Learning to Remove Wrinkled Transparent Film with Polarized Prior

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通过偏振先验去除褶皱透明薄膜

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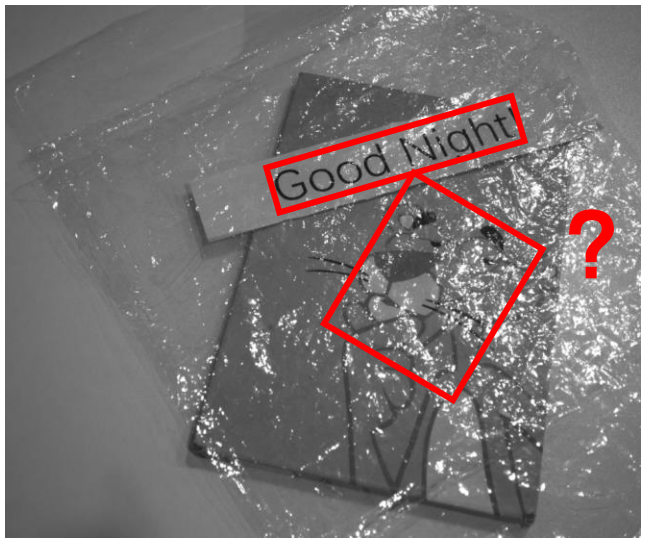
Motivation: Problem in Industry Vision

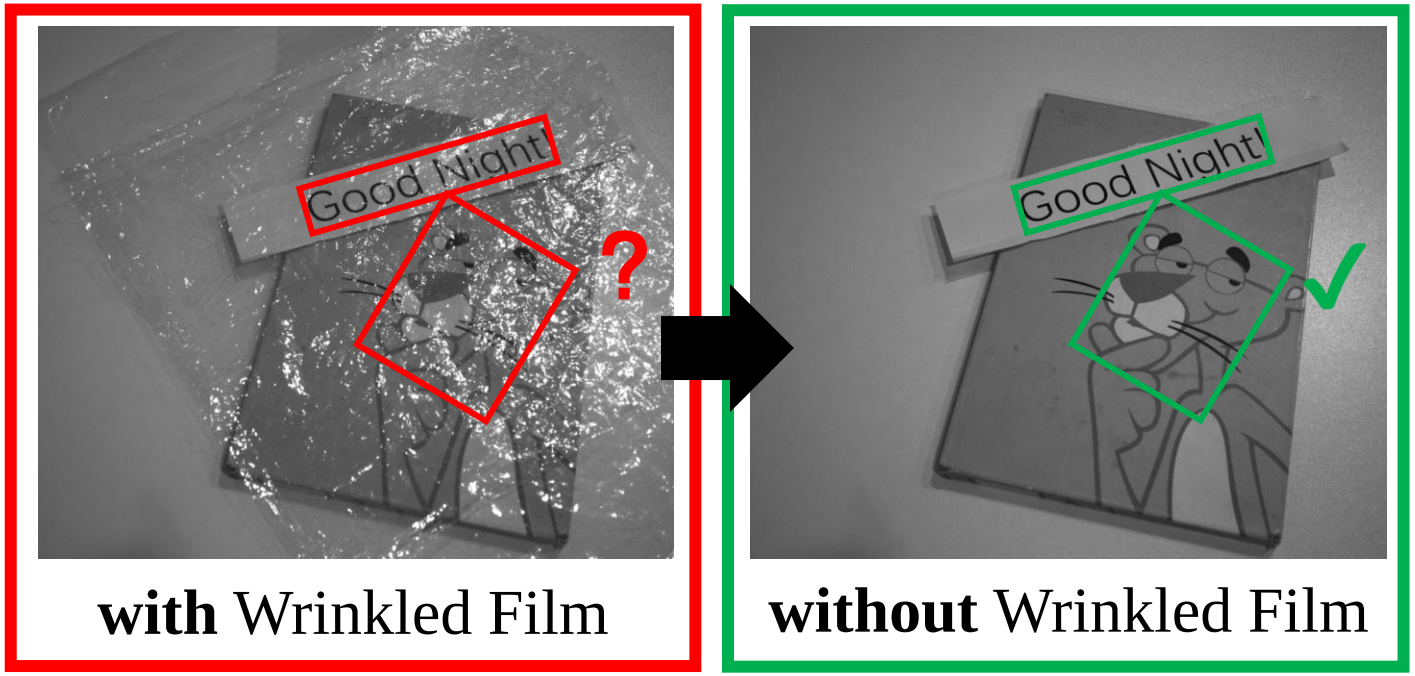
- **Covered by Wrinkled Transparent Film**



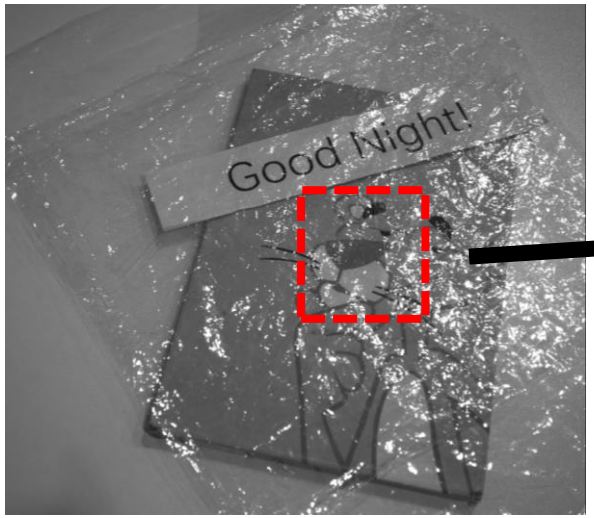
with Wrinkled Film

Motivation: Problem in Industry Vision

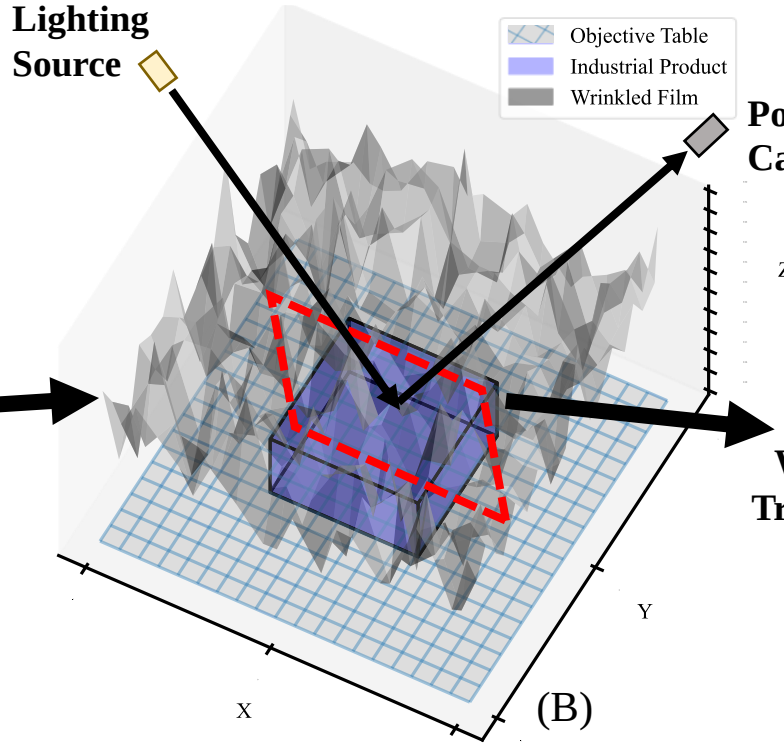
- **Film Removal (FR)**
  - To remove the interference of wrinkled transparent films.
  - To reconstruct the original information under films.



Physics Model of the Wrinkled Transparent Film

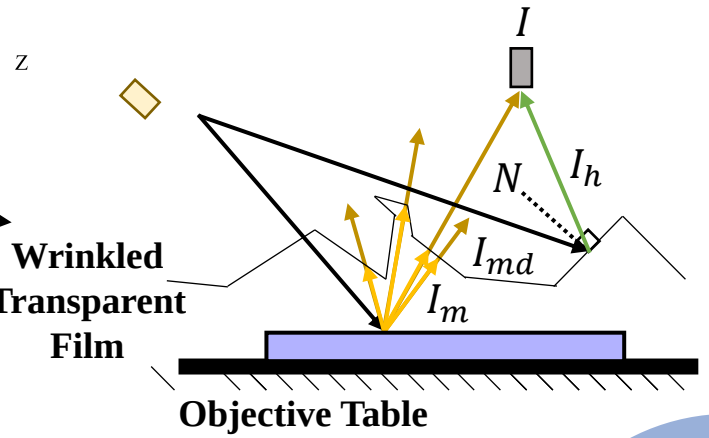


(A)



(B)

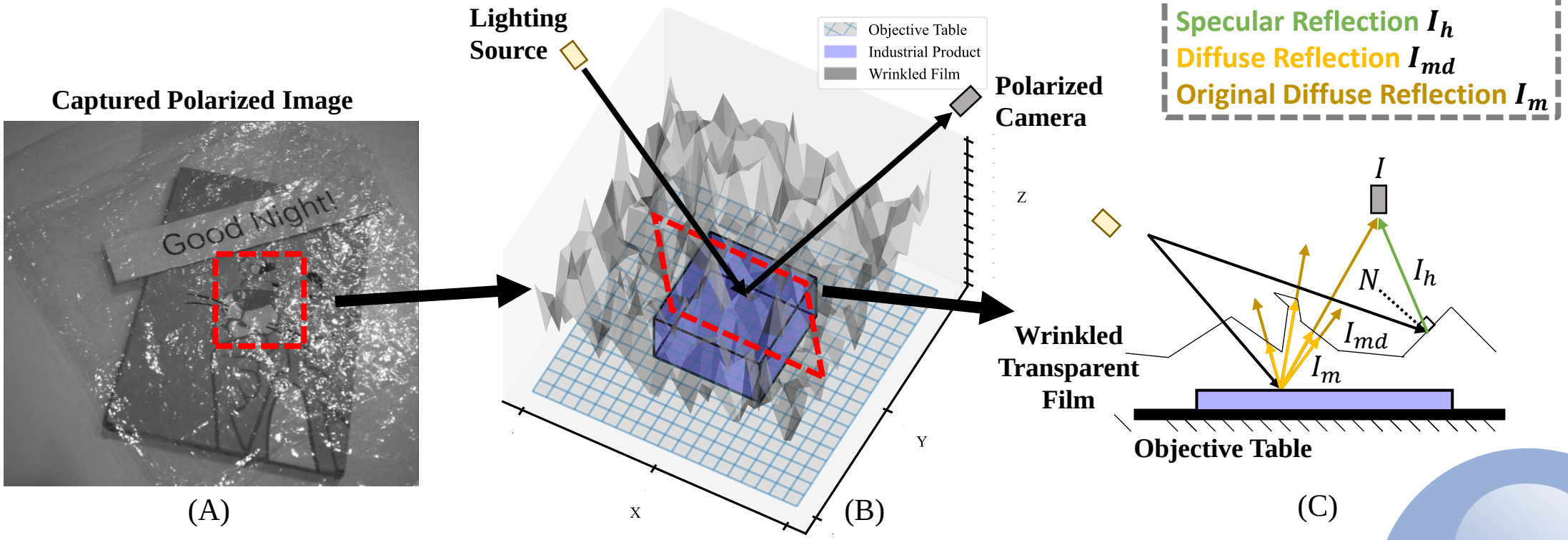
Specular Reflection I_h
Diffuse Reflection I_{md}
Original Diffuse Reflection I_m



(C)

- All compositions are $I = I_{md} + I_h = I_m + I_d + I_h$ + : linear superposition

… to Optimizing Goal

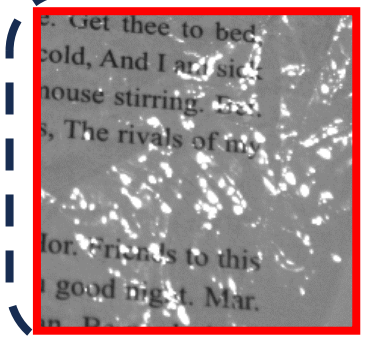


- All compositions are $I = I_{md} + I_h = I_m + I_d + I_h$ **+ : linear superposition**
- Our final goal is $I_m = I - I_h - I_d$ **- : decoupling operator**

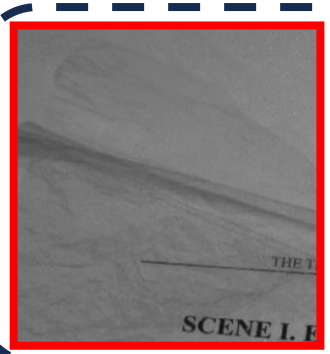
Methodology: Two Component

$$I_m = I - I_h - I_d$$

***Two* Decoupling Components**



Specular Highlight
I_h



Other Degradation
I_d

for Specular Highlight: Use Polarized Light to Locate

- **[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:

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

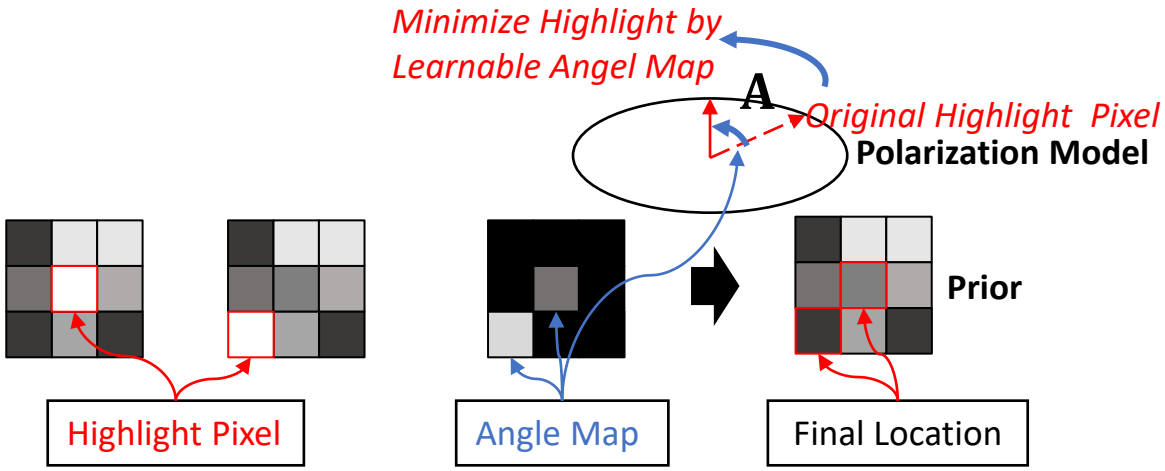
- Since I_h is the only polarized component that is determined by θ, P can also be formulated as:

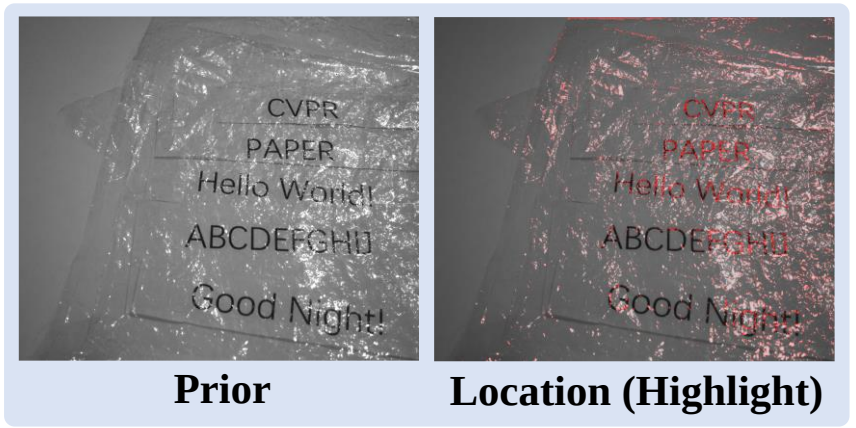
$$\begin{aligned} P &= I_m + I_d + \min I_h \\ &= I_m + I_d + \min_\theta I_p(\theta) \\ &= I_m + I_d + \min_\theta \left(I_{max}\cos^2\theta + I_{min}\sin^2\theta\right) \end{aligned}$$

for Specular Highlight: Use Polarized Light to Locate

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

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





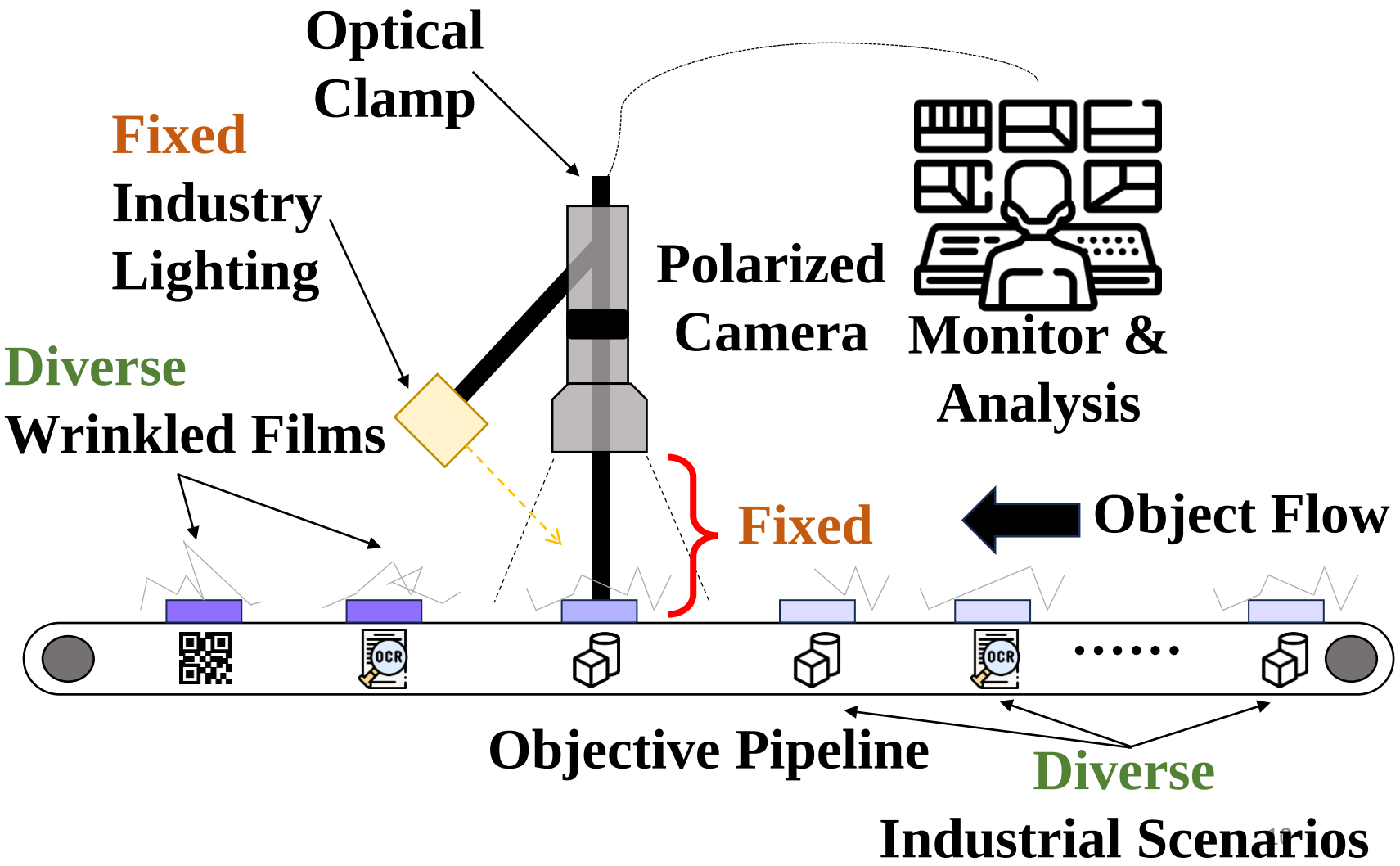
for Other Degradations

- **[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:

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

How to Collect **Data**? – Capture at Industrial Pipeline

- **Industrial Optical Photography Pipeline**



How to Collect **Data**? – Capture at Industrial Pipeline

How to maintain the Data Diversity and Robustness?

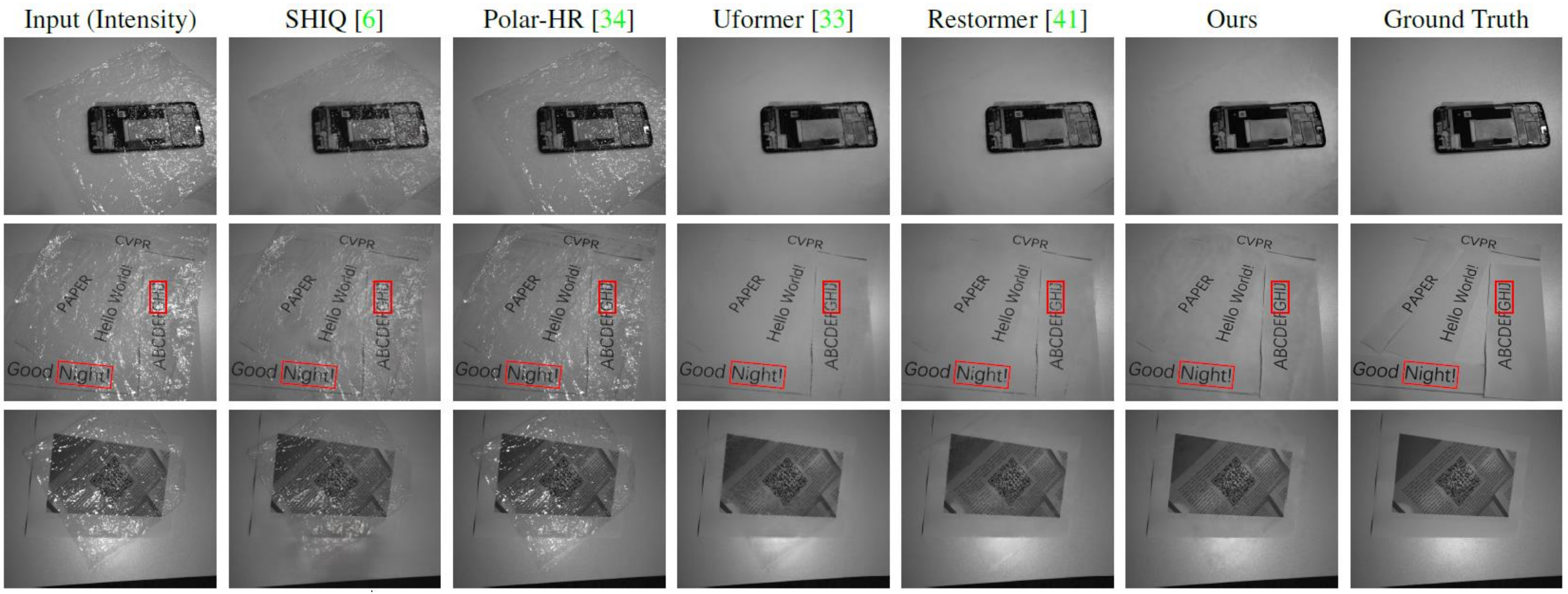
- **315** dynamic industrial scenarios.
- **Three types**: QR codes, text, and products.
- **Diverse properties**: coverage areas, film thicknesses, levels of wrinkling.
- **Fix**: to minimize the influence of errors external.

Quantitative Comparison

		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**	$\mathbf{1.23 \times 10^{-5}}$

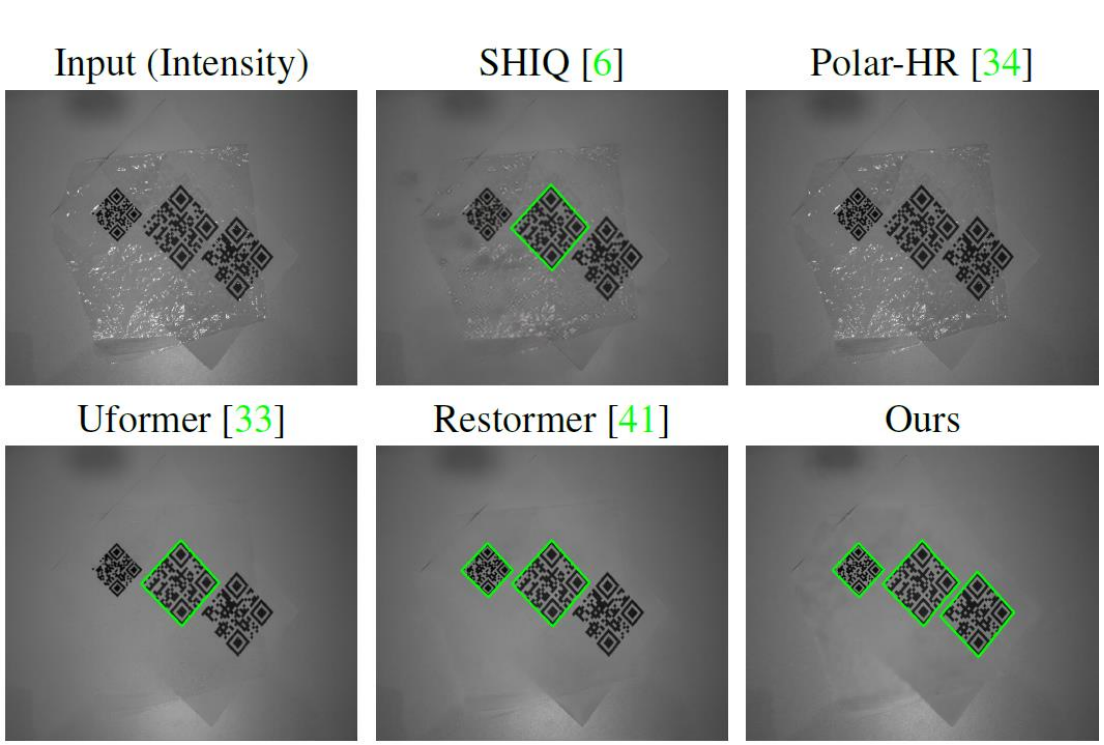
- **[Table 1]** Quantitative evaluation in image reconstruction with 10-fold cross-validation.

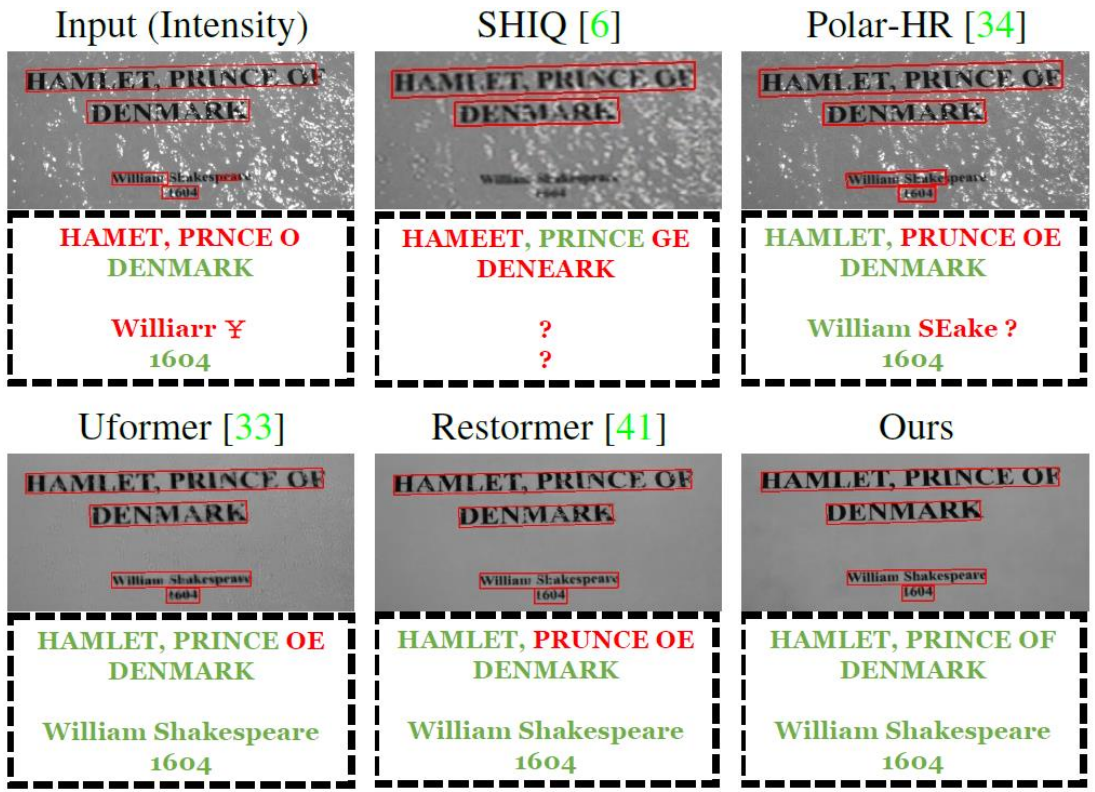
Qualitative Evaluation



➢ **[Figure 1]** Qualitative Evaluation in image reconstruction.

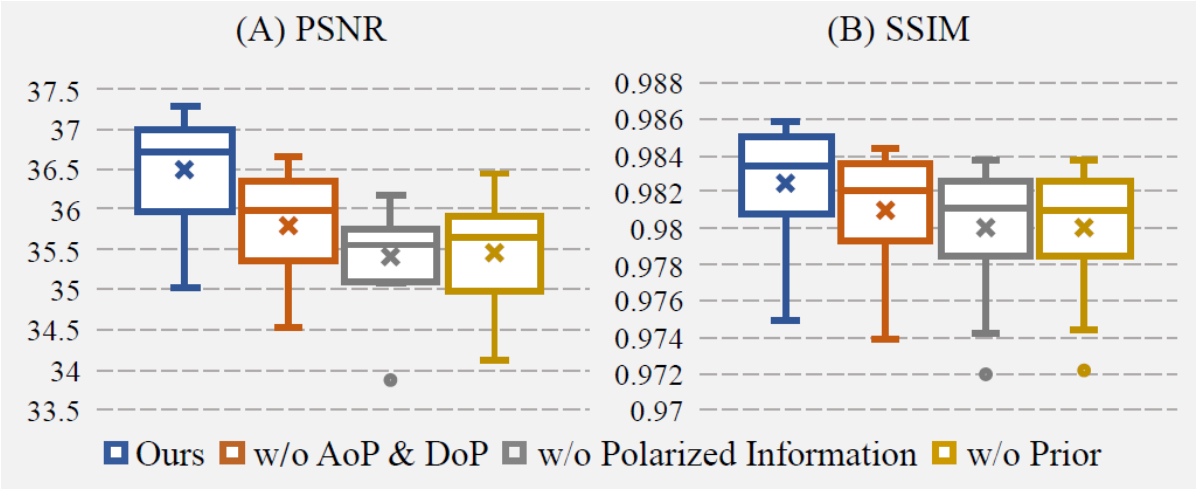
Qualitative Evaluation in **Industrial Environment**



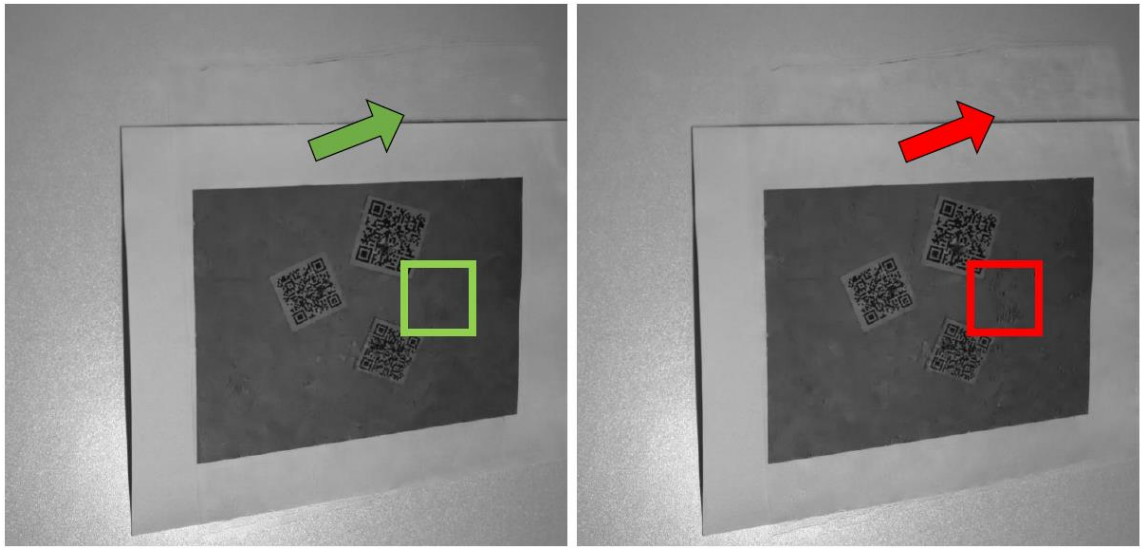


➢ **[Figure 2-3]** Qualitative Evaluation in Industrial Environment. (QR Reading & Text OCR)

Ablation Study



- Quantitative evaluation in Ablation Study



- w/o Polarization Information

Thanks

28/04/2024

Paper Link

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