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Learning to Remove Wrinkled Transparent Film with Polarized Prior

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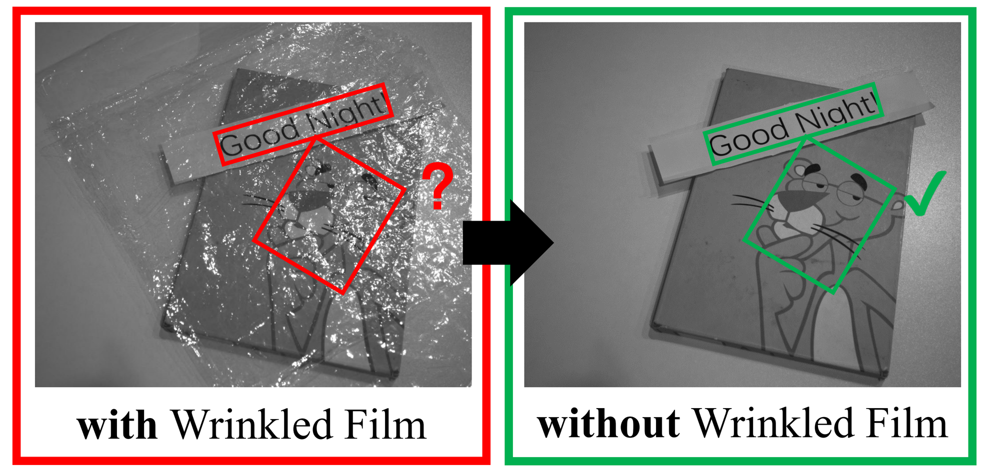
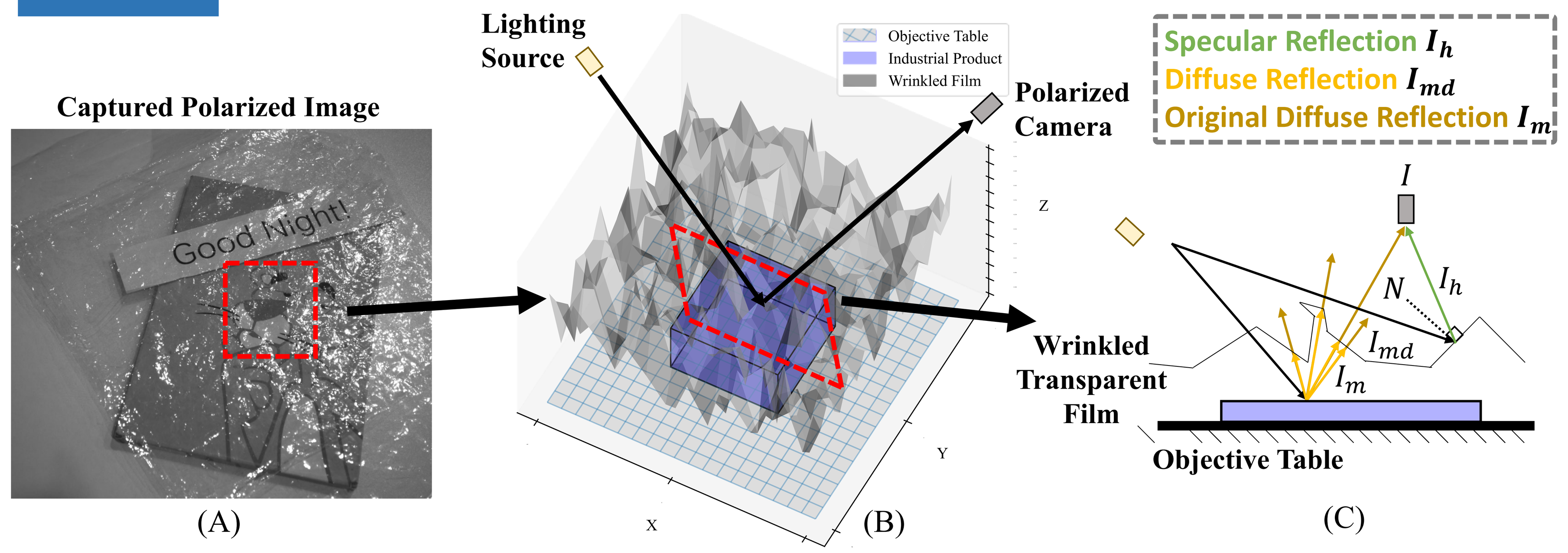
New Problem in Low-Level Vision

Film Removal (FR)

- To remove the interference of wrinkled transparent films.
- To reconstruct the original information under films.
- Application: industrial recognition systems.



Physics Model of Wrinkled Transparent Film

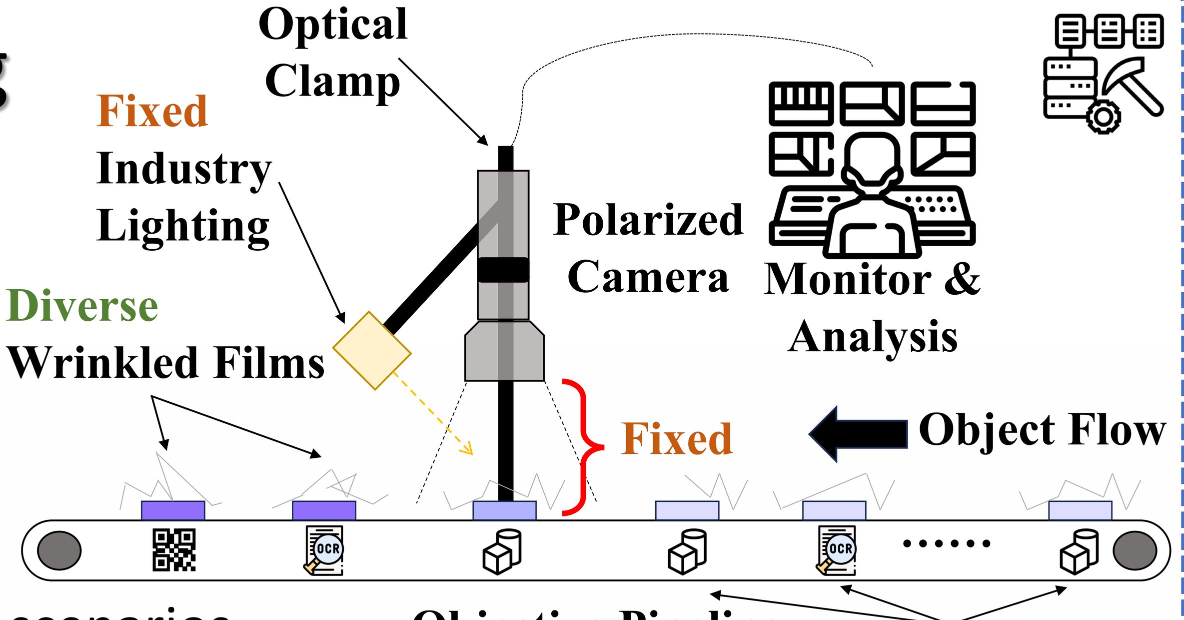


- All compositions are $I = I_{md} + I_h = I_m + I_d + I_h$ (+ : linear superposition)
- Our **final goal** is $I_m = I - I_h - I_d$ (- : decoupling operator)

Data Engineering

Industrial Optical Photography Pipeline

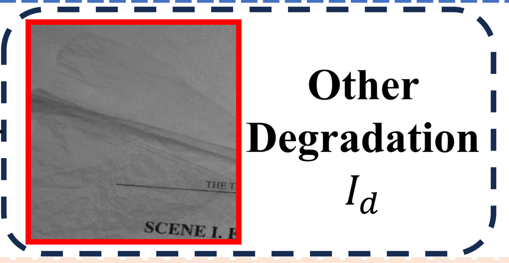
How to maintain the Data Diversity and Robustness?



- 315 dynamic industrial scenarios.
- Three types: QR codes, text, and products.
- Diverse properties: coverage areas, film thicknesses, levels of wrinkling.
- Fixed: to minimize the influence of errors external.

Methodology

Two Parts



- **[Observation] Specular Reflection (Highlight) I_h is Polarized.**
- **[Solution] Estimating a Polarized Prior for Locating I_h**
- The Prior is: $P = I_m + I_d + \min I_h$
- The polarized version of the prior, can be acquired with Malus's Law and the elliptical polarization model, therefore: $I_h = I_p(\theta) = I_{max}\cos^2\theta + I_{min}\sin^2\theta$
- Since I_h is the only polarized component that is determined by θ, P can also be formulated as:

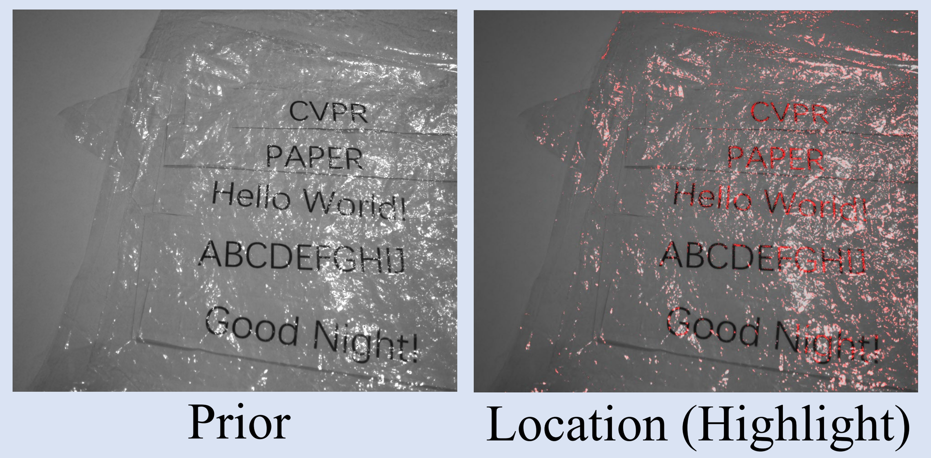
$$P = I_m + I_d + \min I_h = I_m + I_d + \min_\theta I_p(\theta) = I_m + I_d + \min_\theta (I_{max}\cos^2\theta + I_{min}\sin^2\theta)$$

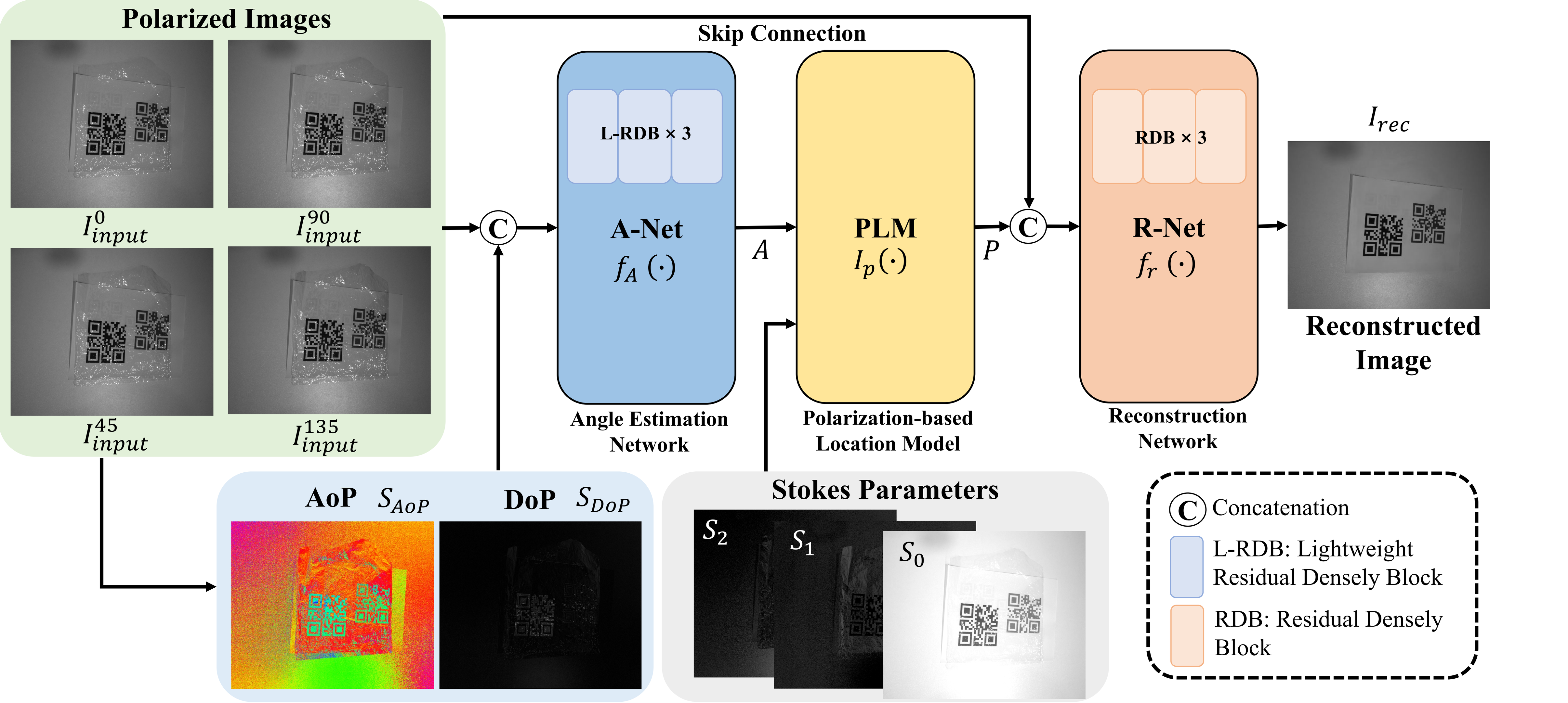
- Finally, we estimate pixel-wise θ, with a learning-based network (A-Net), to obtain the angle map A:

$$A = f_A(I^0_{input} \oplus I^{45}_{input} \oplus I^{90}_{input} \oplus I^{135}_{input} \oplus S_{AoP} \oplus S_{DoP})$$

- **[Solution] Reconstructing I_m**
- To recover the image, we set a reconstruction network f_r to decouple both I_d and I_h, with P.
- The reconstruction process can be expressed as:

$$I_{rec} = f_r(I^0_{input} \oplus I^{45}_{input} \oplus I^{90}_{input} \oplus I^{135}_{input} \oplus P)$$





Experiment

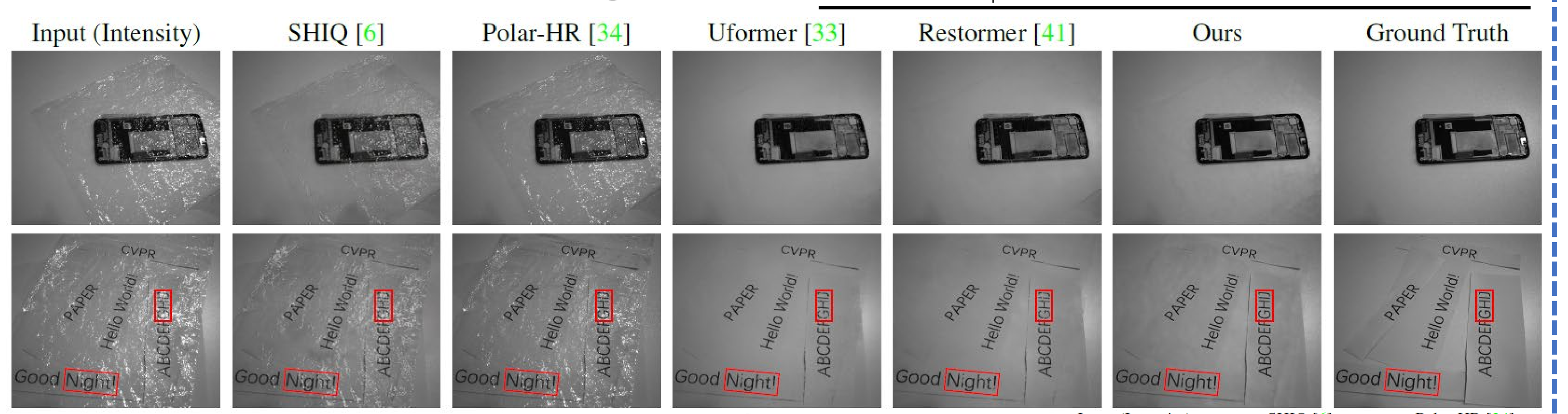
[Table 1] Quantitative evaluation in image reconstruction with 10-fold cross-validation.

		K1	K2	K3	K4	K5	K6	K7	K8	K9	K10	$\mu\uparrow$	$\sigma\downarrow$
SHIQ [6]	PSNR	23.47	22.11	21.95	21.69	21.77	21.03	20.86	20.46	21.10	21.31	21.58	0.64
	SSIM	0.7899	0.7640	0.7416	0.7439	0.7459	0.7465	0.7499	0.7412	0.7465	0.7300	0.7499	2.41×10^{-4}
Polar-HR [34]	PSNR	23.31	22.80	22.13	21.58	21.94	22.00	22.03	21.99	22.18	21.95	22.19	0.22
	SSIM	0.7642	0.7421	0.7220	0.7099	0.7064	0.7098	0.7128	0.7017	0.7102	0.6968	0.7176	3.80×10^{-4}
Uformer [33]	PSNR	31.85	31.95	31.39	31.19	31.81	32.04	31.68	31.98	31.85	31.01	31.68	**0.11**
	SSIM	0.9519	0.9456	0.9371	0.9364	0.9434	0.9421	0.9438	0.9435	0.9457	0.9363	0.9426	2.17×10^{-5}
Restormer [41]	PSNR	34.35	35.02	34.44	33.71	34.88	35.13	34.31	34.33	34.51	32.49	34.32	0.52
	SSIM	0.9771	0.9770	0.9721	0.9678	0.9757	0.9746	0.9742	0.9741	0.9759	0.9633	0.9731	1.75×10^{-5}
Ours	PSNR	**36.76**	**37.29**	**36.62**	**35.12**	**36.93**	**37.21**	**36.24**	**36.67**	**36.94**	**35.02**	**36.48**	0.57
	SSIM	**0.9852**	**0.9859**	**0.9822**	**0.9767**	**0.9845**	**0.9833**	**0.9836**	**0.9830**	**0.9850**	**0.9749**	**0.9824**	$\mathbf{1.23 \times 10^{-5}}$

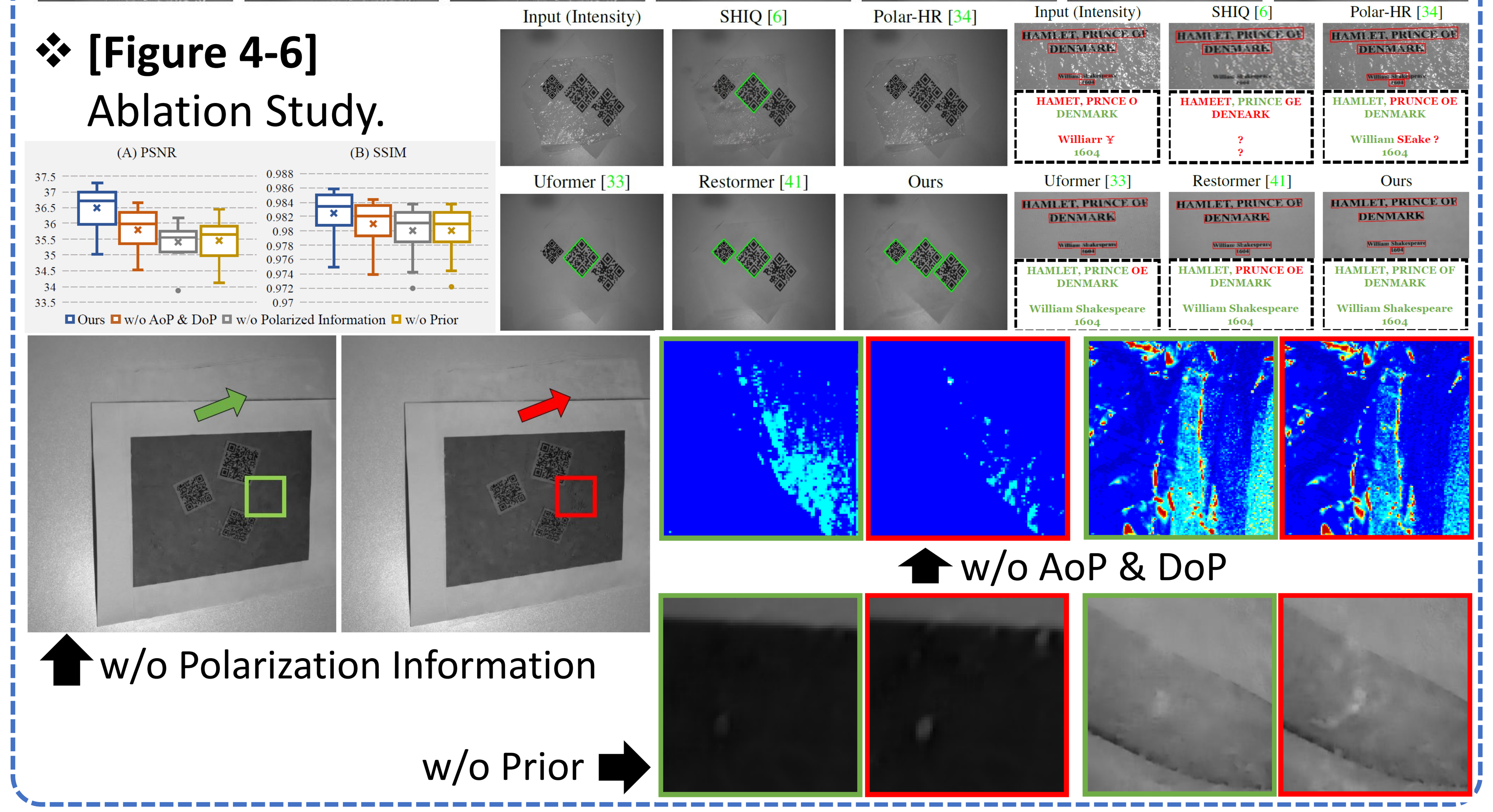
[Table 2] Quantitative evaluation of QR Reading Rate.

	SHIQ [6]	Polar-HR [34]	Uformer [33]
Read Number	7	17	18
Read Rate	8.05%	19.54%	20.69%
	Restormer [41]	**Ours**	**Ground Truth**
Read Number	24	**63**	87
Read Rate	27.58%	**72.41%**	100%

❖ **[Figure 1-3]** Qualitative Evaluation.



❖ **[Figure 4-6]** Ablation Study.



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