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Controlling the Shapes of the Moiré Patterns Generated Using the Interferometry and a Spatial Light Modulator

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Abstract: ***Moiré patterns are generated by the superposition of two periodic patterns of close frequencies. This present paper proposes a simple method to bridge the conventional gap between interferometry and moiré patterns by generating moiré patterns using straight-line interference fringes from a Michelson interferometer like setup and a circular grating pattern generated on a Spatial Light Modulator (SLM). The visible variation in the geometrical shapes of the moiré patterns by varying the ratio of the periods of the two periodic patterns has also been presented. The experimental results match with the simulation results.***

Keywords*: Moiré, Interferometry, Spatial Light Modulator, Optics, Engineering physics*

I. INTRODUCTION

Moiré fringe patterns are certain frequency beat-patterns, which are quite often observed in the daily life. Certain fringe patterns, recorded while taking photographs of the television screens, the mechanical fringe patterns seen while looking through two layers of mosquito nets etc. are some of the most common examples of the moiré patterns. These moiré patterns are produced if two or more closely spaced periodic or quasi-periodic patterns are superimposed on one another. The superposition can be a ordinary mechanical superposition as well, which usually is not done in case of interferometry. 'Moiré' is a basically a French word for a certain kind of silk textile in which these patterns were first observed. Over the years, the moiré pattern has gained significant popularity in different fields like metrology, structural analysis, microscopy etc. as a cheaper and easier alternative to conventional interferometry based techniques.

Lord Rayleigh [1] was one of the pioneers in the field of the study on the moiré patterns. Detailed analytical and numerical studies on different kinds of moiré fringes were done by Amidror et al. [2] and Patorski et al. [3]. Caldero´n-Hermosillo et al. [4] did some studies on complex amplitude of Spatial Light Modulator (SLM) using the moiré method. Blau et al. [5] and Röhrich et al. [6] used moiré in structural illumination microscopy.

Yu et al. [7,8] has performed an in-depth image domain study of the visible moiré patterns. Yu et al. [8] has also showed generation of different moiré patterns for different period ratios of the gratings used to produce the moiré patterns.

Different fringes are generated with different schemes of optical interferometry also. However, in most of cases, the interference fringes and the moiré fringes are used or generated independently. But, considering the advantages and the disadvantages of interferometry and moiré patterns, it can be easily concluded that the merging of both the techniques has a lot of potential in several aspects like easier analysis and introduction of more flexibility to the setup. For example, in a Michelson interferometer setup, by tilting a mirror in the setup, the fringe-density and/or the orientation of the fringes can be varied. On the other hand, if the method proposed in this paper, is used in together with the above mentioned Michelson interferometer setup to generate moiré fringes using the Michelson interferometer fringes and the circular grating pattern generated on a Spatial Light Modulator (SLM), then in addition to the change in the fringe-density and/or the fringe orientation, the shape of the moiré fringes also visibly changes depending upon the ratio of the period of the interferometric fringe pattern and the period of the circular grating pattern shown on the SLM. Just by looking at the shape of the resulting moiré pattern, some idea about the ratio of the periods of the two periodic patterns and direction of the tilt of the mirror can be approximately estimated. A Spatial Light Modulator (SLM) is a device that has the ability to modulate the amplitude or phase or both of a light beam incident on it. Hence, the primary endeavour of the present paper is to bridge this gap between interferometry and moiré patterns by producing the moiré patterns making use of the interferometric fringes and circular grating pattern on the Spatial Light Modulator (SLM) and to study how visually the geometric shapes of the generated moiré pattern change by changing the frequency ratio of the interferometric fringes and the SLM pattern.

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II. MOIRÉ GENERATION

The functions of transmittance of a linear grating and a circular grating can be written as [8]:

$$m_1(x,y)=\frac{1}{2}\cos\left(\frac{2\pi}{\tau_1}x\right)+\frac{1}{2} \quad (1)$$

and

$$m_2(x,y)=\frac{1}{2}\cos\left(\frac{2\pi}{\tau_2}\sqrt{x^2+y^2}\right)+\frac{1}{2} \quad (2)$$

Here, equation (1) is for the linear grating and equation (2) is for the circular grating. τ_1 and τ_2 denote the periods of the linear grating and the circular grating respectively. Amidror [9] did an extensive study on the grating periodicities and their effects. When the ratio of τ_1 and τ_2 is close to 1 and τ_1 is just greater than τ_2, elliptical moiré fringes are generated. But, if the ratio is far away from 1 then parabolic moiré patterns become visible. On the other hand, when the ratio of τ_1 and τ_2 is close to 1 and τ_2 is just greater than τ_1, hyperbola shaped moiré fringes are generated. Some simulation examples, resulting in the elliptic, parabolic and hyperbolic moiré patterns for ratios of the periods τ_1 and τ_2 equal to 1.1, 0.5 and 0.9, have been shown in Fig. 1 (a), Fig. 1 (b) and Fig. 1 (c) respectively. It is evident that even for a small change in the ratio of the periods, drastic variation in the shapes of resulting moiré pattern takes place.

The density linear fringes of the can be changed by varying the tilt of the mirror. This paper uses basically a Michelson interferometer like setup, where one mirror of the conventional Michelson interferometer has been replaced with a Spatial Light Modulator (SLM).

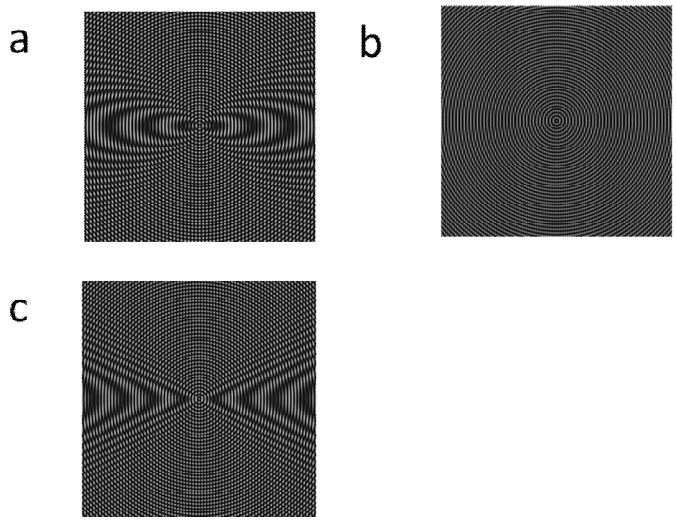

Fig. 1 (a) Elliptic moiré pattern for the ratio of the period of the linear fringe pattern τ_1 and the period of the circular grating pattern τ_2 equal to 1.1, (b) parabolic moiré pattern for the ratio of the period of the linear fringe pattern τ_1 and the period of the circular grating pattern τ_2 equal to 0.5, and (c) hyperbolic moiré pattern for the ratio of the period of the linear fringe pattern τ_1 and the period of the circular grating pattern τ_2 equal to 0.9.

In this experimental setup, the illumination source is 632.8 nm red He-Ne LASER. Next, the beam is tightly focused on the pinhole using the 40X microscope objective and the central peak intensity part of the focused beam is filtered out from the higher order diffraction rings using the pinhole. The diverging light beam, coming out of the pinhole, is collimated with a lens. In this way, the original narrow beam coming out of the laser is expanded. Then, the expanded beam is divided into two parts using a cube beam splitter with transmitted part being directed towards a reflective Spatial Light Modulator (SLM) and the other reflected part being directed towards the mirror. When no pattern is generated on the SLM, the parallel beam incident on the SLM is reflected and diffracted from the SLM surface such that it gets divided into a central undeviated zeroth order and several deviated diffracted higher orders because the SLM has pixels arranged in a grid pattern, which acts like a mesh grating of very high frequency.

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This undeviated zeroth order of the diffracted beam coming out of the SLM and the reflected beam from the mirror returns to the beam splitter and they interfere with each other to form straight-line fringes, observed on the screen as shown in Fig 2 (a). This straight-line fringe generation is exactly like the interference in a conventional Michelson interferometer. The frequency of the straight-line interference fringe pattern can be varied by changing the tilt of the mirror in the setup and the fringe-density increases with increased amount of the tilt. Now, if a circular grating pattern, as shown in Fig. 2 (b), is generated on the SLM, then this circular grating pattern is introduced in the beam propagation path and it is superimposed with the previous straight-line fringe pattern (generated due to the interference) to form the moiré patterns. Now, by changing the tilt of the mirror, the ratio of the periods of straight-line fringe pattern, generated because of interference and the circular grating pattern, generated by the SLM can be changed to form elliptic, parabolic and hyperbolic moiré patterns as shown in Fig. 2 (c), Fig. 2 (d) and Fig. 2 (e) respectively. The orientation of the fringe and hence that of the resulting moiré patterns can also be varied by controlling the mirror tilt direction.
The higher order diffraction patterns coming from the SLM do not enter the setup because the high-frequency mesh grating pattern of the arrangement of pixels on the SLM cause them to get diffracted at very high angles and the setup is also limited by the apertures of the components like the apertures of the lenses, beam splitters etc.

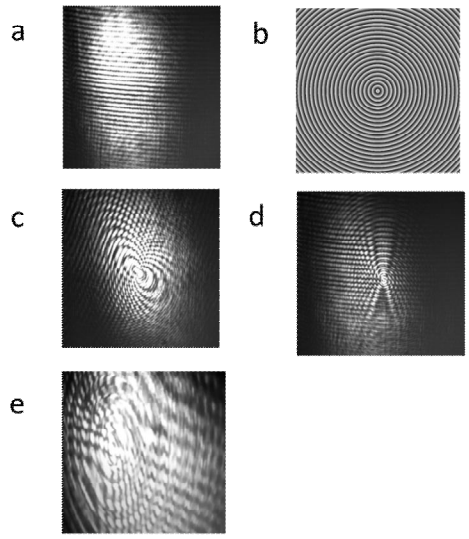

Fig. 2 (a) Straight-line fringe pattern generated from the interference of the beam coming from the mirror and the undeviated zeroth order beam diffracted from the SLM surface and (b) circular grating pattern shown on the SLM, (c) elliptical moiré pattern, (d) parabolic moiré pattern and (e) hyperbolic moiré pattern.

III. CONCLUSIONS

This paper presents a simple method for generation and controlling moiré patterns using Spatial Light Modulator and an interferometric setup. The experimental results conform to the simulation results. The selection of the straight-line fringe pattern and the circular grating pattern is also quite appropriate since the former provides variation in one linear direction and the later one provides variation in the radial direction making the setup suitable for studying variation in the samples having variation in profile etc. along a particular linear direction or in radial direction. Also, using this combination of periodic patterns, only by observing the change in the geometrical shapes of the moiré patterns (ellipse, parabola or hyperbola) approximate ratio of the periods of the two patterns, used to generate the moiré pattern, can be estimated visually. Apart from this, in this single setup, only by switching off and on the circular grating pattern, only the straight-line interferometric fringe pattern (due to the Michelson interferometer like setup) and the moiré patterns can be obtained without any physical change in the setup. By tilt-control of the mirror the frequency and the shape of the moiré fringes and the orientation of the fringes can be controlled.

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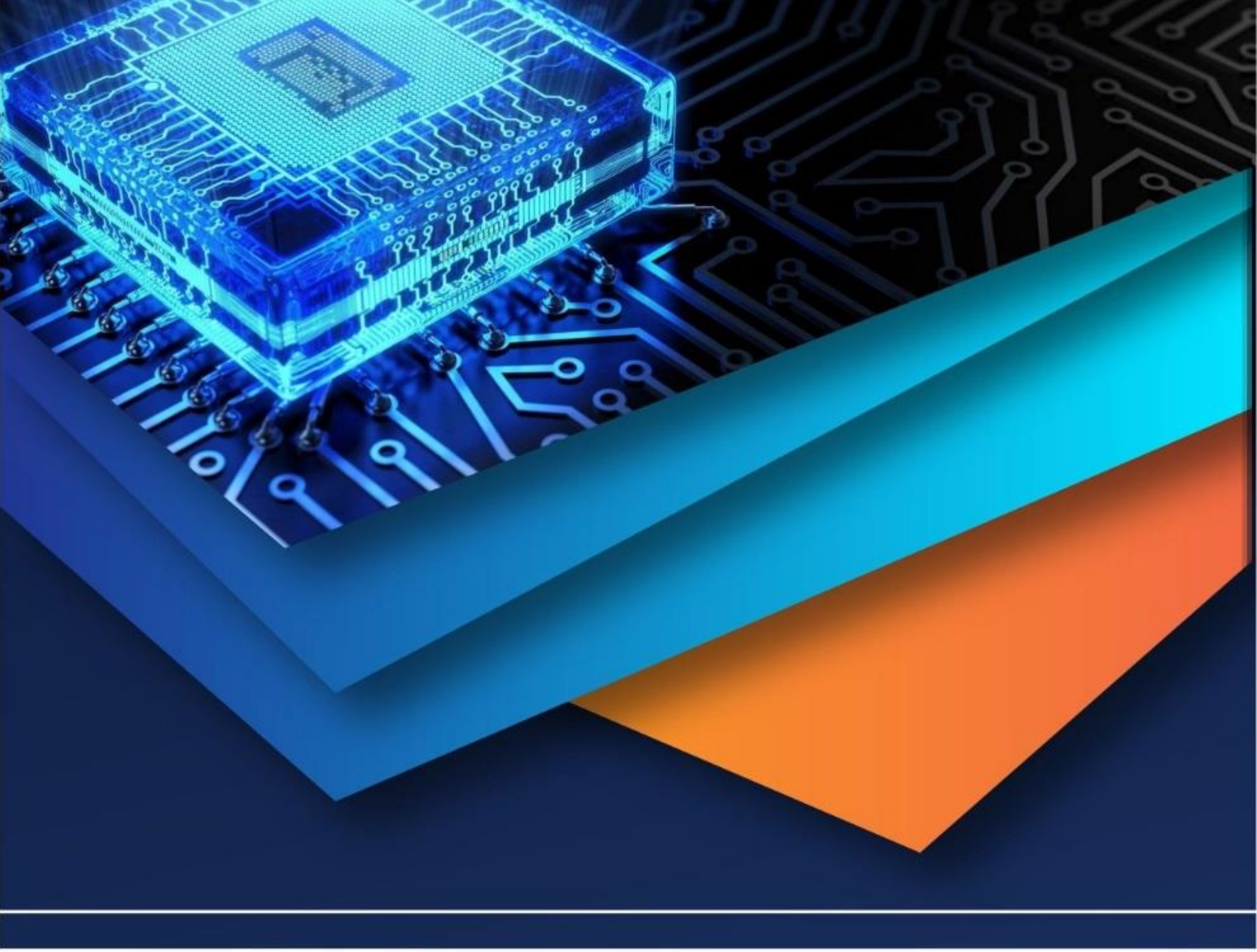

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