PHASE RECOVERY OF A FRINGE PATTER USING SOFT-COMPUTER WITH GA-FSD TECHNIQUES

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Abstract

To visualize, measure and know the dimensions or deformations of micrometric surfaces of little pieces, mirrors, lenses of different optical equipment such as modern microscopes, powerful electronic binoculars, lasers, metal surfaces, etc; it is necessary to apply non-destructive or non-invasive techniques. Interferometry is a branch of Optical Metrology responsible for using measurement techniques from the interference of two or more light beams. In this article we present the soft computation technique that combines excellently Genetic Algorithms with the Guided Frequency Demodulation technique. With the combination of both techniques estimating the parameters or elements that correspond to the phase of the test object; this phase provides all the characteristics of the micro measurement such as shape, topography, dimensions, etc. The implementation of these techniques showed excellent performance in closed fringe patterns.

Key word: fringe pattern, optimization and phase recovery

INTRODUCTION

Optical interferometry is a series of physical techniques to know various characteristics of different kind of objects such as aberrations, deformations, plains, disturbances in physical variables (for example temperature gradients), mechanical stress analysis, depth measurements, etc. To any technique capable of obtaining the interpretation of optical interferograms (fringe pattern) is known as: phase demodulation, phase estimation, phase recovery, since the phase is the mathematical parameter sought [1]. The accuracy of the phase recovery depends to a large extent on the quality with which the fringe pattern was recorded. A few years ago, in conjunction with the various technological advances, several techniques have been implemented in the demodulation of interferograms, for example: the combination of parametric methods with genetic algorithms [2], [3], [4]; Zernike polynomials with soft computing techniques [5], Particle Optimization [6], technique of guided search regularization [7]; among other. There is no universal method in the demodulation of the phase, each depends largely on the characteristics of the interferogram.

The problem of phase recovery can be treated largely as an optimization problem. In the last decade genetic algorithms were applied together with the estimation of the coefficients of a Zernike polynomial of order "n" in which a population of chromosomes are purified until reaching the correct coefficients of the polynomial and thus to recover the searched phase. Within the optimization techniques is the "cost function" which considers the similarity between the observed fringe pattern and the recovered fringe pattern. Recently in another technique by soft computation was applied the optimization by swarming of particles in the demodulation of an interferogram [6] in the same way makes use of a cost function which generates a percentage that between smaller is indicates an approximation closer to the problem solution.

MATERIAL AND METHOD

Optical metrology in turn relies on optical interferometry to measure physical quantities in various areas of science and technology [9]. In recent years great advances have been made with soft computing applied to the analysis of fringe patterns. Optical interferometry deals with the iteration of two or more light rays [10]. The recovery of the phase $\varphi(x, y)$ is the most important task in any technique in interferometry, the phase is then the physical variable to be measured. Figure 1; shows the arrangement of the Twyman-Green interferometer which produces a fringe pattern from the surface or test element. The image is recorded by a digital camera for later computational processing. Mathematically the image is expressed by the equation $I(x, y) = a(x, y) + b(x, y) * \cos(\varphi(x, y))$ where $I(x, y), a(x, y)$ and $b(x, y)$ belong to the fringe pattern, background illumination and amplitude modulation of the image in spatial coordinates [11].

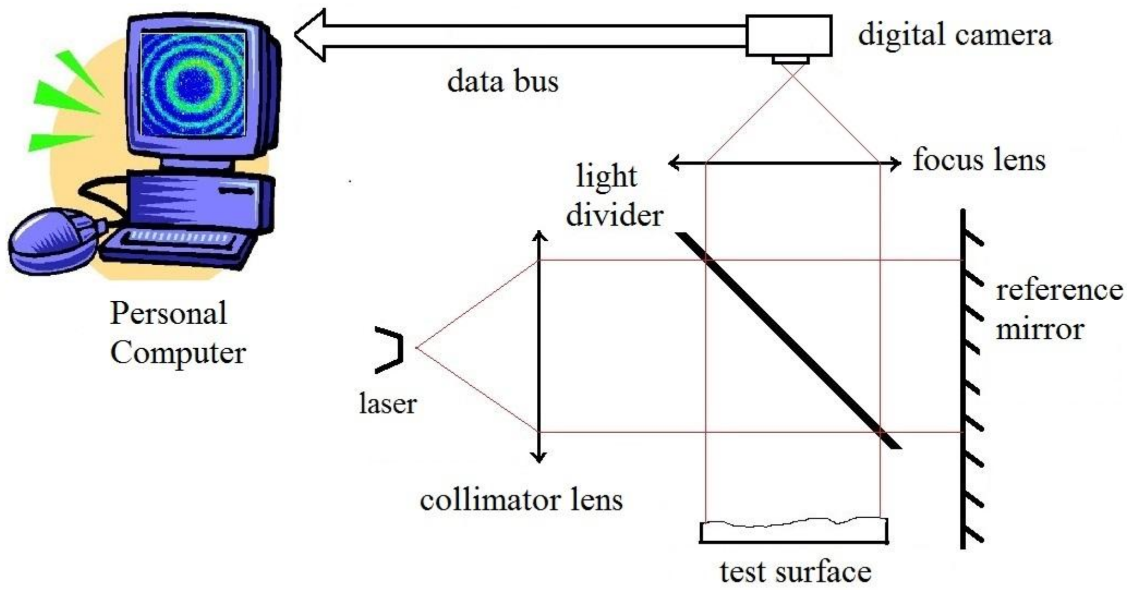

Fig 1 Digital capture of an interferogram

GA

In terms of genetic algorithms (GA), a population with "n" individuals or chromosomes in which each of the variables to be estimated are found, these are evaluated in the cost function following a series of steps that are described below:

- The cost function is defined
- The population is initialized
- The cost function is evaluated with the entire initial population
- It creates a new population of individuals performing the tasks of crossing, mutation, selection, etc.
- Individuals that generate a high error are deleted and instead individuals with a minor error are inserted
- A criterion of unemployment is placed
- The result is decoded obtaining the solution to the problem

Each iteration in creating a new population is known as generation. The evaluation of the objective function is done with real values and the tasks of crossing, mutation and selection are done with binary values, so it is necessary to do constant binary to real conversions and vice versa.

FSD

The Frecuency Secuential Demodulation (FSD) technique is an algorithm proposed by Kemao in 2007 [13], which is a novel technique for the demodulation of fringe patterns. The first step is to normalize the interferogram equation from a digital filtering and then become $I_n(x,y) = \cos(\varphi(x,y))$. The next step is to obtain the direct phase by simply applying the function $\hat{\varphi}_{wa}(x,y) = \cos^{-1}(I_n(x,y))$. The first approximation of recovery phase can be the equation $\tilde{\varphi}_a(x,y;u,v,\tilde{\mathrm{p}}) = \hat{\varphi}_{wa}(x,y) + \xi_{xa} \cdot (x-u) + \xi_{ya} \cdot (y-v)$ where $\tilde{\varphi}_a$, $\tilde{\mathbf{p}}(u,v)$, (x,y), (ξ_{xa}, ξ_{ya}) and the operator "$\cdot$" , are the estimated phase of the pixel to be demodulated, the vector of the two intermediate frequencies of the sub- image in study, the pixel coordinates under study, the search process frequencies and the dot product, respectively. The estimated fringe pattern is defined by $\tilde{I}(x,y;u,v,\tilde{p}) = cos[\tilde{\varphi}_a(x,y;u,v,\tilde{p})]$. Now the cost or energy function is defined as the square of the virtual interferogram difference and the real

interferogram from $E(u,v;\tilde{p}) = \sum_{y=-\infty}^{\infty}\sum_{x=-\infty}^{\infty}[g(x-u,y-v)[\tilde{I}(x,y;u,v,\tilde{p}) - I_n(x,y)]^2]$, where $g(x,y)$ is the window or sub image in study. Local frequencies are estimated by computationally minimizing the energy function. The extraction of the frequency estimated by the GA which is a vector of two calculated values of the pixel under study, mathematically remains $\hat{p}(u,v) = [\hat{\omega}_{xa}(u,v), \hat{\omega}_{ya}(u,v)]^T$.
The process that is performed when applying GA-FSD in the demodulation of the fringe pattern is dividing the entire image into 5x5 pixel windows as shown in figure 2. The study pixel and its 8 neighbors are selected by applying the algorithm GA-FSD obtaining the pixel phase.

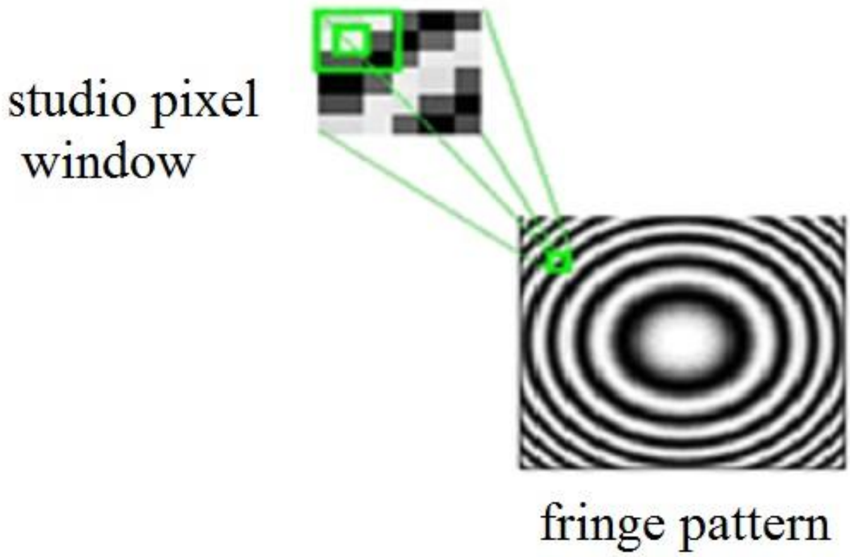

Fig 2 Pattern of closed fringes divided into windows of 5x5 pixels.

RESULT
The values of the parameters within the GA depend on the pattern of closed fringes to be demodulated. The implementation was performed in Matlab 2011, below is the result of a synthetic interferogram from the new GA-FSD technique. The example corresponds to a “cacahuate” interferogram of 120x120 pixels defined by the following equation $I_n(x,y) = 30 * exp((-(x-78)^2 - (y-78)^2)/50^2) + 30 * exp((-(x-178)^2 - (y-178)^2)/50^2)$, which was divided into sub windows N_{xy} of 5x5 pixels assuming the phase totally local and linear. The best GA parameters chosen for this interferogram were: 2300 individuals, 12 bits per gene, 2 coefficients (variables to be estimated per pixel), 440 generations, so the total number of bits per chromosome was 24, the search limits [-0.35, 0.35], the cost function was minimized around the pixel in analysis (x_n, y_n) and its 8 neighbors. When the GA-FSD technique ends a sub window, it is continued in the next sub window, the process ends until the entire interferogram is completed. In figure 3a. the closed fringe pattern is shown, the initial or direct phase $\hat{\varphi}_{wa}(x,y)$ is indicated by Figure 3b. Figure 3c and 3d correspond to the estimated frequencies $\hat{\omega}_{xa}(u,v)$ and $\hat{\omega}_{ya}(u,v)$, the figure 3e. corresponds to the phase with ambiguity error $\varphi_{err}(x,y)$ when applying the GA-FSD algorithm. The correct or error-free phase of ambiguity $\varphi_e(x,y)$ (figure 3.f) is obtained by changing the sign of the result of each pixel, following a continuity between the pixels through the entire tissue of the image of the recovered phase.

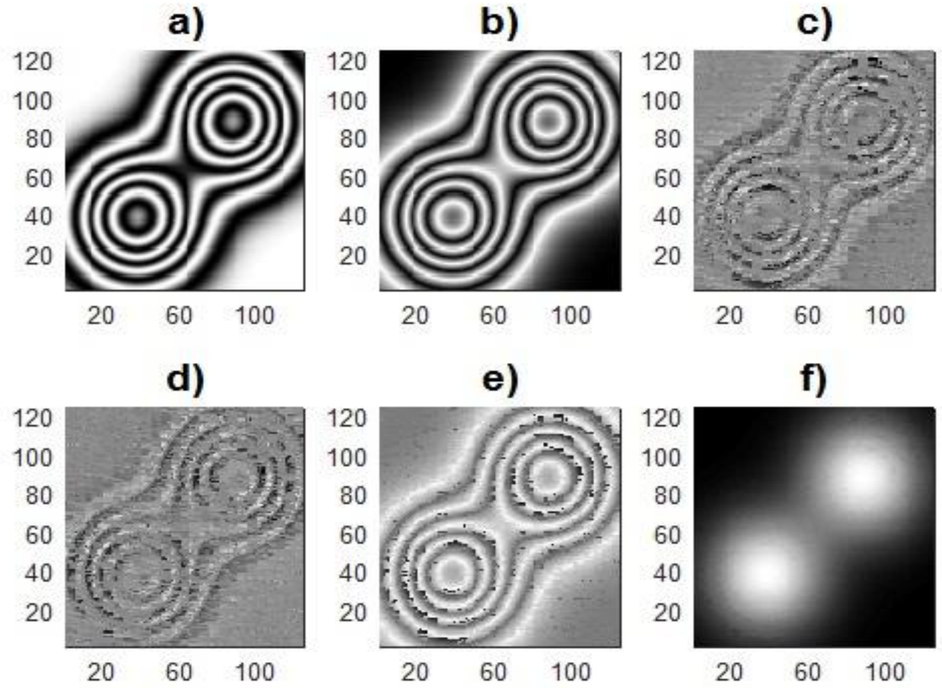

Fig 3 Demodulation of syntetic interferogram called "cacahuate" by GA-FSD. a) interferogram; b) direct phase of interferogram; c-d) estimated frecuency along x and y axis; e) recovery phase with ambiguity error and d) correct continuous estimated phase.

If the correct estimated phase is plotted in 3 dimensions, it is possible to observe the goal of applying the GA-FSD technique as shown below (Figure 4).

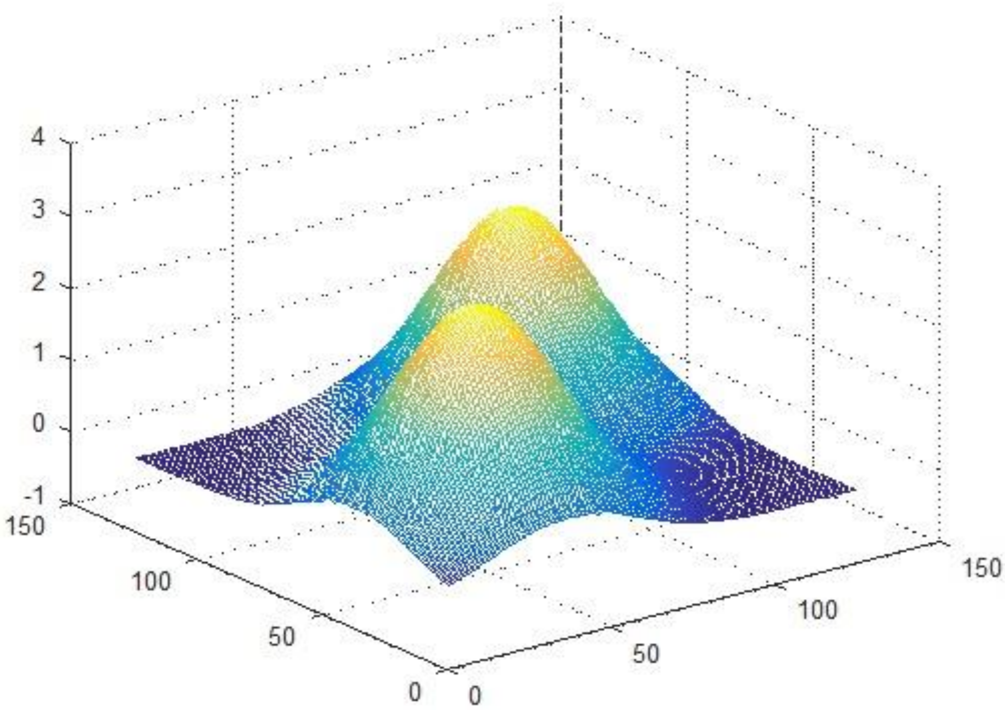

Fig 4 Recovery or estimation of the 3D phase of an interferogram "cacahuate" from the proposed AG-FSD algorithm

DISCUSSION

A Twyman-Green interferometer consists of a beam splitter (silver half mirror) and two mirrors. When the light passes through the silver half mirror/splitter of the beam (partially reflecting) it is divided into two rays with different optical paths (one towards the reference mirror and one towards the test surface). The return rays are reflected and recombined in the beam splitter before reaching the detector (camera). The difference in the path of the two rays generates a phase difference that forms an interference edge pattern. Next, the pattern in the detector is analyzed to evaluate the characteristics of the wave, the properties of the material or the displacement of one of the mirrors (depending on the measurement for which the interferometer is used). There are different techniques of demodulation of fringe patterns, the exposed one (soft-computer) is very appropriate to the current computer equipment, thanks to the fast processing speeds.

CONCLUSION

Demodulation of a synthetic fringe pattern named as “cacahuate” was presented. The AG-FSD technique generates excellent results in closed-fringe patterns with a not too close ring distance. Demodulation is done by minimizing the objective function or cost function with the help of Genetic Algorithms for each pixel in conjunction with its 8 neighbors, the energy function is treated as a high quality tool in the demodulation of fringes. Demodulation with sub-images of 5x5 pixels generates excellent results, with larger windows loses continuity in the estimated tissue losing resolution also the error in the demodulation is greater. Applying the FSD demodulation technique is relatively simple because only two variables are estimated, these are known as spatial frequencies ω_x and ω_y, instead of using a polynomial of order "n" that estimates more variables according to the order of the polynomial. The parameters of GA varies depending of the analysis interferogram.

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