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3D Holographic Display and Its Data Transmission Requirement

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ABSTRACT -In this paper, we briefly introduce the full-color 3D holographic display system developed in Data Storage Institute. The bandwidth requirement of current system is analyzed to be about 10 Gbps. To address this requirement, the network interfaces between hologram loading and launching platforms are developed. Based on our analysis, the bandwidth requirement will increase to be in the range of 100 Gbps ~ 1 Tbps with the enhancement of system performance. Two approaches using hologram data compression and object data transmission are discussed in order to solve the high bandwidth requirement problems.

I. INTRODUCTION

Three-dimensional (3D) display can be realized by using stereoscopic (with glasses), auto-stereoscopic (glasses-free), volumetric and holographic display technologies [1]. Current commercially available 3D display product is based on stereoscopic principle, which only utilizes human binocular depth perception to create 3D illusion.

3D holographic display has been considered as an ultimate glasses-free true-3D display technology because it can provide all depth cues and eliminate eye fatigue or visual discomfort [2-4]. It has been considered as an alternative to current stereoscopic displays on the market [3]. Recently streaming holographic videos over network to the display systems has become an important research topic [5-7]. However, transmission of digital holographic 3D videos over network will require high data bandwidth because of its large amount of hologram data [8-10].

In this paper, a full-color 3D holographic display system developed in Data Storage Institute (DSI) is used for the first time to demonstrate the digital holographic video transmission over 10 Gbps network. After a brief introduction to the display system, we report the hologram transmission flowchart and network architecture. Streaming the holographic video of a color 3D dancing bear at 60 fps over the above network has been successfully demonstrated. The growing bandwidth requirements (100 Gbps – 1 Tbps) of future 3D holographic display systems are also analyzed and discussed in view of the enhanced system performance and future network bandwidth capability. Finally we discuss two approaches to reduce the bandwidth requirement through hologram data compression and object data transmission.

II. 3D HOLOGRAPHIC DISPLAY SYSTEM

We have recently developed a full-color 3D holographic display system in DSI, which contains red, green and blue (RGB) lasers, optics for expanding and combining of laser sources, spatial light modulators (SLMs), and optics for filtering and magnification of reconstruction. RGB laser sources are expanded to 50 mm beam size, combined together and expanded again to 80 mm, and finally shined on SLMs. Full-color display is realized by multiplexing RGB holograms launched onto multiple SLMs. When the holograms on SLMs are shined with laser light, the fringe patterns in holograms will diffract the laser light into intended directions and reconstruct the 3D object in space [11]. A pair of lenses is used after the SLMs to filter off unwanted multiple order reconstructions, twin image and zero order laser beam. The same pair of lenses also magnifies the 3D reconstruction to 3 inch size in diagonal.

The flowchart of hologram transmission for full-color 3D holographic display demonstrated in this work is shown in Fig. 1. RGB holograms are generated from original color 3D object data, stored in SSDs on loading platform, read out and transmitted to launching platform via network, and finally launched onto SLMs for 3D object reconstruction.

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III. DATA BANDWIDTH AND STORAGE REQUIREMENTS

During offline generation of holograms, 3D objects are transformed into 2D computer-generated holograms (CGHs) by a computation program on GPU-based computing platform. The 3D objects are placed inside an object space sampled at 1920 × 1080 × 50 (width × height × depth), which also defines the 3D volume sampling in reconstruction space. The holograms used in our display system are binary phase holograms, and have a dimension of 6400 × 1024 pixels. The computation program uses split look-up tables (S-LUT) on GPUs [12] for fast CGH computation speed. One color bear

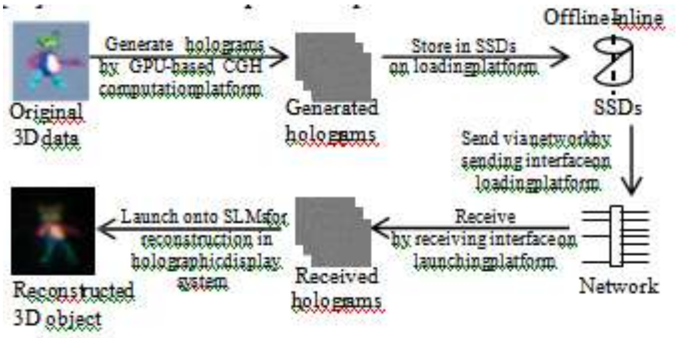

Fig. 1. Hologram transmission flowchart for 3D holographic display.

with ~150k 3D object points took us about one second for a single-frame CGH computation with current display system parameters on 6 nVidia GTX285 GPUs.

After CGH computation, hologram data are formatted into blocks according to the format used by SLM in our system. Each SLM has a pixel count of 1280 × 1024, and the driver of SLM uses 1 DVI frame of 24bit RGB color to launch 24 binary phase holograms onto the SLM. As a result, each block of hologram data has the size of ~31.5 Mbit. We can reconstruct full-color 3D object from a 6.5-Mpixel hologram. Within the same DVI frame, 24 holograms are computed with different random phases added to the same object frame to reduce laser speckle noise and obtain better reconstruction quality. This means that the bandwidth is increased to 24 times. The total data bandwidth of a holographic video is 9.44 Gbps at 60 object frames per second (1440 binary holograms per second). Hologram data are stored in high speed SSDs on loading platform for high speed readout.

During inline play-back of holographic video, hologram data are first read out from SSDs and buffered in main memory of loading PCs. There are 8 physical SSDs on 4 PCIe SSD cards in 2 loading PCs. Each physical SSD provides 281.1 MBps average sequential read speed. The total average read ability of hologram data is 2.25 GBps, which is sufficient for 9.44 Gbps hologram data bandwidth requirement.

After being loaded into the memory on the loading platform which acts as server on remote site, hologram data are transmitted via network to the launching platform that is directly connected with the SLMs in the holographic display system. Details of hologram transmission over network will be covered in the next section.

After being received and placed in the memory on the launching platform, holograms are launched onto SLMs for reconstruction of 3D object in the holographic display system. As the driver of SLM uses DVI interface, the SLM is treated as a miniaturized display screen and launching of holograms is done by displaying them on the SLM screen. As hologram data are formatted into blocks according to the requirement of SLM after CGH computation, at the point of launching the hologram data blocks are transferred from the memory to the graphic cards in the launching platform as images without any modification on data.

IV. HOLOGRAM TRANSMISSION OVER NETWORK

In order to meet the 9.44 Gbps bandwidth requirement of our current 3D holographic display system, we set up a local network that consists of ten 1-Gbps channels. The network architecture is schematically shown in Fig. 2. A graphical user interface (GUI) has also been developed to preview original 3D data, to select holographic video from hologram data loading server, to send commands to play/pause/resume/exit holographic videos, and to display hologram data transmission speed over the network.

After being read out from SSDs, each block of hologram data is packaged with application layer

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header and tale for transmission via network using TCP/IP data stream, as shown in Fig. 3. The header has 12 bytes and consists of 4 byte begin mark "#BEG", 4 byte package sequence number and 4 byte

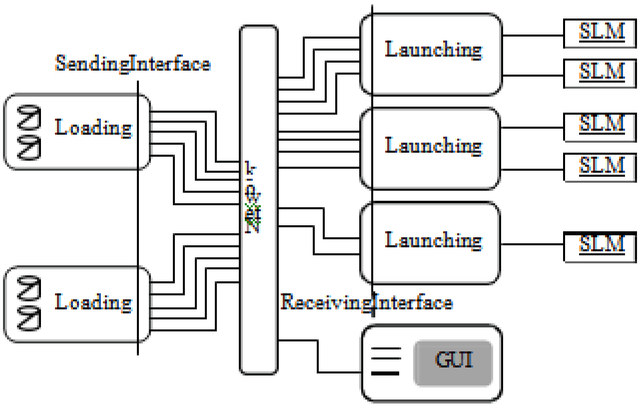

Fig. 2. Architecture of hologram transmission network.

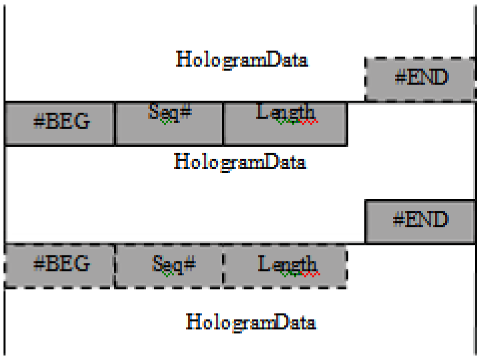

Fig. 3. Hologram datapackage.

Package length in the unit of byte. The tail has 4 bytes and only contains 4 byte end mark "#END". The reason for the use of TCP/IP data stream is because of its in-order and error free advantages, which preserve the order and content of hologram data during transmission via network. However, TCP/IP stream is continuous, i.e. packages sent into the stream are all connected. The begin mark and the end mark are used to signal the beginning and ending of a hologram data package. The sequence number is used to verify the order of hologram data package. It comes out that hologram data packages are a lways in order after transmission. The length is used to tell the receiving program how much data it should get from network and treat this block of data as a whole without touching it.

After getting application layer header and tail, the hologram data package is sent into the network, designated to the receiver. On both sending and receiving ends of the network, ten GbE connections are used. Each loading PC has five GbE connections, each of which is used to carry data for one SLM. Each SLM uses two GbE connections to receive data from the two loading PCs. The network is divided into five subnets, in such a way that connections on the same PC are all in different subnets and each SLM can receive data from both loading PCs.

After being received from the network, data from TCP/IP stream are divided into packages by the begin and end marks. Successfully going through sequence number and length verification, the application layer header and tail are removed and the hologram data blocks are recovered. Recovered hologram data blocks will be temporally stored in the main memory of launching PCs and eventually launched onto SLMs for reconstruction of 3D objects.

In order to demonstrate successful hologram transmission over the above described network, we generated a holographic video (70 GB for 1-min video) by computing holograms from a 3D model of an animated color dancing bear (~150k 3D object points). The transmitted holographic video was smoothly played back at 60 fps with our 3D holographic display system at a remote site. A snapshot of the reconstructed holographic video of the 3D color dancing bear is shown in Fig. 4, which was captured by a normal 2D camera.

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V. BANDWIDTH PROBLEMS

High data bandwidth requirement is one key issue in the development of holographic display system [10]. If the hologram data are transmitted over network, this requirement must be fulfilled by the network. It is very important for future network-based holographic 3D TV broadcasting applications. The requirement relates to various factors such as reconstructed object size, color, parallax and refresh rate. Various research groups have reported the results of their holographic display systems. Fig. 5 shows the bandwidth for transmitting the hogel data over an Ethernet reported by Arizona group [5], together with the bandwidth requirements analyzed based on the published system parameters from MIT [6, 7], Chiba [13] and QinetiQ [14] groups by assuming their hologram data are transmitted over network. The prediction of future bandwidth requirements by referring to the reported results is also plotted in Fig. 5 with open symbols. Taking into consideration the future network development, which can be represented by IEEE 802 standard [15] and assuming mass market products are available two years after respective IEEE 802 standards are first established, it can be seen from Fig. 5 that the bandwidth required by holographic display is approaching to the highest bandwidth that can be provided by available network, or even exceeds future network’s capability.

Effective pixel count of the holographic display system is one key factor that determines the data bandwidth requirement. The enhanced system performance such as larger reconstructed 3D object size, bigger viewing angle, more colors and parallax effects will increase the effective pixel count of hologram per object frame. The effective pixel count multiplied by refresh rate and bit-depth of hologram pixel defines the bandwidth requirement. Fig. 6 shows the

Fig. 4. 3D color bear reconstructed from transmitted hologram data.

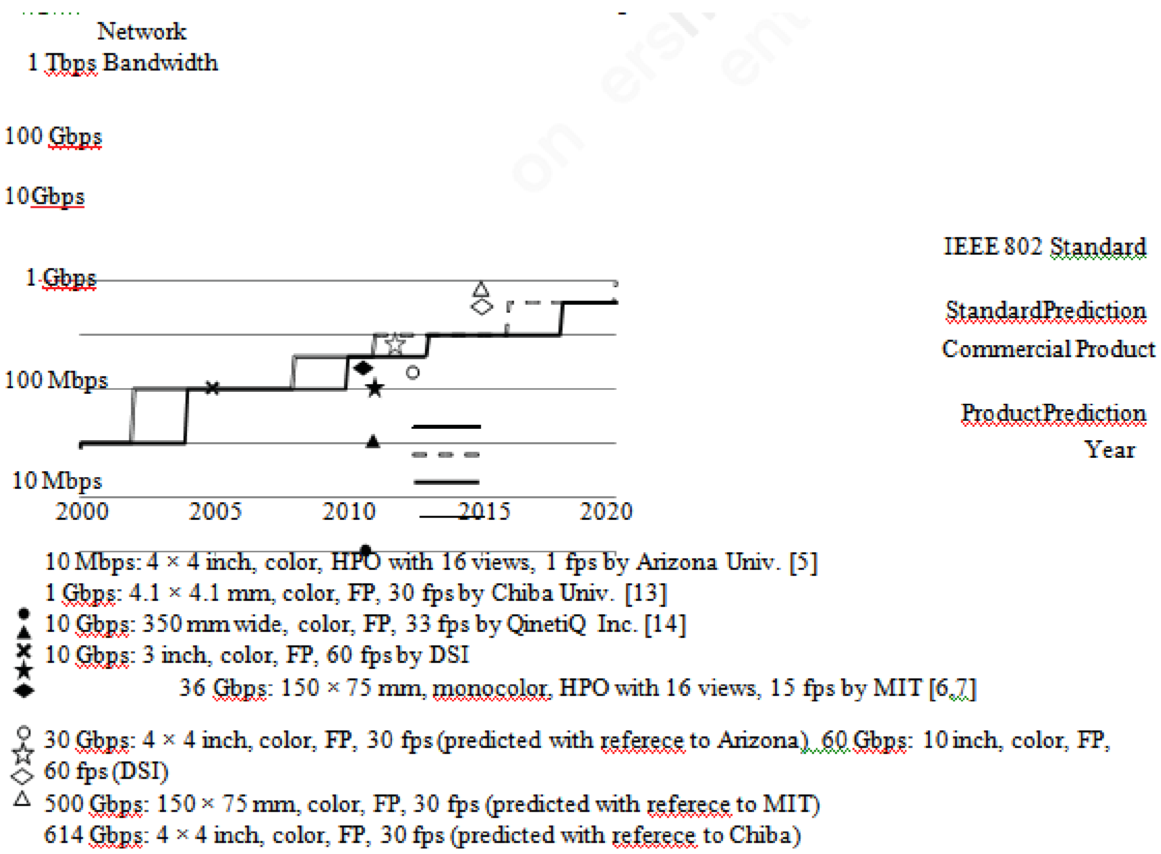

Fig. 5. Bandwidth requirements vs. IEEE 802 standards and commercial products. HPO - horizontal parallax only; FP - full parallax.

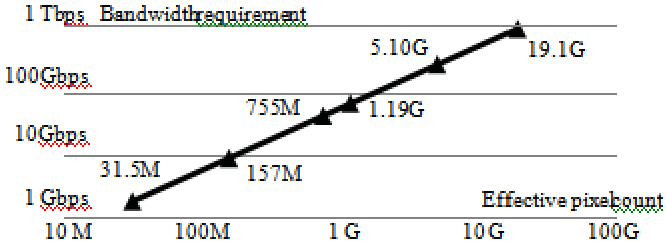

Fig. 6. Bandwidth requirement vs. effective pixel count.

Trend of bandwidth requirement with the increase of effective pixel count. In Fig. 6, the refresh rate is assumed to be 60 fps, and bit-depth of hologram pixel is assumed to be 1 bit per pixel. It is clear that larger effective pixel count introduced by the advanced development of holographic display system will continue to boost the bandwidth requirement. It has become a critical issue to be addressed for the broadcasting of holographic videos over network.

VI. POTENTIALSOLUTIONS

In order to achieve practical holographic 3DTV broadcasting over network in the future, besides developing high-bandwidth network technologies, the bandwidth requirement also needs to be reduced. Two approaches using hologram data compression and 3D object data transmission (Fig. 7) could be applied to address this issue.

A. Hologram Data Compression

Hologram data compression for transmission is one method to reduce the bandwidth requirement, which is suitable for the holographic display system with architecture similar to that shown in Fig. 1. In the case of holography, holograms are treated as random data because of weak correlations among

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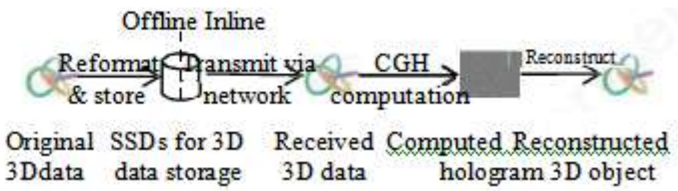

Fig. 7. Flowchart of 3D object data transmission.

hologram pixels. The compression of hologram needs to be lossless, in order to preserve resolution of hologram. There are various lossless random data compression methods, the best of which can achieve ~50% compression ratio on average [16]. However, no matter which lossless random data compression method is used, there are still worst cases when hologram data cannot be compressed or even grows in size. Real-time decompression is required for smooth playback of holographic video. To decompress data at 60 Gbps level is by itself a challenge to both software and hardware.

B. 3D Object Data Transmission

Another method to reduce network transmission bandwidth is to transmit 3D object data instead of computed holograms and its flowchart is shown in Fig. 7. Recently, the MIT group [6, 7] demonstrated this method by capturing simple motion of human body in 3D with a Kinect camera (640 × 480), transmitting the motion 3D data over network at about 50 Mbps and reconstructing it on their holographic display system at 15 fps. The diffraction specific coherent (DSC) Panoramagrams were computed from the received motion 3D data with 3 GPUs in a PC in real-time for the Mark II holographic display [7].

3D object data are normally smaller than hologram data. For example, raw 3D object data of 1920 × 1080 × 50 and 24bit color at 60 fps require 149.3 Gbps bandwidth. Because object data are highly co-related and most object point positions are empty, it could be compressed with high ratio, possibly 100:1. This could reduce the bandwidth requirement to 1.5 Gbps. As CGH computation is done locally, parameters and correction can be set specifically for the holographic display system. However, local computation of hologram requires real-time CGH computation, which is another challenge in the development of holographic display system.

VII. CONCLUSION

A full-color 3D holographic display system with the laser speckle reduction technique implemented has been developed in DSI, which is capable of displaying about 3-inch 3D object with a bandwidth requirement of 9.44 Gbps.

In order to meet the bandwidth requirement, both hologram data loading and launching platforms are built with high speed SSDs and PCs. A local network consisting of ten 1Gbps channels is established and the sending/receiving interface between the network and loading/launching platform is also developed with a sending/receiving program. The hologram data packages transmitted using TCP/IP data stream via the network can be reliably played back as a holographic video at 60 fps with the display system developed. There is a growing bandwidth requirement in the range between 100 Gbps and 1 Tbps with the increase of the

Effective pixel count, which is directly related to the system performance such as displayed 3D object size, viewing angle and parallax effect. New network technologies need to be developed to meet such a high bandwidth requirement. Meanwhile two approaches using hologram data compression and 3D object data transmission could be used to reduce the bandwidth requirement for practical holographic video transmission over network.

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