Using pipeline classifier-regressor in the problem of recognizing wavefront aberrations

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Abstract

In this work, training and recognition of the types of aberrations corresponding to individual Zernike functions have been carried out by the pattern of the intensity of the point scattering function (PSF) using convolutional neural networks. The PSF intensity patterns in the focal plane were modeled using the Fast Fourier Transform algorithm. When training a neural network, the learning coefficient and the number of epochs for a dataset of a given size were selected empirically. The average prediction errors of the neural network for each type of aberration were obtained for a set of 15 Zernike functions from a dataset of 15 thousand PSF pictures. As a result of training, for most types of aberrations, averaged absolute errors were obtained in the range 0.012–0.015, however, the determination of the aberration coefficient (magnitude) requires additional research and data, for example, calculating the PSF in the extrafocal plane.

Keywords

Wavefront aberrations, point spread function, focal plane, fast Fourier transform, neural networks

1. Introduction

Recognition and compensation of wavefront aberrations are in demand in various applications associated with the use of optical systems from space exploration to improving vision [1–5].

Not being able to directly measure the phase of the light field, it is necessary to determine it indirectly, including by measuring the intensity of the light field. There are various approaches to solving this problem, but new methods are also being developed.

Interferometry is one of the well-known methods that provide high accuracy in determining the deviations of the wavefront at very large aperture sizes. The accuracy of interferometers, especially heterodyne ones, is of the order of λ / 100. However, the method also has significant drawbacks: the laboriousness of decoding interferograms, the sensitivity of the measuring equipment to vibrations, and the need for the physical presence of a reference wavefront. At the initial stages of the development of optical production, the shadow method was used to control spherical surfaces; however, shadow patterns are difficult to quantitatively interpret, and the shadow setup, like the interferometer, must have high rigidity and be protected from vibrations.

The purpose of this work is to investigate the possibility of using neural networks to solve the problem of recognizing not only the type but also the level (magnitude) of the wavefront aberration from the PSF pattern in the focal plane.

Thus, in this work, we use a neural network to solve the regression problem. In a regression problem, we aim to predict the outcome of a continuous value such as probability or price. This problem differs from the classification problem, where we aim to select a discrete quantity from a list of classes.

2. Theoretical basis

Consider an aberrated wavefront in the form of a field described as follows:

$$g(r,\phi) = \exp\left[i\psi(r,\phi)\right] \tag{1}$$

We will assume that the phase in (1) is represented by a superposition of Zernike functions:

$$\psi(r,\phi) = \sum_{n,m} b_{nm} Z_n^m(r,\phi)\,, \tag{2}$$

where $Z_n^m(r,\phi)$ are the Zernike functions of order (n, m):

$$Z_n^m(r,\phi) = A_n R_n^m(r) \begin{Bmatrix} \cos(m\varphi) \\ \sin(m\varphi) \end{Bmatrix} \tag{3}$$

$A_n = \sqrt{(n+1)/\pi}$ is the normalization coefficient, $R_n^m(r)$ are the radial Zernike polynomials [17], and b_{nm} are the superposition coefficients.

3. Conclusions

Within the framework of this work, PSF patterns in the focal plane were modeled for the coherent case, and the neural network was trained to recognize the type of aberration and its magnitude (coefficient). It should be noted that PSF pictures in the incoherent case, which is more consistent with practical applications of aberration studies, will have a different form. However, the proposed approach, based on training a neural network for a certain set of pictures, is universal from this point of view; therefore, the procedure, in this case, will not change, although the recognition results may change. When training a neural network, the learning coefficient and the number of epochs for a dataset of a given size were selected empirically. The mean prediction errors of the neural network for each type of aberration were obtained for a set of 15 Zernike functions from a dataset of 15 thousand pictures of coherent PSFs in the focal plane.

4. References

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