Real-Time Spatiotemporal Division Multiplexing Electroholography of Point-cloud 3D Model Comprising 920,000 Points Using Multiple GPU Cluster System

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Keywords: Spatiotemporal division multiplexing electroholography, Real-time electroholography, Multiple GPU cluster system, Gigabit ethernet network

ABSTRACT

We demonstrated real-time electroholographic 3-D movie reconstruction using spatiotemporal division multiplexing technique on a multiple GPU cluster system including 13 GPUs connected through gigabit ethernet network. We succeeded to display reconstructed 3-D movie consisting of 912,462 object points.

1 INTRODUCTION

Real-time electroholography using computer-generated holograms (CGHs) is thought to realize ultimate 3-D TV. However, the practical use of real-time electro-holography is limited by the complexity of the CGH calculations and requires high-performance computational power.

A graphics processing unit (GPU) has high-performance floating-point calculations at low cost. In 2006, fast CGH computation using a GPU has been reported [1]. A fast computation of 20 mega pixel CGH using multiple GPU (multi-GPU) cluster system with twelve GPUs and twelve display devices has also been reported [2]. Parallel calculations of large-pixel-count CGH are suitable for multi-GPU cluster system. However, it is not easy for a multi-GPU cluster system to accomplish fast CGH calculations when the CGH transfer between the PCs becomes a bottleneck. Usually, this problem occurs only in multi-GPU cluster systems with a single spatial light modulator. To overcome this problem, real-time electro-holography using a multi-GPU cluster system with 13 GPUs and the InfiniBand network has been proposed [3]. In our previous work [4], we proposed the method to reduce the CGH transfer data, and succeeded in real-time electroholography using GPU cluster system with generic gigabit Ethernet network and a single spatial light modulator (SLM).

While, for realizing real-time electroholography with less computational power, the spatiotemporal division multiplexing technique has been reported [5]. This technique reduces the amount of CGH calculation under the persistence of vision of the eyes. In our previous work [6], we tried to apply the spatiotemporal division technique to real-time electroholography using a GPU cluster system with 13 Maxwell GPUs (Nvidia GeForce GTX TITAN X) connected through gigabit ethernet network.

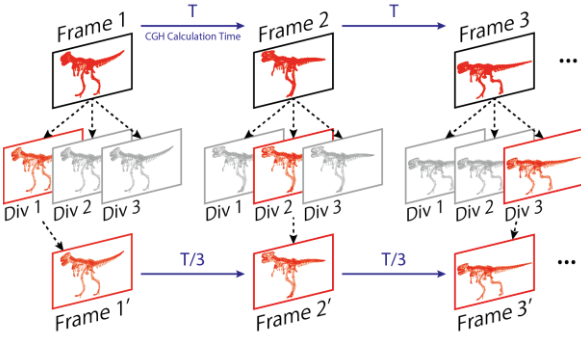

Fig.1 Spatiotemporal division multiplexing technique.

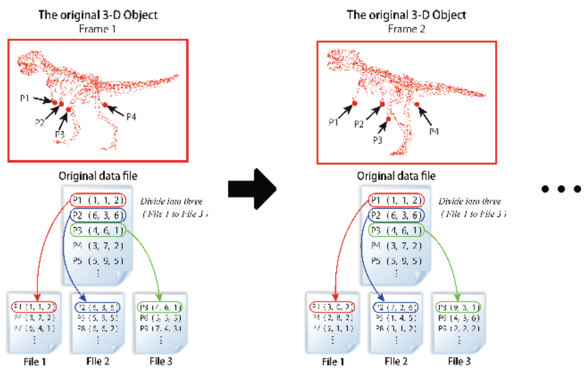

Fig.2 How to divide spatially original 3-D object.

In this article, we apply the spatiotemporal division technique to real-time electrohologrphy using GPU cluster system with 13 Pascal GPUs (Nvidia GeForce GTX 1080Ti). Finally, we realized real-time electroholography of point-cloud 3-D model comprising 912,462 points.

2 CGH CALCULATION

We used a simple algorithm to calculate an in-line hologram from the 3-D object expressed by the point cloud. For a 3-D object comprising of N_p points, the light intensity of each point on CGH is calculated by the following equation:

$$I(x_\alpha, y_\alpha) = \sum_{j=1}^{N_p} A_j \cos\left[\frac{\pi}{\lambda z_i}\left\{(x_\alpha - x_j)^2 + (y_\alpha - y_j)^2\right\}\right], \quad (1)$$

where $I\,(x_h, y_h, 0)$ is the light intensity of the point $(x_h, y_h, 0)$ on the hologram. (x_j, y_j, z_j) and A_j are the coordinate and intensity of the j-th point on a 3-D object, respectively. λ is the wavelength of the reference light and N_p is the total number of the object points. The computational complexity of Eq. (1) is $O\,(N_p HW)$, where H and W are the height and the width of SLM. Therefore, the amount of CGH calculation becomes enormous.

3 SPATIOTEMPORAL DIVISION MULTIPLEXING TECHNIQUE FOR FAST CGH COMPUTATION

Figure 1 illustrates the spatiotemporal division technique when original 3-D object is divided into three objects at each frame [5]. For example, in the spatiotemporal division technique, at Frame 1' of the reconstructed 3-D movie, we use the CGH made from Div 1-1 which is one of three divided objects at Frame 1 of original movie. We use the dividing technique by serial number of object points on original 3-D object.

Figure 2 shows the outline of the dividing technique in three division. Firstly, all object points on original 3-D object are numbered serially. Secondly, in the original data file shown in Fig. 2, the coordinate data of object points is listed in the ascending order of serial object point number. Finally, the listed coordinate data in the original data file is divided into three files (File 1 to 3) in the order of serial object point number. File number is equal to the remainder of dividing object point number by three.

The coordinate data of the divided part Div 1-1 shown in Fig. 1 is stored in File 1. In the same way, the coordinate data of the divided parts Div 2-2 and Div 3-3 is stored in File 2 and File 3, respectively. In the spatiotemporal division multiplexing technique, we periodically use one of three files at each frame. The CGHs of the selected parts are calculated and sequentially displayed on a SLM. As a result, the computational time can be reduced by the factor of division rate while visually continuous real-time 3-D movies can be reconstructed under the persistence of vision of the eyes.

4 IMPLEMENTATION

Figure 3 shows proposed multi-GPU cluster system consisting of 13 GPUs (NVIDIA GeForce GTX 1080 Ti) and generic gigabit ethernet network. The system consists of CGH display node (PC 0) and CGH calculation nodes. In the multi-GPU cluster system, CGH display node (PC 0) has a single GPU (GPU 0) and also functions as a network file system server. The coordinate data of 3-D object points is stored in CGH display node. CGH calculation nodes calculate all the CGHs for the reconstructed 3D movie in parallel. CGH display node receives the calculated CGHs from CGH calculation nodes and displays the CGHs on the SLM.

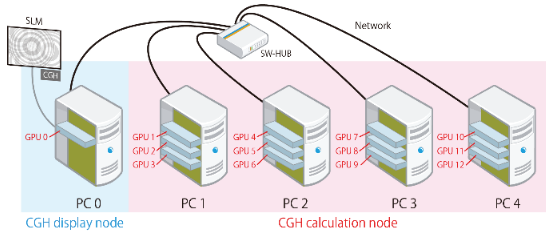

Fig.3 Proposed multi-GPU cluster system.

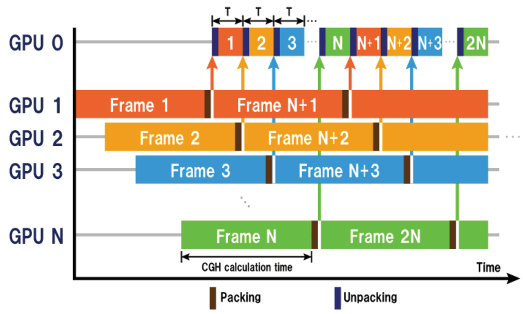

Fig.4 Outline of CGH calculation using multi-GPU cluster system.

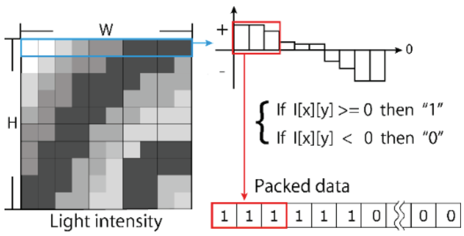

Fig.5 The transfer data packed by binarizing the light intensity of computer-generated hologram.

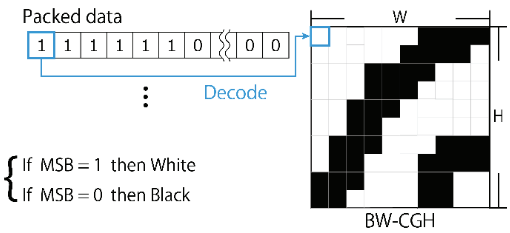

Fig.6 The binary computer-generated hologram reproduced from transfer data.

Figure 4 shows timing chart of real-time time-division electroholography using the proposed multi-GPU cluster system. In PC 1, GPU 1, GPU 2 and GPU 3 calculate the light intensities of CGHs of Frame 1, Frame 2 and Frame 3 in the original 3-D movie, respectively. And respective GPU produces the respective transfer data packed by binarizing the light intensities of CGHs of respective frame as shown in Figure 5. GPUs from GPU 4 to GPU 12 calculate CGHs in the same manner as the CGH calculations by GPUs from GPU 1 to GPU 3, and the respective transfer data is produced after respective GPU of CGH calculation nodes calculates the CGH of respective frame. The respective transfer data is sent to CGH display node (PC 0). After the CGH display node receive the respective transfer data from CGH calculate nodes, the CGH display node reproduces the binary CGH from the respective transfer data as shown in Figure 6, and displays the CGHs in turn.

5 RESULTS AND DISCUSSION

Table 1 show the specifications of the GPU used in this article. In our evaluation, the division factor by spatiotemporal division multiplexing technique was configured to 1, 2, 4, 6. Table 2 shows the achieved frame rate of proposed method against the number of space division. The proposed method achieved at 37.9 fps when the number of space division is six.

Furthermore, we evaluated the reconstructed 3-D movie using the proposed spatiotemporal division multiplexing method with multi-GPU cluster system. Figure 7 (a) shows the original 3D model "fountain" comprising 912,462 points. Fig.7 (b)-(e) show the snapshot of the reconstructed 3D movie against the number of space divisions. One of three liquid crystal display (LCD) panels equipped with a projector (Epson Inc. EMP-TW1000, pixel pitch: 8.5 µm, resolution: 1920 × 1080), was used as the SLM. Consequently, we found that the reconstructed 3D movie is clear when the number of divisions corresponds to six.

6 CONCLUSION

We realized real-time electroholography of 3-D object comprising 912,462 points using a multi-GPU cluster system with generic gigabit ethernet network.

ACKNOWLEDGEMENT

This research was partially supported by the Japan Society for the Promotion of Science (JSPS) KAKENHI (C) 18K11399, KAKENHI (A) 19H01097 and Telecommunications Advancement Foundation.

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Table 1 Specification of GeForce GTX 1080 Ti

GPU clock	1,480 MHz
CUDA cores	3,584
Memory config	12 GB GDDR5
Memory clock	11.0 Gbps
Memory bandwidth	484.0 GB/s
Theoretical performance	10.61 TFLOPS

Table 2 Frame rate of electroholography using spatiotemporal division multiplexing technique.

Number of Division	Object points	Frame rate (FPS)
No division	912,462	6.4
Two-division	456,231	12.8
Four-division	228,116	25.4
Six-division	152,077	37.9

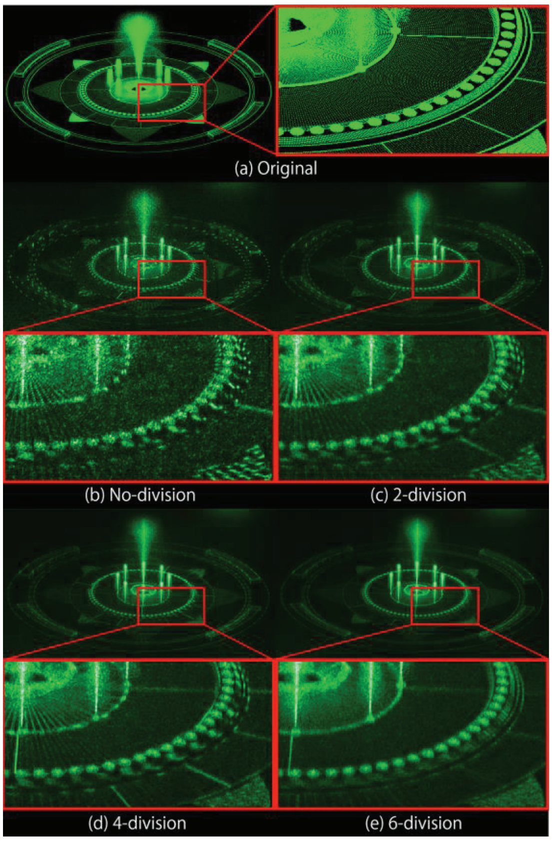

Fig.7 The snapshots of the reconstructed 3D move using the proposed method.

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