

Fast Calculation Method for Computer-Generated Holograms Using Saccade Suppression by Lowering the Resolution Based on Fresnel Zone Plate Reduction

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ABSTRACT

Saccade is a very rapid movement of our both eyes that transfer between two or more gazing center, with almost no sensitivity of visual information from the eyes to the brain. In this study, it is possible to reduce the computational complexity of CGH by lowering the resolution of the CGH when the saccade occurred.

Keywords: Computer-Generated Hologram, Saccade, Fast Calculation

1 INTRODUCTION

As we are requiring more realistic images and 3D experiences, the three-dimensional technologies are developing dramatically recently. These technologies can easily generate vivid 3D objects, but they may make users feel impaired or sick. Therefore, holography has been proposed as the ultimate 3D display method that satisfies all of the physiological factors that humans require [1].

Holography is a technique for recording all light information to generate an interference pattern (hologram) by causing the interaction of coherent object light and reference light. The technique of using computer simulation to generate a hologram is called the CGH technique. This technique has some advantages, such as not needing a complicated optical system (which holography needs) and having the ability to generate animation. However, they still have some problems, and one of these is the long calculation time.

2 SACCADE OF HUMAN EYE

Saccade, which is a very rapid movement of our both eyes that transfer between two or more gazing center [2]. Usually, the amplitude of saccade is less than 1 degree, and to an unexpected stimulus (such as shift from one object to another), saccade normally take about 200 ms to initiate, and the duration time is about 20-200 ms (depending on the amplitude of saccade). Although saccade is involuntary movement that can not be controlled by will, the direction and frequency of saccade can be affected by attention. When a saccade occurred, the sensitivity of visual information from the eyes to the brain decreases dramatically. Therefore, in this study, it is possible to reduce the computational complexity of CGH by lowering the resolution of the CGH when saccade occurred with no observable effect for the viewer to

observe the CGH reconstruction image.

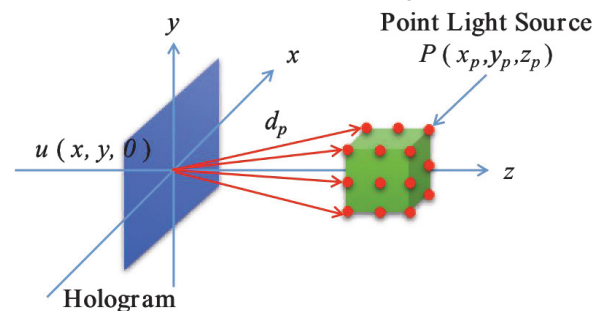


Fig. 1 Point-based method

3 CONVENTIONAL METHOD OF CGH

3.1 Point-based method

Object light is very important when we generate a CGH. Also, several researches have been done to calculate the object light, which can be divided into point-based methods [3], holographic stereogram methods [4, 5], and Fourier transform methods [6]. In this study, we calculated the object light using point-based method, and then we generated the CGH by using ray-tracing method.

The point-based method, which uses a lot of point light sources to lay over the object has the advantage of being able to show any shape of object very detailed. However, on the other hand, to show an object with a very high quality, the number of point light sources increases dramatically, and a much longer calculation time is required.

We show the point-based method in Fig. (1) to explain the amplitude distribution on the hologram plane. First, we assume the position of a point light source in P , so the light wave from P to the hologram plane H_p can be calculated by Eq. (1). The distance between the point source and the hologram plane which is shown in Eq. (1) is d_p , and can be calculated with Eq. (2). And A_p is the amplitude, k is the constant number with $2\pi/\lambda$, and λ is the wavelength. And finally, we assume the number of point light sources in N , and the amplitude distribution of an object on the hologram plane can be calculated by adding light waves one by one using Eq. (1), and inferred to Eq. (3).

$$H_p(x, y, x = 0) = \frac{A_p}{d_p} \exp(-jkd_p) \quad (1)$$

$$d_p = \sqrt{(x - x_p)^2 + (y - y_p)^2 + (z - z_p)^2} \quad (2)$$

$$u(x, y) = \sum_{p=1}^N (H_p(x, y, z = 0)) \quad (3)$$

3.2 Ray-tracing method

Ray-tracing method is a very special method in graphic field by calculating several rays from a certain viewpoint to get the full RGB information in a scene. Using ray-tracing method can be possible to obtain all the light information in a scene very well. And then, by obtaining the RGB color of related pixel from the viewpoint, the rendering would be done. Furthermore, the rays which coming from the viewpoint are calculated pixel by pixel on the screen, so the ray-tracing method can show a very high quality of image, animation or game etc., but on the other way, to show such a high quality, the huge amount of calculation is needed. In the previous researches of CGH field, rays are omitted from the viewpoint with a fixed angle, and the scene will be rendered when the rays intersect to the object. By using ray-tracing method to CGH [7], the CGH rendering can be able to display the whole scene really vivid.

4 PROPOSED METHOD

4.1 Saccade suppression

Saccade occurs every time when we move our eyes very fast, but since visual information is interrupted during the saccade, our visual image is stable even when the eyes move very fast. Such blocking of visual information is called "saccade suppression". In the VR area, research has already been made to create an illusion of moving a virtual space larger than the physical space by focusing on saccade eye movement and rotating the scene slightly at the time that saccade occurred [8]. If this method applied to CGH, there is a huge advantage that the resolution of the entire CGH screen can be reduced while the viewer will not have any observable effect and the amount of CGH calculation can be significantly reduced when saccade occurs as shown in Fig. (2). However, since the duration of saccade is only in a very short time, even if the saccade is detected, the resolution of the CGH image can not be reduced in real time. Therefore, we will prepare CGH animation in advance and use the jumping motion of the object to cause the saccade and to display several frames after the jumping motion of object with a low resolution. Subjective experiments will be conducted by showing this CGH animation to the subjects and evaluating whether they feel the animation is blurred or not. Then, by comparing the calculation time of the blurred

CGH animation with the calculation time of the CGH

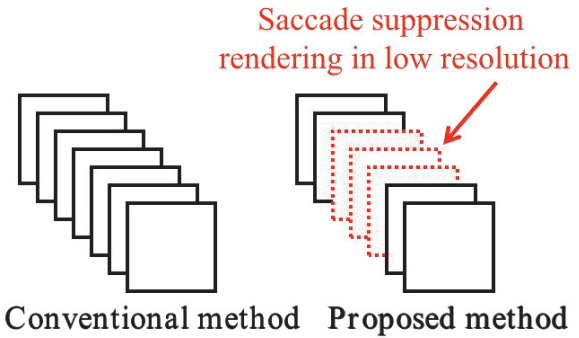


Fig. 2 Fast calculation with saccade suppression

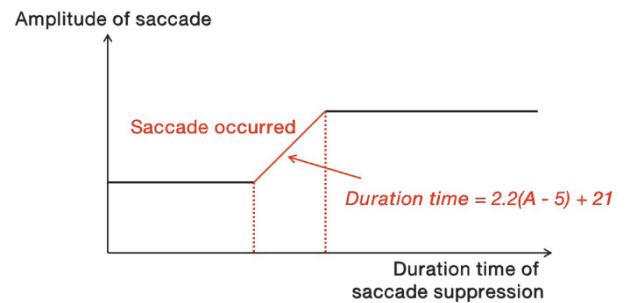


Fig. 3 Saccade suppression

animation calculated by the conventional method, the high-speed calculation of CGH using saccade can be proved.

However, only when we can accurately measure the duration of saccade time can the viewer not feel the animation become blurred. Fortunately, it has been proved that the saccades are very rigid, and there is almost a stable relationship between amplitude and duration. The relationship between gaze amplitude and duration is fixed and can be used to indicate whether a particular eye movement is normal. Normally, the relationship between saccade amplitude and duration is linear. The equation for the straight line through the subject data is $2.2(A - 5) + 21$ (A is the amplitude in degree and $A > 5$).

By this equation, we can calculate the duration of saccade time due to the amplitude of the jumping motion of object, and can accurately showing the number of frames in low resolution while the saccade is occurred with no observable effect for viewers to watch the animation. Also, we made a graph about the saccade suppression as shown in Fig. (3).

4.2 CGH resolution lowering

In this study, saccade suppression is used to reduce the CGH calculation time. As the method, CGH animation is prepared in advance, and the jumping motion of the object is used to cause the saccade, and several frames after the jumping motion are displayed in low resolution. Then, this CGH animation is shown to the subject and

subjective experiment is performed in the form of evaluating whether the subjects feels blurred or not.

Unlike CG, CGH can not reduce the resolution by simply reducing the number of pixels. So, to reduce the resolution of CGH, it is necessary to reduce the number of rays which are emitted to an object from the viewpoint. However, when the number of rays decreases, gaps will be seen in the reconstruction image. In order to solve that problem, we need to fill these gaps up between these discrete points.

Zone plate is a optical pattern which is consist of several rings. The zone plate obtains the same effect not because of the relief shape but by a concentric pattern made of fine opaque and transparent. Going back to the past, it sometimes called Fresnel zone plates because it comes from research by Fresnel. And a CGH is recorded by all this zone plates from the point light sources in the whole scene. And also, based on the Rayleigh theory, the size of the reconstruction point is determined by the diameter of the zone plate as shown in Eq. (4).

$$\omega_{FZP} = C_{\omega} \lambda F \quad (4)$$

In this equation, C_{ω} is an constant number, λ is the wavelength of light, and the F number is the division of the distance z_r with the diameter of the zone plate D , so, we can replace the F with z_r and D as

$$\omega_{FZP} = C_{\omega} \lambda \frac{|z_r|}{D} \quad (5)$$

Therefore, we can fill these gaps up by reducing the diameter of the Fresnel zone plate, so that the size of the point light source can be larger, and the gap can be embedded. In this way, the computational complexity can be significantly reduced benefit from the decrease of the ray number compared to the conventional CGH calculation method [9, 10]. By doing so, a fast CGH calculation can be realized.

5 EXPERIMENTS

5.1 Environment of the experiments

In this section, we are going to talk about the environment of the experiments of our proposed method.

First, to understand whether the saccade is occurred correctly by the jumping motion of object, we need to use a head-mounted device to detect the movement of our eyes which is called ET-3D10. ET-3D10 can detect the movement of eyes, and can show the amplitude of eye movement. Therefore, we can determine whether the saccade occurs by simply observing the amplitude of the movement of the eye. And then, we connected the ET-3D10 with our holographic device [11] to make sure the display of CGH animation and the detection of eye movement can be started in the same time. The

parameters of holographic device are shown is Table. (1),

Table 1. Parameters of holographic display

Pixel pitch of SLM	6.4 x 6.4 [μm]
Number of pixel	1,920 x 1,080 [pixels]
Refresh rate of SLM	180 [Hz]
Wavelength of each color	Red:625 [nm] Green:525 [nm] Blue:465 [nm]

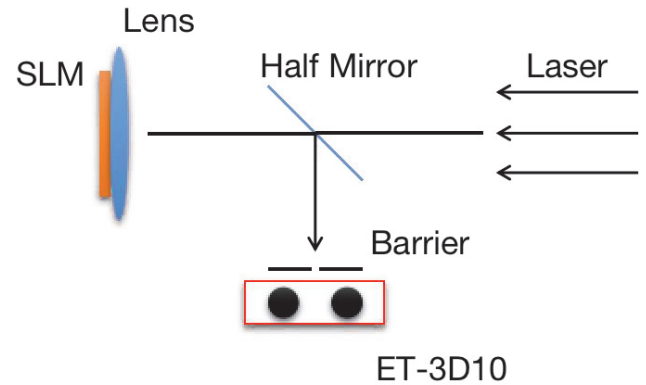


Fig. 4 Conceptual of Holographic device with ET-3D10

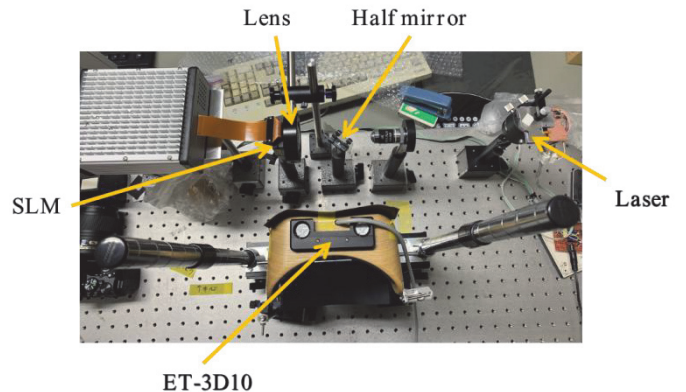


Fig. 5 Real shot of Holographic device with ET-3D10

and the conceptual and the real shot of the device we made are shown in the Fig. (4) and Fig. (5).

5.2 Subjective experiments

Here, we are going to talk about the subjective experiments which is used to test whether there is a observable effect for the viewers to observe the CGH reconstruction image or not. The test will present each subject with several kinds of animation (each is 60 FPS) which is the jumping of object to different place to occur the saccade, and each animation will be shown in several seconds.

The test will be divided into several steps to make sure the accuracy of the results.

First of all, we know that human beings react to stimuli from the outside world, such as the start of athletes after firing a gun, etc, is not a moment to respond from receiving stimuli to transmitting to the action, but it takes a short time. Although the average reaction time of human being is about 0.2s (which is about 12 frames of our CGH animation, and we call it delay frame), the individual differences are still very obvious. To our experiments, the set value of the delay frame will affect the result of the evaluation, so we decide to set the delay frame from 6 frames to 17 frames (which equals to the reaction time from 0.1s to 0.3s), and subjects need to evaluate each animation with different delay frame.

Next, we need to find out whether the different resolution of CGH animation during the saccade time affect the result of evaluation, so we set the resolution to 0% (which means showing in black while the saccade occurred), 10%, 30% of the original CGH animation while the saccade occurred.

In summary, we are going to perform the subjective experiments in different delay frame and different resolution, and each subject needs to evaluate 36 animations about whether he/she feels any observable effect with MOS method.

6 CONCLUSIONS

In this study, we proposed a fast calculation method for CGH using saccade suppression by lowering the resolution based on Fresnel zone plate reduction. We made the device which can be used to detect the eye movement called ET-3D10 connected to our holographic device and make sure both of them can start at the same time. This new device can be used to test the accuracy of our proposed method. Furthermore, we designed the subjective experiments with different delay frames, different resolution which is lowered during the saccade time to understand whether there is an observable effect for viewers while watching the animation, and evaluate in MOS method. In the future, we will perform these experiments to prove the correctness of our proposed method.

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