Recent Advances in Techniques of Holographic Interferometry and Holographic Microscopy in Optical Metrology

Marcos R. R. Gesualdi [1]

[1] Universidade Federal do ABC

E-mail: marcos.gesualdi@ufabc.edu.br

Abstract: This work presents our advances in techniques of holographic interferometry and holographic microscopy in Optical Metrology. We present the Phase-Shifting Real-Time Photorefractive Holographic Interferometry (PSRTHI), for micro-structures, wave-optics and surfaces analysis in engineering and biotechnology areas, and Photorefractive and Digital Holographic Microscopy (PRDHM) applied in the analysis of intensity and phase values from 3D surfaces and optical waves in static and dynamic processes. The experimental results perform an accurate quantitative measurement with promises potentialities of this method for in situ visualization, monitoring and analysis in micro-structures, wave-optics and surfaces.

Keywords: Holography, Digital Holography, Holographic Interferometry, Microscopy, Optical Metrology.

1. INTRODUCTION

Holographic Microscopy and Interferometry are powerful optical methods for observing no perturbative phenomena and analyzing wave fronts, as well as for no destructive testing [1-2]. The real-time holographic techniques allow visualizing and analyzing surfaces with accuracy and reliability, as well as the *in situ* monitoring of the studying systems. Photorefractive Holograpic Interferometry (PRHI) is a technique broadly used because it does not require chemical processing after the hologram recording, the crystals do not exhibit fatigue, have high spatial resolution and short response time. We use the photorefractive crystals of the sillenite family ($Bi_{12}SiO_{20}$ or $Bi_{12}TiO_{20}$ suitable for dynamic applications.

The photorefractive crystals are light-sensitive and possess an electro-optical effect. The hologram recording is produced due to a refractive index modulation caused by photoinduced charge transport (diffusion, drift, and photovoltaic effect). This modulation depends on the spatial distribution of the incident light intensity. PRHI has plenty of applications in: measuring deformations, vibrations, stress analysis, optical metrology, surface contouring, quantitative measurements of amplitude and phase of the object wave in static and dynamic processes. The reconstruction of the phase information of the photorefractive holograms is usually done by using phase-shifting, in which the phase of the object wavefront is calculated using intensity interferograms captured in sequence [3-9]. There are some works that use Digital Holography (DH) [10-13] in conjunction with PRH for studying the refractive-index changes in the crystals. However, this technique (PRDH) is usually employed with mechanical phase shifting (by means of PZTs), where the PRDHM (Photorefractive Digital Holographic Microscopy) is implemented for studying static samples [9]. The computational holography is the potential for experimental generation of the special optical beams [14-15].

This work presents our advances in techniques of holographic interferometry and holographic microscopy in Optical Metrology. We present the Phase-Shifting Real-Time Photorefractive Holographic Interferometry (PSRTHI), for micro-structures, wave-optics and surfaces analysis in engineering and biotechnology areas, and Photorefractive and Digital Holographic Microscopy (PRDHM) applied in the analysis of intensity and phase values from 3D surfaces and optical waves in static and dynamic processes.

2. EXPERIMENTS AND RESULTS

We use the experimental setup for PRHI with photorefractive sillenite crystals as the recording medium[3-9]. The recording laser beam was collimated and divided into reference and object beams with equal optical paths, see equation (1):

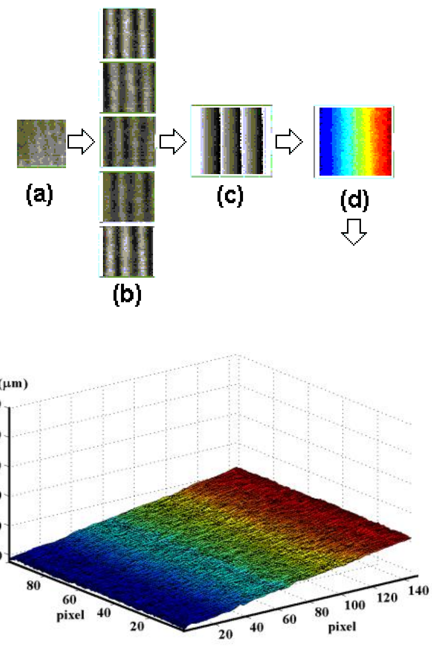

FIGURE 1. Plane mirror micro-rotations analysis by PRHI.

$$I_1(x,y) = I_{0,R2}(x,y) + I_{0,D}(x,y)\left[1 - e^{(-t/\tau)^2}\right] + 2\sqrt{I_{0,R2}(x,y)\cdot I_{0,D}(x,y)\left[1 - e^{\left(-\frac{t}{\tau}\right)^2}\right]}\cos\Delta\Phi \qquad (1)$$

where, DΦ is the phase-shift of the holographic pattern $I_1(x,y)$, which will be digitalized by CCD camera (ImagingSource Inc) and by digital reconstruction the amplitude and phase image will be finally obtained. The results is showed in Fig. 1-4.

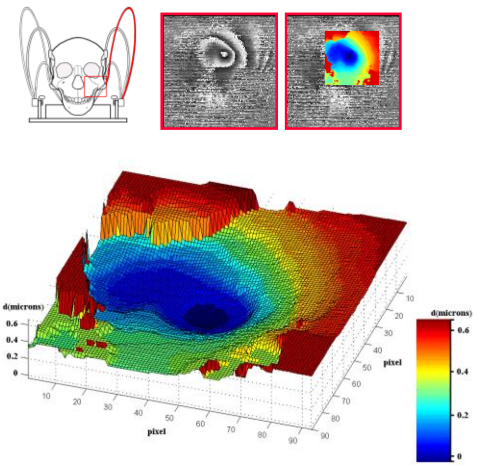

FIGURE 2. The mastigatory human skull analysis by PRHI.

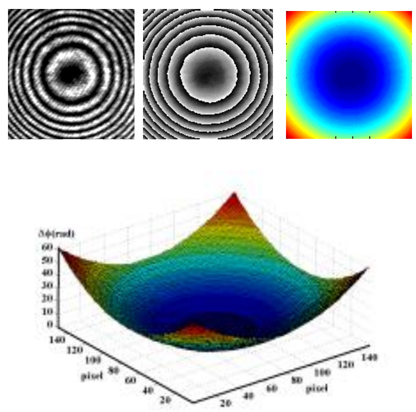

FIGURE 4. The wave optics analysis by PRHI.

The experimental holographic setup (Fig. 5) we developed is based on a Mach-Zehnder interferometer for studying micro-samples:

Digital Microscopic Holography and Photorefractive Holographic Microscopy. It was implemented a single (adaptable) holographic experimental setup for the entire process that allowed us to record three-dimensional microscopic digital and photorefractive holograms, as well as to perform their numerical reconstruction.

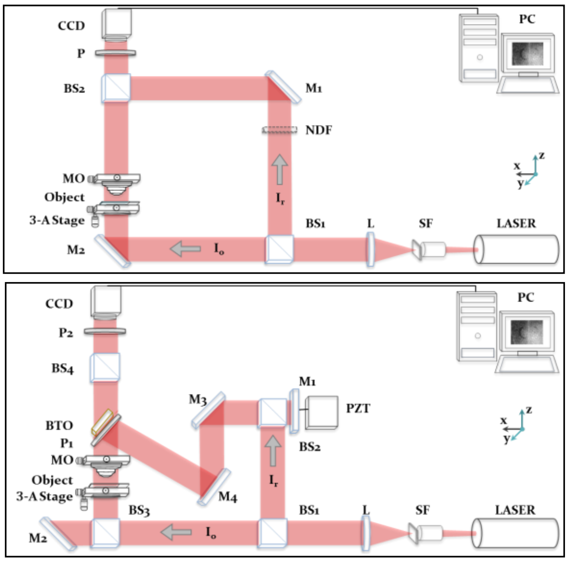

FIGURE 5. Schematic arrangement of (a) Digital Holographic Microscopy and (b) Photorefractive Holographic Microscopy. It was used a He-Ne laser, a CCD camera, a 50X Microscope Objective (MO), and a 3-Axis Translation Stage; SFs are spatial filters, Ls are lenses, BSs are beam splitters, Ms are mirrors, NDF is a neutral density filter, Ps are polarizers, PZT is a piezoelectric actuator, and BTO is a photorefractive crystal.

The camera uses an array of 1024 × 768 pixels with pixel size of 4.65 μm and 24-bit scale output. An USB-2 cable connects the camera to the computer. The image reconstruction is performed by the HOLODIG program supported in MatLab© using Double Propagation reconstruction algorithms [9-13]. In this software, the phase and amplitude of the object wave are reconstructed and the removal of the phase discontinuity (unwrapping process) is realized directly. The images reconstruction (phase and amplitude) was done by mean of the DPM method using one hologram.

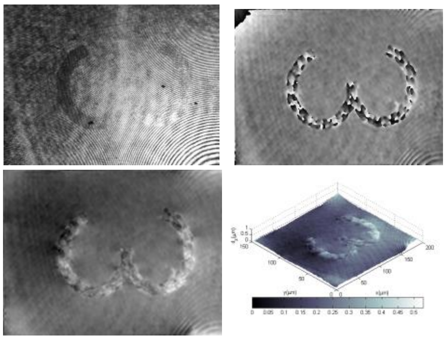

FIGURE 6. USAF 1951 target G3-E3: (a) digital hologram (b) reconstructed phase map (c) unwrapped phase map and (d) quantitative three-dimensional profile.

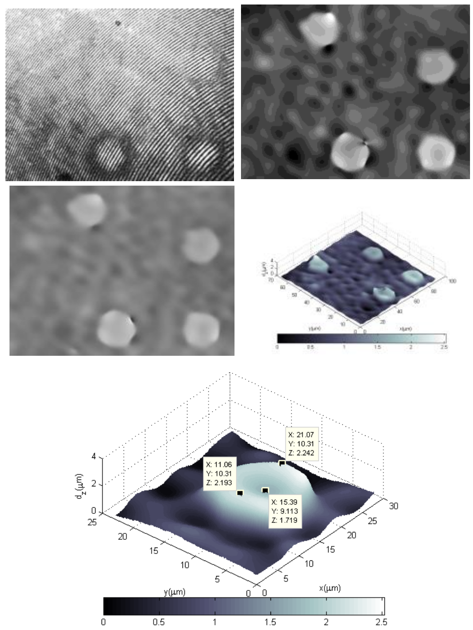

FIGURE 7. Human blood cells: *Erythrocytes* (a) digital hologram (b) phase map (c) unwrapped phase map and (d) three-dimensional profile. Single cell: (e) reconstructed 3D profile.

The samples used for verifying the implemented arrangement include an USAF 1951 Resolving Power Test Target (Fig. 6) and human blood cells (Fig. 7). We were able to quantitatively measure the dimensions of the samples from the unwrapped phase maps: being 49,61μm long for the numeral 3 and 10μm diameter and (1,7- 2,2)μm thickness for the cell; which is in agreement with the reported data.

3. CONCLUSIONS

This work presents our advances in techniques of holographic interferometry and holographic microscopy in Optical Metrology. We present the Phase-Shifting Real-Time Photorefractive Holographic Interferometry (PSRTHI), for micro-structures, wave-optics and surfaces analysis in engineering and biotechnology areas [3-9], and Photorefractive and Digital Holographic Microscopy (PRDHM) applied in the analysis of intensity and phase values from 3D surfaces and optical waves in static and dynamic processes [10-13]. The experimental results perform an accurate quantitative measurement with promises potentialities of this method for in situ visualization, monitoring and analysis in micro-structures, wave-optics and surfaces.

The authors would like to acknowledge to CAPES, FAPESP and UFABC for the financial support.

REFERENCES

[1] D. Gabor, A new microscopic principle, Nature, 161, 777, 1948.
[2] J. W. Goodman, Introduction to Fourier Optics (MacGraw-Hill, San Francisco, Calif., 1968).
[3] M. R. R. Gesualdi, D. Soga and M. Muramatsu, “Real Time Holographic Interferometry using Photorefractive Sillenite Crystals with Phase-Stepping Technique”, Opt and Laser Eng., v. 44, n. 1, p. 56-67, 2006.
[4] M. R. R. Gesualdi; E. A. Barbosa; M. Muramatsu. Advances in Phase-Stepping Real-Time Holography using Photorefractive Sillenite Crystals. Journal of Optoelectronics and Advanced Materials, v8, 1574, 2006.
[5] M. R. R. Gesualdi; D. Soga; M. Muramatsu; R. D. Paiva Jr. Wave optics analysis by phase-shifting real-time holographic interferometry. Optik (Stuttgart), v. Press, p. 01-05, 2008.
[6] M. R. R. Gesualdi; D. Soga; M. Muramatsu, Surface Contouring by Phase-shifting Real-Time Holography using Photorefractive Sillenite Crystals. Optics and Laser Technology, v. 39, p. 98-104, 2007.
[7] M. R. R. Gesualdi; M. Mori; M. Muramatsu; E. A. Liberti; E. Munin. Phase-Shifting Real-Time Holographic Interferometry applied load transmission evaluation in dried human skull. Appl. Optics, v. 46, 5419, 2007.
[8] M. R. R. Gesualdi; M. Muramatsu, E. A. Barbosa. Light-induced Lens Analysis employing Phase-Shifting Real Time Holographic Interferometry. Optics Communications, 281, 5739-5744, 2008.
[9] I. V. Brito; M. R. R. Gesualdi; J. Ricardo; F. Palacios; M. Muramatsu; J. Valin. Photorefractive digital holographic microscopy applied in microstructures analysis. Optics Comm. , v. 286, p. 103-110, 2013.
[10] J. Ricardo; F. Palacios; M. Muramatsu; M. R. R. Gesualdi; M. A. L. Prieto. Digital holographic microscopy with photorefractive sillenite Bi12SiO20 crystals. Optics and Lasers in Engineering, 51, 949-952, 2013.
[11] M. R. R. Gesualdi; I. V. Brito; J. Ricardo; F. Palacios; M. Muramatsu; J. Valin. Photorefractive Digital Holographic Microscopy: an application in the microdevices surfaces. Journal of Microwaves, Optoelectronics and Electromagnetic Applications, v. 12, p. AoP184-AoP191, 2013.
[12] J. R Perez, F. Palacios, E. Gonçalves, R. da Silva, M. Muramatsu, M. R. R. Gesualdi and J. Valin, “Two-source contouring method by Digital Holography”, Proc. SPIE 5622, 1422 (2004).
[13] J. O. Ricardo, M. Muramatsu, F. Palacios, M. R. R. Gesualdi, O. Font, J. Valin, M. Escobedo, S. Herold, D. F. ; Palacios, G. F. Palacios; A. Sánchez. Digital holography microscopy in 3D biologic samples analysis. Journal of Physics. Conference Series, 274, 012066-1-8 (2011).
[14] Vieira, Tarcio A.; GESUALDI, MARCOS R. R.; Zamboni-Rached, Michel . Frozen waves: experimental generation. Optics Letters, v. 37, p. 2034-2036, 2012.
[15] Vieira, Tárcio A.; Zamboni-Rached, Michel ; Gesualdi, Marcos R.R. Modeling the spatial shape of nondiffracting beams: Experimental generation of Frozen Waves via holographic method. Optics Communications (Print), v. 315, p. 374-380, 2014.