# A Fast Animation Generation System for Computer-Generated Hologram Using Ray-Tracing Method

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*Abstract*—**CGH is a technique that simulates the recording of holography. Although CGH has a lot of advantages, it also has many disadvantages, such as a long computation time and difficulty in generating animation. In this research, we introduce an animation system for CGH that can realize the complex movements of multiple objects with a fast calculation method. The experiments demonstrate the effectiveness and high-speed calculation of the animation system.**

*Keywords—computer-generated hologram; animation; fast calculation; complex movement*

## I. INTRODUCTION

As we ask for more realistic images and 3D experiences, commercial products such as 3DTV [1], 3D game machine [2], etc. have been developed along with conventional two-dimensional display technology. Three-dimensional technology is popular, and various studies have been conducted. Stereoscopic display is one technology representative of the future society as a display technology of "showing an object to be there." Although this technology easily generates binocular disparity, it cannot realize other elements such as focus and congestion, so it is said that a "natural" stereoscopic display method is hard to realize. Actually, a stereoscopic display with only a binocular parallax, may make users feel impaired or sick. Holography has been proposed as the ultimate 3D display method that satisfies all of the physiological factors that human beings require [3].

Holography is a technique of recording all light information to generate an interference pattern (hologram) by causing the coherent of object light and reference light. The technique of using computer simulation to generate a hologram as electronic image data is called CGH. CGH has advantages, such as not needing a complicated optical system (like holography does) and having the ability to generate animation. However, it still has a lot of problems, like having a long computation time and not being able to generate animation easily.

Considering that CGH is expected to be used to generate animation that is not only simple movements of single objects, it needs a system that can easily control the complex movements of multiple objects.

With the goal of performing animations based on the ray-tracing method, which is good for graphic expression of CGH [4], and using a high-speed computation method by dividing moving objects and static objects [5], we developed a high-speed animation system that implements complex movements such as parallel movement, rotation, scaling, and the appearance and disappearance of multiple objects. Furthermore, we showed its effectiveness.

In this study, we first introduce the conventional method of CGH, then, we introduce the fast calculation method of CGH. Finally, we introduce our proposed method.

## II. CONVENTIONAL METHOD OF CGH

### A. Calculation of object light

In order to generate CGH, it is necessary to calculate object light. There are three methods of calculating object light, roughly divided into a point-based method [6], a holographic stereogram method [7, 8], and a method using a Fourier transform [9].

In this study, object light is calculated by a point-based method, then CGH is generated using ray-tracing. Here, the calculation of the point-based method is described. The point-based method is a method of covering an object with a point light source and calculating it. The advantage is that it can be applied to any object by a lot of point light sources. However, as the number of point light sources increases, a long calculation time is required.

When the point-based method using to display an object, the amplitude distribution on the hologram is indicated by $O(x, y)$. As shown in the Fig.1, assuming that the position coordinates of a one-point light source are $(x_i, y_i, z_i)$, the light wave from this point light source to the hologram plane is represented by the following equation $E_i(x, y, z = 0)$. The distance from the point source to the hologram plane is $r_i$, $A_i$ is the amplitude, $k$ is $2\pi / \lambda$, and $\lambda$ is the wavelength.

$$E_i(x, y, z = 0) = \frac{A_i}{r_i} exp(-jkr_i) \qquad (1)$$

$$r_i = \sqrt{(x-x_i)^2 + (y-y_i)^2 + z_i^2} \qquad (2)$$

Therefore, if the number of point light sources is $N$, the amplitude distribution $O(x, y)$ on the hologram plane of the
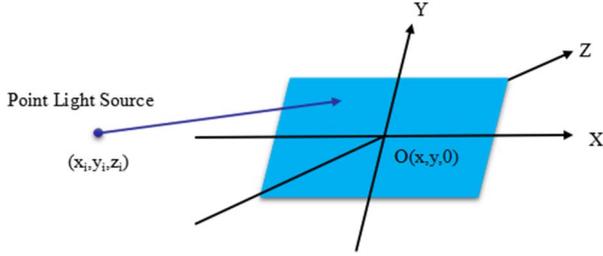


Fig. 1.   Point-based method

entire object to be displayed can be calculated by adding light waves from the respective point light sources. The following equation represents $O(x, y)$.

$$O(x,y) = \sum_{i=1}^{N} E_i(x,y,0) \qquad (3)$$

## III.  FAST CALCULATION METHOD OF CGH

In the fast calculation method, objects in the animation are divided into moving objects and static objects. First, this method calculates light wave propagation for static objects at the beginning and stores the object light wave on the hologram plane obtained. The light waves of the stored static objects are called the base frame. Next, the light waves of the moving objects are added to the base frame and the light waves from the hidden portion are subtracted to realize the calculation of the hidden surface processing. By repeating these calculations for each frame, the amount of calculation can be reduced and fast-speed calculation can be realized.

Next, we would like to introduce the calculation of light wave propagation for moving objects and static objects.

### A.  Calculation of light wave propagation

In this method, it is necessary to calculate light waves from static objects first. This calculation is performed in the same manner as the conventional point-based method.

The result the base frame, and the light wave distribution on the hologram plane recorded as the base frame is defined as $u_{base}(x, y)$. This processing is shown in Fig.2.

Next, we need to calculate the moving object for each frame in the animation. We should first use ray tracing to acquire the point light source information from the objects, as shown in Fig.3. The point sources constituting the moving object are $M_1$ and $M_2$, and the parts hidden by the moving object are $S_1$ and $S_2$ in *Static Object1*.

As a result, in the first frame, the light wave distribution $u_1(x, y)$ on the hologram plane is $u_{base}(x, y)$ of the base frame in which the light wave of the static object is recorded, adding light waves $u_{M1}(x, y)$ and $u_{M2}(x, y)$ from light sources $M_1$ and $M_2$ and adding light waves $u_{S1}(x, y)$ and $u_{S2}(x, y)$ from $S_1$ and $S_2$ of the static object concealed by $M_1$ and $M_2$. The light wave distribution $u_1(x, y)$ is calculated by the following equation.
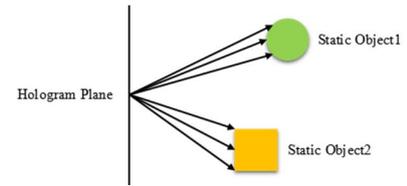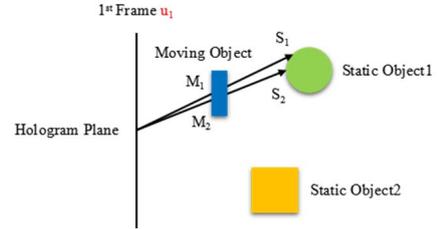


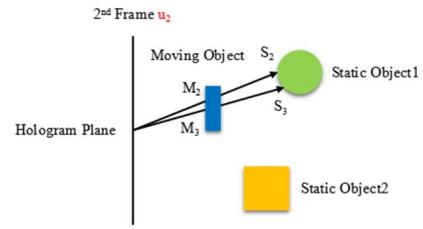Fig. 2.   Base frame



Fig. 3.   1$^{st}$ frame



Fig. 4.   2$^{nd}$ frame

$$u_1(x,y)=u_{base}(x,y)+u_{M1}(x,y)+u_{M2}(x,y)-u_{S1}(x,y)-u_{S2}(x,y) \qquad (5)$$

In the next frame, the calculation of moving objects can be done almost in the same way. As shown in Fig.4, when the moving object moves down into the second frame, the light wave distribution $u_2(x, y)$ of this frame can be calculated by the following equation. Here, $u_{M3}(x, y)$ is the light wave of $M_3$ and $u_{S3}(x, y)$ is the light wave from $S_3$ hidden by $M_3$.

$$u_2(x,y)=u_{base}(x,y)+u_{M2}(x,y)+u_{M3}(x,y)-u_{S2}(x,y)-u_{S3}(x,y) \quad (6)$$

Finally, we can generalize the calculation of this method by the following equation. The light waves from the moving objects is $u_{Mi}(x, y)$ and the light waves hidden by the moving objects is $u_{Si}(x, y)$.

$$u_l(x,y) = u_{base}(x,y) + \sum_{i=1}^{N} u_{Mi}(x,y) - \sum_{i=1}^{N} u_{Si}(x,y) \qquad (7)$$

## IV.  PROPOSED METHOD

In the previous chapter, we introduced the fast calculation method, a method of dividing objects into moving objects and static objects, to perform fast calculation focusing on the characteristics of CGH animation.

However, in animations, it is necessary to control both simple motions of a single object and more complicate motions

of multiple objects. Therefore, we developed a fast animation generation system using fast calculation method.
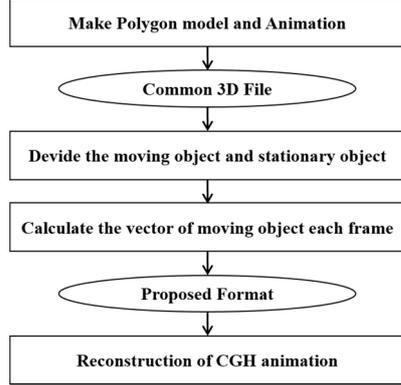


Fig. 5. Proposed animation generation system

In this section, we describe the special format used in this system and propose an algorithm to calculate the translation, rotation, scaling, and the appearance and disappearance of objects at high speed. We also experimented to confirm the effectiveness of this system.

### A. Special format

In order to calculate the CGH using a fast calculation algorithm, it is necessary to distinguish between moving objects and static objects. In addition to static objects, moving objects must contain information of movements. In order to create an animation, it is necessary to set the key frame. The proposed animation system identifies the key frame and distinguishes the static objects from the moving objects. Then, flags such as "Static" are assigned to static objects and "Moving" are assigned to moving objects. When calculating, the results of static objects are stored as base frame, so that static objects and moving objects can be distinguished correctly.

For moving objects, it is necessary to record data of translation, rotation, scaling, and appearance and disappearance. Therefore, the proposed system calculates the movement vector, the rotation angle, and the scaling ratio for each frame of each moving object and outputs the data together in this special format. For appearance and disappearance, when an object appears and disappears, a key frame is set and recorded in the format in order to easily control the appearance and disappearance of this moving object. It is possible to reduce the amount of data compared to the method of outputting object data for each frame.

### B. The animation generation of CGH

In the previous section, the recording of movement information is described. Each piece of information is calculated by the proposed animation system and recorded in a special format. After that, using the special format, you can input the information into the fast calculation rendering engine, and then generate the animation of CGH.

The calculation procedure of animation generation is shown in Fig.5. First, we created polygon models with 3DS MAX. After that, we created the animation for this scene and saved it in a general 3D file. We selected an FBX file that

contains information about the animation. However, in order to render CGH with a fast calculation algorithm, it is necessary to distinguish between moving objects and static objects, so, we need to use the special format. In the proposed animation system, the motion vector, the rotation angle, and the scaling factor for each frame of the moving object are also calculated using the key frame method and described them into the special format. It is then possible to generate interference fringes of CGH that can be used to reproduce CGH animation. In addition, calculation of CGH data and various kinds of conversion are processed as affine transformations during calculation. Finally, by displaying the generated interference fringe, the reproducing device makes it possible to see the reconstructed images of the animation.

Regarding the calculation time in this method, since rendering is performed using a fast calculation method that divides moving and static objects, we need to first calculate the base frame. After that, it is necessary to calculate only moving objects and hidden surface removal for each frame. This calculation time is expressed by the following equation. The calculation time of the base Frame is $T_B$, $T_M$ is the calculation time of the moving objects, $T_S$ is the calculation time of the hidden surface removal, $N$ is the number of frames, and $T_F$ is the time to record the object information to the special format.

$$T = T_B + N(T_M + T_S) + T_F \qquad (8)$$

## V. EXPERIMENTAL AND RESULTS

To demonstrate the effectiveness of our proposed method, we made a CGH animation by the proposed animation system and measured the calculation time of the animation.

The parameters of the computer used in this study are shown in TABLE I. Further detailed information on the reconstruction device used in the experiment is shown in Fig.6 and TABLE II.

### A. CGH animation

In order to confirm the effectiveness of the animation generation system, 24 frames of CGH animation were generated with the proposed animation generation system. From the results, the hidden surface removal with the dolphin, the character, and the mountain was done accurately. From the viewpoint of moving objects, it was confirmed that motion control by animation generation system was realized. The captures of the animation are shown in Fig.7.

### B. Calculation time of the animations

The calculation time is shown for the generated animation in TABLE III, and the results are summarized as a graph in Fig.8. Detail information on the object is written in TABLE IV.

However, the time to record object information up to the special format of animation is about $1ms$, and it is understood that there is no influence on CGH animation generation.

This result shows that the calculation time was about $4$ to $6$ times faster than the point packing method. Therefore, it was proven to be able to maintain the high speed of the proposed animation generation system.
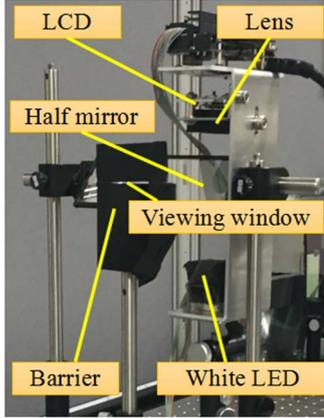
| Focal length of lens | 100 [mm] |
|---|---|
| Distance between SLM and lens | 8.0 [mm] |

TABLE III.     CALCULATION TIME

| Number of frames | Calculation time [ms] | |
|---|---|---|
| | Point-based | Proposed |
| 1 | 968 | 968 |
| 9 | 8,712 | 1,976 |
| 17 | 16,456 | 2,984 |
| 24 | 23,232 | 3,866 |

TABLE IV.     INFORMATION OF EACH OBJECT

| Object | Number of object points | Number of object faces |
|---|---|---|
| Dolphin | 2,049 | 3,810 |
| Character H | 496 | 988 |
| Character U | 384 | 764 |
| Mountain | 320 | 558 |

## VI. CONCLUSION

We developed an animation generation system based on a fast calculation method that uses ray tracing and reported its effectiveness through experiment.

Regarding the computation time, the animation generation system in this paper created animations based on a fast calculation rendering engine that often focused on speeding up the light wave propagation unit.

Because it was very fast compared with the calculation time of the point-based method, it was able to control various kinds of exercise while maintaining high speed.

In this study, the CGH animation generation system implemented the minimum necessary functions. Therefore, as a future project, it is necessary to improve further algorithms so that various functions can be realized.

## REFERENCES

[1] L. Zhang and J. T. Wa, "Stereoscopic image generation based on depth images for 3DTV", IEEE Transactions on Broadcasting 51, 191–199 (2005).

[2] J. J. Laviola, "Bring VR and spatial 3D interaction to the masses through video games", IEEE Comp. Grap. Appl. 28, 10–15 (2008).

[3] D. Gabor, "A new microscopic principle", Nature 161, 777–-778 (1948).

[4] T.Ichikawa, K.Yamaguchi, and Y.Sakamoto, "Realistic expression for full-parallax computer--generated holograms with the ray-tracing method", Applied Optics. 52, pp.A201--209(2013).

[5] Ryosuke Watanabe, Yuji Sakamoto, "Fast Generation Method for Computer-Generated Hologram Animation with Hidden Surface Removal Using Ray Tracing Method", JSAP-OSA Joint Symposia (The 75th JSAP Autumn Meet-ing 2014), 20a-C4-7, (2014).

[6] J. P. Waters, "Holographic image synthesis utilizing theoretical", Appl. Phys. Lett. 9, 405-407 (1966).

[7] D.J.DeBitetto, "Holographic panoramic stereograms synthesized from white lightrecordings", Appl. Opt 8, 1740--1741 (1969).

[8] M.C.King, A.M.Noll, and D.H.Berry, "A new approach to computer generated holography", Appl.Opt. 9, 9471--9475(1970).

[9] K. Matsushima and S. Nakahara, "Extremely high-definition full-parallax computer-generated hologram created by the polygon-based method", Appl. Opt. 48, H54--H63 (2009).

Fig. 6.   Reconstruction device



(a)1st Frame          (b)6th Frame          (c)18th Frame
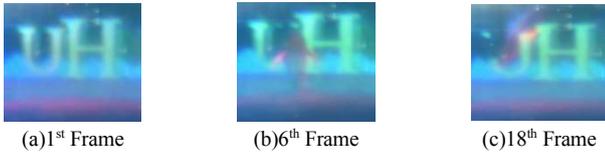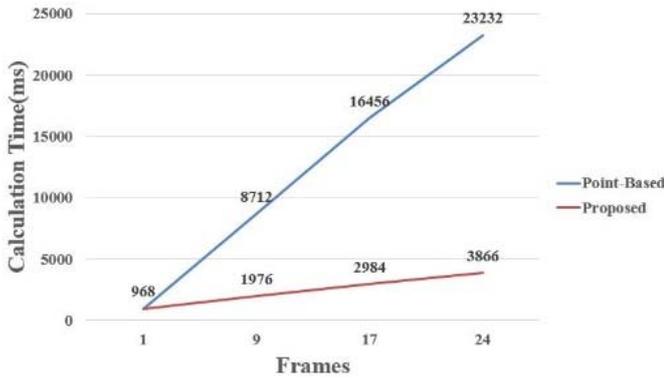
Fig. 7.   Captures of Animation



Fig. 8.   Calculation time

TABLE I.     COMPUTER PARAMETERS FOR EXPERIMENTS

| Computer parameters for experiments | |
|---|---|
| CPU | Intel Core (TM) i7-4720HQ |
| OS | Windows 10 Professional 64 bits |
| Memory capacity | 16 [GB] |
| Clock frequency | 2.60 [GHz] |
| GPU | NVIDIA GeForce GTX 980M |

TABLE II.     COMPUTER PARAMETERS FOR EXPERIMENTS

| Pixel pitch of SLM | 9.6 (H) x 9.6 (V)[μm] |
|---|---|
| Number of Pixels | 1280 x 768 [pixels] |
| Refresh rate of SLM | 180 [Hz] |
| Wavelength of red, green, blue | 625, 525, and 465 [nm] |