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An Interferometeric Technique Utilizing Holographic Optical Elements (HOEs) For Imaging Through Scattering Media

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ABSTRACT

Imaging through scattering media as fog and smoke represents a very great problem in practice. Different holographic techniques have been demonstrated a successful solution for this problem, but their usefulness is limited in field conditions by the requirement of a separate coherent reference beam and perfect stability of the holographic recording apparatus. In this paper, an interferometric imaging technique that utilizes holographic optical elements (HOEs) as a diffraction grating is presented. The obtained results show a great improvement in the image quality over the known classical techniques.

KEY WORDS

Holographic Optical Elements (HOEs)
Holography
Imaging through scattering media.

1. Introduction

The preservation of phase information is the property of holography that allows the retrieval of image information in spite of random phase variations of a wave caused by a non-uniform medium. There are two basic approaches in compensating for random phase effects.

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One is to pass the conjugate wave back through the same medium to form a real image of the object in the same location as the object [1,2]. The other is to cause the object and reference waves to pass through the same phase- distorting medium so that the effect of the medium is canceled when the square law recording takes place [3]. Speckle interferometry can be done also through a random medium [4]. In addition, the general approach of imaging in the presence of atmospheric turbulence is to measure [5] or estimate [6] the wavefront distortion and then apply the corresponding correction with active optical devices [7,8].

On the other hand, it has been recognized that the separation of the scattered light field from the desired unscattered signal provides a viable approach for improving the imaging performance [9]. The improvement achieved with the imaging techniques based on the separation of the scattered and the unscattered signal was limited in practice. This is due to the fact that as the energy of the image spectrum is centered on the origin and in performing the high pass filtering, a substantial amount of signal energy is lost. To produce a much higher degree of contrast improvement, an effective approach is to shift the signal image spectrum away to a region where the system noise is low. This allows the entire image spectrum to pass through the filter. To produce the necessary carrier frequency, various interferometric techniques can be utilized.

Spitz [10] and Stetson [11] independently demonstrated the viability of using the holographic technique for imaging through scattering media. Later on, Lohmann and Schmalfuss[12] had developed a real time technique for processing the interferometric signals. However, their technique is effective only if the target is a transparent object. Its usefulness is therefore limited to dark transmission type of applications. Moreover, for transparent targets, a high degree of image enhancement can be achieved even without the use of interferometric techniques by performing a low pass filtering on the received light field. Holographic techniques have been demonstrated in the laboratory successfully but its effectiveness would be severely limited if it were applied in actual field conditions. However, the most serious drawback of the conventional holographic technique is its sensitivity to mechanical vibrations and atmospheric disturbances. Thus, even though the conventional holographic technique has been found to be effective in imaging through a scattering medium, its applicability in the field is doubtful.

2. Theory

Assume that we use an imaging system to image or detect an object or scene in the presence of a scattering medium as shown in figure (1). At the image plane, the light field is the superposition of the unscattered and the scattered light fields. Since the scattered light field is spatially incoherent over the integration period, the scattered and the unscattered components add by their intensities at the image plane. In addition, the speckle pattern resulting from the scattered light field is averaged to a uniform bias. Since the spectrum of the uniform bias concentrates at the origin of the frequency plane, it can be filtered out with a DC stop. By this filtering process we can improve the contrast of the target image. In fact, the improvement achieved by this technique is limited. First of all, the side lobes of the DC term could contribute significantly to the filtered image. Secondly, the energy of the image spectrum is also centered on the origin and in performing the high pass filtering, a substantial amount of signal energy is lost. As the system noise, such as film grain noise is highest at low frequencies, it is clear that the contrast improvement attainable by a DC stop is very limited.

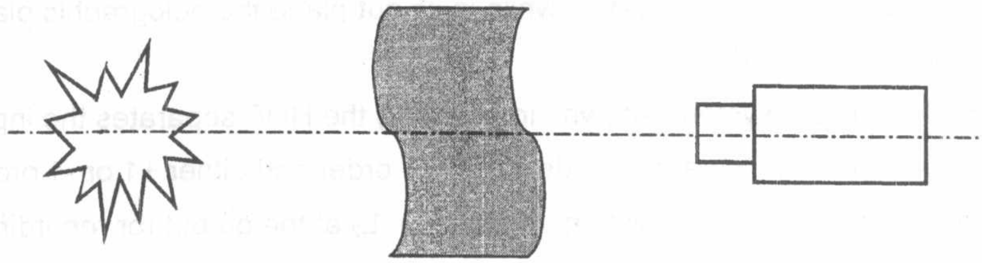

Figure (1)

To produce a much higher degree of contrast improvement, an effective approach is to shift the signal image spectrum away from the DC term to a region where the system noise is low. This allows the entire image spectrum to pass through the filter. To produce the necessary carrier frequency, various interferometric techniques can be utilized such as the conventional holographic techniques and the grating speckle interferometer.

To use holographic techniques in practice, the optical path difference between the reference beam and the object beam must be less than or equal to the coherence length of the light source. This requires a prior knowledge of the range of the target and this precise knowledge of the target range may not be available in most practical cases.

The fundamental concept introduced by the holographic techniques is the creation of a sinusoidal carrier modulation for the unscattered light. The modulated signal is then separated from the constant bias by band-pass filtering. The need for a reference beam has limited the usefulness of holography in many practical applications. The same basic concept introduced by holography (the creation of sinusoidal carrier modulation for the unscattered light) can be implemented without the use of separate reference beam. A sinusoidal carrier modulation can be produced with the scattered light by interfering the image light field with itself. This can be done by a grating interferometeric system [9] in which two gratings are used. The first separates the input light fields into two equal parts and the second grating recombines them at the recording plane.

In this work we use an imagery system, where in its input-plane is placed a HOE which plays the role of a diffraction grating while in its out-plane the holographic plate is placed as shown in figure (2).

In this the interferometric system shown in figure (2) the HOE separates the input light field into three parts 0, +1, and -1 orders. The 0- order and either +1 or -1 order are recombined by a lens (or a system of lenses) L_2 at the output (or recording) plane. The interference of the two diffracted light fields produces a sinusoidally modulated object image, where the intensity is given by [13,14]

$$I(x,y)=|g(x,y)|^2\left[1+\cos 2\pi G_o x\right]$$

Where g(x,y) is the amplitude of the image field at the point (x, y) in the image plane and G_o is the spatial frequency of the interference pattern recorded on the HOE which plays the role of a diffraction grating. The phase of the sinusoidal fringes is independent of the phases of the input light.

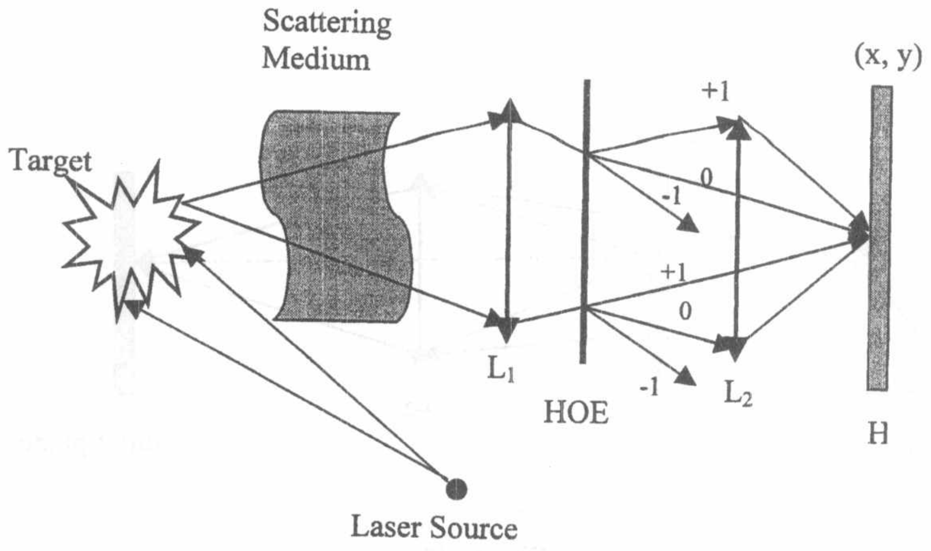

Figure (2)

The light from each point of the HOE is recombined at the output plane such that a fixed phase difference exists between the interfering image points. Thus using such an imaging system for imaging through a scattering medium a stationary fringes are obtained. If the object is stationary, the phase differences between adjacent image fields formed by the unscattered light are fixed and their interference produces stationary fringes. On the other hand, adjacent image fields formed by scattered light have a time-varying phase relationship. Such moving fringes formed by the scattered light can be averaged out with an integrating detector such as films or holographic plates. When the interferometric system shown in figure (2) is used to image on object or a target through a scattering medium, the intensity at the output plane is given by

$$I(x,y)=B^2+A^2|g(x,y)|^2\{1+\cos[2\pi G_o x+\varphi(x,y)]\}$$

Where $\varphi(x,y)$ is the phase difference between interfering light waves from two image points on the output plane, and A^2 and B^2 are the intensities of the unscattered and scattered light respectively.

After linearly recording the image intensity on the holographic plate the target image can be separated from the bias term by inserting the developed transparency in an optical processor such that shown in figure (3)

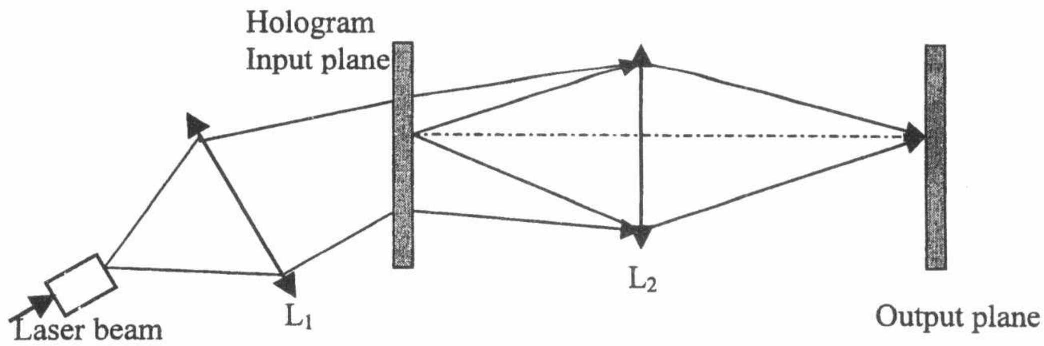

Figure (3)

Reconstruction of the target image using an (coherent) optical processor. The input transparency is imaged into the output plane by the lens L_2. The choice of G_o depends on the characteristic of the recording material, since the noise decrease exponentially with G_o. Also the MTF of the recording material decreases with increasing G_o. As a result an optimum value of G_o exists. This value must match the characteristic of the recording material in order to optimize the performance.

3. Experimental results

Dissolving powdered milk in a glass-sided tank filled with water created the scattering medium. The suspended fat particles create a volume scattering field with characteristics quite similar to that of fog. The models of two cars were used as targets and they were illuminated directly with a He-Ne laser beam after its spread out by a microscope objective. The experimental results are shown in figures (4, 5), where in figures (4-a) and (5-a) the target images are obtained directly in the absence of the scattering medium, but in figures (4-b) and (5-b) the target images are obtained directly through the scattering medium, and in figures (4-c) and (5-c) the target images are obtained in the presence of the scattering medium and using the interferometric system shown in figure (2). The used plates are Agfa Gevaret 10E75.

(a) (b) (c)

Figure (4)

(a) (b) (c)

Figure (5)

The HOE is the lensless Fourier transform hologram of an aperture uniformly illuminated in direct light [13-16]. From figures (4-b) and (5-b) it is clear that no images can be obtained directly through the scattering medium using the classical photography. Using the proposed interferometric technique, which utilizes a HOE as a diffraction grating in the input of an imaging system, it is possible to obtain images of relatively good contrast compared to those of figures (4-a) and (5-a).

4. Conclusion

We presented in this work an interferometric technique utilizing an imaging system in its input plane, a HOE is used as a diffraction grating. The major advantage offered by this system is that it's relative high tolerance to normal vibrations and air disturbances. Using such system it is also possible to relax the perfect stability requirements in a holographic recording process. Thus using this proposed holographic interferometric imaging system, it is possible to obtain images of objects in the presence of scattering media such as (***fog, dust, smoke***, ...etc.).

Moreover, as the obtained images are of improved contrast, it is possible to increase the visibility range.

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