Progress on deep-phase-retrieval Shack-Hartmann wavefront sensors for astronomical telescopes

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Abstract

Traditional wavefront reconstruction methods based on slope measurements limit the capability of Shack-Hartmann wavefront sensors to detect high-order aberrations. To ensure high signal-to-noise ratio sub-aperture spot images, the number of microlenses used to segment the wavefront in the Shack-Hartmann wavefront sensor is limited. For conventional wavefront reconstruction methods based on singular value decomposition or least-squares methods, it means that the number of reconstructed aberration modes is limited when the condition number of the reconstruction matrix is held in a relatively small range. We propose the Deep-Phase-Retrieval Wavefront Reconstruction (DPRWR) method to extend the Shack-Hartmann sensor's detection range of aberration modes under finite sub-apertures, at the same time improving the aberration detection accuracy. This method builds a nonlinear fitting model between Shack-Hartmann images and aberration mode coefficients by utilizing neural networks to mine more feature information in spot images. In this paper, the application limits, performance bounds, and robustness of this method were investigated in point source experiments. It was found that the aberration modes of about 3 to 6 times the number of sub-apertures can be measured by DPRWR with high accuracy when the full width of the spot at half height is higher than about 1 pixel and the bit depth is higher than 2-bit. Moreover, as regard to measuring the wavefront of extended scenes, an extended scenes-independent feature image extraction method is proposed to reduce the effects of object shape information on wavefront measurement. In combination with the DPRWR network, this method enables Shack-Hartmann sensors to obtain higher accuracy measurements of higher-order aberrations in extended scenes compared to the slope-based method.

Keywords: Wavefront Sensing, Shack Hartmann, Deep Phase Retrieval

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