Compact Holographic Memory Using E-O Beam Steering

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Abstract—An innovative holographic memory system has been developed at JPL for high-density and high-speed data storage in a space environment. This system utilizes a newly developed electro-optic (E-O) beam steering technology for beam steering to enable high-speed random access memory read/write without moving parts. Recently, a compact CD-sized holographic memory breadboard has been developed and demonstrated for holographic data storage and retrieval. Detail technical progress will be presented in this paper.

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1. INTRODUCTION

JPL, under current sponsorship from NASA Earth Science Technology Office, is developing a high-density, nonvolatile d Compact holographic memory (HM) system to enable large-capacity, high-speed, low power consumption, and read/write of data for potential commercial and NASA space applications [1-4]. This HM consists of laser diodes, photorefractive crystal, spatial light modulator, photodetector array, and I/O electronic interface. In operation, pages of information would be recorded and retrieved with random access and high-speed. The nonvolatile, rad-hard characteristics of the holographic memory will provide a revolutionary memory technology to enhance the data storage capability for all NASA s Earth Science Missions. In this paper, an innovative holographic memory technology developed at JPL will be presented. The system architecture, key device and components, and a recent experimental demonstration of holographic memory storage/retrieval will also be described.

2. HOLOGRAPHIC MEMORY SYSTEM ARCHITECTURE

JPL has developed new Random Access Memory (RAM) that would simultaneously satisfy non-volatility, rad-hard, long endurance as well as high density, high transfer rate, low power, mass and volume. The holographic memory architecture is shown in Figure 1. Collimated laser beam first enters PBS_1 (polarizing beam splitter 1) and on exit, is split into two beams. The input beam subsequently passes through the data SLM (spatial light modulator), L_3 (lens 3) — M_1 (mirror 1) — M_2 — M_3 — L_4 and then reaches the PRC (a Fe: LiNbO3 photorefractive crystal). The lens pair L_3 — L_4 will relay the data SLM throughput image onto the PRC, the mirror set M_1 — M_2 — M_3 will fold and increase the light path length to make it equal to that of the reference beam. The reference beam, after exiting PBS_1, will subsequently pass through L_3 — PBS_2 -$BSSLM_1$ (Beam Steering SLM 1) - PBS_2 - L_3 — PBS_3 -$BSSLM_1$ — PBS_3 — L_4 and then reach the PRC. The data beam and the reference beam intersect within the volume of the PRC to form a 90° recording geometry. Both beams are polarized in the direction perpendicular to the incident plane (the plane formed by the reference and signal beams). L_3 — L_4 is a lens pair to relay the $BSSLM_1$ onto the PRC surface. BSSLM1 will scan the reference beam along the horizontal plane (or the x-axis) in parallel with the C-axis. $BSSLM_2$ will steer the reference beam in the vertical plane (y-axis, or the fractal plane). During holographic data recording, the interference pattern formed by each page of input data beam and the specifically oriented reference beam will be recorded in the PR crystal. The reference beam angle (and location) will be altered with each subsequent page of input data. During readout, the data beam will be shut down and the reference beam will be activated to illuminate the PR crystal. Due to the principle of holographic wavefront reconstruction, the stored page data, corresponding to a specific reference beam angle, will be readout. The readout data beam will exit the PRC and pass through M_4 and L_5 before reaching the Photodetector (PD) Array. Note that the lens set L_3 — L_4 — L_5 will relay the input SLM to the PD array. The magnification factor, caused by the lens set, is determined by the aspect ratio between the data SLM and the PD array.

3. 2-D ANGULAR-FRACTAL MULTIPLEXING SCHEME

As depicted in Figure 1, by using two 1-D BSSLMs cascaded in an orthogonal configuration, a 2-dimensional angular-fractal multiplexing scheme has been formed, for the first time, in a JPL developed breadboard setup to enable the high-density recording and retrieval of holographic data.

In experiments, holograms were first multiplexed with x-direction (in-plane) angle changes while y direction angle holds unchanged. After finish the recording of a row of holograms, we then changed the y direction (perpendicular to the incident plane) angle, and recorded the next row of holograms with x-direction angle changes. Both x and y angle changes are fully computer controlled and can be randomly accessed. Currently we have successfully performed the recording and retrieval of long video clips of high quality holograms using this compact breadboard.

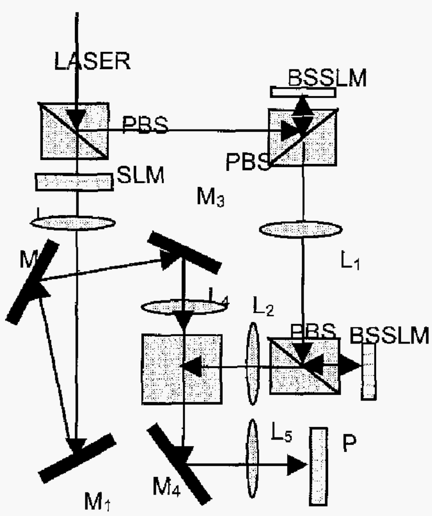

Figure 1. System architecture of compact holographic memory breading using a 2-D E-O angular-fractal multiplexing beam steering technology.

4. BEAM STEERING SPATIAL LIGHT MODULATOR

The BSSLM used in out experimental investigation has been custom developed by the Boulder Nonlinear System Inc. (BNS) for JPL This device is built upon a VLSI back plane in ceramic PGA carrier. A 1-dimensional array of 4096 pixels, filled with Nematic Twist Liquid Crystal (NTLC), is developed on the SLM surface. The device aperture is of the size of 7.4 μm x 7.4 μm, each pixel is of 1.8 μm x 7.4 μm in dimension.

The principle of operation of this BSSLM is illustrated in Figure 2. Since the SLM is a phase-modulation device, by applying proper addressing signals, the optical phase profile (i.e. a quantized multiple-level phase grating) would repeats over a 0-to-2π) ramp with a period d. The deflection angle q of the reflected beam will be inversely proportional to d:

$$\theta = \sin^{-1}(\lambda/d)$$

where λ is the wavelength of the laser beam. Thus, beam steering can be achieved by varying the period of the phase grating

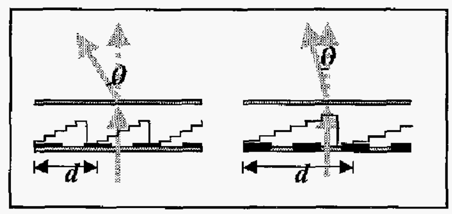

Figure 2. Beam steering using a phase modulation SLM with variable grating period.

For example, if each period d consists of 8 phase steps each with 1.8 μm pixel pitch. The period d will be 14.4 mm. With the operating wavelength at 0.5 μm, the total beam steering angle will be about +/- 3.2° . The total angle of diffraction will be 6.4°. In the next development step, the pixel pitch can be reduced by 0.5 μm and the corresponding total beam steering angle will be increased to 22.5°.

The Number of resolvable angles of the steered beam can be defined by:

$$M = 2m/(n+1)$$

Where m is the pixel number in a subarray, and n is the minimum number of phase steps used. For example, the number resolvable angle M of a 4096 array (i.e. m = 4096) with of 8 phase levels (i.e. n = 8) would be 910. The current device is configured into eight 1 x 512 subarray due to the resolution limits of the foundry process. Therefore there are only 129 resolvable angles are available for the BSSLM used in our experimental setup. A photo of the liquid crystal BSSLM used in our experimental set up is shown in Figure 3.

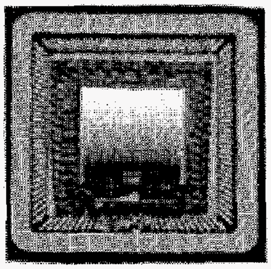

Figure 3. A photo of the LC BSSLM.

We have developed a custom phase-array profile driver and use a LabView based system HW/SW controller for the downloading of this driving profile to the BSSLM. Figure 4(a) shows the driving voltage profile used to achieve a very high diffraction efficiency (> 80%) for the steered beam. A sample of beam steering trace is shown in 4(b).

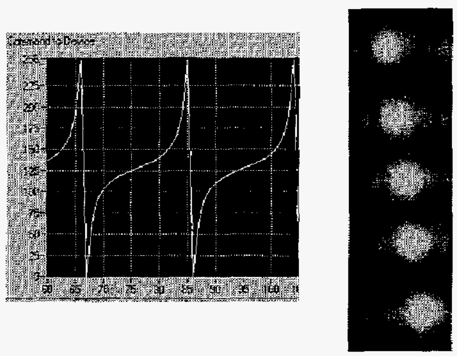

Figure 4. (a) BSSLM voltage driving waveform for high-efficiency beam steering using the LabView controller. (b) An example of the steered beam trace recorded using the BSSLM.

Unique advantages of this E-O beam steering scheme include: absence of mechanical motion, high-transfer rate (1Gb/sec), and random access data addressing, low-volume and low power.

5. CD-SIZED COMPACT HOLOGRAPHIC MEMORY BREADBOARD WITH 2-D E-O ANGULAR-FRACTAL BEAM STEERING

JPL has recently developed a miniaturized CD-sized holographic memory breadboard. A photo of this breadboard is shown in Figure 5. The layout of this system follows the system schematic shown in Figure 1. This CD-sized holographic memory breadboard, measuring 10 cm x 10 cm x 1 cm, is the most compact holographic memory module developed to date. The compact size of the VLSI based BSSLM together with advanced optics design has enabled the drastic reduction in the system volume from book-size to CD-size. This breadboard is capable of recording 10 Gbs of holographic data. The current system design would make it possible the easy replacement of the key devices when a upgraded version becomes available. These key devices include the Spatial Light Modulator, the BSSLM, and the PD array. Moreover, the system storage capacity would be increased by up to 2 orders of magnitude when a high-resolution BSSLM is developed.

The CD-sized holographic memory breadboard has been developed with a comprehensive LabView based system controller. Hence autonomous data recording and retrieval would be available upon full integration of the system.

During the data storage test and evaluation, we have utilized the grayscale Toutatis Asteroid image sequence for benchmark testing. Some example of retrieved holographic images of the Toutatis asteroid, excerpted from a long recorded video clip, are shown in Figure 6.

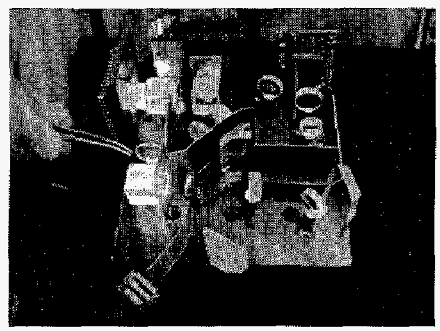

Figure 5. Photo of JPL Developed Compact Advanced Holographic Memory Breadboard of the size of a CD-sized (Volume of 10 cm x 10 cm x 2.5 cm, or 4 x 4 x 1) using a 2-D E-O Beam Steering Technology with an Angular-Fractal Multiplexing Scheme.

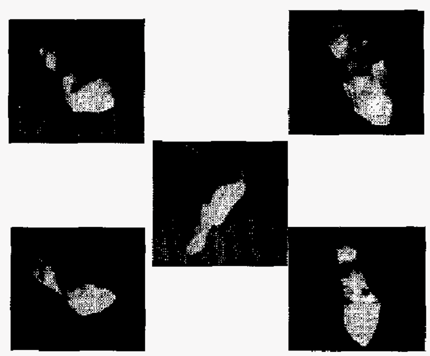

Figure 6. Example of retrieved holographic images of the Toutatis Asteroid.

6. SUMMARY

JPL has successfully developed an advanced holographic memory technology to enable high-density and high-speed holographic data storage with random access during data recording and readout. An innovative E-O beam steering scheme, achieved by utilizing liquid crystal beam steering device, has been experimentally implemented. Recently, a CD-sized holographic memory breadboard has been integrated and demonstrated for successful holographic data recording and retrieval. This breadboard is the most compact one developed to date.

7. ACKNOWLEDGMENTS

The research described in this paper was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.

8.REFERENCES

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