Progressive Power Lenses (PPL) Characterization with Multi-Wavelength Speckle Interferometry

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Abstract: This work presents a method for spherical and aspherical lens characterization based in dual-wavelenght Digital Speckle Pattern Interferometry (DSPI). The spherical power and the astigmatism distribution are taken from reconstructed wavefront by using Zernike polynomials

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1. Dual wavelength DSPI

The human eye has the ability to rapidly change the focal length of the crystalline to see objects at different distances. With time the crystalline gradually losses elasticity, hindering the eyes accommodation, a problem know as *presbyopia* [1]. The Progressive additional lens was created as a solution to overcome this visual defect. They are made to have a crescent dioptric power from the upper side to lower side of the lens, which makes a difficult task for a whole field characterization.

This work presents a simple method for spherical and aspherical lens characterization based in two-wavelenght Digital Speckle Pattern Interferometry (DSPI). In this technique two slightly detuned diode lasers illuminate the speckle interferometer simultaneously, generating contour interference fringes related to the synthetic wavelength $\lambda_S \equiv \lambda_1\lambda_2/|\lambda_2-\lambda_1|$ where λ_1 and λ_2 are the emission wavelengths of the lasers, in this case $\lambda_1\lambda_2 \gg |\lambda_2-\lambda_1|$. The resultant intensity from interference with two lasers appears as high-spatial frequency speckle pattern with a background caused by the reference beam. In order to improve fringes visibility we applied the subtractive method, taking a frame with the first speckle pattern and acquiring a second frame with a decorrelated speckle pattern. This decorrelation occurs with sinusoidal signal applied to a piezoelectrical transducer (PZT) attached to the object mirror.

To remove the background, a low-pass filtering with a Fast Fourier Transform was used after the subtraction. The resulting image intensity $I(x,y)$ will shows the object covered by contour fringes without the reference background according to [2],

$$I(x,y) = I_0 \cos^2\left[\frac{\pi}{\lambda_S}(\Gamma_S(x,y)-\Gamma_R)\right] \quad (1)$$

where I_0 is the bias intensity of the speckle pattern, $\Gamma_S(x,y)$ is the optical path of the object wave through point (x,y) on the object surface, Γ_R is the optical path of the object wave, and λ_S is the synthetic wavelength. The two-wavelength speckle pattern is modulated by a low spatial frequency interferogram according to λ_S, as shown in figure 1a. To reconstruct the image, we evaluated the fringe pattern through the four-stepping method [3], combining four sequentially $\pi/2$-phase shifted interferograms of intensities I_0, I_1, I_2 and I_3, and unwrap the phase with the branch-cut method.

2. Spatial power distribution calculation

From reconstructed image of the light emerging from test lens, we can rewrite all weighted values $H(\rho,\theta)$ of this wavefront into Zernike series. Those series are a sort of orthogonal polynomials that arise in the expansion of a wavefront function inside a circle of unitary radius. Each term can be expressed in polar coordinates terms ρ and θ by Zernike coefficients $A_{n,m}$ according to [4],

$$H(\rho,\theta) = \sum_{n,m} A_{n,m} Z_{n,m}(\rho,\theta) \tag{3}$$

The Zernike polynomial $Z_{n,m}(\rho,\theta)$ is defined as

$$Z_{n,m}(\rho,\theta) = \begin{cases} \sqrt{2(n+1)}R_n^m(\rho)\cos(m\theta) & for\ m \geq 0 \quad (4a.) \\ -\sqrt{2(n+1)}R_n^m(\rho)\sin(m\theta) & for\ m < 0 \quad (4.b) \end{cases}$$

The radial function $R_n^m(\rho,\theta)$ in turn is written as

$$R_n^m(\rho,\theta) = \sum_{s=0}^{(n-|m|)/2} \frac{(-1)^s(n-s)!}{s!\,[(n+|m|)/2-s]!\,[(n+|m|)/2-s]!}\rho^{n-2s} \tag{5}$$

The term n in equation 5 indicates the radial dependence, where n is either zero or a positive integer, and m represents the azimuthal degree. The set of the coefficients $A_{n,m}$ can be obtained from the orthogonality properties of the Zernike polynomials as

$$A_{n,m} = \int_0^1 \int_{-0}^{2\pi} Z_{n,m}(\rho,\theta)H(\rho,\theta)\rho d\theta d\rho \tag{6}$$

As a consequence of its geometry the progressive lenses present a vertex corridor with spherical power distribution and null astigmatism which are narrower in the region of intermediate vision and wider in the regions of distant and near vision. Since the (cylinder) astigmatism along the x-direction is an important parameter of a progressive lens, it is convenient to express the wavefront coordinate H in terms of the cartesian coordinates $x = \rho\sin\theta$ and $y = \rho\cos\theta$.

To proceed the power distribution calculation, we consider the wavefront emerging from the lens, expressed in Zernike terms, and two parallel light rays p and q normal to the wavefront. The plane at a distance f from the wavefront, where rays p and q converge is the focal plane of the lens, so that the local optical power is written as $\theta_{PL}(x,y) = 1/f(x,y)$, where point (x,y) is located at the vicinity of P and Q.

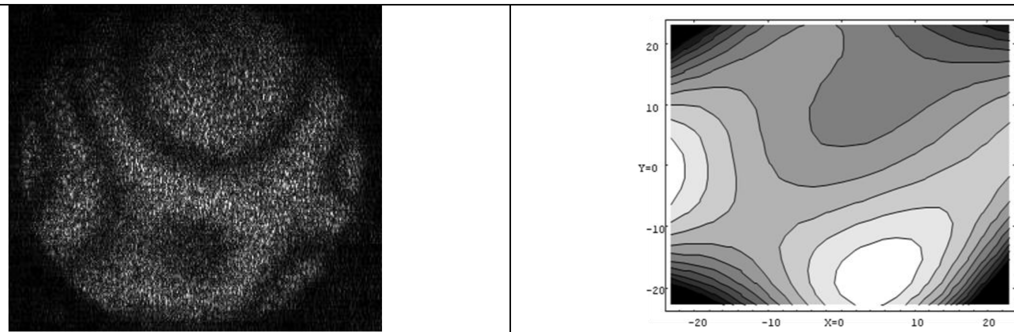
Averaging the diopter power rather than the focal length is a much more reasonable approach. The test lens power can be expressed as

$$\phi_{PL}(x,y) = \frac{1}{2}\left(\frac{\partial^2 H}{\partial x^2} + \frac{\partial^2 H}{\partial y^2}\right) \tag{7}$$

3. Experiments

We employed two 40 mW diode lasers emitting around 660 nm as light sources. The lasers were tuned by properly varying their current drivers. The light transmitted through the lens impinges a diffusive glass plate, so that the speckle image of the glass plate is modulated by contour fringes corresponding to the wavefront generated by the test lens. The interferogram describing the wavefront passing through the lens is captured and evaluated through the phase-stepping and phase unwrapping techniques mentioned previously.

Figure 1a shows the contour fringes modulated by the high spatial frequency speckle pattern generated by a progressive lens, while figure 1b shows the lens optical power distribution.



(a) (b)

Figure 1: a- Speckle pattern, b- Wavefront of a progressive lens in terms of Zernike polinomial

4. Conclusions

This work presented a new methodology for progressive power lens characterization based on two-wavelength speckle pattern interferometer. This technique proved to be a practical way for characterizing progressive lens and correlated applications, once it enables to retrieve full information from the entire wavefront.

The accurate selection of the wavelength of the laser sources allows to control the necessary precision and sensitivity of the interferometer in function of the needed scale for sample analysis. This characteristic makes this technique a suitable choice for wavefront sensing applications.

5. References

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