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Simulation of a Spatial Light Modulator for Holographic Data Storage System

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Abstract*-- Holographic data storage is regarded as a potential technique for the next generation optical data storage with extremely high capacity and ultrafast data transfer rate. In holographic data storage system, page wise data are stored as holograms within the recording media. In this paper, Spatial Light Modulator (SLM) is simulated. The SLM is a device which is used to encode digital data pages onto a laser beam and it spatially modulates the coherent beam of light according to the electronic data pages. The spatial filtered laser beam falls on the panel of the SLM and gets intensity modulated. Thus the electronic data pages are converted into optical data pages. This modulated data pages are interfered with the reference beams to produce holograms. Multiple data pages can be stored on a single location using various multiplexing techniques such as angle multiplexing, wavelength multiplexing which results in a high density data storage system. The stored data pages are reproduced by illuminating the hologram with the corresponding reference beam. The data is read in parallel over one million bits at once, thus resulting in fast data transfer rate.

***Index Terms*—Interference pattern, holographic data storage system, object beam, reference beam, Spatial Light Modulator**

I. INTRODUCTION

Optical Holography is the process by which the light field is recorded by using two or more mutually coherent beams from a laser. It has the capability to produce three-dimensional images which cannot be obtained through conventional photography. The distinctive characteristic of holography is recording both the amplitude and phase of the light which is coming from the scene to be recorded. Hence the phase information must also be converted to intensity variations. The recording medium records the interference pattern between the reference beam and the object beam. This interference pattern is known as the hologram [1]. Two major commercial applications of holography are in security and data storage. Holographic data storage is an optical data storage technology which offers greater storage capacity, faster transferability and longer shelf life than the currently available storage devices. Holographic Versatile Discs (HVDs) are the devices that contains data in a holographic manner with a storage capacity of 3.9TeraBytes (3.9 TB) at a data rate exceeding 1Gbits/sec [4]. Once the recording material is exposed to light, the interference patterns are stored permanently and cannot be forged in any way. Hence it offers highly secured data storage. The holographic storage offers a shelf life up to about 50 years.

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According to the method of writing the input patterns on the SLM, commercially available SLMs are broadly divided into two basic types: Optically Addressed Spatial Light Modulator (OASLM) and Electrically Addressed Spatial Light Modulator (EASLM). OASLM converts incoherent light to spatial modulation. In this method, the input pattern is converted to an optical image and is displayed on the SLM. The image on the SLM is created and changed by shining light encoded with an image on its front and back surface. Whereas EASLM converts electrical signals to spatial modulation[3].This device acts as an interface between the optics and electronics. Each element on the SLM is supplied with a voltage that represents the shade and intensity value of the corresponding pixels in the input image. This paper proposes a method for simulating the SLM. The spatial light modulator is a device that spatially modulates a coherent beam of light according to a control input. Here the panel of the SLM is simulated on which the light beam falls and gets intensity modulated [9]. This beam is interfered with the reference beam to produce the interference pattern called hologram.

II. EXPERIMENTAL SETUP

The experimental setup is shown in Fig 1. Laser is used as the input light source as it is coherent in nature. A semiconductor laser or a He Ne Laser which emits red light of wavelength 632nm is used. Light from the laser is split into two – transmitted beam and reflected beam, using a beam splitter with a splitting ratio of 50:50[2]. The transmitted light is passed through spatial filter which removes the aberration in the beam due to dusty or detrimental optical variations in the laser and is called reference beam. The transmitted light is passed through the spatial filter and then falls on the panel of the SLM. The panel of SLM is encoded with the required information with the help of computer software. The light passing through the panel of the SLM gets modulated according to the electronic information in it. The modulated light emerging from the SLM is known as the object beam. For perfect interference of the two beams, the path length of the object beam & the reference beam from the beam splitter must be equal or the path difference should be zero[5]. The reference beam and object beam interfere with each other to form the interference pattern which in turn is stored as a single spot on the holographic storage material. By altering one or more characteristics of the reference beam (angle, wavelength etc.), multiple data pages can be superimposed at the same location and this process is called multiplexing. If the angle of the reference beam is changed, it is known as angle multiplexing. If the wavelength of the reference beam is changed it is called wavelength multiplexing.

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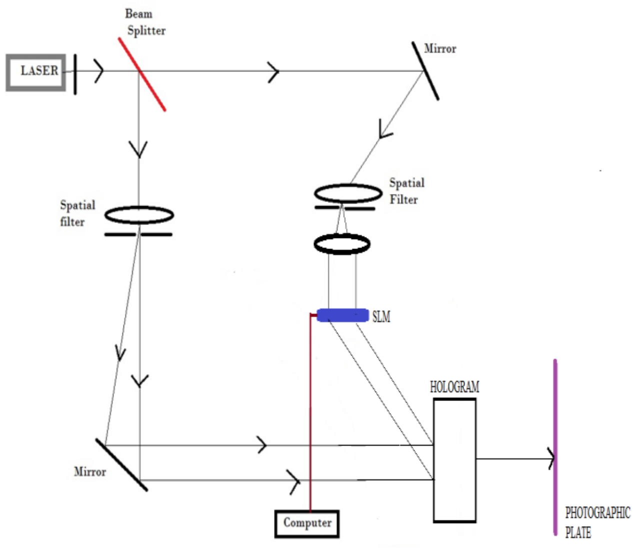

Fig. 1: Basic block diagram

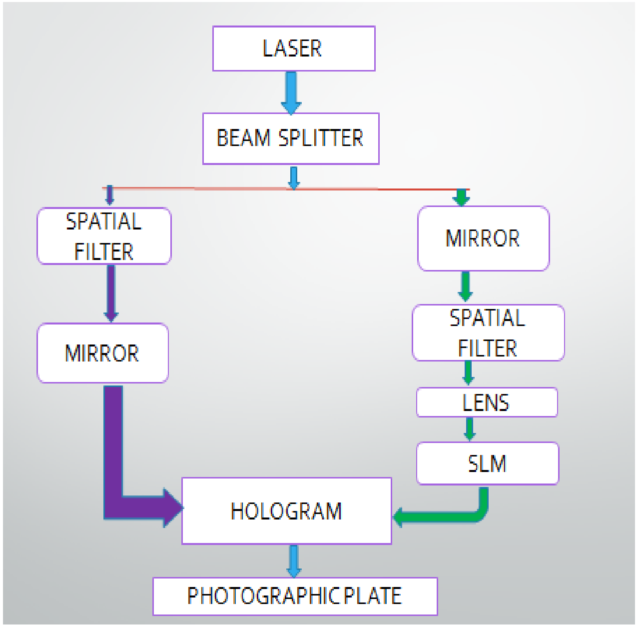

Fig. 2: Flowchart of the whole phenomenon

III. DESIGN OF THE SPATIAL LIGHT MODULATOR

Spatial Light Modulator is an essential element in any holographic data storage system. It is used to encode digital data pages onto a laser beam. The data istransferred from thecomputer to the SLM. The values of these data corresponds to low and high intensity values. SLM is a device that formats incoherent optical data or electronic data so that they can be processed with the help of coherent light. It is basically a planar array of thousands of pixel shaped elements, where each element is an independent optical switch that can be programmed to either allow or to block the light passing through it. SLM is used to control the light in two-dimensions. It comes in various specifications such as 256x256, 512x512[8]. The intensity of light gets modulated according to the electronic input. SLM basically consist of an address part and a light modulation part. Such types of SLM are called transmissive SLMs. The information to be stored is written onto the address part using MATLAB [7]. The light when passed through this SLM gets modulated according to the information in the address part. Hence the name Spatial light modulator as the light is modulated spatially.

IV. MATHEMATICAL BACKGROUND

The equations required for the simulation of SLM are discussed here. The SLM is based on Fresnel Diffraction. The basic equation for Fresnel diffraction is:

$$U(x,y) = \frac{e^{jkz}}{j\lambda z} \int \int_{-\infty}^{\infty} U(\xi,\eta)\, e^{j\frac{k}{2z}[(\xi-x)^2+(\eta-y)^2]}\, d\xi d\eta \qquad (1)$$

where

$U(\xi,\eta)$is the the intensity of plane P2 due to the incident light intensity U(x,y) on plane P1separated by free space and a distance 'd' as shown in Fig 3.

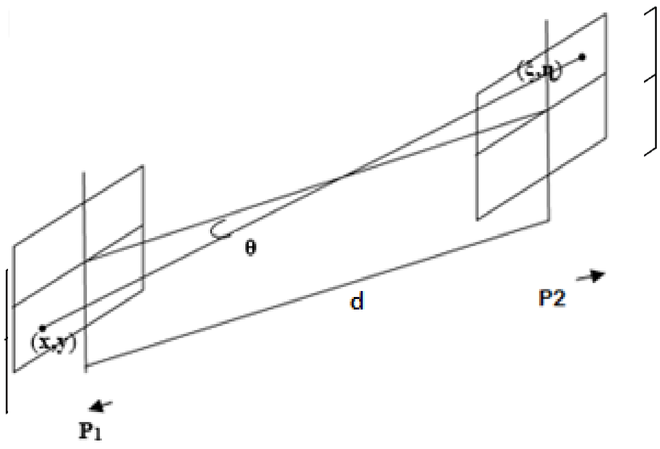

Fig. 3: Fresnel Diffraction

The Spatial light modulator has a transmittance function:

$$t(x) = \left[\sum_{k=1}^{L}\sum_{n=0}^{M-1} rect\left(\frac{x-(k-1+n.L).\Lambda_p}{n_{ff}.\Lambda_p}\right).e^{\left(i\frac{2\Pi}{L}k\right)}\right] \qquad (2)$$

where : n_{ff}-linear fill factor

L -number of phase levels

Λ_p - pixel pitch of the SLM.

The Fourier of the above equation is taken for other calculations for the simulation of SLM. The resulting equation is:

$$F\{t(x)\} = \left[n_{ff}\Lambda_p \operatorname{sinc}\left(\Lambda_p k_x n_{ff}\right)\sum_{k=1}^{L}\sum_{n=0}^{M-1} e^{-i2\pi k_x \Lambda_p (k-1+nL)} e^{i\frac{2\pi}{L}k}\right] \qquad (3)$$

This is the fundamental equation of the spatial light modulator. Based on this the SLM can be completely simulated[6].

V. SIMULATION AND RESULTS

In this paper MATLAB software is used for the simulation of the SLM panel. The simulation of all the blocks in the flowchart as shown in Fig 2 is done sequentially. The laser beam is assumed to be a direct delta function which passes through the spatial filter and acts as the reference beam as shown in fig 7. The information is written in the corresponding MATLAB code.

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The data page is first converted into binary values, which is then encoded to the SLM. Any information can be written into the SLM in real time as shown in fig 4. This will model the panel of the SLM according to the information as shown in fig 5. A black and white SLM panel is created according to the data (white stands for data-1 and black stands for data-0). The beam when passed through the panel of the SLM gets modulated according to this information as shown in fig 6 which becomes the object beam. The Fast Fourier Transform (FFT) of the reference beam and object beam are taken to produce the hologram of the data page as shown in fig 8 which is encoded into the SLM. This data page can be retrieved by taking the Inverse Fast Fourier Transform (IFFT) of this hologram and the corresponding reference beam [10] as shown in fig 9.

For example:

i) Consider the input :

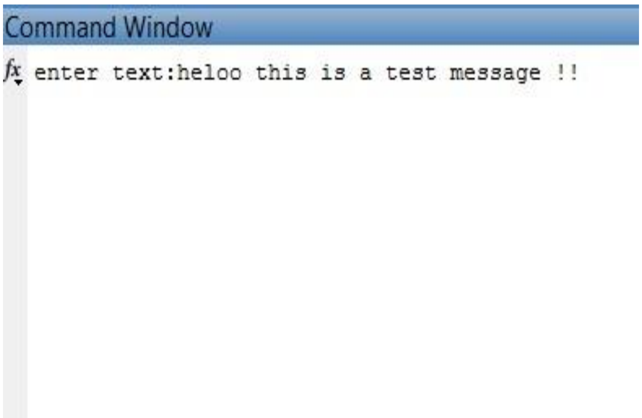

Fig. 4

The 64*64 SLM panel for the above input is as follows:

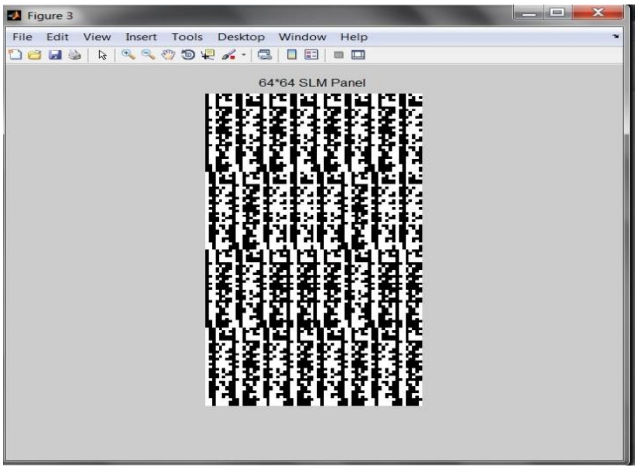

Fig. 5

The object beam will be:

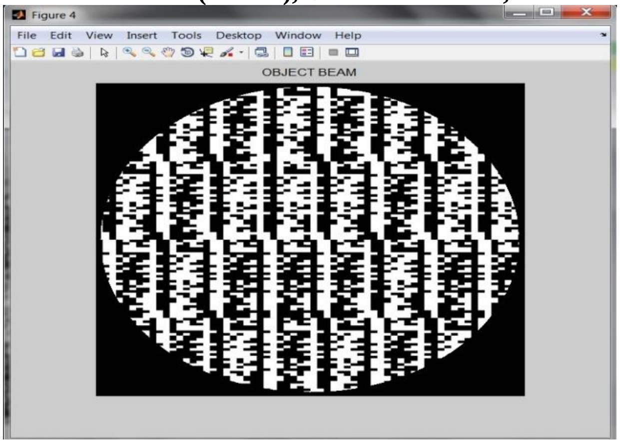

Fig. 6

The reference beam is shown below:

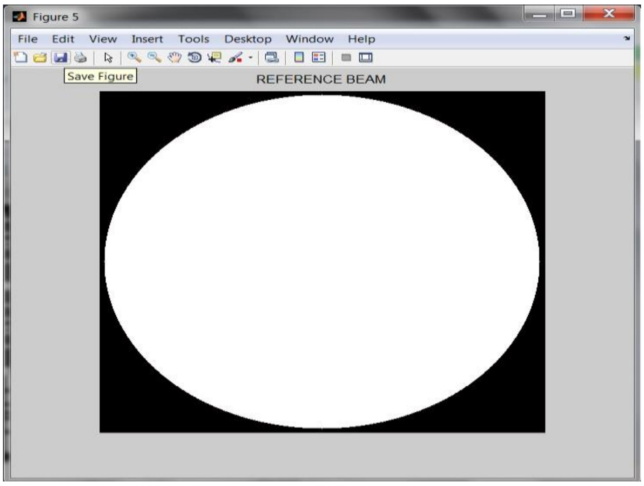

Fig. 7

The resulting hologram of the input data will be:

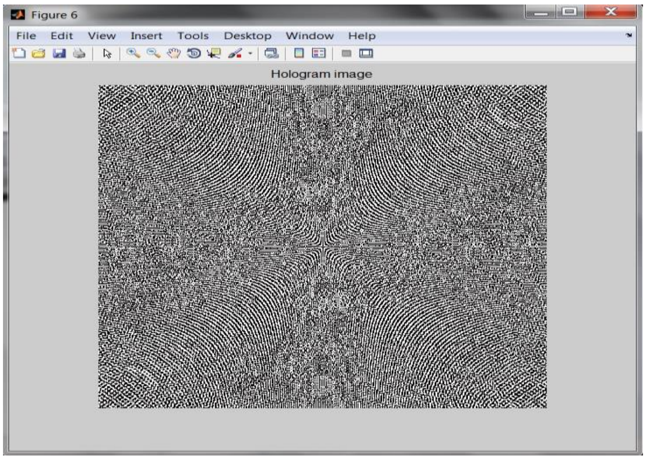

Fig. 8

The electronic data can also be reconstructed as follows:

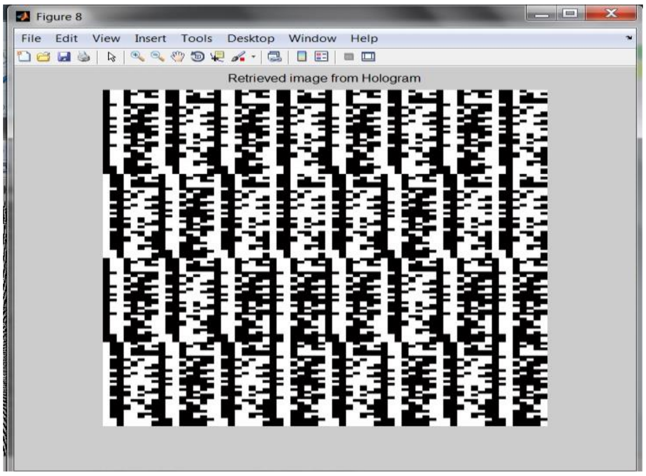

Fig. 9

VI. CONCLUSION

In this paper, the model of a Spatial Light Modulator panel with resolution 64x64 pixels with real time input data pages is developed. This resolution can be varied to any dimension such as 256x256 or 512x512 pixels according to the requirement. The simulation of the panel of SLM is most essential part of the holographic data storage system. Once this is completed, the recording of the hologram can be done easily and the data pages can be stored in just a matter of time.

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