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A ROBUST APPROACH TO RECONSTRUCT OCULAR ABERRATIONS FROM MEASUREMENTS WITH NOISE

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Precise measurement of ocular aberrations is crucial for effective vision corrections, such as laser refractive surgeries and customised contact lenses. In clinical practice, multiple wavefront measurements are taken from each patient to enhance accuracy. However, these repeated measurements introduce significant variability due to pupil size fluctuations, aberrometer misalignments, and accommodation of the eye's optical system. Previous studies have primarily investigated this variability through changes in Zernike coefficients (ZCs). In this study, the variability of ZCs was explored by incorporating measurement noise into the raw local slope data recorded from the Shack-Hartmann aberrometer, rather than focusing solely on output coefficients. Synthetic data representing various eye conditions, including astigmatism, myopia, keratoconus, and keratoplasty were used, with normally distributed random noise ($\mu = 0, \sigma^2 = 1$) added to simulate real-world measurement variations. Spatial smoothing was applied to the noisy data using Tikhonov regularisation, and optimal smoothing parameter was computed through the generalised cross-validation method to produce a representative wavefront. The results of this study are presented via Signal-to-Noise (S/N) ratios for individual ZCs, comparing the performance of least squares and spatial smoothing approaches. It was observed that spatial smoothing consistently yields significantly lower S/N ratios ($< 2\ dB$), indicating the high capability to detect noise variability through spatial approach. In contrast, the least square approach yields higher S/N ratios ($> 10\ dB$), indicating its limited capacity to manage measurement variability. This work offers new insights on taking the effects of measurement variability in ocular wavefront analysis. These findings lead us to conclude that spatial smoothing not only improves the reliability of Zernike coefficients' estimation but also has direct implications for clinical practice, enabling ophthalmologists to make better-informed decisions in customized vision correction procedures including laser refractive surgeries and tailoring contact lens designs. This approach can lead to more accurate diagnoses and better customisation of corrective procedure, ultimately improving patient outcomes in vision care.

Keywords: Signal-to-Noise ratio, Spatial smoothing, Variability, Zernike coefficients