# Polarization-Aware Low-Light Image Enhancement

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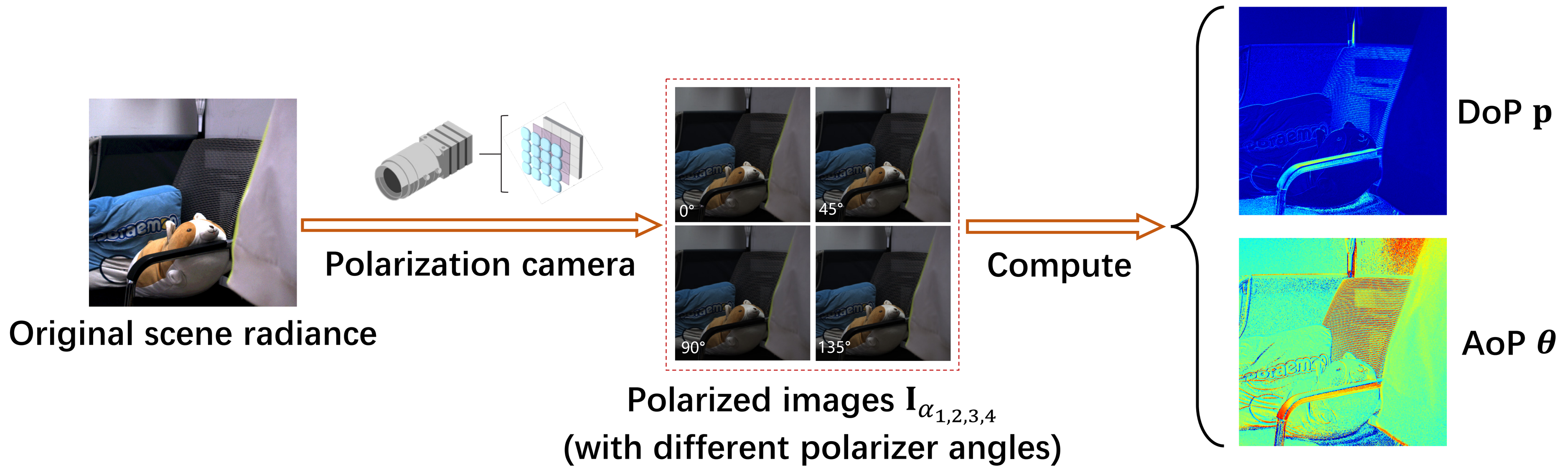
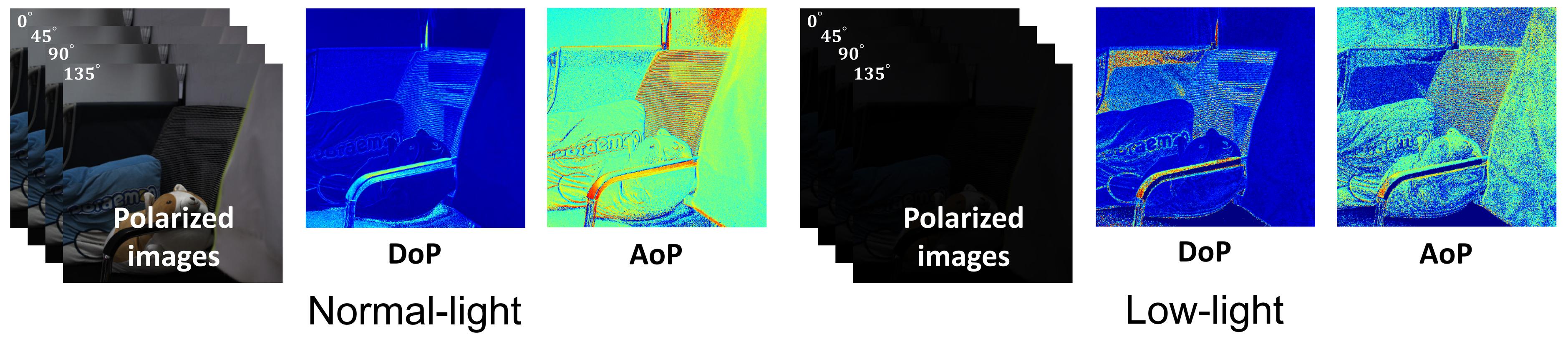
## Contributions

- A Stokes-domain enhancement pipeline
  - for polarized low-light images.
- A polarization-aware dual-branch network
  - tailored to the pipeline.
- Two applications demonstrating the benefits of enhancing polarized low-light images
  - including reflection removal and shape from polarization.

## Background & Motivation



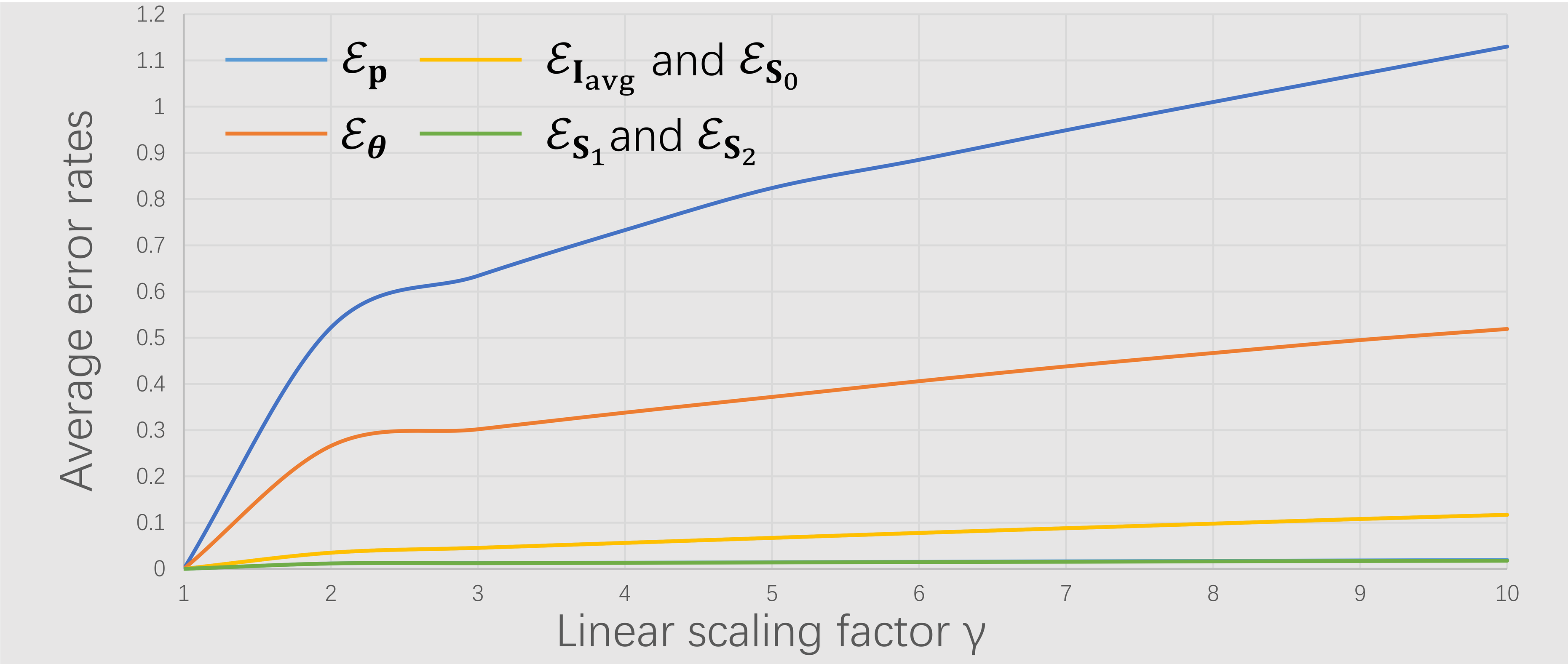

- A polarization camera can capture four polarized images $\mathbf{I}_{\alpha_{1,2,3,4}}$ with different polarizer angles $\alpha_{1,2,3,4} = 0°, 45°, 90°, 135°$ in a single shot.
  - The degree of polarization (DoP) $\mathbf{p}$ and angle of polarization (AoP) $\boldsymbol{\theta}$ can be directly obtained from $\mathbf{I}_{\alpha_{1,2,3,4}}$.
  - Useful for polarization-based vision applications whose accuracy is closely related to polarization-relevant parameters.




- However, in low-light conditions:
  - The captured polarized images tend to be dark and noisy.
  - The obtained DoP and AoP tend to be severely degenerated.
  - The performance of polarization-based vision applications becomes poor.
- Therefore, it is of great interest to enhance multiple polarized low-light images of the same scene for acquiring the DoP and AoP accurately.

## Method

### Error rate analysis




Low-light polarized image: $\hat{\mathbf{I}}_{\alpha_i} = \frac{1}{\gamma}\mathbf{I}_{\alpha_i} + \mathbf{N}_i \quad (i = 1,2,3,4)$

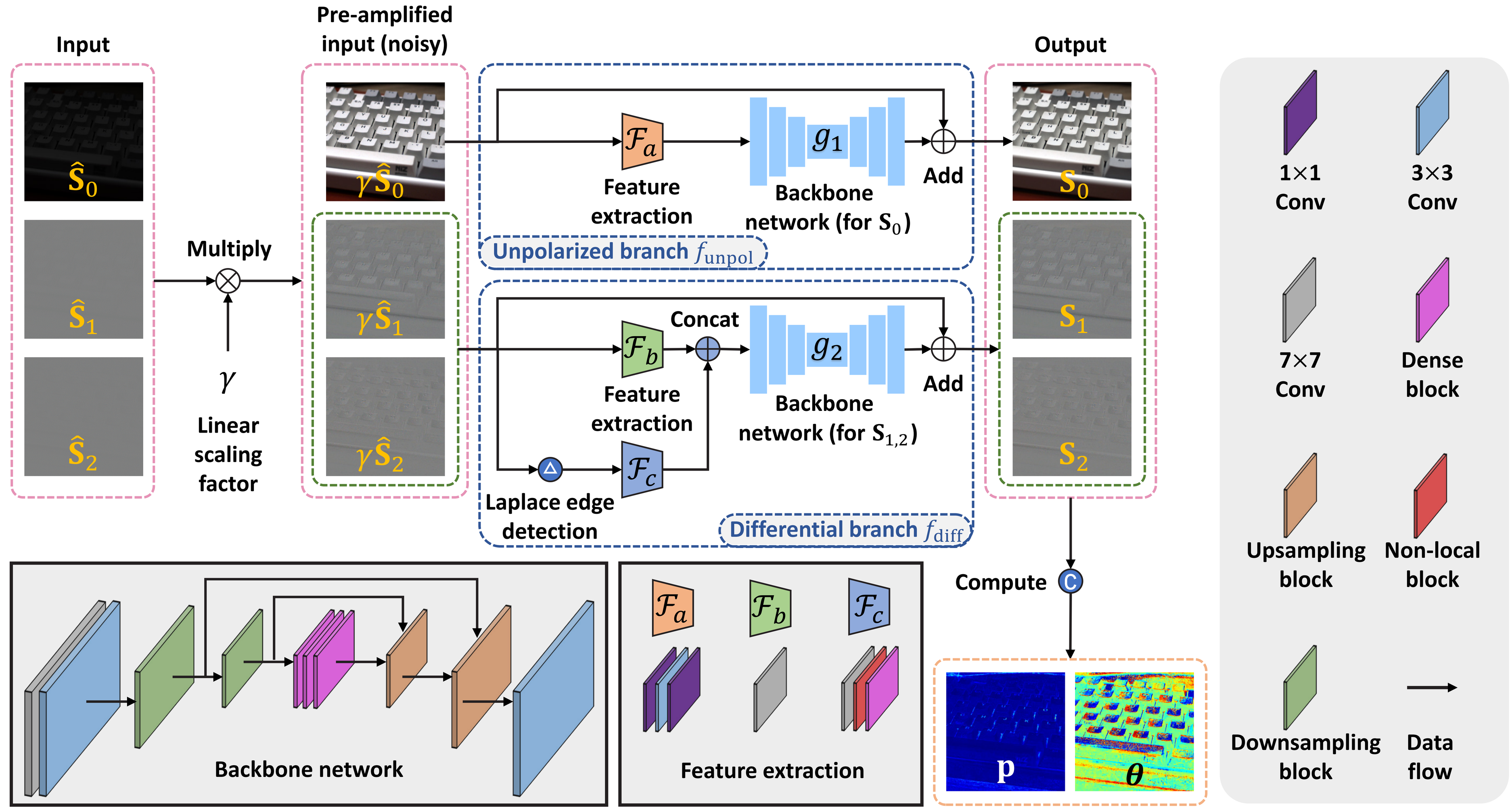
where $\gamma$ is a linear scaling factor denoting the image irradiacne reduction, and $\mathbf{N}_i$ is a noise term which is mainly affected by $\frac{1}{\gamma}$.

$\mathbf{S}_{0,1,2}$ are the Stokes parameters defined as

$\mathbf{S}_0 = \frac{1}{2}(\mathbf{I}_{\alpha_1} + \mathbf{I}_{\alpha_2} + \mathbf{I}_{\alpha_3} + \mathbf{I}_{\alpha_4})$, $\mathbf{S}_1 = \mathbf{I}_{\alpha_3} - \mathbf{I}_{\alpha_1}$, and $\mathbf{S}_2 = \mathbf{I}_{\alpha_4} - \mathbf{I}_{\alpha_2}$.

- The error rates of the Stokes parameters are lower than the polarized images, which means enhancing in the Stokes domain could be very promising.

### Pipeline and network




Two branches to perform enhancement on $\hat{\mathbf{S}}_0$ and $\hat{\mathbf{S}}_{1,2}$ independently:

- Unpolarized branch $f_{\text{unpol}}$: for enhancing the unpolarized image $\hat{\mathbf{S}}_0$.
- Differential branch $f_{\text{diff}}$: for enhancing the "differential signals" $\hat{\mathbf{S}}_{1,2}$.

## Experiments

### Quantitative results on the PLIE dataset

| | PSNR-p | SSIM-p | PSNR-θ | SSIM-θ | PSNR-$\mathbf{S}_0$ | SSIM-$\mathbf{S}_0$ |
|---|---|---|---|---|---|---|
| Ours | **27.15** | **0.765** | **16.42** | **0.336** | **39.19** | **0.977** |
| IPLNet | 25.32 | 0.715 | 16.21 | 0.276 | 22.84 | 0.930 |
| EnlightenGAN | 24.55 | 0.652 | 13.55 | 0.190 | 22.14 | 0.887 |
| UTVNet | 24.14 | 0.636 | 12.18 | 0.271 | 18.45 | 0.821 |
| Zero-DCE | 19.34 | 0.527 | 12.09 | 0.134 | 17.48 | 0.815 |

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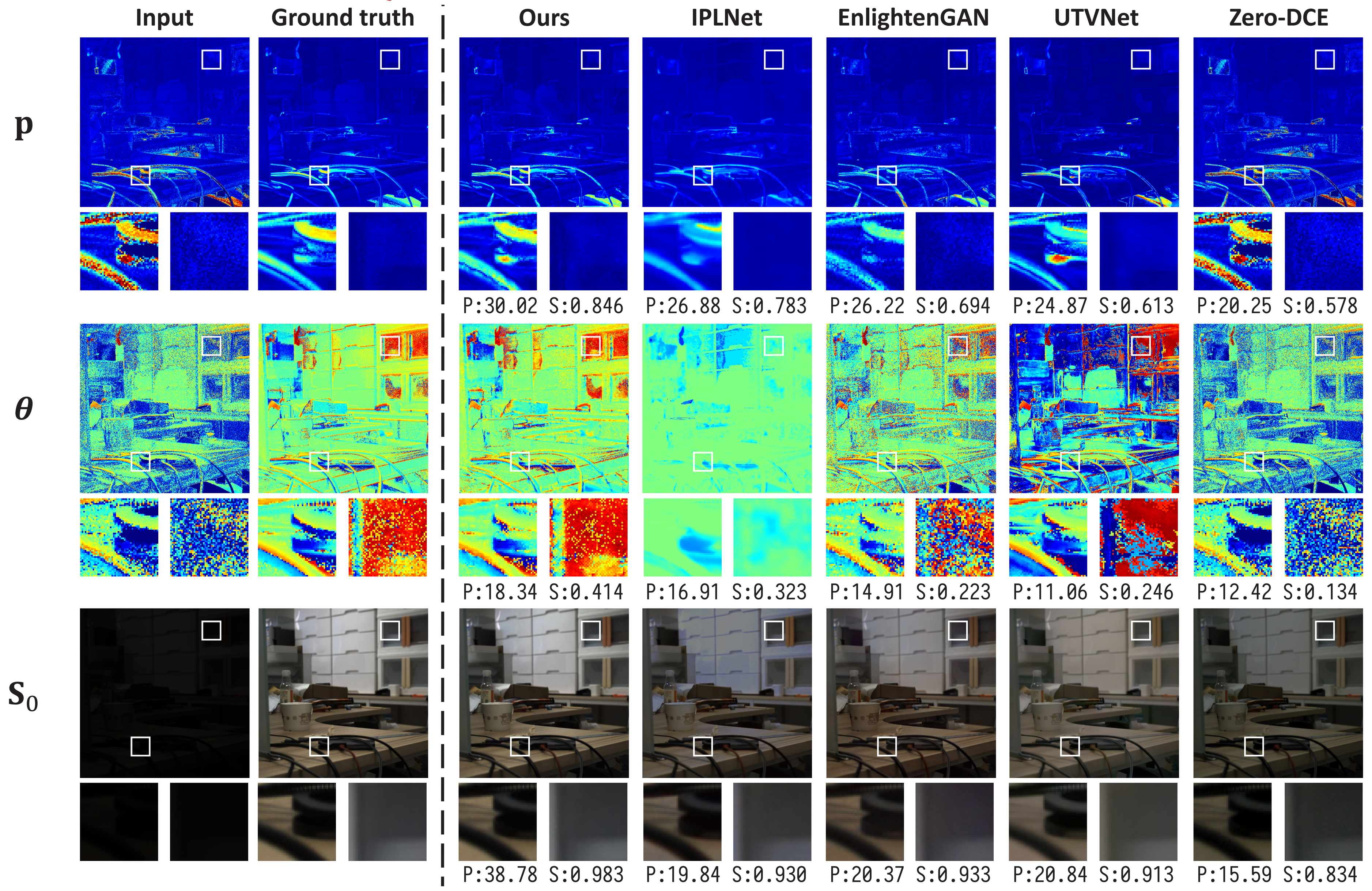
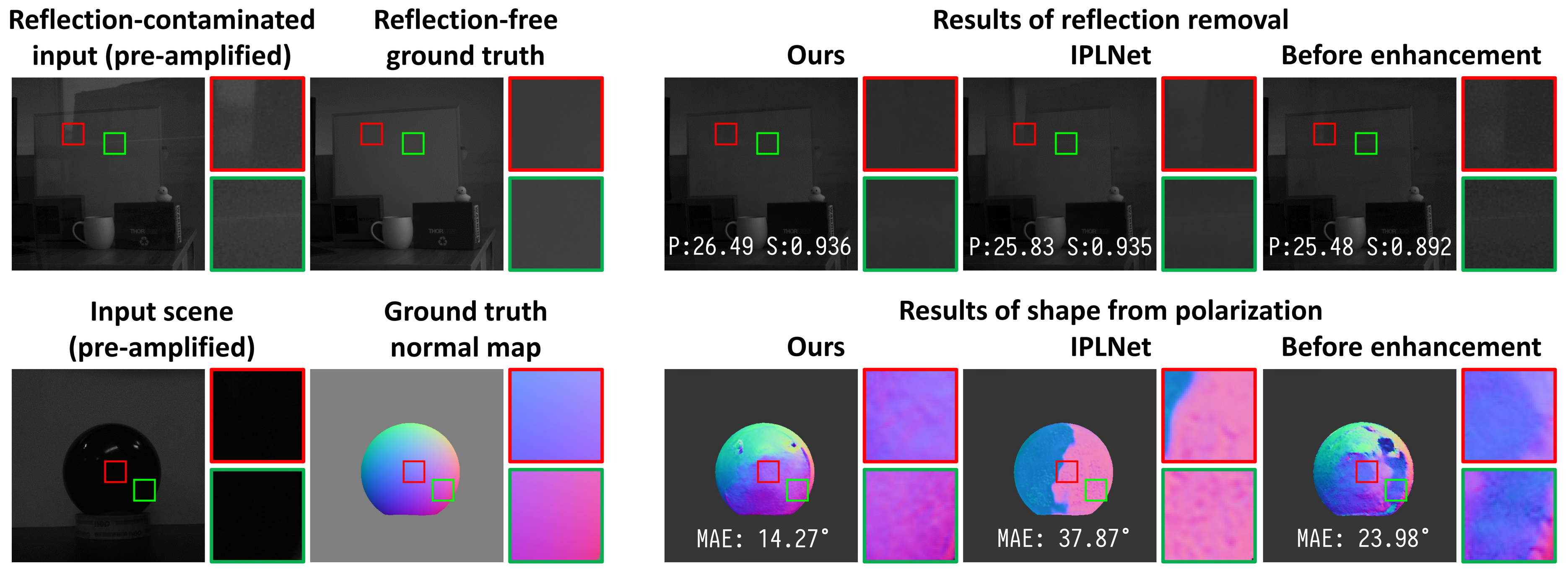



### Applications: reflection removal and shape from polarization




- P: PSNR  S: SSIM  MAE: mean angle error