Polarimetric Neural Field via Unified Complex-Valued Wave Representation

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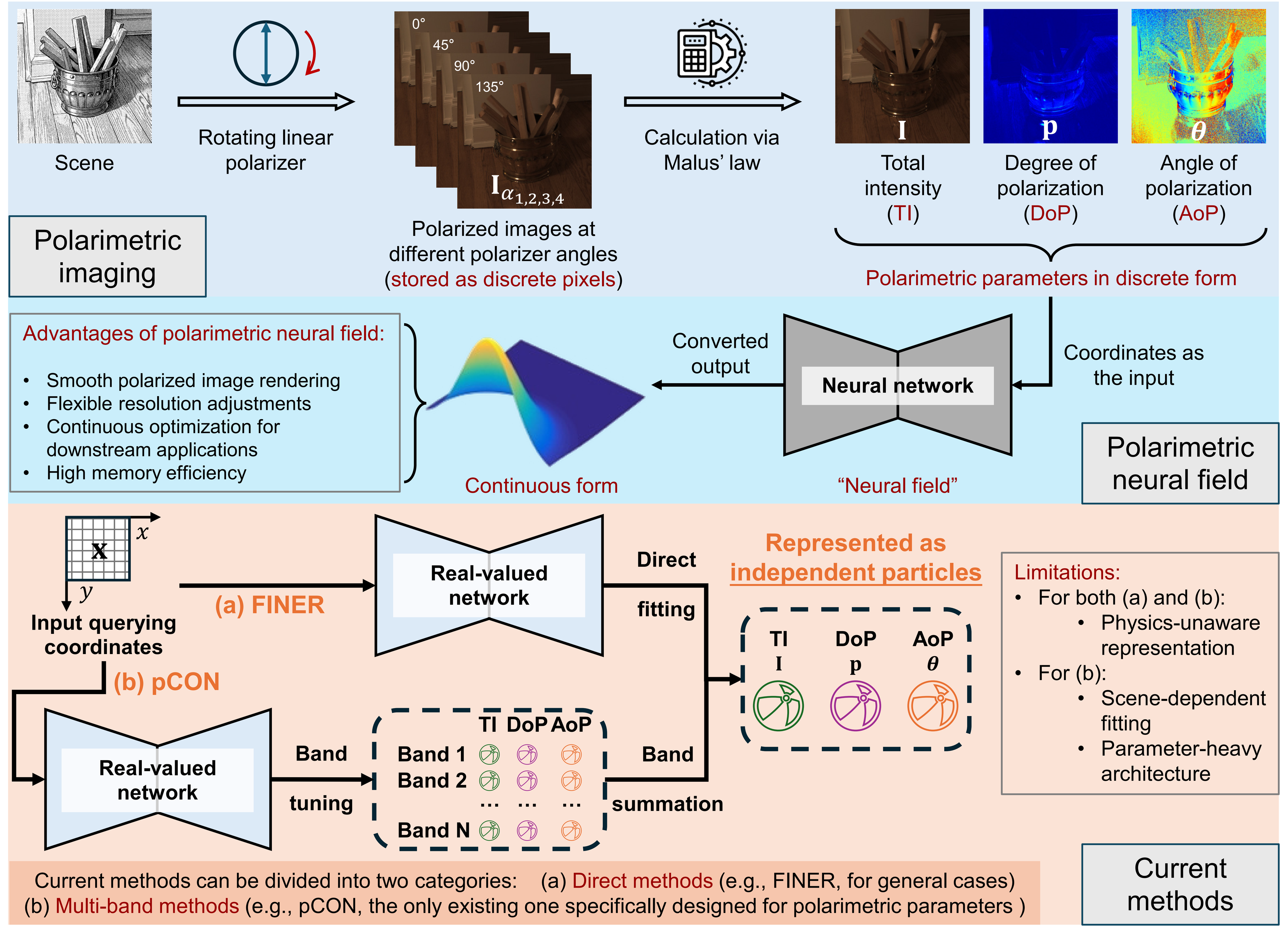
Contributions

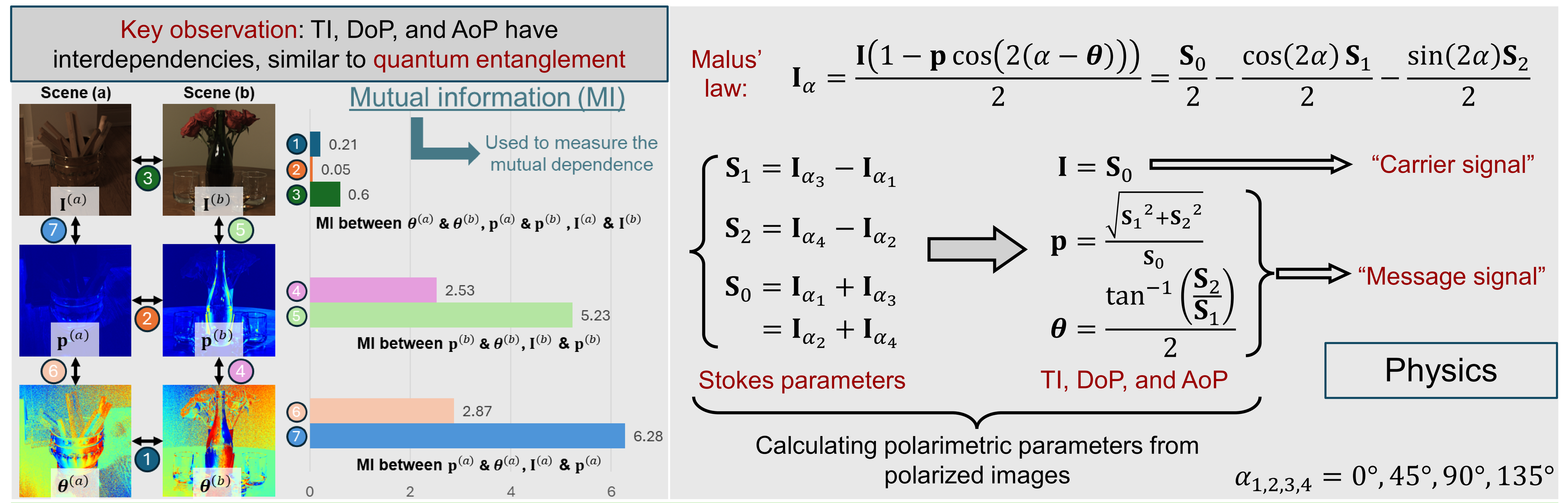
- A physics-grounded representation scheme
  - integrating the physical meanings and interdependencies of the polarimetric parameters into a unified wave.
- A tuning-free fitting strategy
  - fully decoupling the fitting process from scene dependency and enabling robust retrieval of each polarimetric parameter.
- A lightweight complex-valued network
  - seamlessly adapting to the formulation of wave with a compact architecture and superior performance.

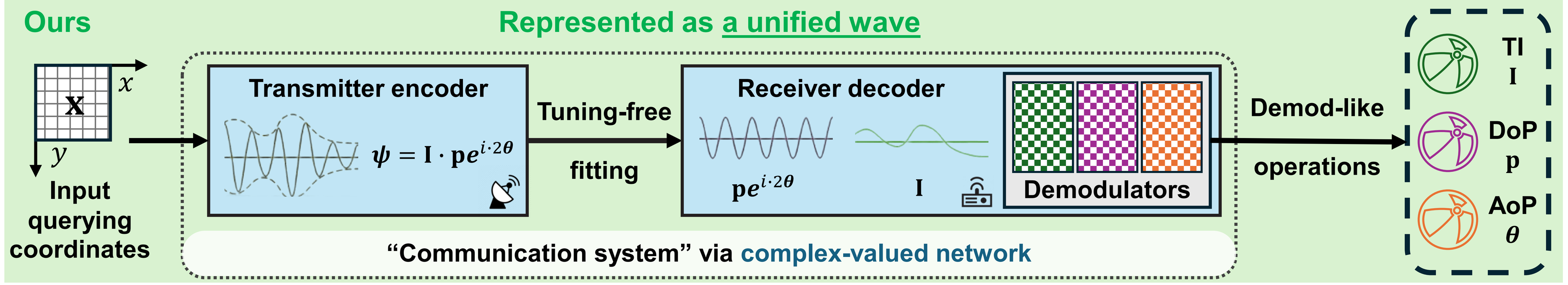
Background & Motivation



- Current methods face the following main limitations:
  - Physics-unaware representation: treating different parameters identically, without considering their physical meanings and interdependencies.
  - Scene-dependent fitting: requiring manually tuning the threshold of each band for each scene, hindering automation in the fitting process.
  - Parameter-heavy architecture: necessitating larger network capacity, leading to increased parameter count and model size.

Method





- The mutual information between two different polarimetric parameters within the same scene is much higher than that between the same polarimetric parameter across different scenes, confirming the interdependencies.
- Representing the polarimetric parameters as a unified wave, we can get

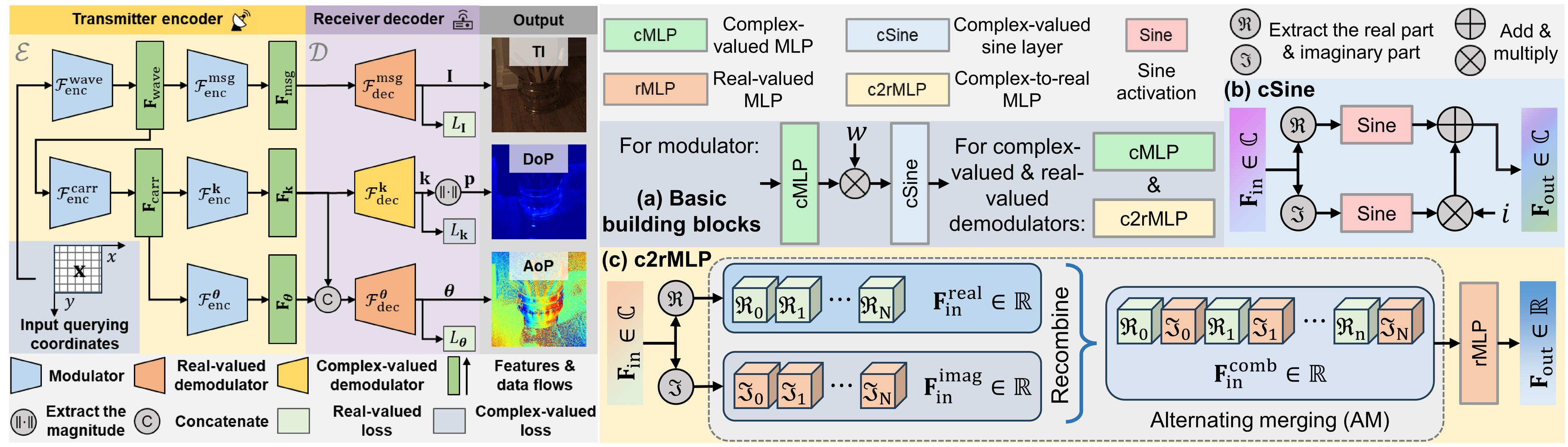
$$\psi(\mathbf{I}, \mathbf{p}, \theta) = ze^{i\gamma} = \mathbf{I}\cdot\mathbf{p}e^{i\cdot 2\theta}.$$

- Rewriting the wave as $\mathbf{I}\cdot\mathbf{p}\cdot(\cos(2\theta) + i\cdot\sin(2\theta)) = \mathbf{S}_1 + i\cdot\mathbf{S}_2$, we can find

  ψ inherently follows the additive properties of the Stokes parameters.

- Modeling the fitting process as a tuning-free "communication system", including a transmitter encoder and a receiver decoder,

  where the wave is treated as a modulated signal, with demodulation-like operations employed to robustly retrieve each polarimetric parameter, similar to separating the carrier and message signals.



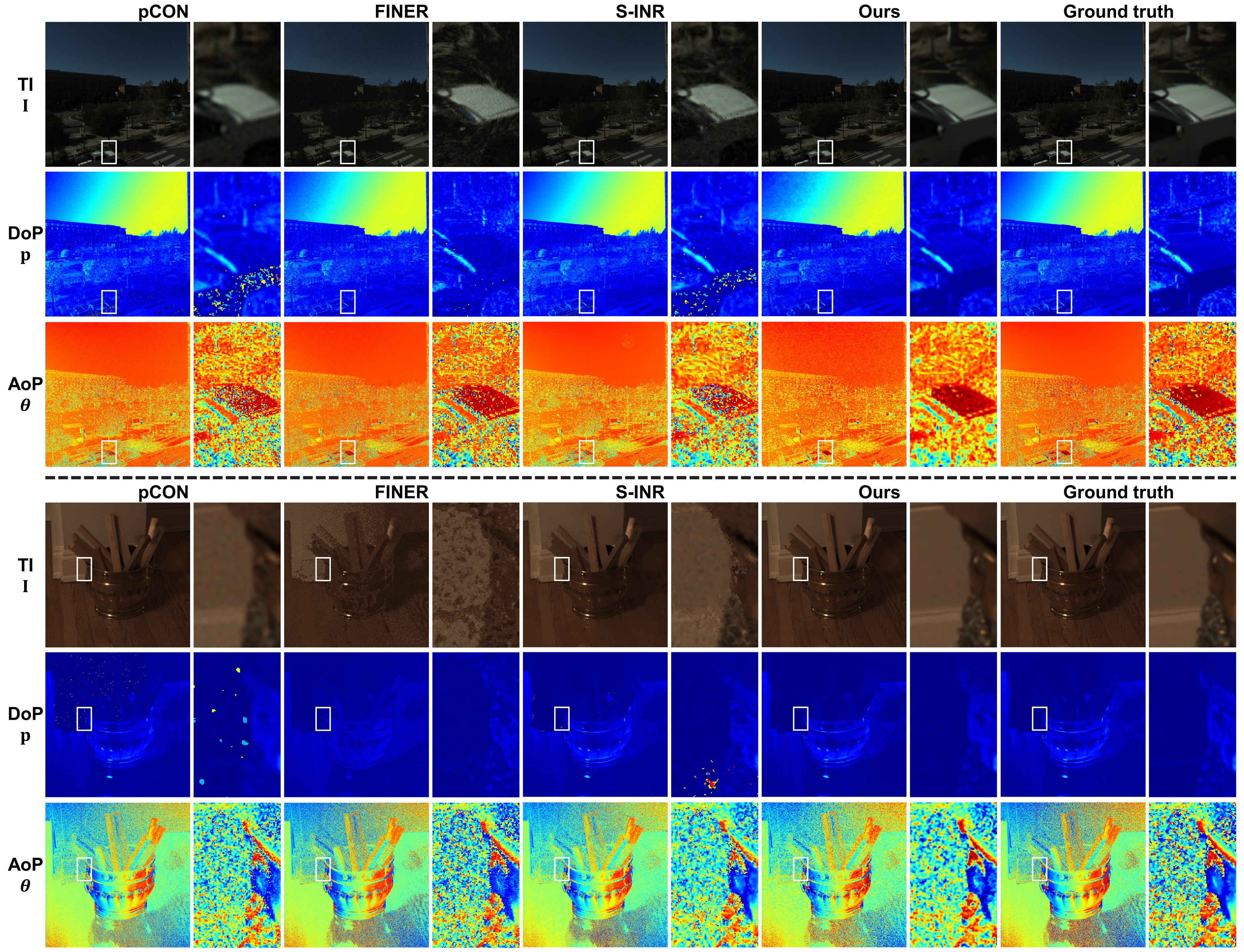
- Due to the inherently complex-valued nature of the wave formulation, we design a lightweight complex-valued neural network, enabling efficient fitting.
  - The transmitter encoder is designed as a top-down hierarchical structure;
  - The receiver decoder is designed as a parallel three-branches structure.

Experiments

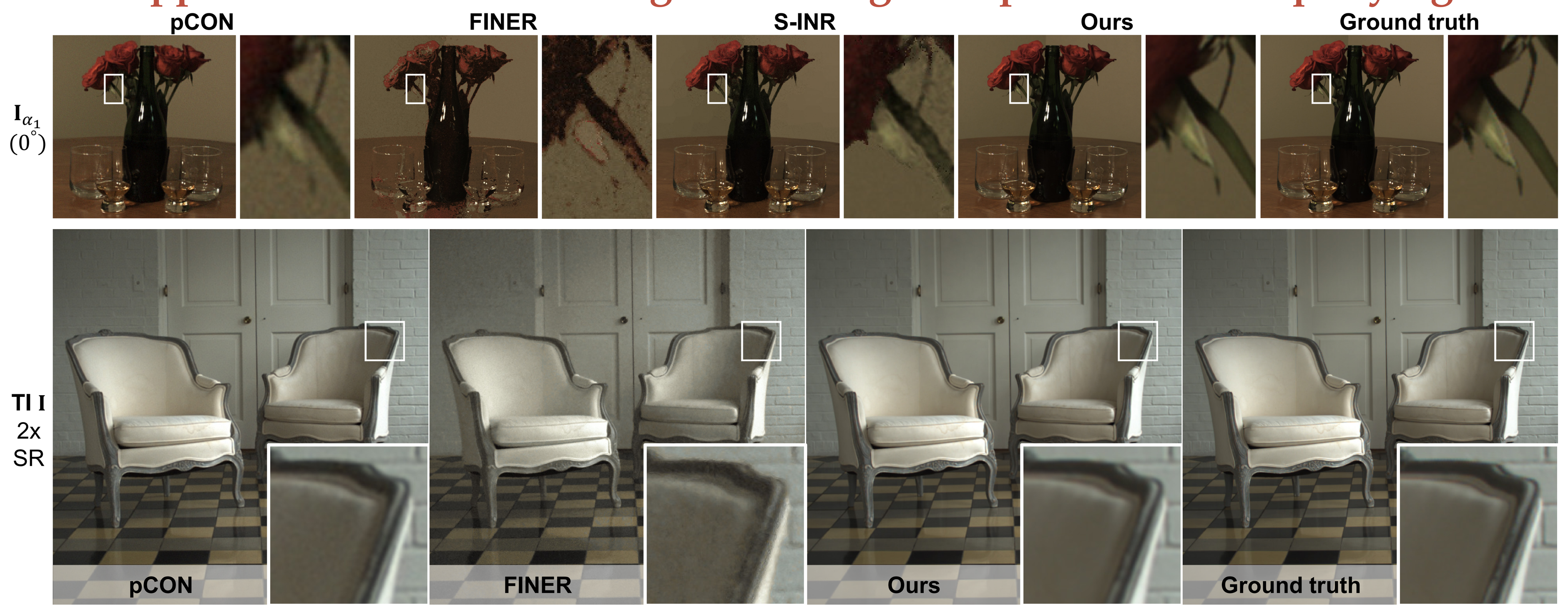
Quantitative results

	PSNR↑/SSIM↑ of the TI (I)				PSNR↑/SSIM↑ of the DoP (p)				PSNR↑/SSIM↑ of the AoP (θ)			
	pCON	FINER	S-INR	Ours	pCON	FINER	S-INR	Ours	pCON	FINER	S-INR	Ours
Building	38.64/0.942	33.32/0.830	36.85/0.918	47.70/0.989	26.84/0.644	27.44/0.679	26.63/0.684	29.23/0.767	21.28/0.710	19.38/0.721	20.81/0.723	21.33/0.622
Firewood	39.95/0.957	27.36/0.647	36.75/0.920	53.54/0.992	33.66/0.775	30.61/0.700	33.56/0.785	36.01/0.857	17.24/0.704	16.78/0.661	17.17/0.653	17.26/0.668
Grater	38.62/0.955	27.84/0.732	37.35/0.940	50.30/0.994	30.13/0.697	26.88/0.543	30.14/0.728	32.97/0.830	17.47/0.682	16.01/0.630	16.48/0.631	16.92/0.637
Pottery	39.03/0.957	28.12/0.749	36.18/0.925	48.54/0.986	32.09/0.769	29.59/0.720	32.15/0.796	35.14/0.864	18.01/0.772	17.36/0.697	17.37/0.722	17.64/0.677
Stream	37.58/0.945	34.21/0.879	36.39/0.935	43.56/0.987	31.90/0.797	30.37/0.731	30.44/0.730	33.24/0.851	24.59/0.786	24.27/0.763	23.97/0.769	24.65/0.788
Sunroom	42.94/0.968	35.91/0.910	40.87/0.960	46.17/0.969	38.49/0.919	36.41/0.885	38.00/0.909	41.35/0.952	28.18/0.852	28.16/0.845	28.13/0.828	28.20/0.857
Valentines	35.98/0.935	28.68/0.771	35.84/0.927	46.60/0.985	30.81/0.750	28.04/0.674	31.51/0.805	34.55/0.868	18.78/0.717	18.04/0.649	18.45/0.745	18.56/0.618

Qualitative results



Applications: Polarized image rendering & Super-resolution querying



* S-INR supports querying only at the resolution used for fitting.