Minimization of the microlens density in a Hartmann-Shack sensor

Otávio G. de Oliveira[1], Davies W. de Lima Monteiro[1]

[1] OptMAlab, room 1212, DEE/UFMG, Universidade Federal de Minas Gerais, Av. Antonio Carlos, 6627 – Pampulha, 31270-010 Belo Horizonte, Minas Gerais (Brazil).

otaviogomes@cpdee.ufmg.br, davies@cpdee.ufmg.br

Purpose

In this work we study the computational optimization of the microlens-array geometry for a Hartmann-Shack wavefront sensor. The optimization makes possible that regular microlens arrays with a larger number of microlenses are replaced by arrays with fewer microlenses located at optimal sampling positions, with no increase of the reconstruction error. The optimization comprises the minimization of the number of necessary microlenses in the array and/or the wavefront reconstruction error, considering a given aberration statistics.

Within an ophthalmological case study, we demonstrate that an array with only 10 suitably located microlenses can be used to produce reconstruction errors as small as those of a 36-microlens orthogonal array. Using simulations, we also analyze the effect of rotation over the performance of the optimal 10-microlens array. Finally, the arrays are fabricated using the fabrication process proposed by D. W. de Lima Monteiro et.al. [1] and tested on an optical setup designed for measuring wavefront aberrations.

Methods

The Hartmann-Shack (H-S) wavefront sensor is now deployed in many different fields, from astronomy to industrial inspection, where the quality of optical media or components can be measured by the distortions they impart on a wavefront transmitted or reflected by them. In ophthalmology, this sensor is a core component of major aberrometers, used to assess the visual quality of the eye and applied to academic research, real-time surgery monitoring and clinical diagnosis.

The microlens array is an important element in the H-S sensor, responsible for sampling the aberrated wavefront into light spots on the focal plane. The position of each light spot relates to the average tilt of the wavefront over the respective microlens. These spot-position coordinates are then used in the modal reconstruction to approximate the wavefront topology with a combination of orthogonal basis functions, e.g. Zernike polynomials.

The wavefront sampling is influenced by the microlens distribution pattern, lens contour and size, number of microlenses and fill factor. Adopted grids typically consist in either orthogonal or hexagonal configurations. Soloviev and Vdovin [2] have discussed the influence of the geometry of a microlens array on the wavefront reconstruction error. Their model indicates the dependency of the reconstruction error on the array geometry. To validate their assumptions, they evaluated different array geometries with Zernike coefficients from the atmospheric-turbulence statistics. Arrays with randomly distributed microlenses generated lower reconstruction errors than regular grids [3], especially when the number of Zernike terms increased beyond 40, for which there was a catastrophic growth of the sampling error.

The search for the optimal microlens array is carried out numerically. Given an array, an algorithm generates input wavefronts based on statistics for typical ocular aberrations and an H-S model performs its sampling and modal reconstruction. The outcome is the root-mean-square (rms) error between the reconstructed wavefront and the input one. This procedure is coupled to an optimization method, using Genetic Algorithm, where the H-S model represents the objective function. Since our emphasis lies on the reconstruction error due to the optical sampling at the microlens array, errors related to photodetection, spot-coordinate detection and electronic sampling are not taken into account. The method searches the microlens array geometry that minimizes the reconstruction error.

Results

The optimization methodology described was applied to three cases: arrays with 10, 16 and 36 microlenses. The best arrays found in all cases were compared to the 16, 25 and 36-microlenses orthogonal arrays through the calculation of the reconstruction error for a fixed random set of 2,000 aberrated wavefronts. The average values and the standard deviations for each case are shown in Fig. 1.

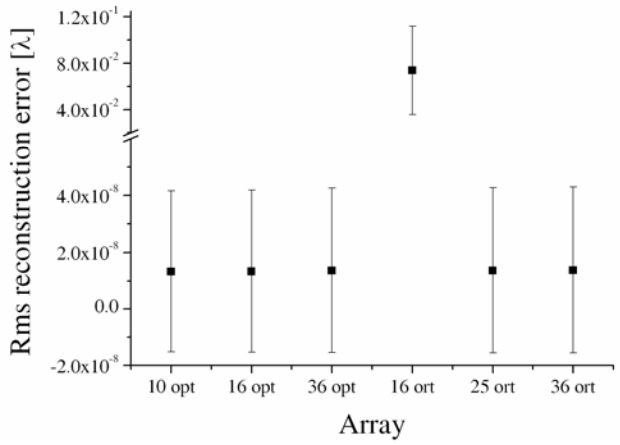

Fig. 1. Average reconstruction error for 16-, 25 and 36- regular and orthogonal arrays calculated over a set of 2,000 wavefront aberrations. 'Opt' stands for optimized array and 'Ort', for orthogonal array. The used λ was 633nm.

Conclusions

The results show that an optimized array can afford fewer microlenses, maintaining a low reconstruction error. As observed before, the reconstruction error comprises both sampling and numerical errors. Strikingly, through this optimization procedure both the reconstruction error and the number of lenses can be concomitantly reduced. The optimization results demonstrate that it is possible to specify the distribution pattern of the 16 microlenses in the array so that it can generate reconstruction errors as low as the ones generated by the 25- and 36-microlens orthogonal arrays and moreover, that arrays with even fewer microlenses, such as 10, can also be used to generate as small reconstruction errors as those from the 25- and 36-microlens orthogonal arrays. Simulation results on the rotation analysis and experimental results with the fabricated arrays will be shown in the final paper.

References

1. D. W. de Lima Monteiro, O. Akhzar-Mehr, P. M. Sarro, G. Vdovin, Single-mask microfabrication of aspherical optics using KOH anisotropic etching of Si, Opt. Express 18 (2003), 2244-2252.

2. O. Soloviev, G. Vdovin, Hartmann-Shack test with random masks for modal wavefront reconstruction, Opt. Express 13 (2005), 9570-9584.

3. R. Navarro, J. Arines, R. Rivera, Direct and inverse discrete Zernike transform, Opt Express 17 (2009), 24269-24281.