Comparative Analysis of the Interferogram Sensitivity to Wavefront Aberrations Recorded with Plane and Cylindrical Reference Beams

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Abstract. The paper investigates the **sensitivity** of interferograms formed using the **structured reference beams**. A study carried out on the use of reference beams with **cylindrical** wavefronts in the interferograms formation to improve the aberrations recognition using a **convolutional neural network**. The applying of a cylindrical reference beam instead of a plane one for recognition of wave aberrations makes it possible to **reduce the mean absolute error** by more than **30%**.

The reference beam:

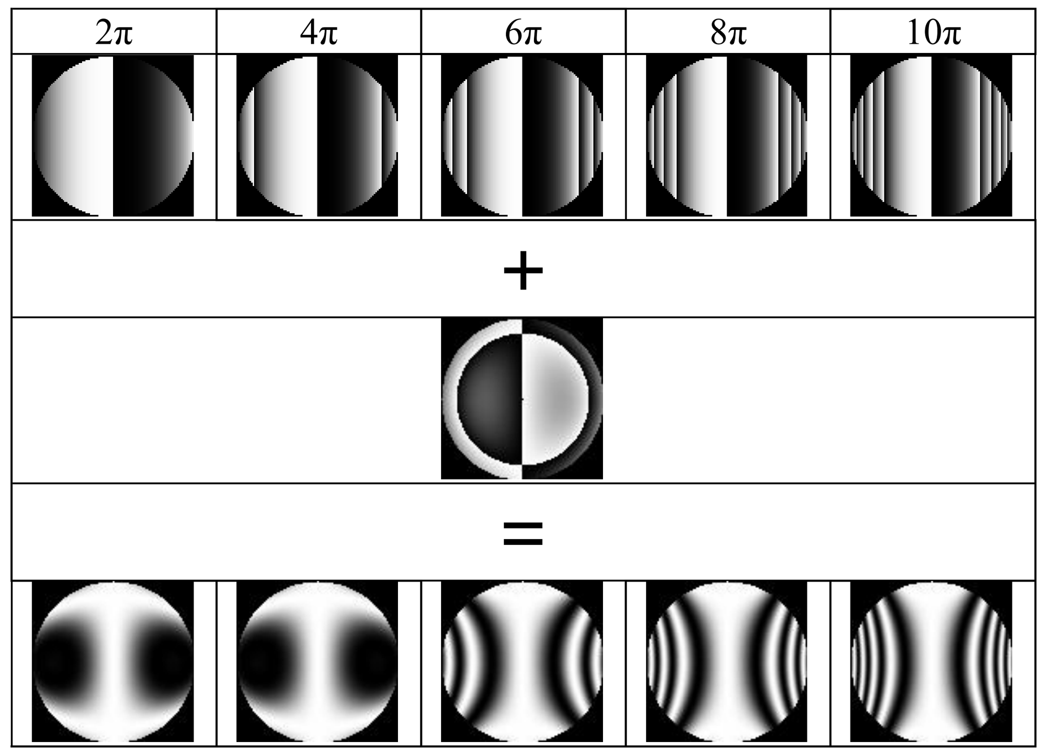
$$E_B(x,y) = \exp\left[iB(x,y)\right]$$

The wavefront aberrations:

$$E_W(x,y) = \exp\left[iW(x,y)\right]$$

The interferogram:

$$I(x,y) = \left|E_W(x,y) + E_B(x,y)\right|^2$$



The interferograms obtained using a plane and structured reference beam corresponding to a cylindrical (cubic) carrier make it possible to form a more complex intensity distribution picture.

$$W(r,\varphi) = 2\pi \sum_{n=0}^{n_{\max}} \sum_{m=0}^{n} c_{nm} Z_{nm}(r,\varphi).$$

$$R_n^m(r) = \sum_{p=0}^{(n-m)/2} \frac{(-1)^p (n-p)!}{p!\left(\frac{n+m}{2}-p\right)!\left(\frac{n-m}{2}-p\right)!}\left(\frac{r}{r_0}\right)^{n-2p}$$

$$Z_{nm}(r,\varphi) = Z_N(r,\varphi) = A_n R_n^m(r)\begin{Bmatrix}\cos(m\varphi)\\ \sin(m\varphi)\end{Bmatrix}$$

$$A_n = \sqrt{(n+1)/\pi}$$

$$B_{p=2}(x,y) = \alpha x^3$$

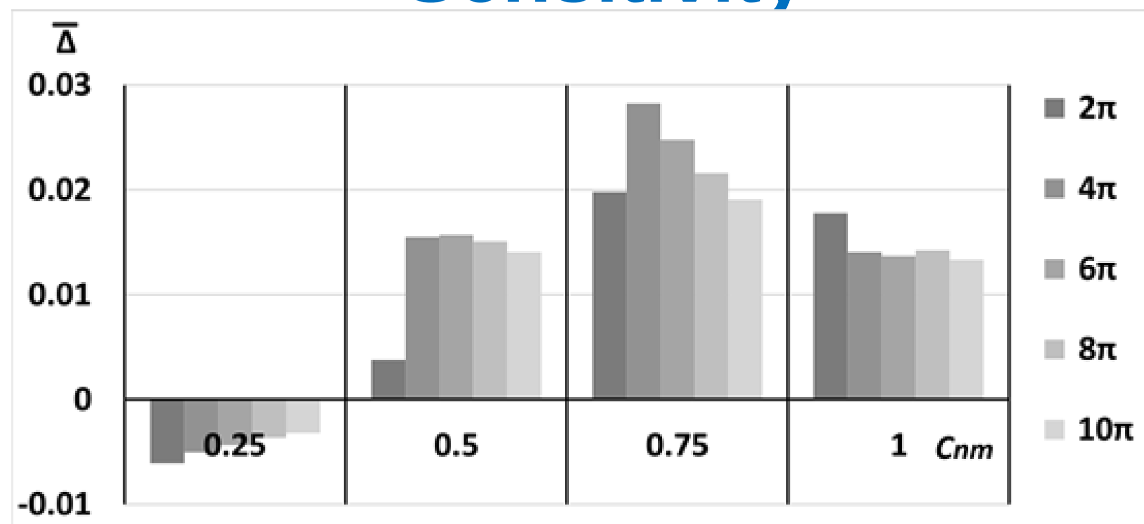
Sensitivity

$$S_p = \sqrt{\iint\left[I_p(x,y) - I_{0p}(x,y)\right]^2 dxdy \Big/ \iint I_{0p}^2(x,y)dxdy}$$

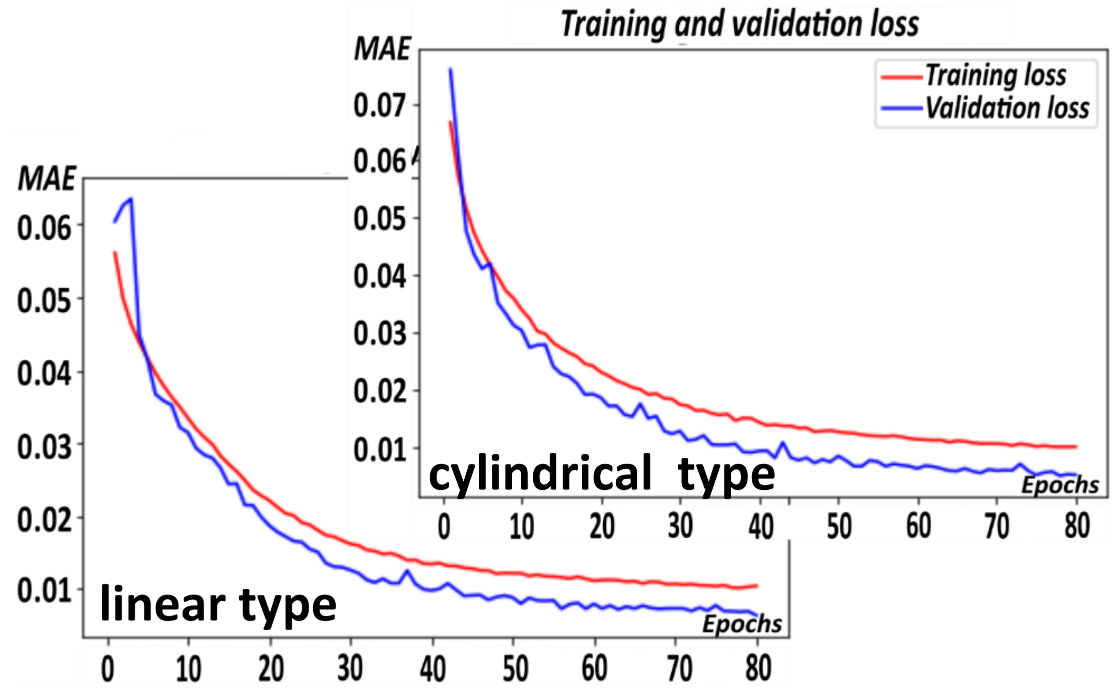
$$\Delta = (S_2 - S_1)/c_{nm}$$

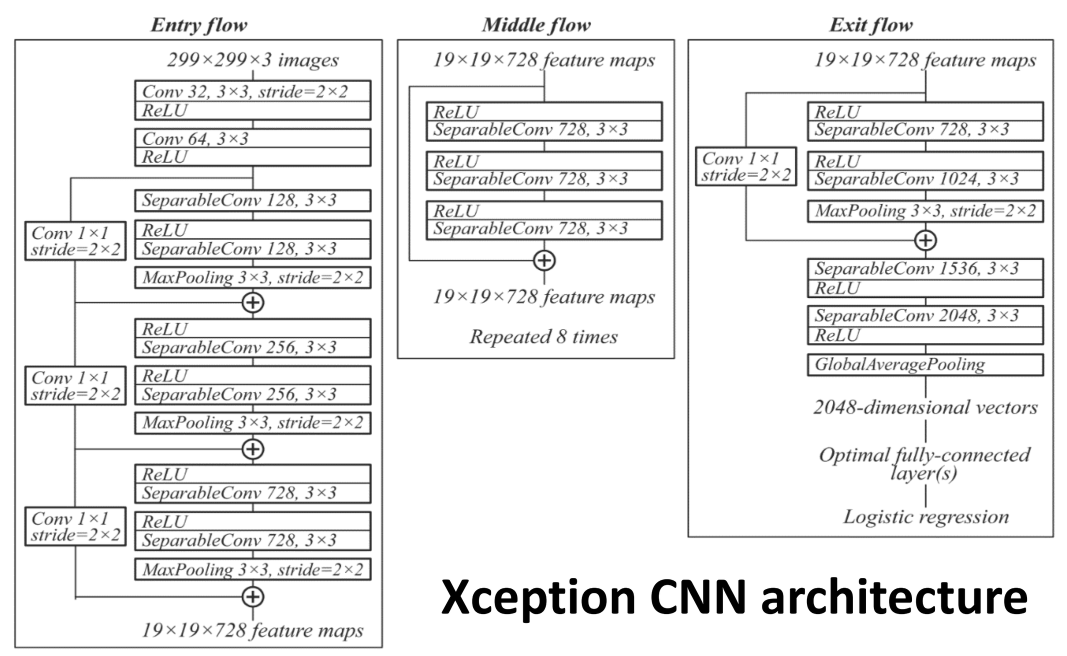
The parameter *S* will allow us to estimate the recognition sensitivity of a linear and cylindrical interferograms, which corresponds to the standard deviation (SD) value of the p-type interferogram formed by an **aberrated** wave $I_p(x,y)$ from the **unaberrated** interferogram $I_{p0}(x,y)$.

Sensitivity



CNN





Xception CNN architecture

Recognition results

The mean absolute recognition error for the model interferograms of various types with a variable reference beam parameter α

Type interferograms	Angle	MAE
Linear	α=2π	0.0063
	α=4π	0.0065
	α=6π	0.0068
Cylindrical	α=2π	0.0050
	α=4π	0.0047
	α=6π	0.0050

- Nvidia GeForce RTX 2070
- 8 GB of GDDR6-type memory
- Keras package for Python language

Conclusion. The use of reference beams with the **cylindrical** wavefronts is proposed to improve the aberration recognition from interferograms using convolutional neural networks. The interferogram **sensitivity** when using a cylindrical reference beam increases **by at least 10%** compared to a plane reference beam for the radially asymmetric types of aberrations, and the **mean absolute error** of aberration recognition **decreases** from 0.0068 to 0.0047.

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