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Diffraction limited imaging through complex scattering media

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ABSTRACT

We present a technique to study the correction of distortion wave front due to a highly scattered medium utilizing Spatial light modulator(SLM) . The effects of changing in the images of computer generated holography (CGH) are studied in the corresponding pattern generated by the SLM. The SLM is a contemporary holographic device based on liquid crystal (LC) pixels, which shape the entering light field by altering its phase, its amplitude, or both, as a function of location on the pixel. Each pixel is acting as a variable wave plate and can present a specific phase shift to an incident polarized light. The SLM technology is a fast developing technique which is energetically combined in various optical systems for dynamic diffractive optical elements imaging. The ability of utilizing the SLM in the controlling of the optical imaging in order to obtain the desired diffraction optical pattern will be investigated. The SLM is utilized to correct wave front aberrations due to a highly scattering medium with He-Ne laser which transmitted through TIO2 and produced a random speckle patterns, a different CGHs are applied to the SLM in order to enhanced the intensity of the distorted beams, The display of the SLM is the optical element that transforms the CGH into the favorite pattern. A bright spot with a contrast proportional to the number of controlled SLM segments is appeared on the screen. This system is accomplished in control of light, and can be used to alter the diffraction pattern of an imaging system very quickly without macroscopic moving parts and it enables very high resolution without the need for complex construction procedures.

INTRODUCTION

Image transmission through nonlinear materials has more interested in studies due to its importance in different applications such as imaging (Christopher *et al*., 2009), random lasing and solar energy (Diederik S. Wiersma., 2013). The propagation of coherence light inside opaque medium, such as biological tissues and the turbulent atmosphere produce a wave front distortion and scattering the light(Vellekoop and Aegerter, 2010),(Yefeng *et al*., 2012). The spatial resolution is fall off rapidly with increasing field angle which limits the resolution of light focusing (Ori *et al*., 2014). The main problem with formation of a focus through a medium containing randomly dispersed scatters is the rapidly destroyed of initial wave front inside the medium due to the multiple scatterings (Xin *et al*. 2012). The spatial distortions can be modified by wave front shaping utilizing SLM with a CGH. The SLM technology is a fast developing technique which is energetically combined in various optical systems for dynamic diffractive optical elements imaging (Ori *et al*. 2012). Because of the control ability for the SLM, the CGHs can be used by means of a programmable SLM which represents the media to calculate the coded arithmetical algorithms and create a real time high resolution of correct holographic displays (Pierrat *et al*., 2008). The SLM achieves high precision and high efficiency laser machining by correcting optical aberration in the turbid medium (Jacopo *et al*., 2012).An approach namely binary amplitude modulation to study the focusing of light through random materials was explored by D.

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Akbulut *et al*., 2010.Another study based on the optical memory effect to improve three dimensional phase conjugated scanning microscopy through turbid medium have been demonstrated by Xin *et al*., 2012. A steady-state technique of focusing coherent light through dynamic scattering media is investigated by C. Stockbridge *et al*., 2012.The dynamical model describes diffraction-limited focus which formed inside or through a turbid medium has been proved theoretically and numerically by Ori *et al*., 2014.In this work, a technique based on high-resolution wave front shaping utilizing a programmable SLM that enables real-time wide-field imaging by using a diffuser is presented. The phase distributions of the CGHs provided in SLM with the application program has been investigated.

Experimental Work:

The experimental setup for the optical imaging system utilizing SLM with He-Ne laser of 632.8nm wavelength in order to study the diffraction pattern of CGH based SLM is schematically shown in figure (1).SLM of Holoeye LC2002 model is used with resolution of 800 ×600 pixels (32 μm square in size) and 256 grey level signal display.

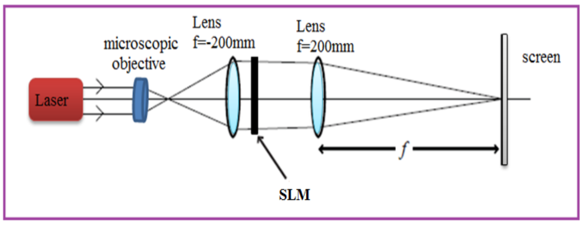

Fig. 1: sketch of the experimental setup, the SLM is used to reconstruct of the CGHs. A lens focuses a beam of light onto a charge coupled device (CCD) camera.

The SLM is localized after the TIO2 in this display system in order to optimize the obtained real image. The optically reconstruct of the CGHs are represented utilizing the SLM with the application and the control programs. The pattern of He-Ne laser which incident on CCD camera is shown in Fig. 2.

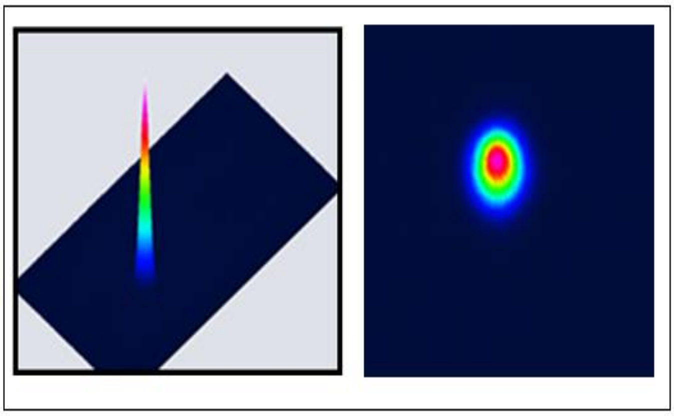

Fig. 2: the intensity profile of the He-Ne laser pulse (a) 3D, and (b) 2D display.

RESULTS AND DISCUSSION

1. Optical reconstruction of CGH utilizing the SLM:

The optical modulating on the real image of He-Ne laser beam is shown in Fig.3 and Fig.4, the effect of changing the Lens phase on the reconstruction image is clear. When polarizing light is incident on SLM it will be modulate due to pixilated liquid crystals (Asi and Abdul halim, 2014).

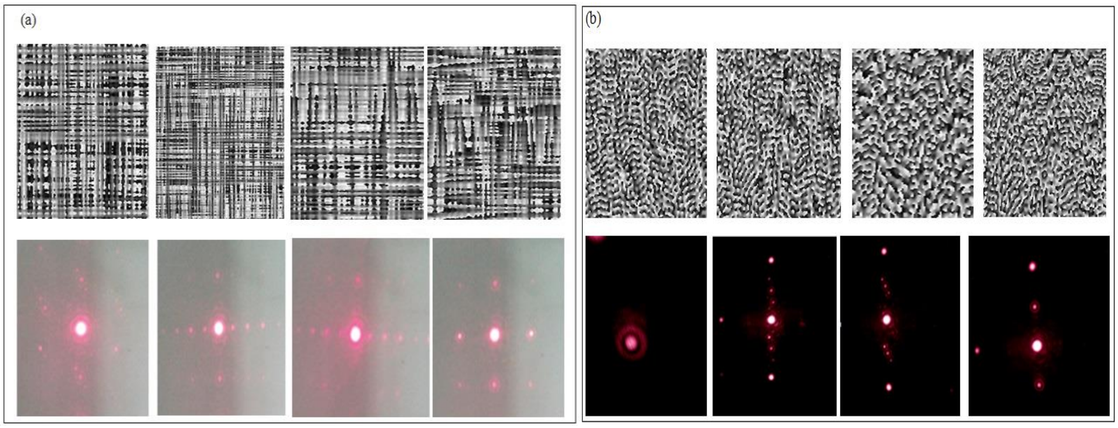

Fig. 3: CGH samples injected into the SLM with its corresponding optical reconstruction utilizing the SLM (a) COORD sample, and (b) Holoeye sample. The figures from left to right: Lens phase=0, 1, 2, and 3 respectively.

The operation of the SLM is able to improve the distorted wave front of light only in a limit wavelength bandwidth range because of the clear scattering of LC for white light (Ventseslav *et al*., 2006).Fig.4 shows the effects of Lens phase on the PMMA grating picture obtained by A.Taranu *et al*., 2010, as a CGH.

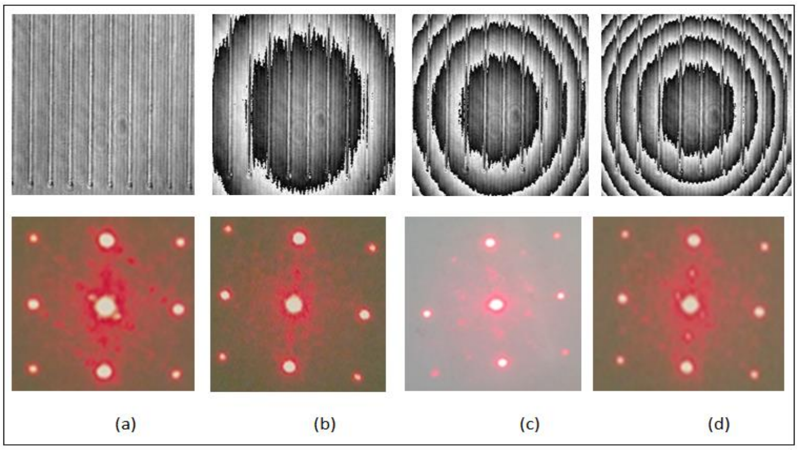

Fig. 4: PMMA grating sample injected into the SLM with its corresponding optical reconstruction utilizing the SLM, (a) Lens phase=0, (b) Lens phase=1, (c) Lens phase=2, and (d) Lens phase=3.

The CGH image with a gray scale signal can improve utilizing a prism phase where all diffraction angles produced by the signal on the SLM are adjusted when such function is superimposed. The results are reported in Fig.5.

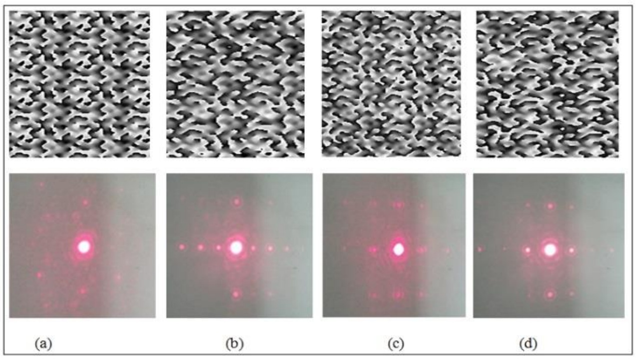

Fig. 5: points sample of CGH injected into the SLM with its corresponding optical reconstruction utilizing the SLM at: (a) prism phase=0, (b) prism phase=1, (c) prism phase=2, (d) prism phase=4.

2. Wave front correction utilizing SLM with injected CGH:

The wave front deformations due to the opaque can be improved in real-time in three dimensions utilizing the feathers of controlling the SLM with CGHs. These CGHs help in the aberrations compensations and reproduce the preferred phase. In Fig.6 the Light from a 632.8 nm He-Ne laser is distorted when it passed through the TIO2 medium and then spatially modulated by a SLM and focused by the lens (f=100mm) on the screen. A disordered speckle pattern is recorded by placing a disordered medium, so the transmitted wave is lost all correlation with the incident wave front because of scattered and diffracted light about a hundred times (Martin, 2014), which will prevent the wave front correction by adaptive optics (Vellekoop *et al*., 2010).

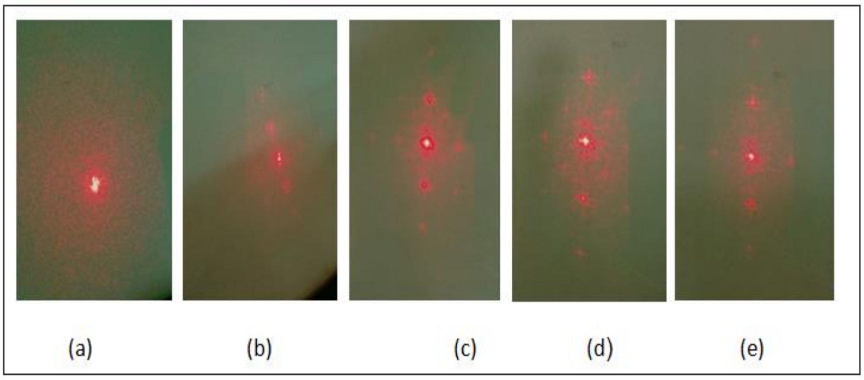

Fig. 6: 2D images, show the effect of SLM with injection CGH on microscopic imaging through turbid medium, (a) Image of diffuser, (b) Putting SLM after diffuser and at prism = 0, (c) Putting SLM after diffuser and at prism = 1, (d) Putting SLM after diffuser and at prism = 3, (e) Putting SLM after diffuser and at prism = -1.The distortion wave front is passed through SLM and monitored on the screen.

When the distorted laser beam is propagates through the SLM, the phase errors are corrected exactly. The intensity pattern from the SLM is changed utilizing the application software and the SLM segments are modified according to the CGH as shown in Fig. 6(b-e). The total degree of freedom of the SLM is reduced by alignment pixels into an adjustable number of square parts. So that the measures amplitude is altered with the SLM video signal, and the undistorted real image of the object is manipulated in its original position, Fig. 6(e). According to(Quanquan *et al*., 2006) the correlation could be restored by shaping the wave front of the incident light using a SLM. The 3D images of these patterns are shown with the injected CGHs in Figs. 7-8. This high resolution wave front shaping has developed as a dominant approach to generate a pointed focus through such as materials (Ori *et al*., 2014).

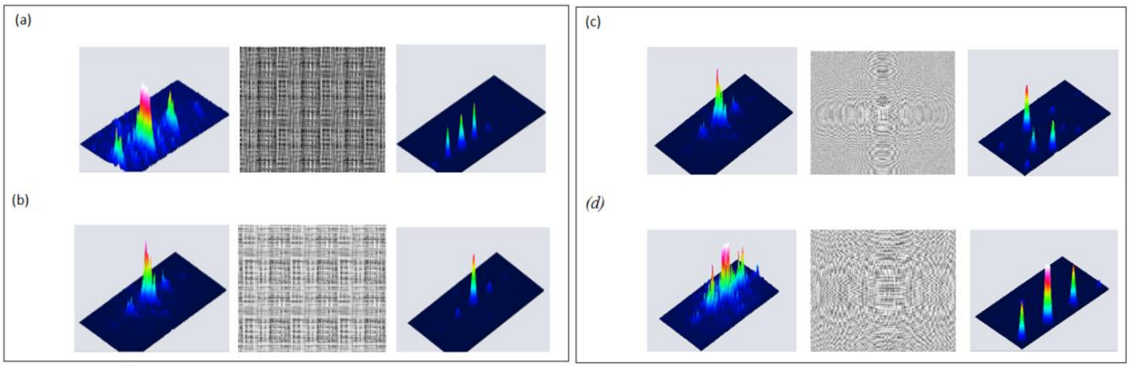

Fig. 7: The effect of the SLM with injection CGH on wave front correction, this images captured with CCD camera, the optical image before optimization(left),the COORD CGH of lens phase=0 CGH injected into the SLM(middle),the optical image after optimization utilizing SLM(right).(a) the PMMA CGH,(b) COORD CGH of lens phase=0, (c) the COORD CGH of lens phase=2, (d)the COORD CGH of lens phase=4 injected into the SLM.

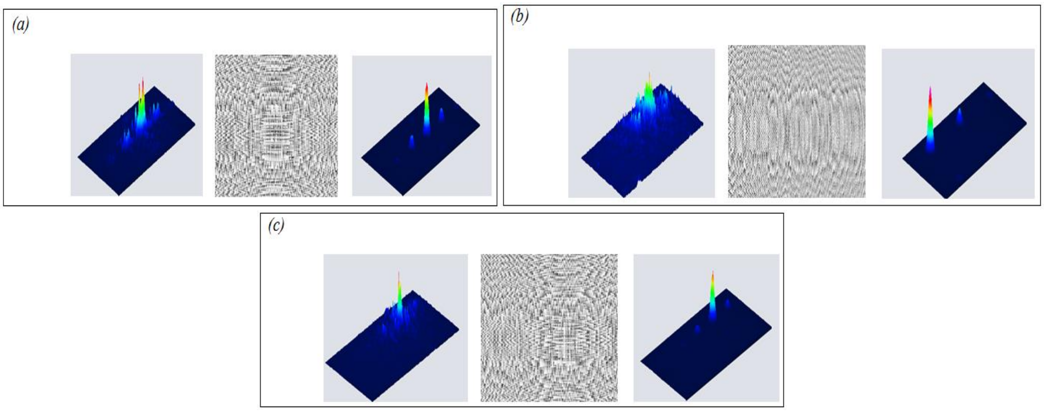

Fig. 8: The effect of the SLM with injection CGH on wave front correction, this images captured with CCD camera, the optical image before optimization (left), the PMMA CGH injected into the SLM(middle),the optical image after optimization utilizing SLM(right).(a) the COORD CGH of prism phase=0,(b) the COORD CGH of prism phase=29 ,(c) the COORD CGH of prism phase=-4.

Conclusions and Outlook:

We have demonstrated three-dimensional diffraction limited through high scattering medium utilizing CGH injected to SLM, we show that the SLM can be successfully focused behind a highly dispersal medium, and corrected the aberration distortion on the CCD. The diffraction performance of the SLM at He-Ne laser beam of 632.8 nm wavelength is evaluated. The effects of SLM on the intensity distribution before and after optimization are studied. The optimal wave front is completely disordered due to the opaque, also the point source is produced a random speckle pattern on the camera which verifies that the sample is intensely scattering. The diffraction patterns could be easily enhanced by applying the appropriate CGH to separable pixels of SLM which will be arranged to correct the specific aberrations of the optical imaging system, the different CGHs lead to a different tilt of the LC pixels which cause a change in direction of the birefringent LCs and therefore a different polarization state. The rise in intensity is probably caused by a natural birefringence of the SLM.

Imaging behind turbid structures utilizing SLM is of great importance in applications of biomedical photonics, where often interesting structures are hidden behind turbid layers. Also it is efficient for real time imaging to establish high-resolution across image disturbing medium without the need for complex construction procedures. Perhaps even more interesting is the ability to focus light inside living tissue turbid tissue. However, an important step towards in vivo deep tissue noninvasive optical imaging, optogenetics and photodynamic therapy has been done by Yan *et al*. 2015.Design a system utilizing the SLM software for further experiments which involve multi-particle position tracking of particles in 3-Dis could be a useful for suggesting work.

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