Interactive Simulation WS15/16
Project Report

EYES - Exchange Your Vision Simulator

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ABSTRACT

Many diseases can be treated well if recognized early. This is also true for eye diseases. So the point of the program presented in this paper is to let the user experience different kinds of eye diseases in order to show him warning signs and confront him with severe states of those diseases. In order to address especially a young audience, the presentation is in form of a small game developed in Unity3D. The player will experience five different eye diseases in different levels in which he will go shopping and collect special items from his shopping list. This scenario was chosen because we believe it to be a common, well known situation. In contrast to other eye disease simulators, which usually show the effects on static images, this one simulates colorblindness, glaucoma, cataract, and myopia/hyperopia interactively. This is achieved by implementing the diseases as image effects using CGI shaders.

1. INTRODUCTION

Eye diseases have been an issue throughout all the human history. In the beginning the focus layed on their treatment. However, Virtual Reality (VR) is more and more pushing into the consumer market and could therefor be broadly used for education and thus prevention of eye diseases. For example, the risk of suffering from retinal detachment can be greatly reduced if the signs are recognized early and a doctor is consulted. Therefore, educational software can be used. In addition, people would hopefully visit a doctor earlier if they already experienced a good simulation of a severe state of a disease, before they actually are in a severe state. Other applications could be testing designs of consumer products like packaging or traffic signs or other signs at public places.

Although there are many simulations available already, they usually work on still 2D images, 2D video streams or static 3D scenes and don't have any game component. Moreover, more sophisticated simulations are probably not easily available for public use and implementing a simulator using Unity3D in terms of an *eye disease asset set* wrapped into a small game could be interesting for a broad audience.

So we implemented three visual disease simulators in Unity3D and applied them in a small game. In this game the player has to collect items in a Supermarket, which is likely to be a well-known situation to everyone.

2. RELATED WORK

There are different eye disease simulators available in the web already. However, common ones, e.g. found on websites of health organizations, alter still 2D images and display them in the browser. For example, the "Sehbehinderungs-Simulator" of ABSV [2] lets the user choose from five different diseases: "Grauer Star" (Cataract), "Makula-Degeneration" (Macular degeneration), "Grüner Star" (Glaucoma), "Diabetische Retinopathie" (Diabetic retinopathy) and "Retinitis Pigmentosa" (Retinitis pigmentosa). These you can test on different images like being at a crossroads, doing a puzzle or filling in a form. There are also real-time simulations available as described by Zhuming [1] but the implementation is not available online.

With regard to color vision deficiency and Unity3D, there is already a color blindness simulation available in the Unity Asset store based on the work of Brettel *et. al.* [4]. However, they focused on Protanopia and Deuteranopia since these are the most common forms. Machado *et. al.* [12] improved this approach by introducing a model for anomalous cones and trying to take the opponent-stage model into account. Their work provides more generality and is therefore adapted in Section 3.3.1.

3. MODELS AND METHODS

The player is able to experience different types of eye diseases varying in severity. The game is set in a supermarket where the player has to shop for different objects. There are five different eye diseases to experience in five different levels.

3.1 General Game Objects

Each level has the same structure and the same objective, they only differ in what the player has to pick up and the diseases he suffers from. He is able to pause the game by pressing `ESC`, then the time stops and he cannot move any longer. This was done with the "Drag and Drop Pause Menu" Asset.

With the pause menu it is also possible to end the game or jump back to the main menu. When the game starts the player is able to see the menu shown in Figure 1. He is confronted with the choice to play or to quit the program. After he hit the play button he can select between the different eye diseases which starts the game. The quit button ends the game. Each of levels got different eye disease which makes it more difficult to finish the level. In every level the player is asked to collect different items to finish his shopping list. The player starts near the entrance of the shop as seen in Figure 2. You can see that in the top left corner a

Figure 1: Shows the Menu which the Player sees at the beginning.

Figure 2: Gives an overview what the player sees when he selected a level.

text field informs the player about the movement and interaction controls. In the top right corner there is his shopping list to show which items he has to collect and bring to the checkstand. He can walk through the shop using `W`,`A`,`S`,`D` and pick up different items like milk or bacon by pressing the `E`-button.

The jump function of the first person controller was disabled so that the player cannot jump on the shelves or over the counters. If the player presses `I` a shopping bag appears where he can see what items he already picked up. Each item got a small description with some information about it, as can be seen in Figure 3.

The supermarket was build up with the *Supermarket Interior* asset. We added a first person controller and colliders to every object to prevent the player from walking through objects. We reworked all items in the supermarket shelves, too, so that every shelf contains just one item type. This simplified the pick up mechanism a lot. All items were added to a database which is provided with the *Inventory Master* asset. All items got a pick up script which gives the player the possibility to collect them. We decided to put just one item with a pick up script in each shelf so that it is not possible to clear the whole racks.

In the database we added the items and some small description. We choose nearly similar meshes like a milk bottle with a red lid and a bottle with a white lid, to show the problems of a person with color blindness.

The shopping list was done with a separate Canvas, in the top left corner, with a text field to show the task to the player. We put an image on it that it looks like an usual crumpled shopping list, too. The game finish when the time runs out or the player goes to the checkstand. In the end he gets points for each correct item he has picked up and a bonus for the leftover time.

In the end the player got his accomplished points shown and can jump back to the menu to pick a different level.

Figure 3: Shows the Shopping Bag and the tool tip of the items.

3.2 Diseases

As described in [15] and [3] effects like blurry or distorted vision, floaters, and reduced field of view can be efficiently implemented by using fragment shaders. As closer described in Section 3.3 we decided to take the four most common eye diseases in Germany: Colorblindness, Myopia and Hyperopia, Glaucoma and Cataract. The last two are more common among older people but for them it is especially important to recognize as early as possible.

3.3 The Human Eye

Since eye diseases are supposed to be simulated in a virtual environment this section begins with a brief overview over the human eye in comparison to man-made cameras and their abstraction of the pinhole camera used in modern computer graphics.

As can be seen in Figure 4 the human eye is a spherical shaped organ letting light enter through the pupil to form an image of the world on the retina. This hole consists of the cornea, the pupil and the lens which act as an objective enabling the eye to focus on various distances and adapt to bright and dark scenes.

The cornea is a transparent layer with a rather fixed shape and therefore a fixed refractive index. It focuses the light on the pupil which prevents too much light from entering the eye like an aperture. The lens finally focuses the light on the retina by altering its shape which effectively changes its focal length. So unlike in cameras focusing is not achieved by altering the distance of the lenses to the sensor but by altering the focal length.

The retina is photosensitive tissue at the back of the eye consisting of rods and cones. Cones are responsible for color vision and operate in daylight light conditions whereas rods are more light sensitive and provide gray-scale night vision. But unlike camera sensors, where red, green, and blue pixels are evenly distributed, the retina has an in-homogeneous layout.

There is the macula, which is an area with a very high rod and cone density. The central part of the macula is

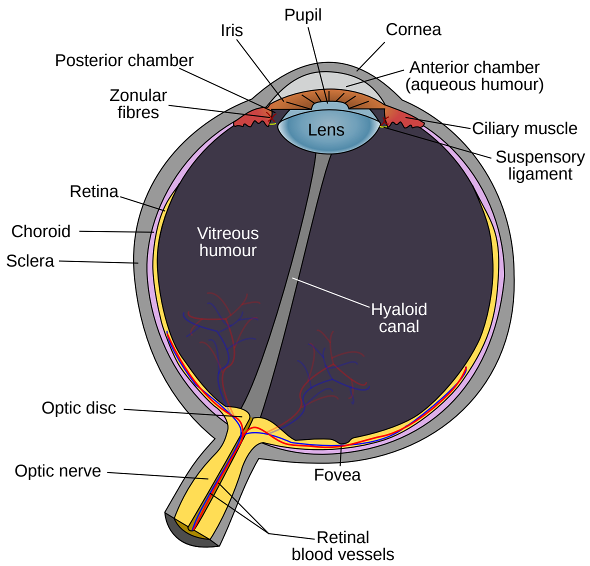


Figure 4: Scheme of the human eye.

called the fovea which consists solely of tightly packed cones. Compared to the macula, the rest of the eye, however, has a fairly low resolution and mostly consists of the non-color sensitive rods.

3.3.1 *Colorblindness*

A first step in simulation color vision deficiency is to understand what color actually is and how humans perceive it. At first color is nothing than an illusion created in our brain. From a physical point of view, light can be thought of a wave and therefore described by the waves spectral intensities $\varphi(\lambda)$. Light hitting the rods and cones stimulates them differently based on the wavelength of the incoming light. This can be described by responsivity curves. For the three cone types L, M, and S of the human eye they are denoted by $\bar{l}$, $\bar{m}$, and $\bar{s}$ and were first determined by a color matching experiment in 1931. Closely related are the color matching functions $\bar{x}$, $\bar{y}$, and $\bar{z}$ which define the CIE XYZ 1931 color space and are known as the CIE 1931 2º standard observer [11]. Given a spectral power distribution φ of a light source, its XYZ color value, also called *tristimulus*, can be computed by the following equations:

$$X = \int \bar{x}(\lambda)\varphi(\lambda) \tag{1}$$

$$Y = \int \bar{y}(\lambda)\varphi(\lambda) \tag{2}$$

$$Z = \int \bar{z}(\lambda)\varphi(\lambda). \tag{3}$$

Color vision deficiency originates from abnormal cone responses or the absence of one or more cone types. People missing one of the L-, M-, or S-cones entirely are called *Protanopes*, *Deuteranopes*, and *Tritanopes* respectively. If all cone types are present but one of them is abnormal in its response, it is referred to as *Protanomaly*, *Deuteranomaly*, and *Tritanomaly* respectively.

The idea of simulating color vision deficiencies is to mimic these changes by computing the new color value based on altered responsivity curves.

Until now the whole discussion was based on actual spectral power distributions. Unfortunately, they are usually not available in computer graphics since colors are usually given as coordinates in sRGB space already.

Brettel and Machado used measured spectral power distributions φ_R, φ_G, and φ_B of their display devices in order to calculate the matrices. Yet, as we don't have those distributions at hand we are going to approximate them.

For further elaboration let all functions be in the space of continuous functions over the visible wavelengths $C([a,b])$ with $a = 390nm$ and $b = 830nm$ and let $\langle f, g\rangle = \int f(\lambda)g(\lambda)\mathrm{d}\lambda$ denote the canonical inner product. Furthermore, let it be noted that the linear combination in the function space transforms directly to the appropriate coefficient spaces for any given stimulus φ and coefficients as in Equation (1):

$$\left(\bar{x}^{\perp}\ \bar{y}^{\perp}\ \bar{z}^{\perp}\right)^{T} = T\left(\bar{r}\ \bar{g}\ \bar{b}\right)^{T} \tag{4}$$

$$\Rightarrow \left(X_{\varphi}^{\perp}\ Y_{\varphi}^{\perp}\ Z_{\varphi}^{\perp}\right)^{T} = T\left(R_{\varphi}\ G_{\varphi}\ B_{\varphi}\right)^{T}. \tag{5}$$

In order to approximate a given spectral power distribution φ let $\bar{x}^{\perp}$, $\bar{y}^{\perp}$, and $\bar{z}^{\perp}$ be an orthogonal basis of the vector space defined by $\bar{x}$, $\bar{y}$, and $\bar{z}$. Then, the best approximation of a color stimulus φ is given by

$$\tilde{\varphi} = X^{\perp}\bar{x}^{\perp} + Y^{\perp}\bar{y}^{\perp} + Z^{\perp}\bar{z}^{\perp}. \tag{6}$$

Especially the sRGB distributions can be expressed via

$$(\tilde{\varphi}_R\ \tilde{\varphi}_G\ \tilde{\varphi}_B) = (\bar{x}^{\perp}\ \bar{y}^{\perp}\ \bar{z}^{\perp})_{XYZ^{\perp}}T_{XYZ\,XYZ}T_{RGB} \tag{7}$$

where ${}_{XYZ}T_{RGB}$ is the sRGB definition based on the XYZ color space and ${}_{XYZ^{\perp}}T_{XYZ}$ the change of basis matrix to the orthonormal basis. By writing Equation (10) in Machado *et. al.* [12] in the following form

$$\Gamma = D\int \begin{pmatrix} WS(\lambda) \\ YB(\lambda) \\ RG(\lambda) \end{pmatrix} (\varphi_R\ \varphi_G\ \varphi_B)\,\mathrm{d}\lambda \tag{8}$$

and using Equation (5) along with Equation (1) in Machado as well as substituting φ_i by $\tilde{\varphi}_i, i \in \{R, G, B\}$ the matrix Γ can be written as

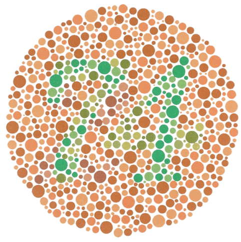
$$\Gamma = {}_{OPP}T_{LMS}\left(\int \begin{pmatrix} \bar{l} \\ \bar{m} \\ \bar{s} \end{pmatrix} (\bar{x}\ \bar{y}\ \bar{z})\,\mathrm{d}\lambda\right) {}_{XYZ}T_{RGB}. \tag{9}$$

The final color vision deficiency simulation can be applied according to the following equation where Γ_{normal} and Γ are Equation (9) instantiated with the normal and altered cone responsivity functions respectively:

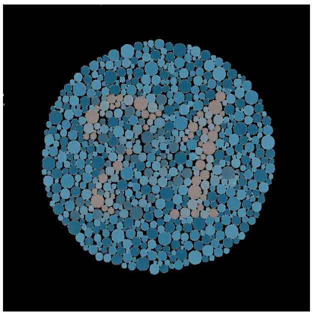
$$\begin{pmatrix} R_S \\ G_S \\ B_S \end{pmatrix} = \Gamma_{normal}^{-1}\Gamma \begin{pmatrix} R \\ G \\ B \end{pmatrix}. \tag{10}$$

This approach is similar to Machado *et. al.* [12] but differs in giving complete freedom in shaping the anomalous responsivity functions. Machado interpolated the shifted functions in order to get more realistic results. Since we wanted to give the player full control over these functions this behavior does not make sense and was therefore not included. The effect of the algorithm on the Isihara color test plate 74 can be seen in Figure 5.

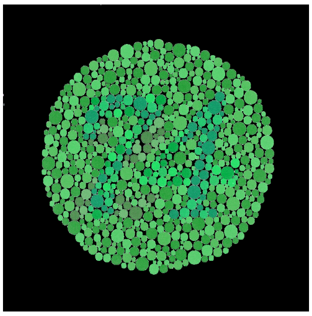
In the game, both approaches can be experienced. We extended the existing asset by the model proposed above by writing a new shader which implements their approach.



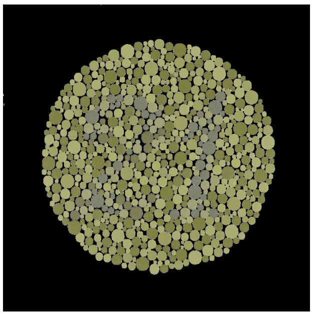
(a) Original plate.



(b) Tritanopic vision with missing S-cones



(c) Protanopic vision with shifted L-cones



(d) Protanopic vision with missing L-cones

Figure 5: Ishihara test plate 74 with different simulations.

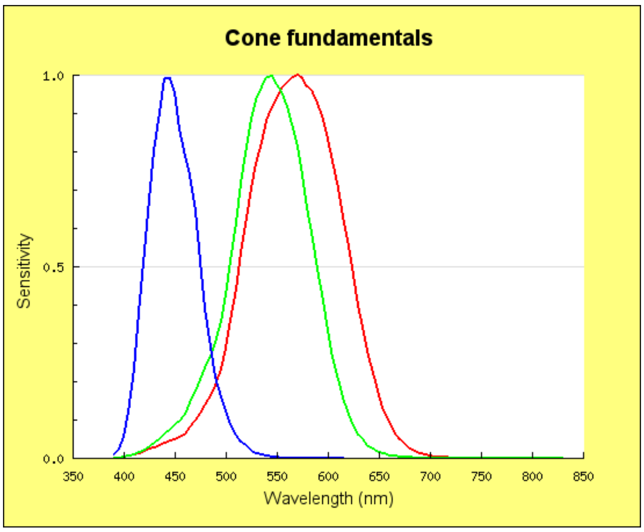


Figure 6: CIE 2º LMS spectral sensitivity functions [10].

Figure 7: Vision of a Person with Glaucoma

Figure 8: Vision of a Person with cataract

3.3.2 Glaucoma

Glaucoma is one of the diseases which damages the optic nerves from the eyes. The result of this is a loss of vision and in the end causing total blindness.

Several studies shown that the eye pressure is the main factor of an optic nerve damage. By Glaucoma the pressure in the eye is too high that the optic nerve gets damaged. Another factor is the blood pressure, this also can in fact the optic nerves.

How much pressure the optic nerves can tolerate is different for each person. So that is why you cant directly say at witch pressure the optic nerves get damaged.

Glaucoma is especially a problem for people with a family history of glaucoma. Or everybody over the age of 60. In case of Africans or Americans the risk is already getting higher at the age of 40.

There are no Symptoms in the beginning, the vision stays normal and it causes no pain. But without treatment, people with glaucoma slowly lose their peripheral vision. That's why people start to see the things at the corner of their vision field badly. That is shown in Figure 7. Over the time the vision field gets smaller and smaller. [8]

That's why we made a shader which blurred the outer region of the vision. So that is difficult to see items in there outer regions of there vision. The picture Figure 7 shows a certain state of glaucoma where already a big part of the outer region of the vision is lost.

3.3.3 Cataract

Cataract is a disease which effects the lens of the eye. The symptoms are: a cloudy of blurry vision, the colors seem more pale, the nightvision is getting much worse and in some cases the person getting some multiple visions.

The protein in the eye arrange to keep the lens clear and let the light pass. But in the older ages the protein cant clear the lens anymore and they starting to clump together. This is called a cataract. Its starts in small areas of the lens and grow lager over the time. Mostly this starts in the center of the lens. Like shown in Figure 8.

The Risk of getting cataract is extremely high for people over the age of 80. The percentage for cataract by people over 80 is about 50. But already at the age of 40 it starts to clump but in this stage is has no effect on the vision. At the age of 50 most of them will start to get vision problems. The risk of cataract it getting higher if you get older but also if you got diabetes it can increase.%. [7]

Because of the symptoms we decided to but a shader on the camara which blurs the hole vision for a bit and the colors look a bit faded.

In Figure 8 you can see the effects, on the vision of a Person with cataract.

3.3.4 Myopia and Hyperopia

Myopia and Hyperopia can have different causes. There are *refractive myopia* types which are caused by a changing refractive index of the cornea or lens and there is *axial myopia* which originates in an increased axial length of the eye as seen in Figure 9. In either case, the focal range of the eye is altered since the lens cannot provide the required focal length for some distances anymore.

At myopia the eyeball stretches and is becoming to long, this can lead to holes in the retina. This can cause damage to the vision. The result of the damage is that the vision gets blurred. In the case of myopia the objects which are far away can not get focused. Many people got problems with Myopia or Hyperopia. In most cases myopia gets diagnosed between the age 8 and 12. Over the year in most cases it will be slightly getting worse. Children of parents with myopia are more likely to get it. Another symptoms which many people suffer is headache if its not corrected by eyeglasses, contact Lenses or a refractive Surgery.

The opposite to myopia is hyperopia, in this case the eyeball is shorter. This changes the shape of the cornea that the lens can cause refractive errors. Hyperopia causes as well a blurry vision but the problem with focusing object is more in the near area, it doesn't effect the vision in the far areas. Hyperopia can effect children and adults, but as well if the parents got it, the children are more likely to get it. It got the same sight effects like myopia, headache or eye pain. The most common treatments are eyeglasses, contact Lenses or a refractive surgery. In order to simulate that in real-time a simulation of focal depth is needed. Yet, it turns out that it is a computationally too expensive task to perform realistic depth-of-field simulations in real-time. Because of that many approaches of faking the effect have been developed. A brief overview over some can be found at [5].

Unity already provides a fast and decent implementation of real-time focal depth in its Standard Assets. This was used to simulate axial myopia/hyperopia by limiting the focal distance.

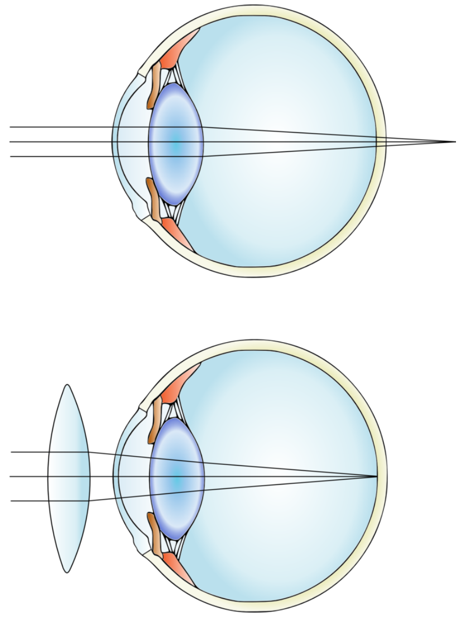


Figure 9: Hyperotic eye and treatment by glasses.

Diopters	59-60 dpt
Focal length	22-24mm
Pupil diameter	2mm - 7/8mm
Cornea-Retina distance	17mm/25mm
f-stop	f/3.2 or f/3.5
Cone of visual attention	55º
Macula	6mm radius, ∼150000 px/mm²

Table 1: Properties of the human eye [6, 14]

The focal depth asset in Unity has various parameters. Interesting ones are *focal distance*, *aperture*, and *blur size*. The blur size in combination with the aperture define the maximum blur radius. The focal distance correlates to the focal length by means of the *thin lens formula*:

$$\frac{1}{d_p} + \frac{1}{d_I} = \frac{1}{f}. \quad (11)$$

Given the cornea-retina distance of 24mm, the focal-length range of the human eye can be estimated by [20,69mm - 24mm] for a distance range from 15cm to ∞.

4. PROJECT REQUIREMENTS

The following section describes how the four project requirements are reflected in the program.

4.1 Science

The game was build CoSMoS compliant, especially the different diseases where researched, modeled, simplified, and implemented. For example the causes of Myopia/Hyperopia were researched and the model adapted to fit the commonly used pinhole camera model used in real-time computer graphics. Furthermore, the model needed to be simplified in order to meet the interactivity requirement. Tests were performed throughout the whole development peaking at the end. Documentation of the scientific parts of the program were created during the development and collected in this paper.

4.2 Gamification

The player can move freely in the supermarket. He gets guidance on the movement controls or environment interaction in form of a text field in the left corner.The goal of the game is to find all the required items in time. The less time the player requires to collect all items, the more points he earns.

4.3 Complexity

Through the different eye diseases, it is every time a new challenge to find the right objects. This will be one of the main learning effects. The other one is to learn with the info texts about the diseases can be recognize and what to do against it.

4.4 Aesthetics

The design of the game is intentionally quite simple so everybody can quickly understand what to do. All text fields were placed in the corners to give the player the option to fully see the influences of the diseases. According to our research, it is the first accessible 3D eye disease simulation with a game component.

The player can get more information of each disease in the menu.

5. SUMMARY & FUTURE WORK

For further development, adding more eye diseases like Kreatoconus, Retinal detachment / Posterior vitreous detachment or Diabetic Retinopathy would be an important point. The severity of diseases could change over the duration of a level or combinations of diseases could occur. It would be nice to have more tasks like driving or working to show the effects in different areas, as well.

The shopping list could become more interactive, i.e. that it tics stuff off when you got it in your shopping bag.

The graphics should be reworked to make it as realistic as possible especially if you using a VR gadget. Vinnikov *et. al.* [15] developed a Gaze-Contingent-Display in order to evaluate the users eye direction and adept the displayed images in real-time. Because the effects of eye diseases follow the eye movement, i.e. are static with respect to the eye coordinate frame, they achieved more realistic results in comparison to rendering gaze-independent images. A consumer solution is under development by the German company SensoMotoric Instruments (SIM) which provides an gaze tracking solution update for the Oculus Rift DK 2 [13, 9]. According to their website they also provide an integration into various VR engines, including Unity3D, available making it especially interesting for this project.

The gaze-direction would be useful to accurately simulate the vision fields and would also be an interesting human interface for the game mechanics.

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