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Deep learning based wavefront sensor for complex wavefront detection in adaptive optical microscopes

Key words: Adaptive optics; Wavefront detection; Deep learning; Zernike coefficients; Microscopy

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Motivation

1. Adaptive optics (AO) has been applied to improve the imaging performance of fluorescence microscopes, which enables the observation of specimen structure and function in biomedical research.

2. Some aberrations induced by the thick tissue have complex distributions, which cannot be reconstructed by traditional algorithms accurately.

3. Deep learning methods have been applied to improve the performance of AO.

Main idea

1. The proposed method combines the point spread function (PSF) image based Zernike coefficient prediction with wavefront stitching.

2. The strategy of connecting two models enables the use of global and local information at the same time.

3. The proposed model is compared with several algorithms and shows good performance.

Method

1. A novel direct wavefront detection algorithm is proposed which consists of two convolutional networks for local wavefronts prediction and global wavefront stitching.

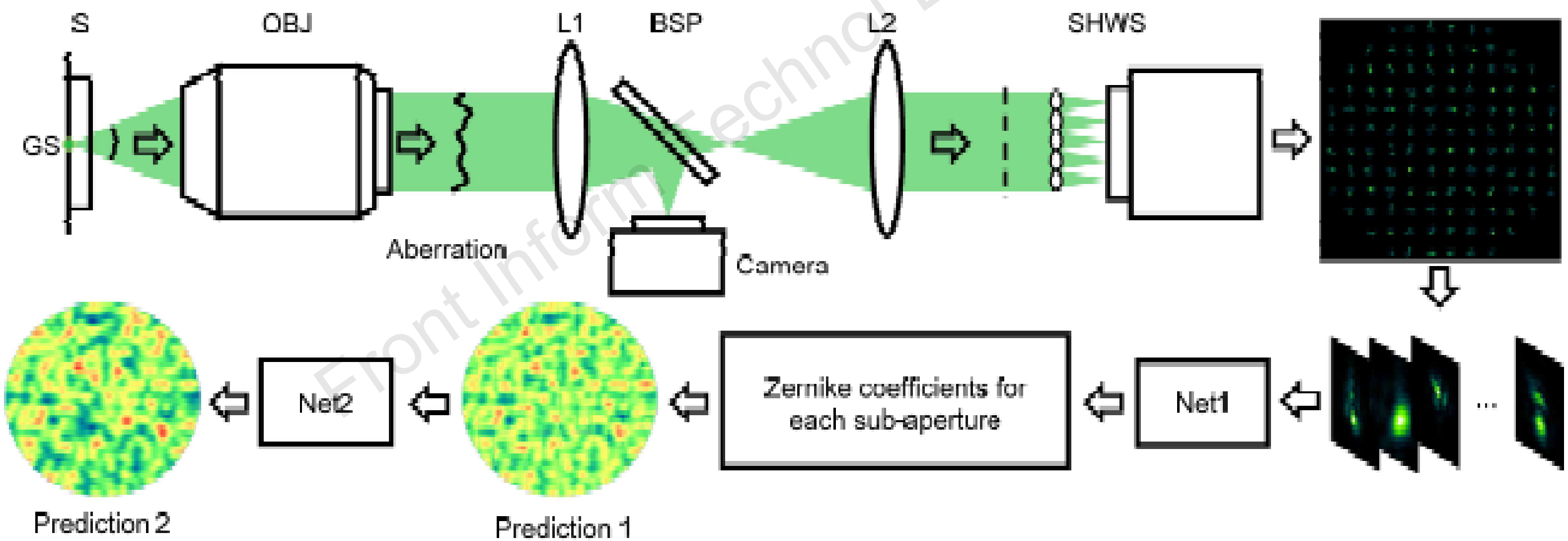

Fig. 1 Illustration of the two-step wavefront detection

S: sample; GS: guide star; L1 and L2: lenses; BSP: beam splitter plate; OBJ: objective lens. The dotted line indicates the pupil plane of the micro-lens array. Prediction 1 indicates the preliminary detected wavefront, and prediction 2 indicates the final wavefront with continuous distribution

Method

Two-step wavefront detection framework

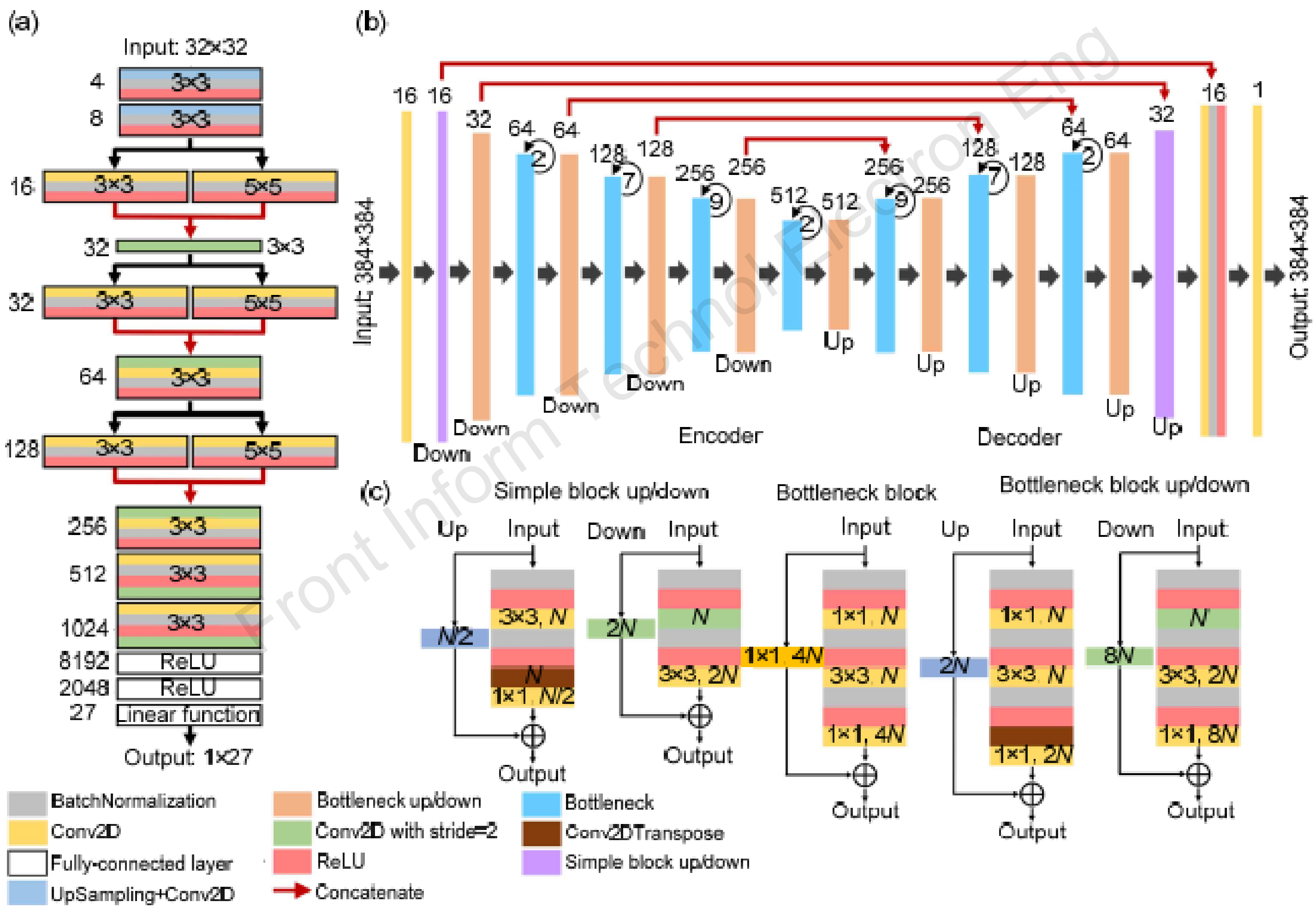

Fig. 2 Illustration of convolutional neural network architectures

Simulation results

1. Test results of our model and related methods

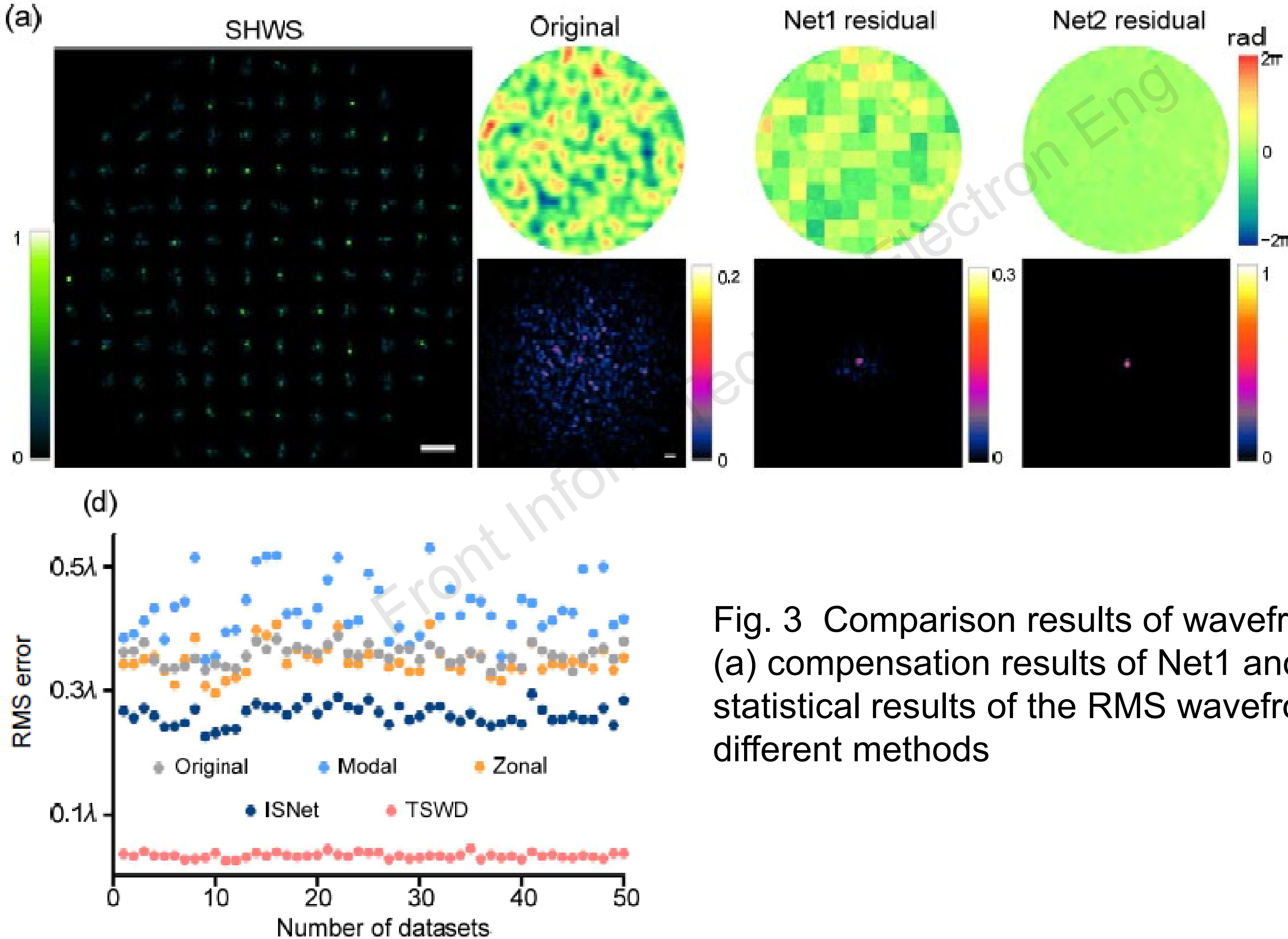

Fig. 3 Comparison results of wavefront detection: (a) compensation results of Net1 and Net2; (d) statistical results of the RMS wavefront errors of different methods

Analytic results

2. Analytic results of our model and related methods with wavefront sensors

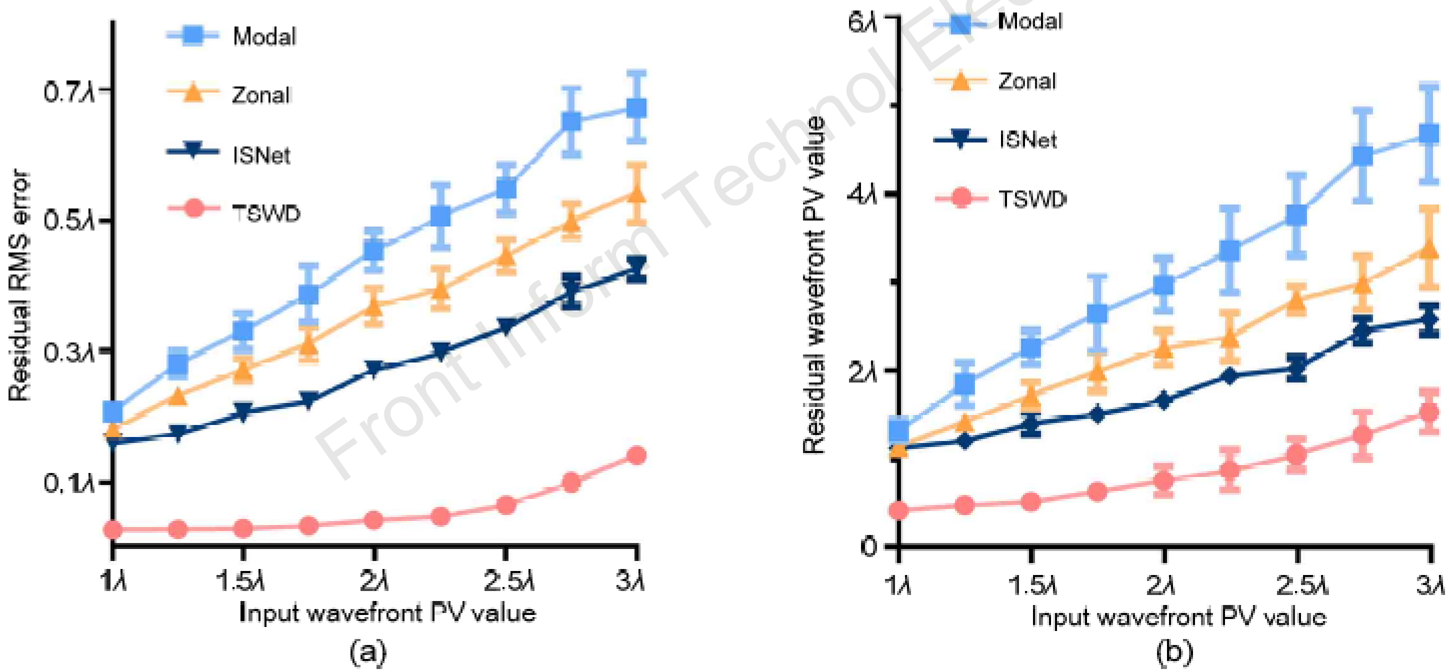

Fig. 5 Detection results with different wavefront PV values

(a) RMS wavefront error vs. input wavefront PV value; (b) Residual wavefront PV value vs. input wavefront PV value. Each group contains nine datasets. Bars indicate the standard deviations

Analytic results

3. Analytic results of our model and related methods with or without wavefront sensors

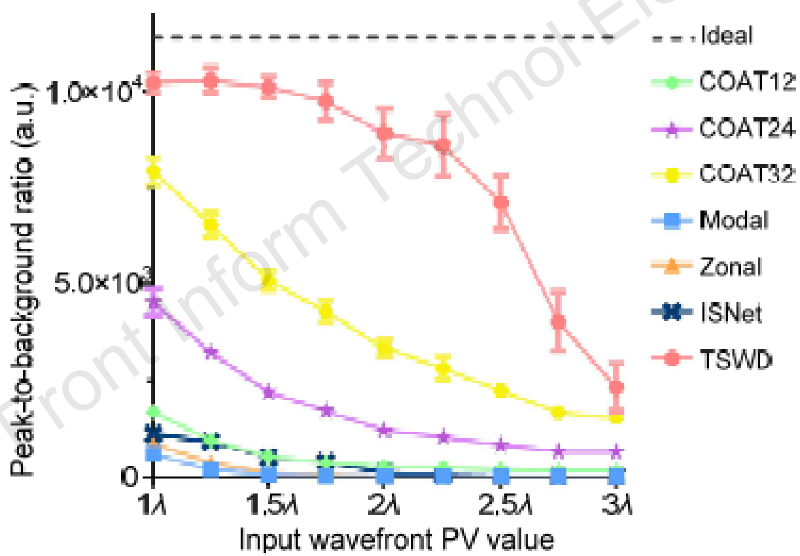

Fig. 7 Comparison of peak-to-background ratios with different methods (81 datasets)

Analytic results

4. Analytic results of our model and modified U-net for different distribution types of wavefronts

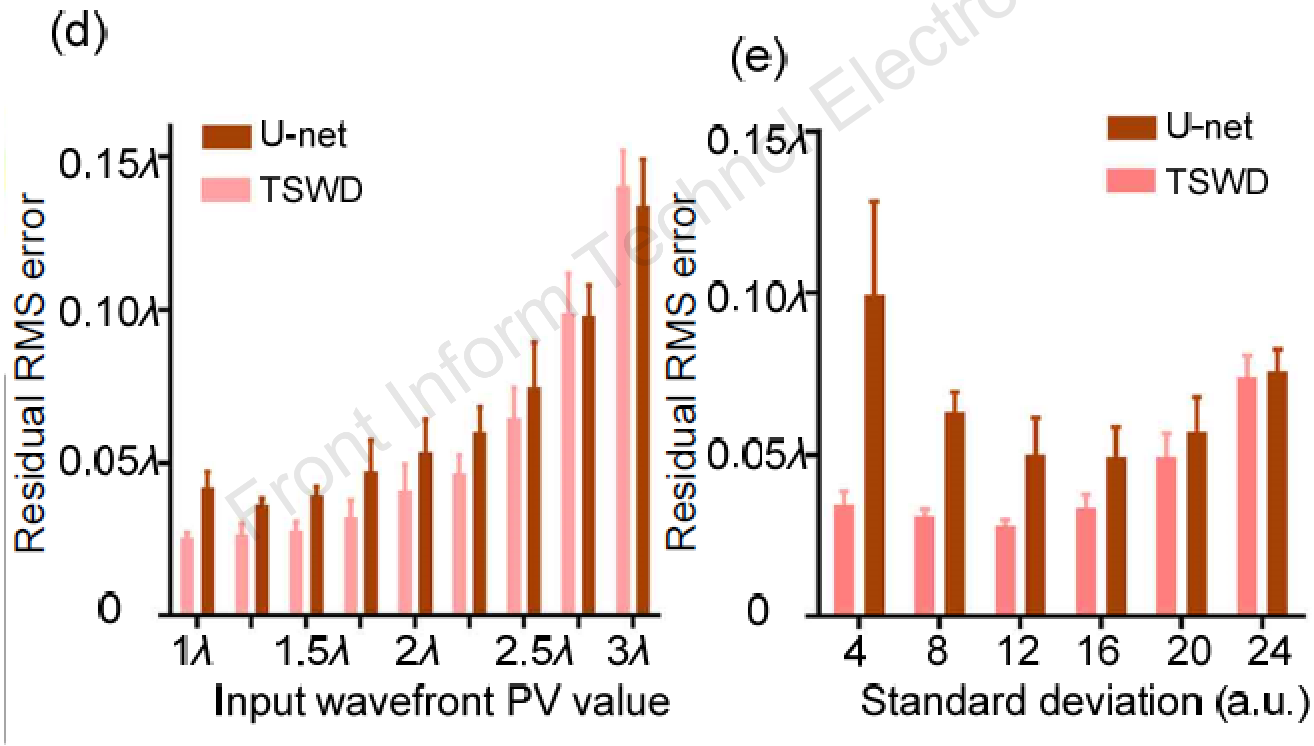

Fig. 8 Comparison of different types of wavefronts between TSWD and modified U-net; (d) RMS wavefront error vs. input wavefront PV value; (e) RMS wavefront error vs. standard deviation

Conclusions

1. We combined the PSF image based Zernike coefficient estimation for local wavefronts and the wavefront stitching method for accurate wavefront reconstruction.

2. Global information and local information were combined in prediction.

3. Compared to the conventional SHWS wavefront reconstruction approaches, the indirect wavefront detection method COAT, and the modified U-net, our method can offer higher wavefront detection accuracy and better generalization ability.

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