Simulating the human eye

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Introduction

The human eye consists of several anatomical parts. Each part contributes to direct and peripheral sight, perception, and eye movement. The key parts of the eye that will be explained in this technical note include the cornea, lens, aqueous chamber, pupil, and retina. Additionally, image interpretation and eye movement will be introduced.

Eye Anatomy

Cornea

The outermost part of the eye is the cornea, which controls the amount of light that enters the eye. The cornea is where the first and largest refraction of light occurs namely when light bends as it enters from air to the cornea (Serbanescu, 2004). Refraction occurs when light bends when going from one medium to the next, like air to water (Mauser, 2011).

Aqueous Humor

Once the cornea refracts light, it travels to the front chamber of the eye. This chamber contains liquid known as the aqueous humor located directly behind the cornea. The aqueous humor liquid flows from the back of the iris toward the front of the lens through the pupil where it has two different drainage paths. When the aqueous humor is not drained properly, it can lead to a pressure buildup in the eye, a symptom typically seen in glaucoma patients. This pressure buildup causes gradual, irreversible loss of peripheral vision (Villamarin, Roy, Vardoulis, Reymond, Stergiopulos, 2012).

Pupil

After being refracted by the aqueous humor the light

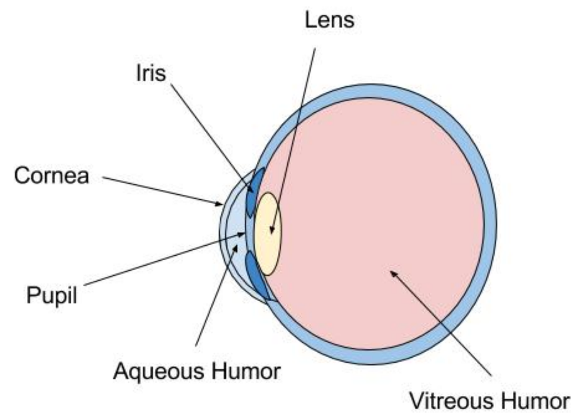

Figure 1. Basic anatomy of the Human Eye

beam enters the pupil. The pupil is a hole that absorbs all light making it is black in color. While it appears that the pupil size changes, it is actually the iris; which is the colored part of the eye that changes the diameter of the pupil. The iris changes to control the amount of light that is entering the eye; it gets larger in darker environments and smaller in bright environments to protect the retina.

Lens

Upon successful passage through the pupil the light beam is then directed toward the lens. The lens receives light beams from the cornea as explained above. The lens is unique is because of its "accommodating" properties, which allow it to change its shape to better focus on images either in the distance or close up (Serbanescu, 2004).

Retina

Directly behind the lens is the vitreous humor chamber that maintains the general shape of the eye. Beyond the vitreous humor is the retina, which is the inner layer of the eye connected to the brain via the optic nerve (Atchison, 2000). The retina is light sensitive and is therefore located further within the eye to ensure it is not damaged by light intensity. The human eye can only see part of the visual spectrum (370-730 nanometers) (Kolb, 2007). This is why infrared (ranging >700 nm) is used to eye track, since it is considered an "invisible light."

How the eye interprets images

When light enters the eye and reaches the retina, the image is actually inverted. Cameras work in a similar manner where the shutter is analogous to the iris contracting to filter light, and the image is inverted (Atchison, 2000). This occurs because of the refraction mentioned earlier. The human lens is comparable to a camera lens, where the lens is flat in the center and curves on the ends. It is the curvature of the lens that causes light to bend when it enters at an angle (Tsuchitani, 2007). Humans do not perceive images as inverted, because the brain processes the images changing them so they appear right side up.

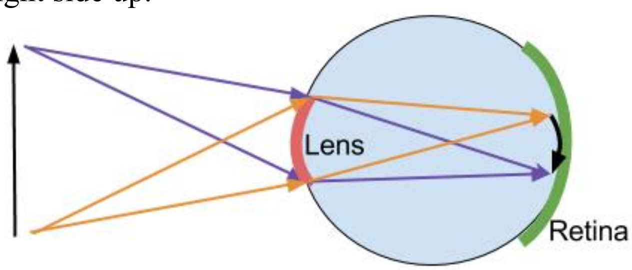

Figure 2: How the eye interprets images

How the eye moves

There are several muscles that contribute to the way the eye moves. Namely, there are six key extraocular muscles. They are critical in moving the eye to focus on a particular image and to stabilize the given image on the retina. Extraocular muscles are often referred to as pulleys. The muscles are "restoring forces" which allows them to bring the eye back to the location at which the net force is equal to zero (Wei, Sueda, Pai, 2010).

Types of eye movement

There are four different types of eye movements that have been documented: saccadic, smooth pursuit, vergence, and vestibulo-ocular (Augustine, Fitzpatrick, Purves, 2001). This report will focus on saccadic eye movements, because these movements are what make tracking the human eye a challenge. Saccade means the sporadic and sudden movements as the eye moves from one fixation point to the next (Augustine, Fitzpatrick, Purves, 2001). Saccade movements occur when someone is reading, looking around a room, or, move from one light stimuli to the next to test the peripheral visual field as in done with glaucoma. Eye tracking is difficult not because a person moves their eyes from one location to the next, but rather because even when someone is focusing on a fixation point, there are involuntary saccade movements that occur (Augustine, Fitzpatrick, Purves, 2001). Saccadic eye movements can reach speeds of 500 degrees per second, which makes tracking the eye very difficult with current camera technology.

Bionic Eyes

There have been many successful attempts at creating bionic eyes that simulate a specific aspect of the human eye, but none have completely captured its complexity. One such study presented at the IEEE Conference on Robotics and Biomimetics investigated the problems with speed and accuracy of current robotic technology (Wang, Zhu, Zou, Zhang, 2015). Given current technology there still remains issues with mimicking binocular vision, head-eye coordination, and microsaccades. Microsaccadic movements, which occur during prolonged eye fixation and contain depth and edge information, are considered an unresolved topic. Another research group in Germany created an eye mechanism that can reach up to 2,500 degrees per second, which is well above the eye's saccade speed of 500 degrees per second (Guizzo, 2010).

Summary

The human eye is a complex organ, which makes light traveling from the cornea toward the optic nerve no trivial matter. While this report has investigated light traveling through an ideal eye there are many diseases that can affect the way an eye performs. One such example is that of glaucoma, which affects three million Americans, and is the leading cause of irreversible blindness worldwide. The human eye has been the topic of many recent research papers in hopes of creating a bionic eye so we can further eye disease, robotic, and neural research.

References

Atchison, D. A., Smith, G., & Smith, G. (2000). Optics of the human eye. http://publicana.ru/files/opticheskaya-sistema-glaza.pdf

Augustine, GJ., Fitzpatrick, D., Purves, D., (2001). Types of Eye Movements and Their Functions. Available from: https://www.ncbi.nlm.nih.gov/books/NBK10991/

Guizzo, E. (2010, November 1). Superfast Robotic Camera Mimics Human Eye. Retrieved March 11, 2017, from http://spectrum.ieee.org/automaton/robotics/industrial-robots/superfast-robotic-camera-mimics-human-eye

Kolb, H. (2005, May 1) [Updated 2007, Jul 5]. Facts and Figures Concerning the Human Retina. In: Kolb H, Fernandez E, Nelson R, editors. Webvision: *The Organization of the Retina and Visual System* [Internet]. Salt Lake City (UT): University of Utah Health Sciences Center; Retrieved from: https://www.ncbi.nlm.nih.gov/books/NBK11556/

Mauser, M. (2011, January). Experiencing Light's Properties Within Your Own Eye. *The Physics Teacher,49*(1), 19-21. doi:10.1119/1.3527748

Serbanescu, R. M. (2004). *The human eye*. Lecture presented at Physics 238Y Lecture 25 in University of Toronto, Toronto. Retrieved from: https://www.physics.utoronto.ca/~sandra/PHY238Y/Lectures/Lecture25_04.pdf

Tsuchitani,C., Ph.D. (2007). Visual Processing: Eye and Retina. *Neuroscience Online: An Electronic Textbook for the Neurosciences*, http://neuroscience.uth.tmc.edu/s2/chapter14.html

Villamarin, A., Roy, S., Hasballa, R., Vardoulis, O., Reymond, P., & Stergiopulos, N. (2012). 3D simulation of the aqueous flow in the human eye. *Medical Engineering & Physics, 34*(10), 1462-1470. doi:10.1016/j.medengphy.2012.02.007

Wang, Q., Zhu, Z., Zou, W., & Zhang, F. (2015). Overview of motion control on bionic eyes. *ROBIO*.

Wei, Q., Sueda, S., & Pai, D. K. (2010). Physically-based Modeling and Simulation of Extraocular Muscles. *Progress in Biophysics and Molecular Biology*, *103*(2-3), 273–283. http://doi.org/10.1016/j.pbiomolbio.2010.09.002