Engineering and Technology Journal e-ISSN: 2456-3358
Volume 07 Issue 07 July-2022, Page No.-1342-1345
DOI: 10.47191/etj/v7i7.03, I.F. – 6.484

Demodulation of Interferogram with Closed Fringes Using the Phase Shifting Technique

H Ulises Rodríguez Marmolejo[1], Daniel Jauregui Acevedo[2], Debani Ximena Rodríguez Muñoz[3]
[1,2]Departament of Electric & Electronics Engineering, Tecnológico Nacional de México Campus Aguascalientes, México
[3]Departament of Electronics Engineering, Centro Universitario de los Lagos CULAGOS UdeG Lagos de Moreno Jalisco, México

ABSTRACT: This research exposes the foundations of optical metrology which occupies one of the most important in optics. A brief description is made of interferometry which in turn is part of the optical metrology. It demonstrates how an interferogram is obtained. It is also explained the way in which one of the most advanced techniques is applied simple in the demodulation of the phase, since the goal of any technique in interferometry is to find the term "phase" which refers to the physical quantity to be measured whether effort, displacement, distance, pressure, temperature, velocity, shape, dimensions, etc; since it is not possible to achieve it by the conventional methods. The phase obtained in the present article corresponds to the image (interferogram) of a pattern of closed fringes of a lens, which uses a technique called phase shift that consists of acquiring several interferograms, which in turn lead to a result known as phase wrapped so it is necessary to apply some method phase unwrapping to obtain the solution.

KEYWORDS: Optics, interferometry, shifts, demodulation, wrapped phase and unwrapped phase.

I. INTRODUCTION

Worldwide, the growth of optics has had as a consequence novel applications in the daily activities of the human being, which are divided into four large areas within all research: optical instrumentation, communications optics, optical metrology and photonics [1]. Inside of optical metrology is the interferometry whose main task is to find the term "phase". Exist dozens of techniques applied in demodulation or obtaining phase [2]. For example, Mitsu Takeda to from a computational processing finds the differences between elevations and valleys of the phase in study [3]. Manuel Servin introduces a modulation space with a conical carrier and from there he estimates the phase [4]. Rodríguez-Vera applies a novel strategy of phase clamping [5], analogous to the clamping cycle of phase of an electronic circuit (PLL). Studies developments in the demodulation of fringe patterns optimization algorithms have been used; Such as genetic algorithms, swarming particles, neural networks, harmonic search, etc. [6]; whose main goal is to minimize a function cost with excellent results. The present article indicates the necessary conditions for have an interference, the basics are demonstrated mathematical and finally the results are shown obtained in the demodulation of an interferogram with closed fringes applying the simple technique by phase shift. If we mathematically relate shifts phase is found in wrapped mode (phase shift) so it is necessary to apply some method of phase "unwrapping" which is not described in this article since the purpose of the investigation is the demodulation of an interferogram.

II. THEORETICAL FUNDAMENTS

The conditions for achieving light interference are known as the Fresnel-Arago laws and are the following:

- ✓ The waves that produce interference have to be consistent. This happens only when they have their origin in the same source and is achieved in a much easier using a laser.
- ✓ The light beams must be linearly polarized. That is, they must vibrate in the same plane.
- ✓ The beams must be monochromatic, which means they have to be of the same frequency, this is achieved by placing an interference filter or using a laser.

The equipment that generates the fringe pattern is known as an interferometer, a good example is the Twyman-Green interferometer which is illustrated in figure 2.1.

The Twyman-Green interferometer works causing two wavefronts to interfere: the "arm" one or the illumination of the surface under test, and the one with the "arm" two or reference; both fronts of wave are recombined by the light beam splitter, then showing the interference of both rays of light at the focal point (focus lens), which is named interference who is taken to a photo by detector (digital camera), the data is stored and reproduced as an interferogram on the screen of a computer.

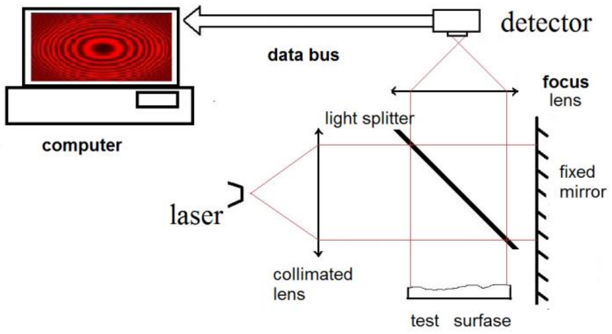

Fig. 2.1 Twyman-Green arrangement.

III. GENERATION OF THE PHASE IMAGE

A digital record of an image of study object which has a projected pattern of fringes, it can be describe mathematically by the expression

(1)

$$I(x,y)=a(x,y)+b(x,y)\cos(\varphi(x,y))$$

where the first term $a(x,y)$ represents a background intensity in the image, the second term $b(x,y)$ can be understood as a factor that determines the visibility of the observed fringes, it is the phase $\varphi(x,y)$ of the optical field that we want to reconstruct [7]. The topography of an object turns out to be directly proportional to the phase term appearing in equation (1).

3.2 Phase shift interferometry

In phase shift interferometers the reference wavefront moves along the propagation direction with respect to the wavefront under test, thus changing the positions of the interference fringes [8]. The technique known as interferometry of phase shift (PSI), It is based on the idea of proposing a set of equations, which allows to determine the difference of phase (4).

3.3 Theoretical basis of the 4-step method.

The four-step method requires four interferograms that are totally independent of the object under test; Interferograms should be recorded or digitized. An optical phase shift is introduced into of the reference beam between each interferogram recorded sequentially. Because the measures are integers, the dependence of the *x, y* axes of the image have to change, by indices *i,ii* between pixel and pixel. The function δ(t) takes four values

$$\delta_i(t)=0,\frac{\pi}{2},\pi,\frac{3\pi}{2};i=1,2,3,4 \qquad (2)$$

Substituting each of these four values into the resulting interferogram intensity pattern equation

$$I(x,y)=a(x,y)+b(x,y)\cos(\varphi(x,y)+\delta(t)) \quad (3)$$

where the function δ(t) is directly proportional to the difference in frequency and time, this difference in frequency increases the linear phase shift between the reference and test beams, thus resulting in four equations describing the four patterns of intensity of the interferograms measured, this is

$$\begin{aligned}
I_1(x,y)&=a(x,y)+b(x,y)\cos(\varphi(x,y))\\
I_2(x,y)&=a(x,y)+b(x,y)\cos(\varphi(x,y)+\frac{\pi}{2})\\
I_3(x,y)&=a(x,y)+b(x,y)\cos(\varphi(x,y)+\pi)\\
I_4(x,y)&=a(x,y)+b(x,y)\cos(\varphi(x,y)+\frac{3\pi}{2})
\end{aligned} \qquad (4)$$

Applying the trigonometric identity, the previous equations are

$$\begin{aligned}
I_1(x,y)&=a(x,y)+b(x,y)\cos(\varphi(x,y))\\
I_2(x,y)&=a(x,y)-b(x,y)sen(\varphi(x,y))\\
I_3(x,y)&=a(x,y)-b(x,y)\cos(\varphi(x,y))\\
I_4(x,y)&=a(x,y)+b(x,y)sen(\varphi(x,y))
\end{aligned} \qquad (5)$$

Solving these four equations to find $\varphi(x,y)$, at each point of the interferogram we have

$$I_4-I_2=2b(x,y)sen(\varphi(x,y))$$

$$I_1-I_3=2b(x,y)\cos(\varphi(x,y))$$

$$\frac{I_4-I_2}{I_1-I_3}=\frac{sen(\varphi(x,y))}{\cos(\varphi(x,y))}=tg(\varphi(x,y)) \qquad (6)$$

$$\varphi(x,y)=tg^{-1}\left[\frac{I_4-I_2}{I_1-I_3}\right]$$

Therefore $\varphi(x,y)$, it corresponds to the demodulation of the interferogram mathematically [9].

IV. RESULT AND DISCUSSION

To implement the optical array, it was used PASCO's reconfigurable interferometer SCIENTIFICS with OS-8514 He-Ne laser emitter (fig. 4.1) and to obtain the images of the trial lens at analyze, an EOS REBEL T6S camera of the Cannon brand which acquires and carries the pattern of stripes to the personal computer, so that the captured images were obtained with the greater sharpness so that they would be easy to process by the phase shift algorithm.

Fig. 4.1 Experimental equipment to acquire the image of the material to be analyzed.

The format in which the images are sent from the acquisition device (camera) to the computer is that of 8-bit JPG format color and size selected in the camera is 100x100 pixels. For image processing interferograms, the Matlab software was used. The way to perform the calculations is based on the management of data arrays. This requires that the format of the digital images will be in BMP and transfer it in 8-bit grayscale, since the use of grayscale in images ensures that the image contains in each of its records only the corresponding intensity value since Matlab uses a single array to store the data. Figures 4.2-4.5 shows the 4 interferograms of 4 different shifts. Inside the image editor (Paint) in case is necesary to cut the image, it is done using the cutting tool contained in the package. After this each image is exported in format 8-bit grayscale linear BMP.

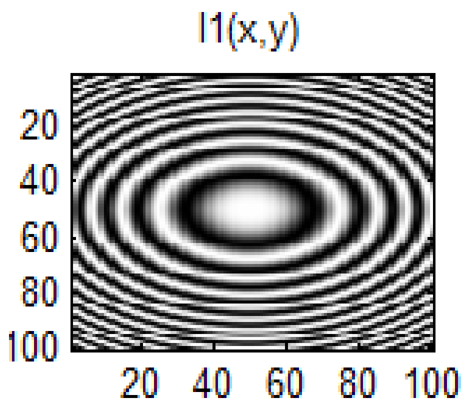

Fig. 4.2 Intensity 1.

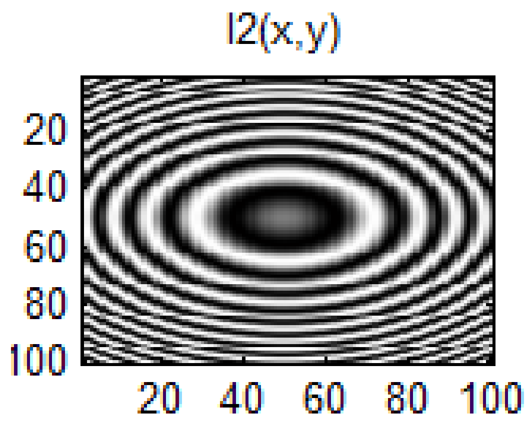

Fig. 4.3 Intensity 2.

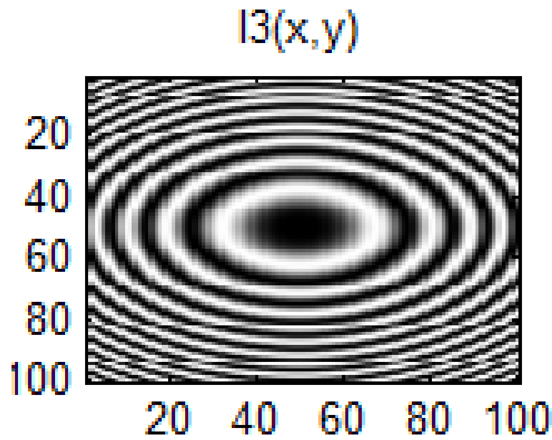

Fig. 4.4 Intensity 3.

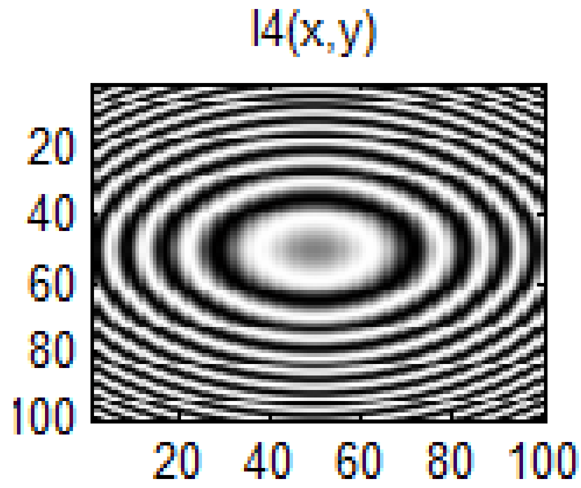

Fig. 4.5 Intensity 4.

Once the 4 shifts have been physically performed which correspond to the 4 closed fringe patterns shown in the previous figures and indicated mathematically by equations (5), we proceed to relate them mathematically in Matlab from (6) so obtain the wrapped phase *(x,y)* whose result is shown in figure 4.6

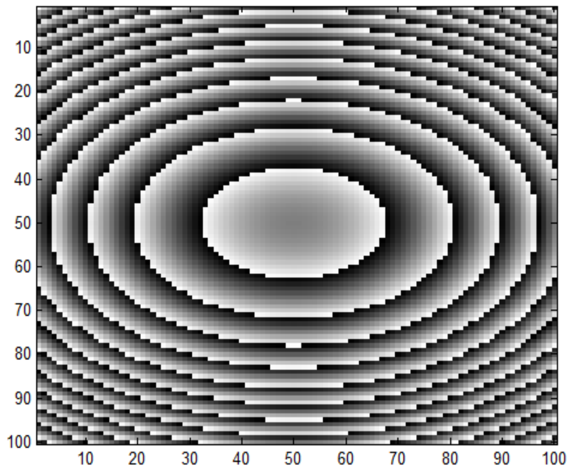

Figure 4.6 Phase obtained from the phase shift technique.

It should be clarified that the one obtained (Fig. 4.6) is in the "wrapped" form, also known as the wrapped phase. It is necessary to apply a phase unwrapping algorithm (unwrapped phase) to visualize the study surface in 3D [10]. In this article, the unwrapping method applied to the wrapped phase of Figure 4.6 is not specified or developed, which is why only the unwrapped phase is shown in figure 4.7.

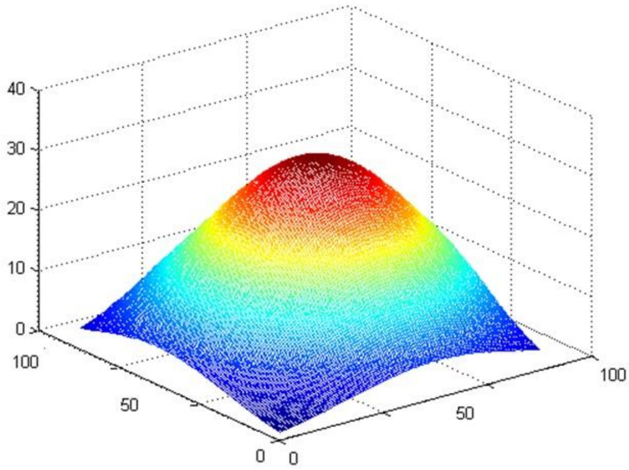

Figure 4.7. Found 3D image of the unwrapped phase.

V. CONCLUSIONS

Optical metrology is an important branch of optics. The physical quantity to be measured or known of the interferogram under study is defined by the phase term $\varphi(x, y)$. Within optical interferometry, the phase shift technique is one of the simplest so in this article it was applied and explained a simple and attractive way; also this method is valid for the analysis of different materials at micrometer level. It also provides information easily understood qualitative and quantitative illustration, as well as being non-invasive and non-destructive. With this research report it is explained a of the simplest techniques to analyze and compare different materials with applications to sampling, whether for quality control, reverse engineering, etc., because in addition to faithfully reproducing contours of the parsed objects, values can be provided numerical (micrometric or nanometric) of the heights and depths.

REFERENCES

1. Hariharan, P. (1996). *Basic of Interferometry*. Academic Press: New York.
2. Goodman, J.W. (1996). *Introduction of Fourier Optics*. Mc. Graw-Hill: Singapore
3. Mitsuo Takeda, Hideki Ina, and Seiji Kobayashi, (1982). "Fourier-transform method of fringe-pattern analysis for computer-based topography and interferometry", *Journal of the Optical Society of America*, Vol. 72, Issue 1, pp. 156-160.
4. Servin, M., Marroquin, J.L. Cuevas, F. (2001). "Fringe-follower regularized phase tracker for demodulation of closed-fringe interferograms", *Journal of the Optical Society of America*, 18(3):689-695
5. Rodriguez-Vera, R Servin M., (1993). "Two dimensional phase locked loop demodulation of interferograms". *J. Mod. Opt.* 40(11), 2087-2094
6. Sulaiman M., Salhi A., Selamoglu B.I., and Kirikchi O.B., (2014). "A Plant Propagation Algorithm for Constrained Engineering Optimization Problems", *Mathematical Problems in Engineering* (1), Article ID 627416, 10 pages
7. Malacara, D., Servin, M., Malacara, Z., (2005). *Interferogram Analysis for Optical Testing*, 2nd ed., Taylor & Francis, Boca Raton.
8. Gåsvik K.J. (2002). *Optical Metrology*, 3rd ed., John Wiley & Sons, LTD, Sussex.
9. Malacara, D., Servin, M., Malacara, Z., (2005). *Interferogram Analysis for Optical Testing*, 2nd ed., Taylor & Francis: Boca Raton.
10. Ghiglia D., Pritt M., (1998). *Two-Dimensional Phase Unwrapping Theory, Algorithms and Applications*, John Wiley & Sons: USA (1998).