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Characterizing holographic displays via numerical simulations

1. **Introduction**

The goal of the assignment was to gain more insight into the topic of holographic displays and computational hologram synthesis. Holograms reconstruct three dimensional objects with the use of light diffraction by making images that appear to be three dimensional. In this task we simulated viewing process that includes the model of the human eye and process of light diffraction.

1. **Results**

* Hologram synthesis from a single point source

In this exercise a hologram was simplified and represented as a 1D array of complex values. We studied three different ways of synthesizing it. Two of them, Fresnel and Rayleigh-Sommerfeld methods are based on wave interference principle. They generate optic waves for each source point of the light. A summation of those waves forms a hologram plane. The third method, holographic stereogram (HS) is an image-based technique that uses captured images of a scene or a synthetically generated scene that are described using light field (LF) concept. Light field is a vector function that represents the amount of light flowing in every direction through every point in space. Hologram plane contains sampled LF information. Fresnel and RS methods cause troubles in real life applications because they require the scene to be illuminated with a coherent light like a laser. Coherent light is a beam of photons that have the same frequency and are all at the same frequency. The last method, HS simulates the process of acquiring optical information and because it is possible to lower sampling requirements it could be computationally less intensive. On the other hand it can be susceptible to aliasing due to insufficient sampling.

* Retinal image formation model

Function *propagateField\_PWD* simulates a process of propagating a light field from a hologram through the pupil to obtain an image on the retina. In the simulation model the hologram, pupil and retina are represented as three parallel planes. Pupil is referred as a lens and a retina as a sensor. Input parameters of the function are the hologram plane, wavelength of the monochromatic light, input sample step, number of samples, the location of the eye, focus distance of the eye and a size of the pupil.

First the function defines focal length of the eye, the width of the hologram and samples plane grids of a lens and a sensor. Next light propagation from the hologram to the pupil is simulated. The propagation of the light is modelled using plane wave decomposition. Function *plane\_wave\_decomp* generates a plane wave for each spatial frequency. Frequencies are defined based on hologram plane and sampling rate. Waves are combined to get total light field using summation and discrete Fourier transform. Then light propagated from hologram goes through the pupil which is mathematically modelled as a lens. Multiplication of transmittance function of a lens and hologram propagated field generates field after the lens. Next step in the *propagateField\_PWD* function is the propagation of the field from lens to a sensor also using *plane\_wave\_decomp* function. In the end the sensor image is obtained by taking a second power of the output field propagated form the pupil and then image is flipped in order to get correct retinal image. The function outputs a resulting retinal image as a 1D array, an array representing grid of a retina and a sampling step.

The eye is modelled as a lens. The distance from the centre of the lens to the focal point is the focal length. Lens’s focal length is fixed and a change in focus can be made by moving the lens. In the human eye the change in focus occurs through the change in lens curvature that is controlled by muscles in the eye.

* Analysis of the retinal images



Figure . PSF for different values of focal distance (Fresnel)

Figure 1. shows point spread functions (PSF) for different values of focal distance (z\_f) of the eye. We set z\_f values on both sides of the source point. The sharpness of the PSF changes for different z\_f. The source point is located in z\_p which in our case equals -0.4m. The further from the z\_p focal distance of the eye is, the lower sharpness of perceived PSF.



Figure . Modular Transfer Function (Fresnel) with maximum for z\_f = -0.4m

Figure 2. shows modulation transfer function. We used linear interpolation to fit the curve to the data points. Function is maximized for z\_f equal to -0.4m which is the same as the location of the source point.

We repeated the same steps for RS method of synthesising the hologram and obtained very similar results.

In the next step we change the location of the source point to z\_p = -0.1m and obtain the following results.



Figure . PSF for source point z\_p = -0.1m (Fresnel)



Figure . MTF for source point z\_p = -0.1m (Fresnel)

In figure 3 the PSF is the sharpest for z\_f = -0.1 and figure 4 shows that MFT function is also maximized when z\_f is equal to z\_p.

In the end we experimented with the size of the pupil. We changed it from the original 5mm to 2mm. We can see that the highest spike in the PSF function is smaller than the highest spike in the original setup. According to the figure 6 the change of the pupil size did not affect MFT function.



Figure . PSF for pupil size equal to 2mm



Figure . MTF for pupil size equal to 2mm

1. **Conclusions**

In this task we synthesized hologram displays using three different methods. Than we familiarized ourself with the process of propagating the field from the hologram through the eye to get a retinal image. We got to know the mathematical model of the human eye and the role of the focal length. In the end we observed how PSF and MTF functions change for different sets of parameters.

Bibliography:

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