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学术论文

# 可逆神经网络校正可变程度的光学像差
# Neural invertible variable-degree optical aberrations correction

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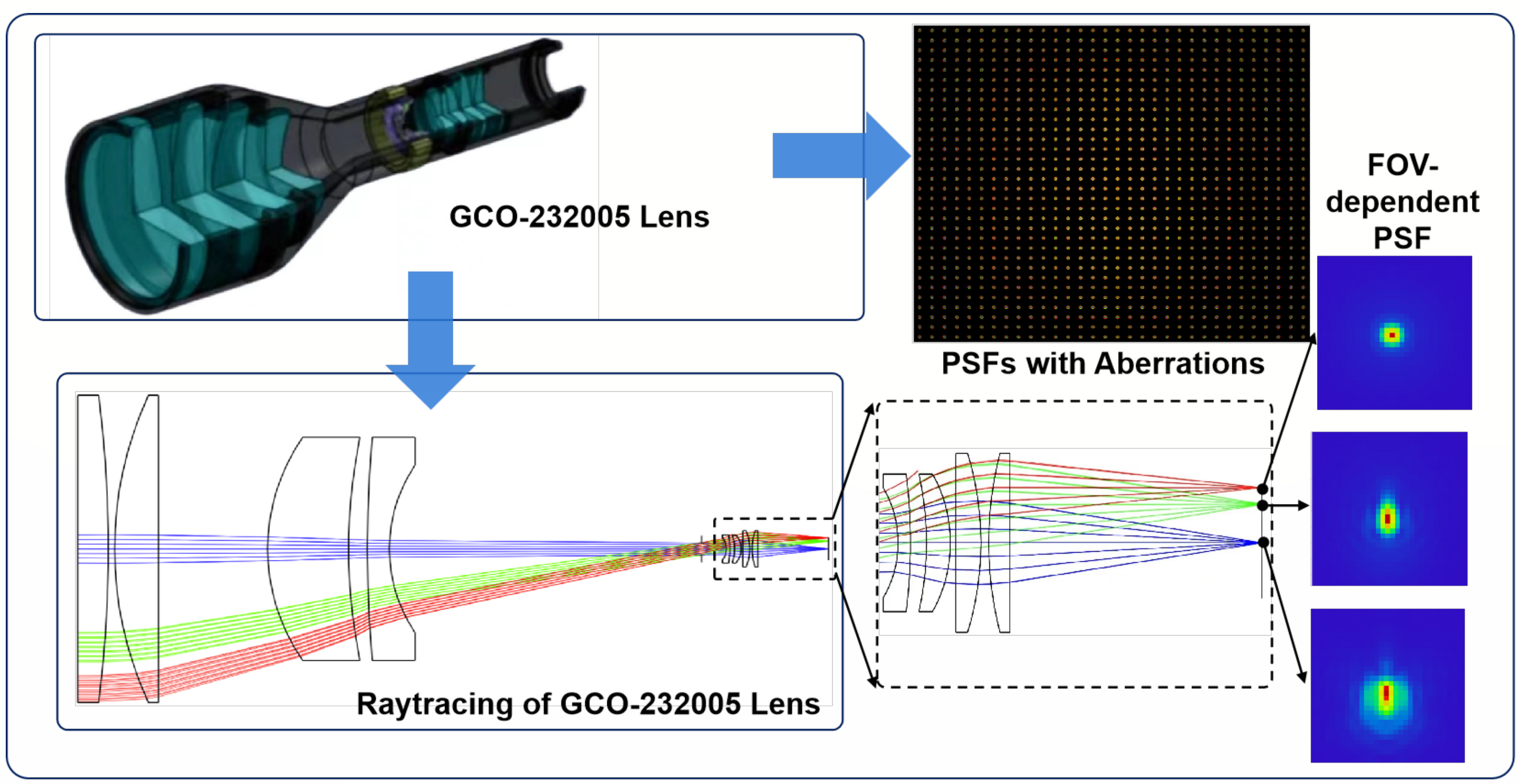
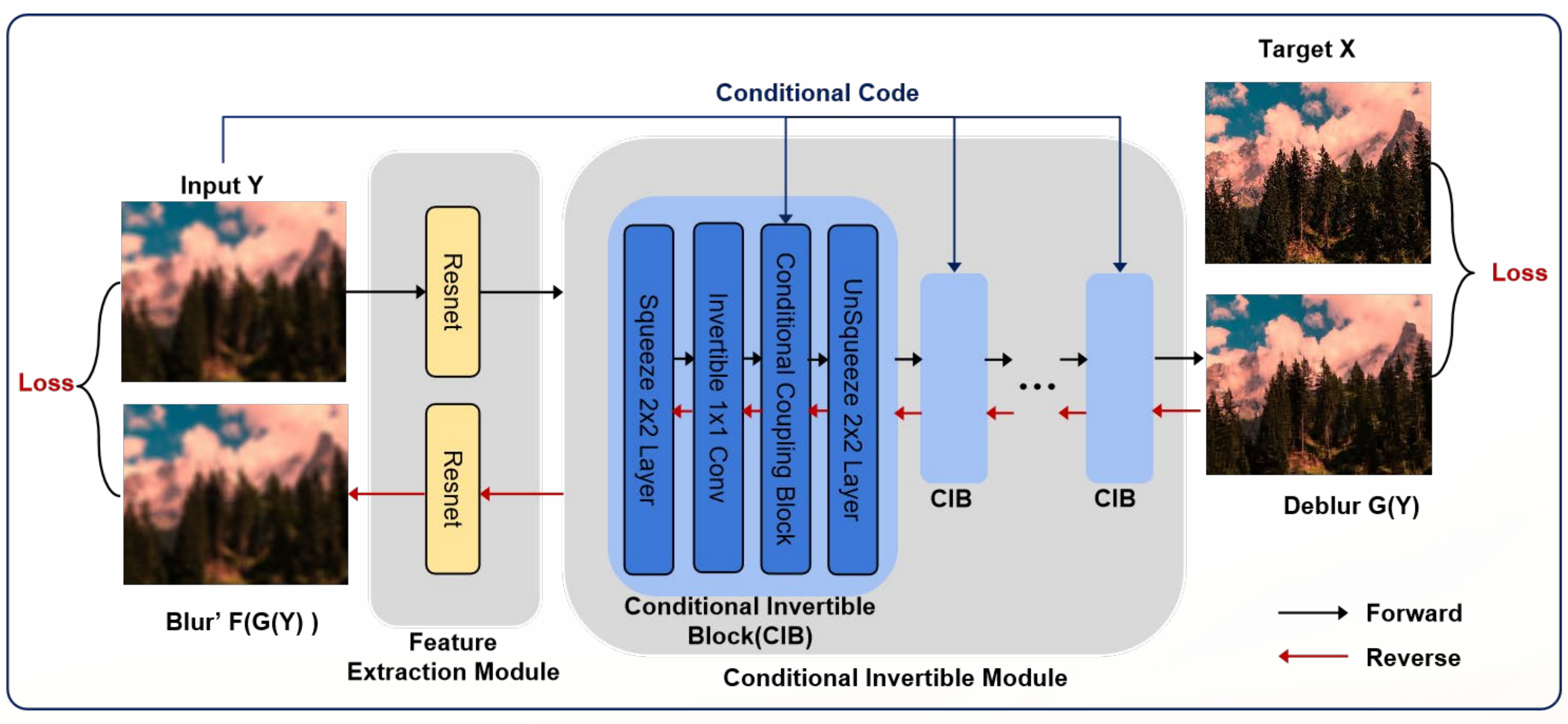
## Introduction

- Optical aberrations are defects introduced in the design, manufacturing and assembly of camera lenses. The defects cause the incident light to diffuse and fail to focus to form a sharp image, producing images with blurry and dispersive appearance.
- Aberration correction by sophisticated lens designs and special glass materials generally incurs high cost of manufacturing and the increase in the weight of optical systems, thus recent work has shifted to aberration correction with deep learning-based post-processing.
- Previous methods use a single feed-forward neural network and suffer from information loss. To address the issues, we propose a novel aberration correction method with an invertible architecture by leveraging its information-lossless property.

## Method

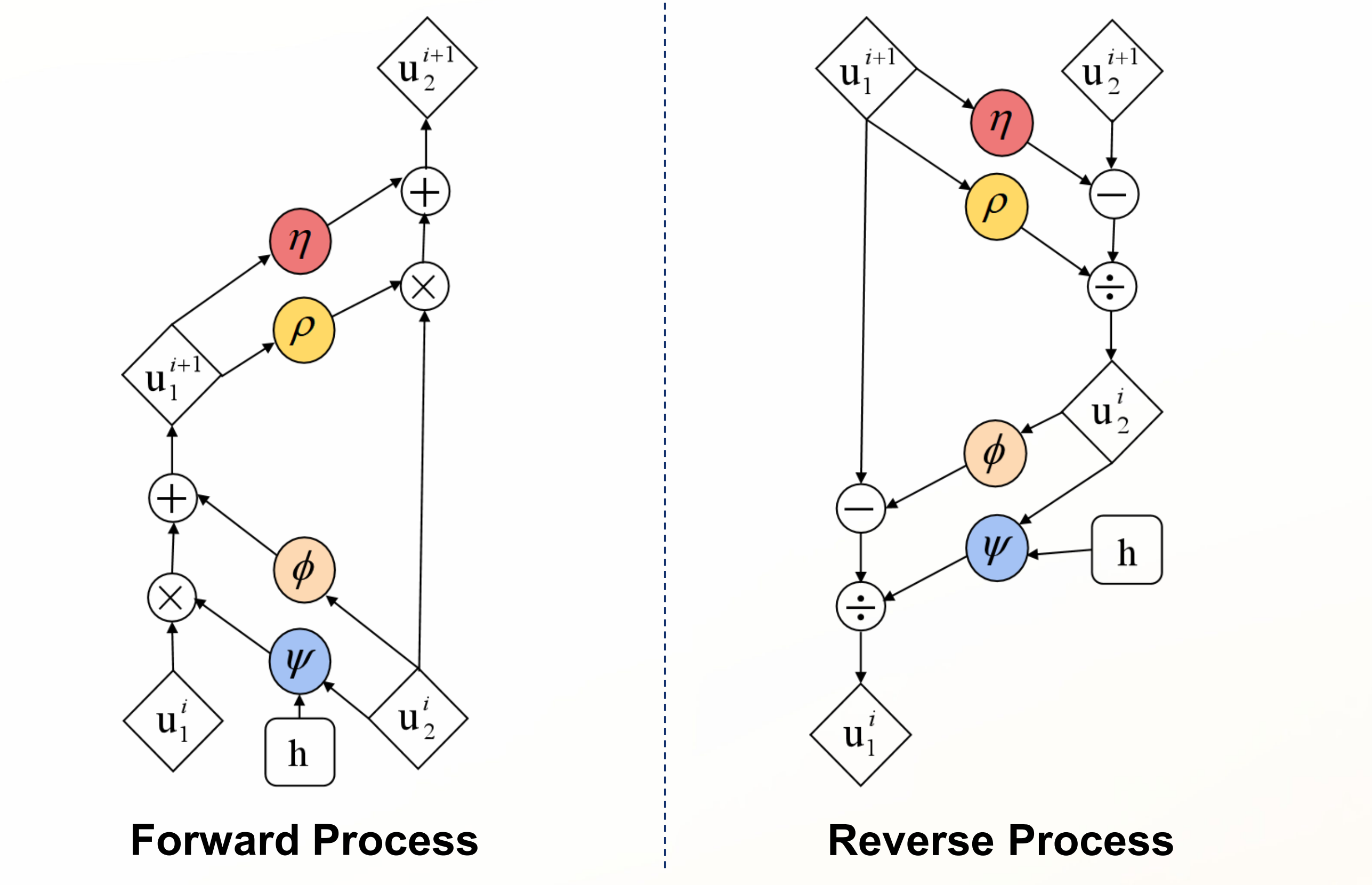


$$I_{degraded}(i,j,d) = I_{sharp}(i,j) \otimes k(i,j,d) + n(i,j)$$



$$u_1^i, u_2^i = Split(u^i)$$
$$u_1^{i+1} = u_1^i \odot \exp\left(\psi\left(u_2^i, h\right)\right) + \phi\left(u_2^i\right)$$
$$u_2^{i+1} = u_2^i \odot \exp\left(\rho\left(u_1^{i+1}\right)\right) + \eta\left(u_1^{i+1}\right)$$
$$u^{i+1} = Concat(u_1^{i+1}, u_2^{i+1})$$

$$u_1^{i+1}, u_2^{i+1} = Split(u^{i+1})$$
$$u_2^i = \left(u_2^{i+1} - \eta\left(u_1^{i+1}\right)\right) \odot \exp\left(-\rho\left(u_1^{i+1}\right)\right)$$
$$u_1^i = \left(u_1^{i+1} - \phi\left(u_2^i\right)\right) \odot \exp\left(-\psi\left(u_2^i, h\right)\right)$$
$$u^i = Concat(u_1^i, u_2^i)$$



**loss function:**

$$\mathcal{L}_{total} = \lambda_1 \mathcal{L}_{forward}(\mathcal{G}(\mathbf{Y}), \mathbf{X}) + \lambda_2 \mathcal{L}_{reverse}(\mathcal{F}(\mathcal{G}(\mathbf{Y})), \mathbf{Y}) + \lambda_3 \mathcal{L}_{edge}(\mathcal{G}(\mathbf{Y}), \mathbf{X}) + \lambda_4 \mathcal{L}_{perceptual}(\mathcal{G}(\mathbf{Y}), \mathbf{X})$$

- We design an imaging simulation process based on ray tracing and spatial convolution to generate large-scale paired datasets with variable degradation degrees.
- We propose an invertible neural network architecture for optical aberration correction that can largely alleviate the information loss problem and improve image quality.
- We introduce conditional encoding modules for the invertible neural network to deal with varying degrees of optical aberrations.
- The reverse loss makes learning process more stable and increases the robustness of neural networks.

## Experiments

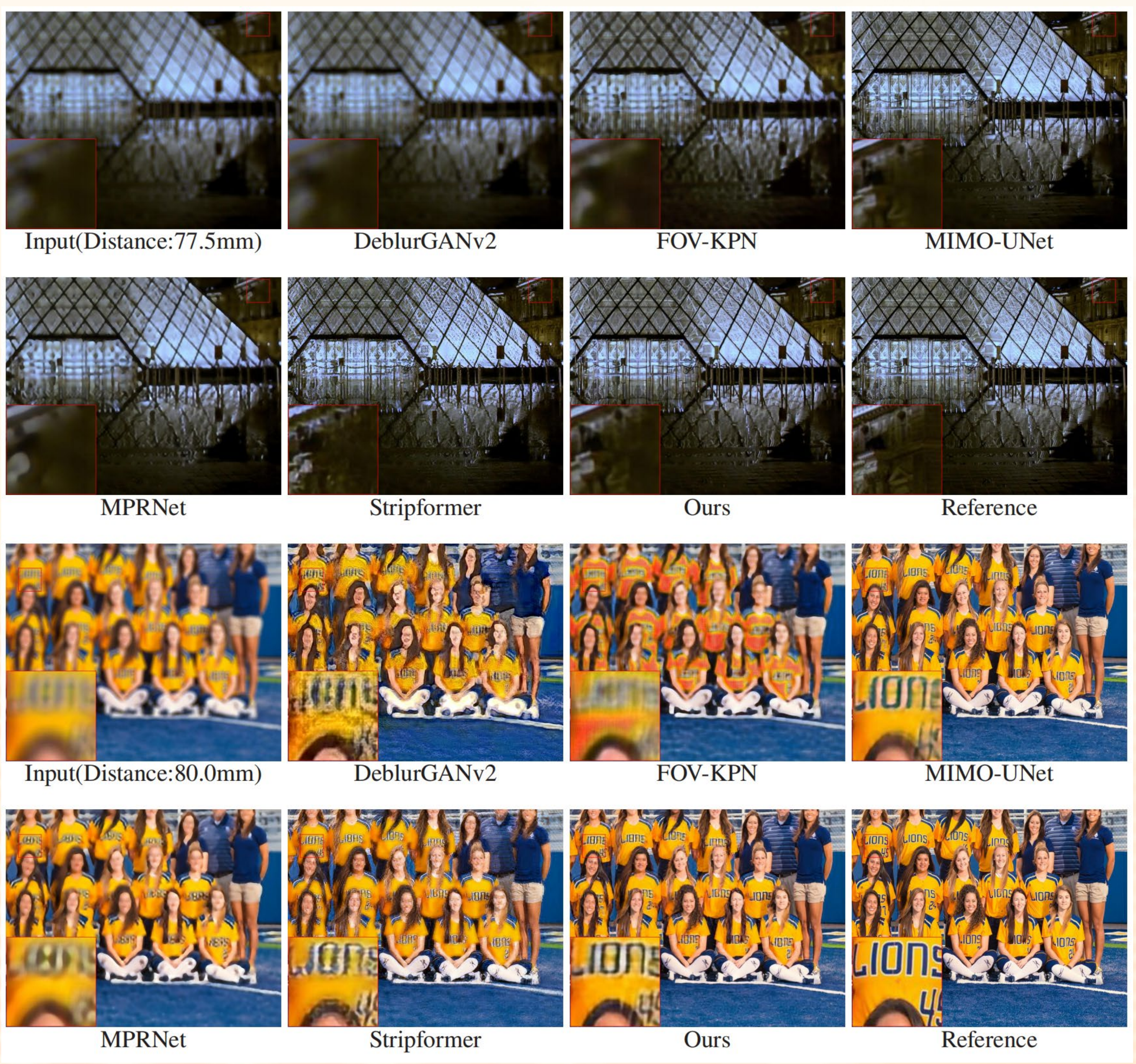


**Table 1. Comparisons of the evaluation metrics on the synthetic dataset and the number of parameters.**[a]

| Method | PSNR ↑ | SSIM ↑ | LPIPS ↓ | Params# |
|---|---|---|---|---|
| Input | 21.0932 | 0.7246 | 0.4427 | |
| DeblurGANv2 [30] | 17.5685 | 0.5712 | 0.4015 | 3.31$M$ |
| FOV-KPN [12] | 20.6122 | 0.7230 | 0.4047 | 4.01$M$ |
| MIMO-UNet [31] | 24.9595 | **0.8493** | **0.1956** | 6.81$M$ |
| MPRNet [32] | 22.3145 | 0.7639 | 0.3393 | 20.13$M$ |
| Stripformer [33] | 23.6378 | 0.8104 | 0.2324 | 19.71$M$ |
| Ours | **25.3004** | 0.8432 | 0.2069 | 10.16$M$ |

**Table 2. Quantitative results of ablation studies in terms of PSNR, SSIM and LPIPS on test dataset.**[a]

| FEM | CC | IN | FOV | PSNR ↑ | SSIM ↑ | LPIPS↓ |
|---|---|---|---|---|---|---|
| | √ | √ | | 23.79 | 0.7989 | 0.3107 |
| √ | | √ | | 23.85 | 0.8042 | 0.2751 |
| √ | | | | 23.21 | 0.7963 | 0.2628 |
| √ | √ | √ | √ | 24.22 | 0.8170 | 0.2530 |
| √ | √ | √ | | **25.30** | **0.8432** | **0.2069** |

[a] The feature extraction module (FEM), the conditional code (CC), the invertible module (IM) and the FOV encoder (FOV).

- Quantitative and qualitative experimental results demonstrate that our method outperforms compared methods in correcting variable-degree optical aberrations.