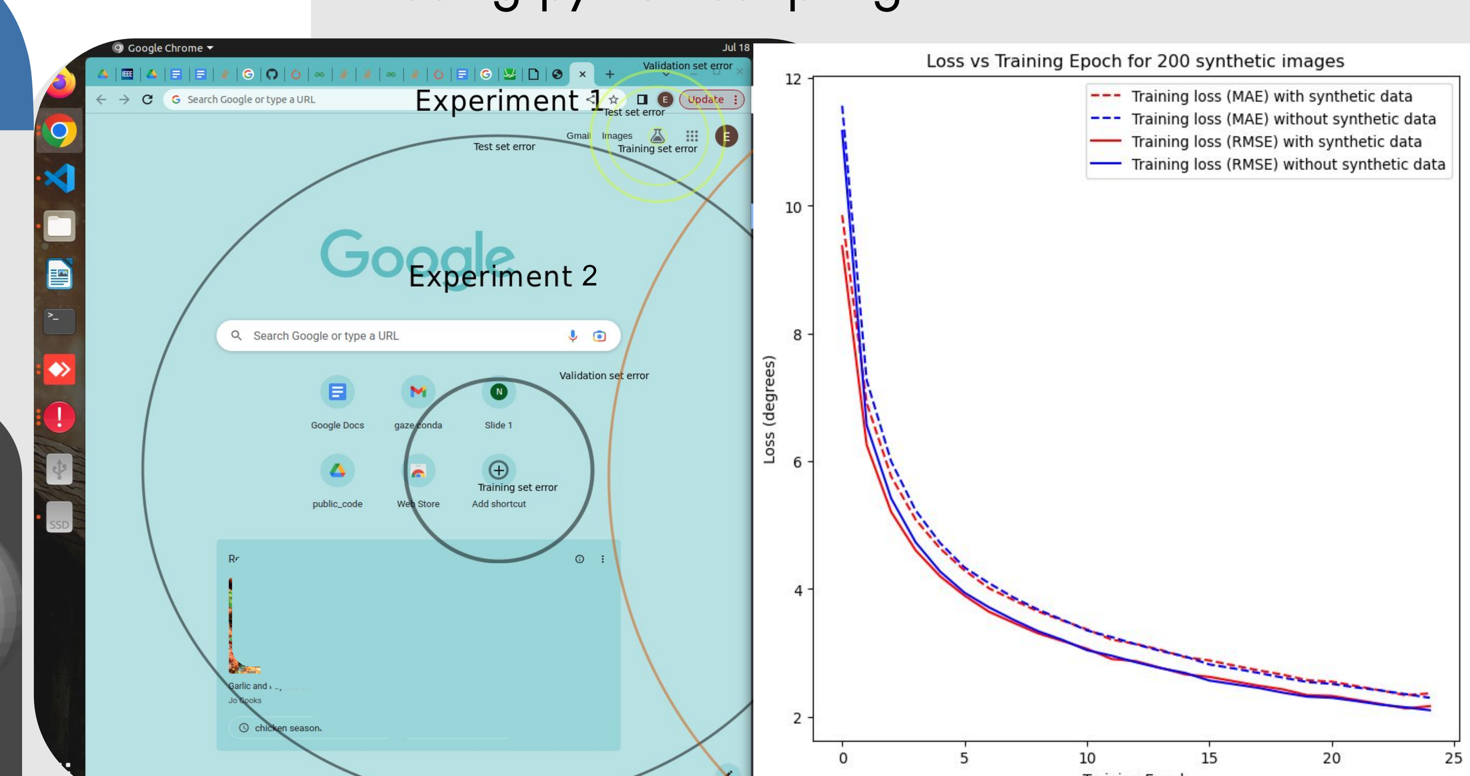

Fig 7. Visualizing gaze estimation error with real data only on the left and a learning curve depicting improved performance with synthetic data on the right

Trained a 6 layer convolutional neural network on 200 synthetic images. Performance initially improved by more than 2 degrees, but this improvement diminished due to the following **limitations**:

- Lack of additional synthetic data (ideally more than 100k)
- Current camera configurations for rendering images does not precisely match the actual camera locations
- Textures need to be modeled with Infrared textures
- Skin texture can be improved to look more realistic

Conclusion

Why is this important?

To ensure consistent and reliable results for a diverse range of individuals, it's vital to create equitable eye tracking technology which is underscored by its clinical applications including the diagnosis of conditions like Parkinson's and assistive technologies such as gaze-based text entry for people with limited motor function (i.e. cerebral palsy). One of the main goals of my research is to reduce bias related to diverse eye structures and human physiology.

Next Steps

- Will start fully automating the rendering process to render more images and increase the accuracy of the neural network
- Will start using infrared textures instead of textures in the visible spectrum
- Will determine the exact location of eye tracking cameras to improve the quality of synthetic images

References

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[2] Edgar Janunts, Marc Kannengießer, Achim Langenbucher, Parametric fitting of corneal height data to a biconic surface, Zeitschrift für Medizinische Physik, Volume 25, Issue 1, 2015, Pages 25-35, ISSN 0939-3889, https://doi.org/10.1016/j.zemedi.2014.02.005.
[3] Navarro R. The Optical Design of the Human Eye: a Critical Review. J Optom. 2009;2(1):3–18. doi: 10.3921/joptom.2009.3. Epub 2010 Nov 4. PMCID: PMC3972707.

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