Dynamic moiré patterns for profilometry applications

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Abstract. In the present work is proposed that dynamic moiré-like fringe patterns produced by photorefraction, with low spatial frequencies, could be used for profile determination of small objects. The Fourier transform profilometry technique is applied in the projected moiré fringe pattern onto an object surface. Basically, the Fourier transform of the projected fringes is obtained. After that, a phase map is generated. Then, the optical profile of object is obtained using phase unwrapping. So, the entire process can be indicated to measure, with good accuracy degree, profile of small objects in sub-micrometer scale in optical mechanical systems.

1. INTRODUCTION

Photorefractive effect is the well controlled combination of photoconductivity and electro optic effect [1]. In the photorefractive effect, a dynamic holographic sinusoidal phase grating could be obtained after illuminating the photorefractive sample by the interference pattern from two colimated laser beams. This process is considered dynamic in the sense that any modification in the writing beams rewrites immediately the induced phase grating in the volume of the photorefractive material.

Moiré-like patterns can be experimentally obtained by the superposition of two or more sinusoidal gratings with slightly different spatial frequencies. Otherwise, moiré-like patterns are induced in the volume of a Bi₁₂TiO₂₀ (BTO) crystal sample used as dynamic holographic media, that is, the holographic sinusoidal phase gratings superimposed are produced with high spatial frequencies (~1,000 lines mm⁻¹) by photorefractive effect.

The photorefractive holographic setup (figure 1) has been used in anisotropic two wave mixing architecture, in diffusion only recording mechanism. This means that the observed moiré-like fringe patterns with low spatial frequencies (~2-5 lines mm⁻¹) is produced like a beat phenomenon [2] due to the dynamic superposition of two sinusoidal phase gratings in the volume of BTO crystal sample.

In the present work is proposed that the observed dynamic moiré-like fringe patterns with low spatial frequencies, obtained in the above described physical conditions, could be used in the profile determination of small objects, using the Fourier transform profilometry. So, it can be indicated to measure, with good accuracy degree, profile of small objects in sub-micrometer scale in optical mechanical systems. In the next section the dynamic moiré-like patterns is more detailed described.

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In the section 3 the experimental procedure is described and finally, in section 4 the results and discussion and the conclusion is the last one.

2. DYNAMIC MOIRÉ LIKE PATTERNS

In this section of paper the dynamic moiré-like patterns are described as induced by the interaction of two sinosoidal high frequency gratings holographically, both generated in the volume of the photorefractive crystal sample, the dynamic holographic media. In the photorefractive effect, one dynamic holographic sinusoidal phase grating could be obtained after illuminating our BTO sample by the interference pattern given by

\[ I(x) = I_0 \left( 1 + M \cos k_x x \right) \]  

In eq.(1) \( k_g = 2\pi/\Lambda \) (where \( \Lambda \) is the grating spacing) is the grating wave number and \( M \) is the fringe modulation rate in the projected interference pattern. After illuminating the sample, taking account of the band transport model [3], the photogenerated carrier displacements, with subsequent trapping, produce a volume space charge electric field given to [4]

\[ E_{sc}(x) = \frac{Dk}{\mu} \frac{m \sin(kx)}{1 + m \cos(kx)} \]  

where \( D \) is the diffusion constant; \( \mu \) is the mobility and the parameter \( m \) is the induced modulation rate. Then, due to the linear electro-optic effect exhibited by the photorefractive materials, a spatial refractive index modulation is produced. This spatial refractive index modulation is given by

\[ \Delta n(x) = \frac{1}{2} r_{41} n_0^2 E_{sc}(x) = \Delta n_0 \sin(k_g x) \]  

and diffraction efficiency given to

\[ \eta = \left[ \frac{\pi \Delta n(x)}{\lambda \cos(\theta_B)} \frac{\sin(\rho l)}{\rho} \right]^2 \]  

where \( \theta_B \) is the incident Bragg angle, \( \lambda \) is laser light source wavelength, \( \rho \) is the optical activity parameter and \( l \) is the crystal sample thickness.

After superposition of two sinusoidal phase gratings of different spacings in the sample volume, two index modulation \( \Delta n_1(x) \) and \( \Delta n_2(x) \), both defined by (3) are produced. Then the refraction index modulation resulting of this superposition is

\[ \Delta n(x) = 2 \Delta n_0 \cos(k_g^m x) \sin(k_g x) \]  

where \( k_g = \left( k_{g1} + k_{g2} \right)/2 \) is the average spatial frequency and \( k_g^m = \left( k_{g1} - k_{g2} \right)/2 \) is the modulation spatial frequency.

In the present work the spatial frequencies, \( k_{g1} \) and \( k_{g2} \), have high values and then, in addition, their values are comparable, that is, \( k_{g1} \sim k_{g2} \); in this case, \( k_g \gg k_{g2} \) and the resulting photorefractive index modulation in the sample volume is spatially modulated. This means that a moiré-like fringe pattern are produced like a beat phenomenon, treated exactly like the interference of two near-frequency traveling waves, but here this phenomenon is due to the dynamic superposition of two sinusoidal phase grating in the BTO crystal sample volume.
3. EXPERIMENT

The experimental setup, indicated in the figure 1, shows two beams with $\lambda=0.633\mu$m coming to a He-Ne laser light source with 35mw nominal power. BS is a variable beam splitter; C’s are collimators and M1,M2,M3,M4 and M5 are mirrors. The light laser beams, one being the “object” beam and another one being the reference beam are projected on the BTO crystal (8x8x8 mm$^3$) entrance face, at an angle $\theta_B \approx 23$ deg. This means, according to the classic Bragg’s law, a sinusoidal phase grating with 1000 lines mm$^{-1}$ of spatial frequency is produced. In this moment one shutter (not shown in the figure) covering both beams is closed, and mirror M5 is rotated by $\sim 1$ degree. This way, opening the shutter an additional sinusoidal phase grating is produced with a small difference in the spatial frequency. Reading both gratings, the moiré like pattern is produced and projected on the screen, where the object (the small metallic cylinder) is placed.

![Figure 1. Experimental setup.](image)

The moiré like pattern produced after the interaction of two sinusoidal phase gratings and projected in the sample to determine your profile is indicated in the figure 2. This image is captured by a CCD camera.

![Figure 2. Fringe pattern projected onto the object surface, a small cylinder.](image)
4. RESULTS AND DISCUSSION

After experimental procedures previously described we have obtained an image showed in figure 2. In order to obtained the object profile the following steps must be performed.

Through a single image of a fringe pattern projected onto the object surface, the Fourier transform is obtained according to the fringe process proposed in ref [5] (see figure 3). After that a phase map is generated (figure 4). And finally, after application of the phase unwrapping, the optical profile of object is obtained, like shown in figure 5. These steps were performed using the public domain Idea software[6] and analyzed by the public domain NIH Image software[7].

Figure 3. Fourier transform of the object with projected fringes from figure 2.

Figure 4. Phase map obtained from the Fourier spectrum shown in figure 3.

Figure 5. Optical profile of object after phase unwrapping.

5. CONCLUSION

In conclusion, we have demonstrated that the dynamic moiré like patterns produced by photorefraction can be used in an interesting optical application. This application, the optical profile determination of a usual object by Fourier transform profilometry [5]. It is a simple, fast, and promise technique particularly indicated to be applied as one step technique supported by any dynamic holographic system like the used here based in the use of photorefraction.
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