NANJING UNIVERSITY

Efficient Snapshot Spectral Imaging: Calibration-Free Parallel Structure with Aperture Diffraction Fusion

Computational Imaging Lab @ Nanjing University

Github Code   CITE Lab

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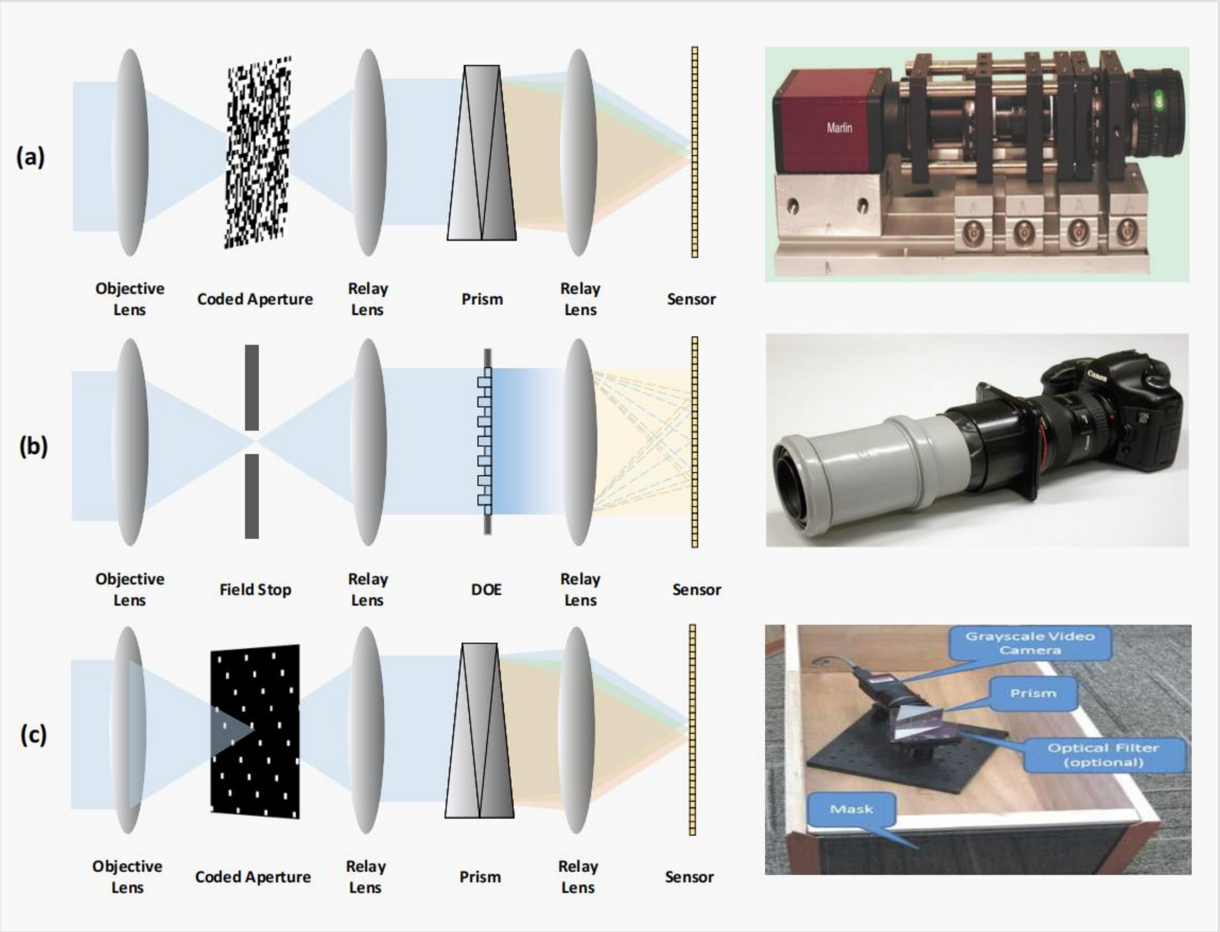
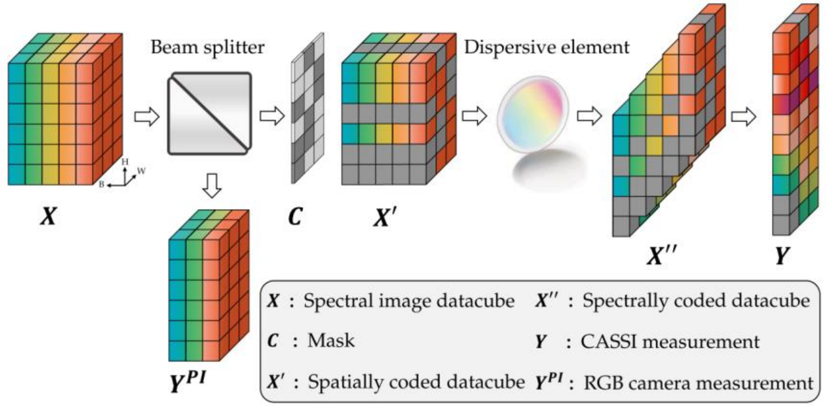
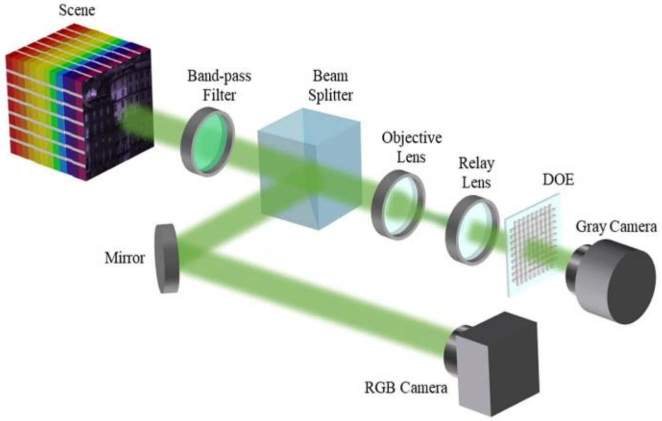
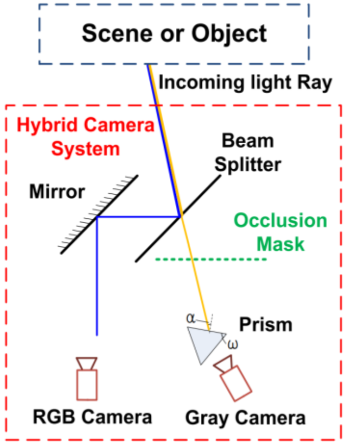
Background



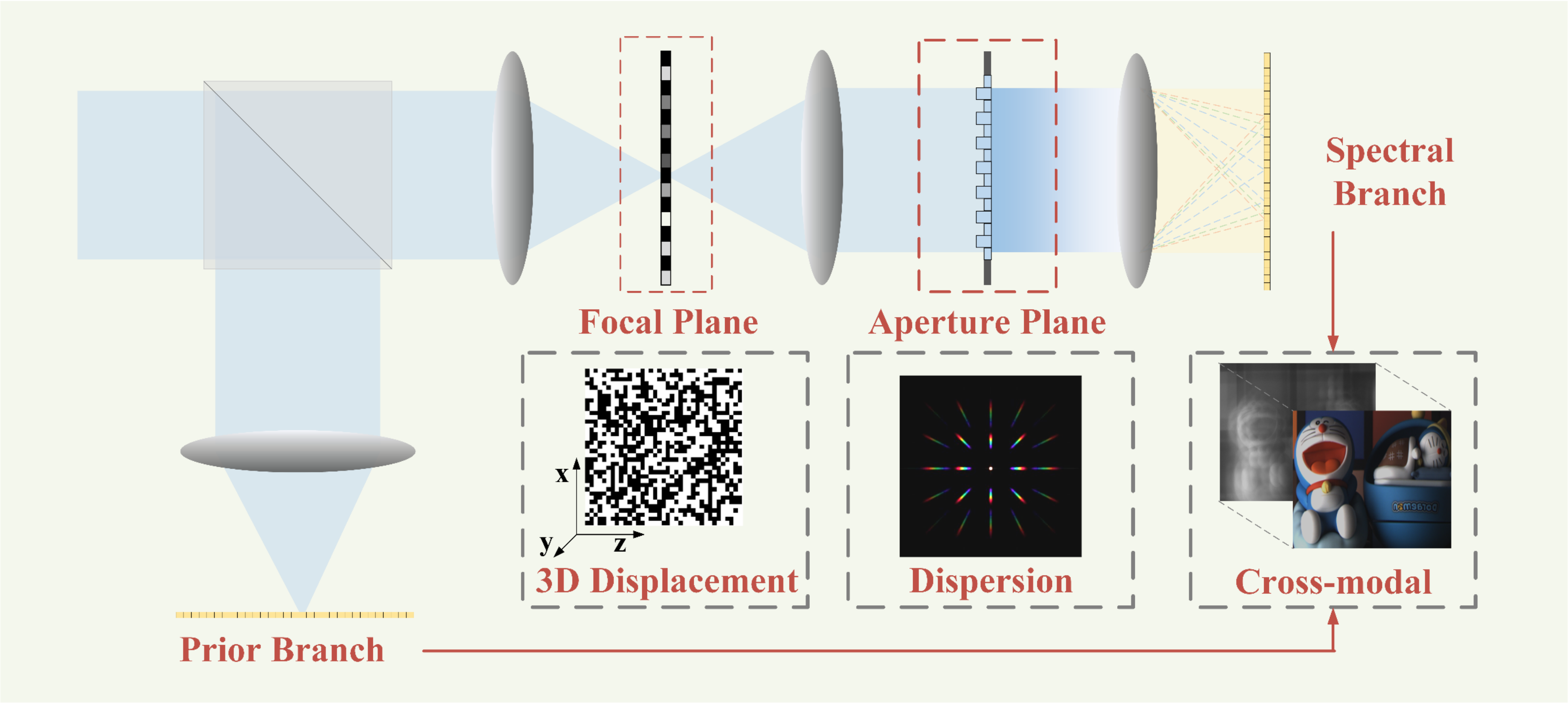






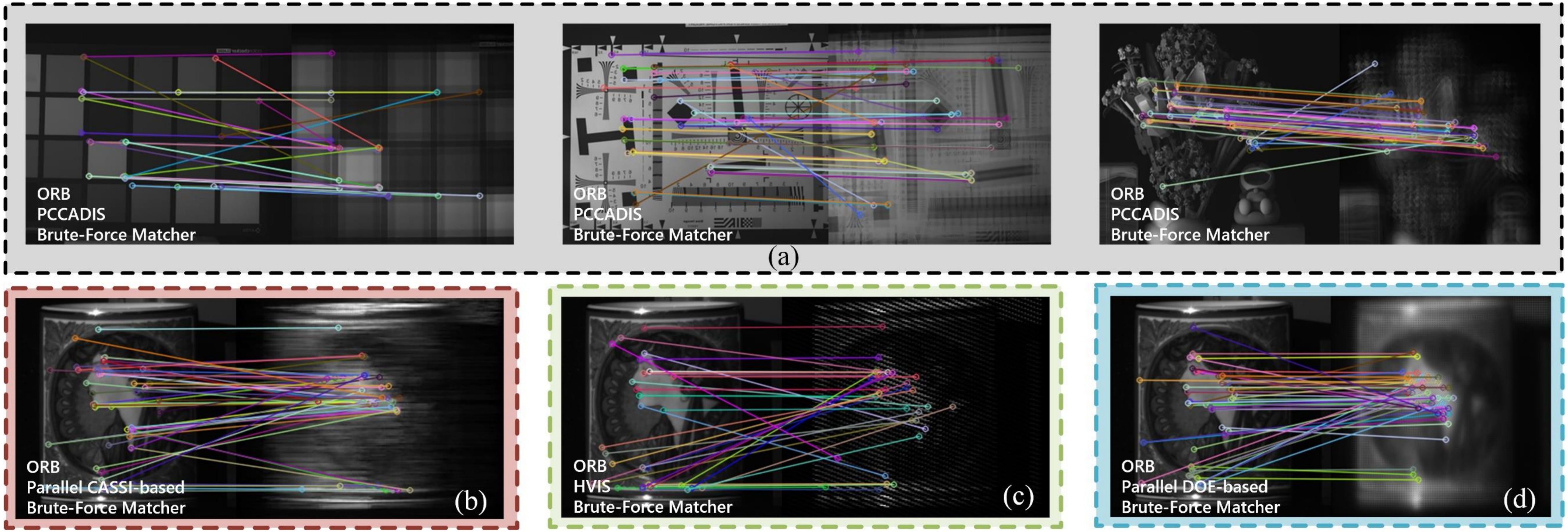
Three core challenges in snapshot spectral imaging: (a) complex structure; (b) Compromised imaging accuracy, and (c) the need for repeated calibrations

Background



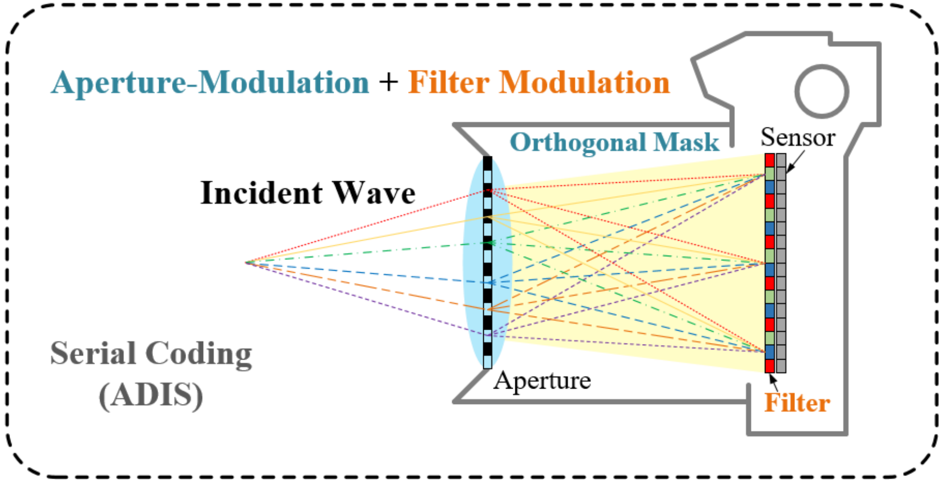
Three main elements to be calibrated in a parallel optical path imaging system

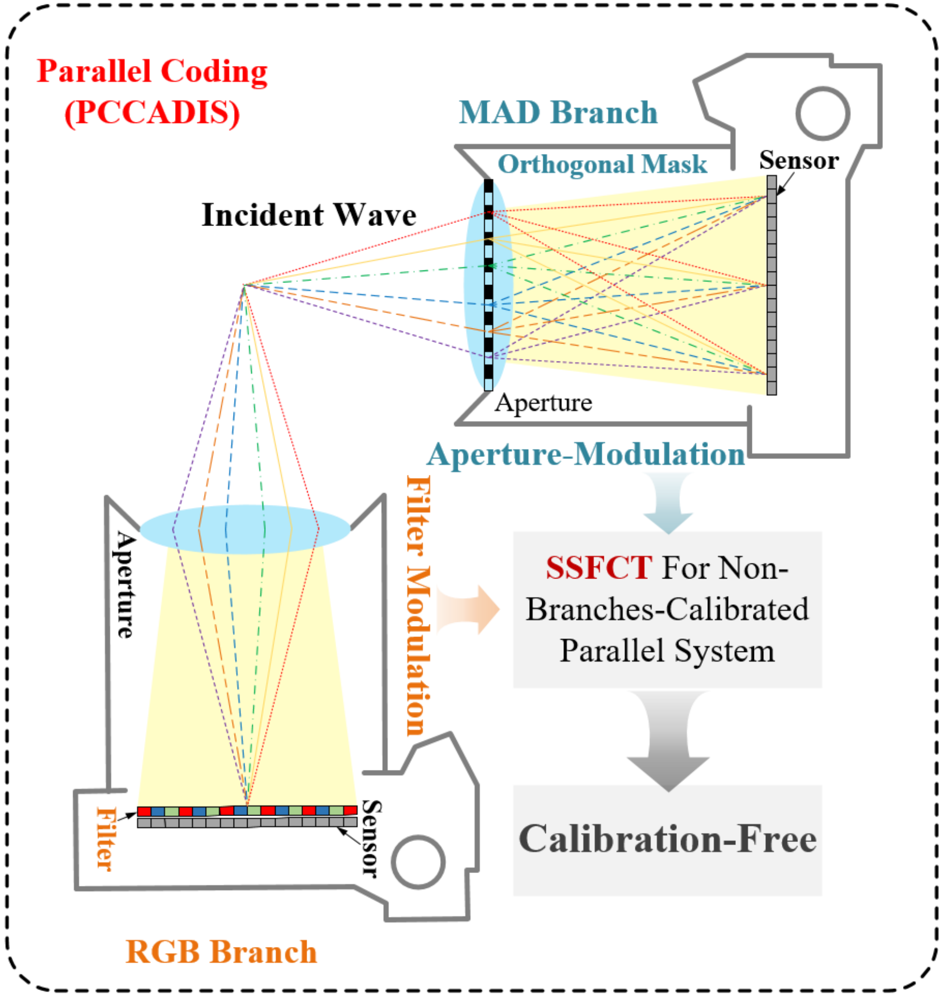
Motivation



Matching of differentiated data obtained from different coded modulation is a difficult problem that cannot be achieved by traditional image registration algorithms

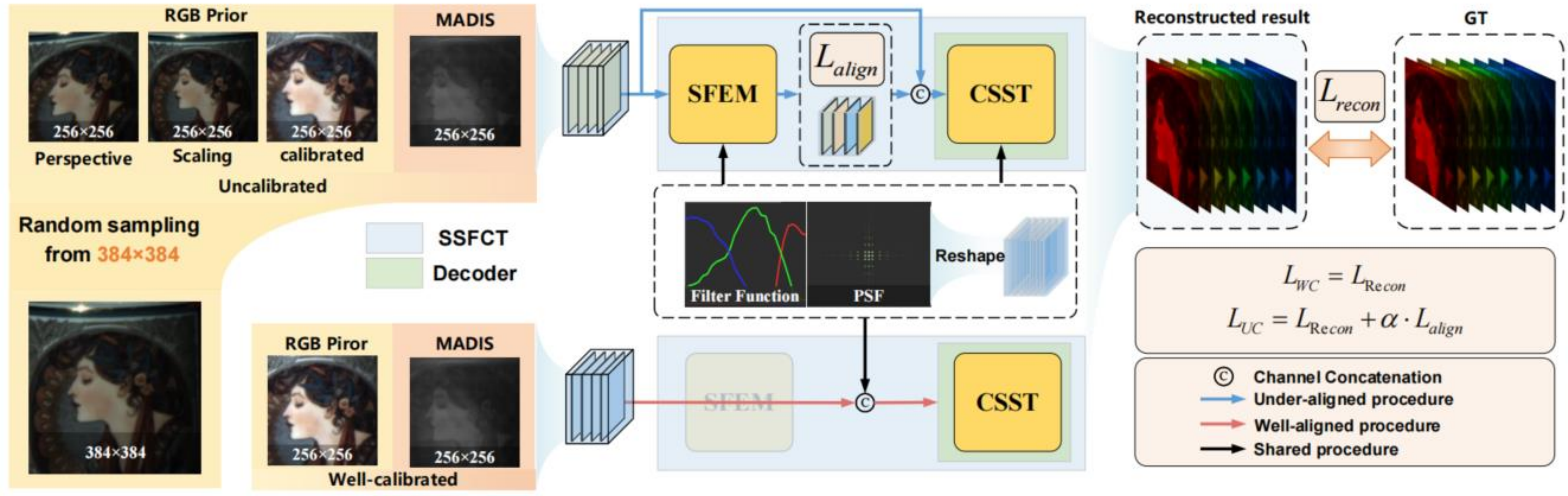
System Overview





The serial coding of ADIS is adapted to parallel coding (PCCADIS). And the fusion and reconstruction of cross-modal images are addressed by algorithmic design that directly skips image alignment

System Overview

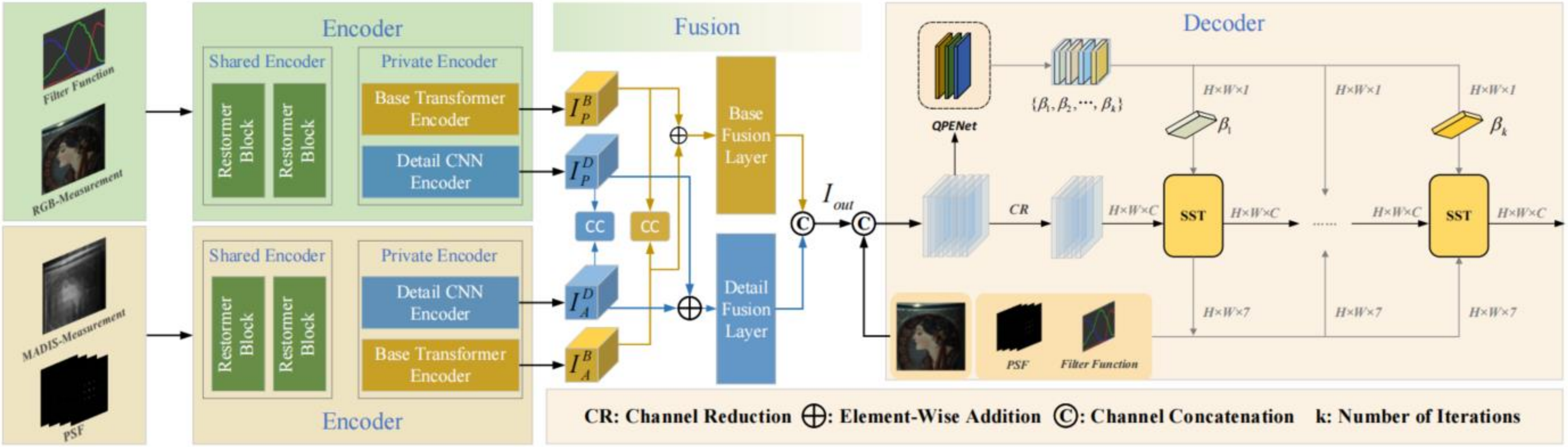


We trained the reconstruction algorithm using data randomly sampled from the data in 384*384 resolution as prior information

Reconstruction Algorithm

We construct the SSFCT Framework based on CDDFuse and deep unfolding architecture:

- SFEM: Transformer+CNN Encoder for feature fusion based on MAD measurements;
- SSFCT Framework: Fusion and reconstruction;



SFEM encodes and guides the fusion of uncalibrated inputs, allowing us to extract matching features from both modalities and use them to recover a high-fidelity data cube

Simulation Experiments

Table 2: Quantitative Comparison of reconstruction results of different algorithms with uncalibrated inputs, Params, FLOPS, PSNR (dB) and SSIM are reported. The PSNR and SSIM of each scene are the mean results of the three different RGB guided images.

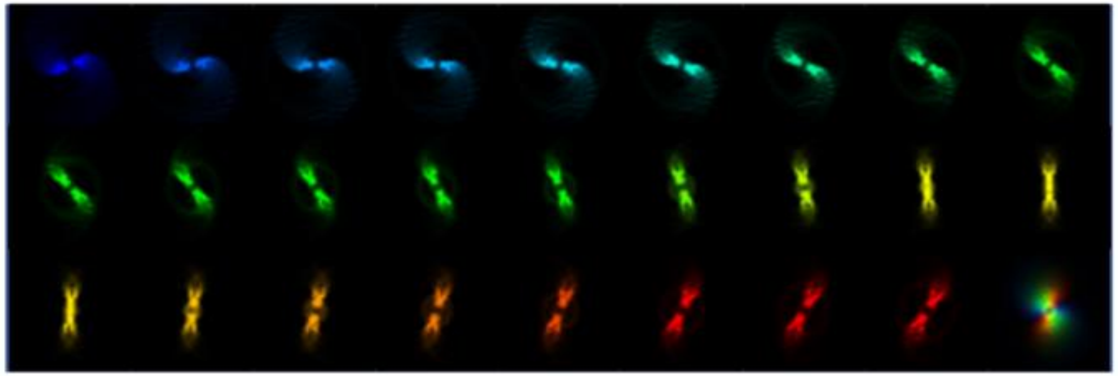
Algorithm	Params	GFLOPS	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	**Avg**
UNet [37]	23.29M	4.90	38.60 0.970	39.12 0.974	36.15 0.957	35.38 0.910	34.49 0.942	34.02 0.935	38.32 0.968	37.23 0.953	35.74 0.954	34.82 0.947	**36.46** **0.951**
Lambda-Net [34]	32.73M	23.29	36.49 0.942	37.63 0.956	34.46 0.929	31.65 0.771	33.23 0.907	32.77 0.898	37.25 0.957	36.48 0.944	35.59 0.940	34.85 0.934	**35.04** **0.918**
TSA-Net [33]	44.25M	91.47	40.38 0.972	40.59 0.975	37.42 0.969	36.34 0.927	**37.27** **0.963**	35.68 0.957	40.15 0.979	38.01 0.954	37.31 0.958	38.00 0.972	**38.28** **0.962**
MST++ [9]	1.34M	17.57	40.81 0.984	40.26 0.982	37.87 0.975	35.83 0.927	35.79 0.947	36.55 0.962	**40.94** 0.981	39.76 0.971	38.56 0.969	37.92 0.974	**38.34** **0.966**
Restormer [52]	15.11M	87.54	**42.00** **0.987**	**42.53** **0.987**	**39.51** **0.980**	**36.68** **0.936**	36.93 0.962	**36.78** **0.968**	40.75 **0.982**	**40.22** **0.977**	**39.31** **0.978**	**40.56** **0.985**	**39.48** **0.974**
SSFCT-9stg (Ours)	6.62M	73.50	**42.67** **0.988**	**43.56** **0.989**	**40.80** **0.985**	**40.89** **0.982**	**39.24** **0.978**	**40.55** **0.981**	**43.99** **0.990**	**39.99** **0.976**	**40.69** **0.979**	**40.93** **0.975**	**41.33** **0.982**

SSFCT-9stg significantly outperforms two recent SOTA methods Restormer and MST++ by 1.85dB and 2.99dB, demonstrating the effectiveness and acceptability of the imaging system

Simulation Experiments

Table 3: Comparisons of ADIS and PCCADIS (PSNR/SSIM)

Methods	lambda-Net	TSA-Net	MST++	Restormer	CSST	SSFCT	Epoches
ADIS	29.62 0.860	30.71 0.915	32.23 0.942	33.29 0.948	34.08 0.958	–	300
PCCADIS(UC)	35.04 0.918	38.28 0.962	38.34 0.966	39.48 0.974	–	41.33 0.982	150
PCCADIS(WC)	36.99 0.935	40.01 0.958	41.43 0.984	41.86 0.984	41.97 0.985	–	150



	ADIS	PCCADIS	DOE-based	Parallel DOE-based
SSFCT / PSNR (dB)	34.08	41.33	36.58	41.79
SSFCT / SSIM	0.958	0.982	0.964	0.984

A comparison of PCCADIS and ADIS proves the effectiveness of the parallel system, and the SOTA performance of the SSFCT algorithm in uncalibration experiments is also demonstrated

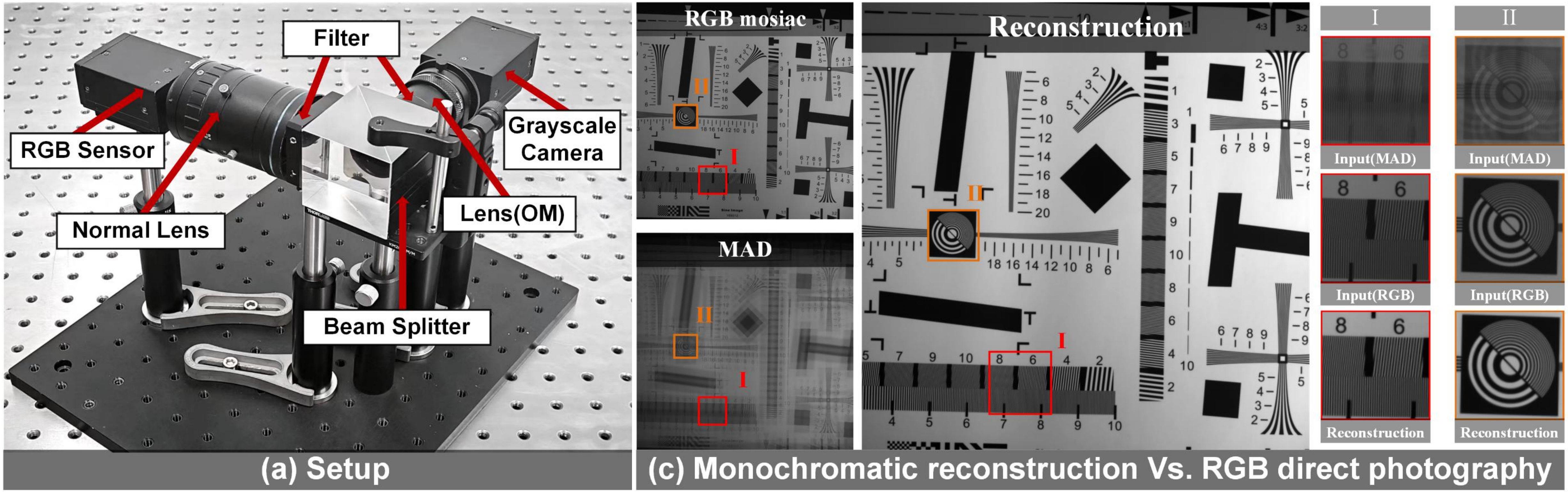
Simulation Experiments

Table 1: Complexity analysis of parallel computational spectral imaging systems. OPS: Optical Path Structure; $Cali_{spa}$: Spatial Calibration of different branches; $Cali_{Disper}$: Dispersion Calibration; $Cali_{PSFs/M}$: PSFs/Mask Calibration; N_{BP}: Necessity of Beam Splitter.

Imaging Method	OPS	$Cali_{spa}$	$Cali_{Disper}$	$Cali_{PSFs/M}$	N_{BP}
PCCADIS+SSFCT	2f+2f	✗	✗	✗	✗
prior branch+PMVIS [13]	2f+4f	✓	✓	✓	✓
prior branch+CASSI [17, 44]	2f+4f	✓	✓	✓	✓
prior branch+CTIS [50]	2f+4f	✓	✓	✓	✓
prior branch+DOE-coded [48]	2f+2f	✓	✗	✓	✓

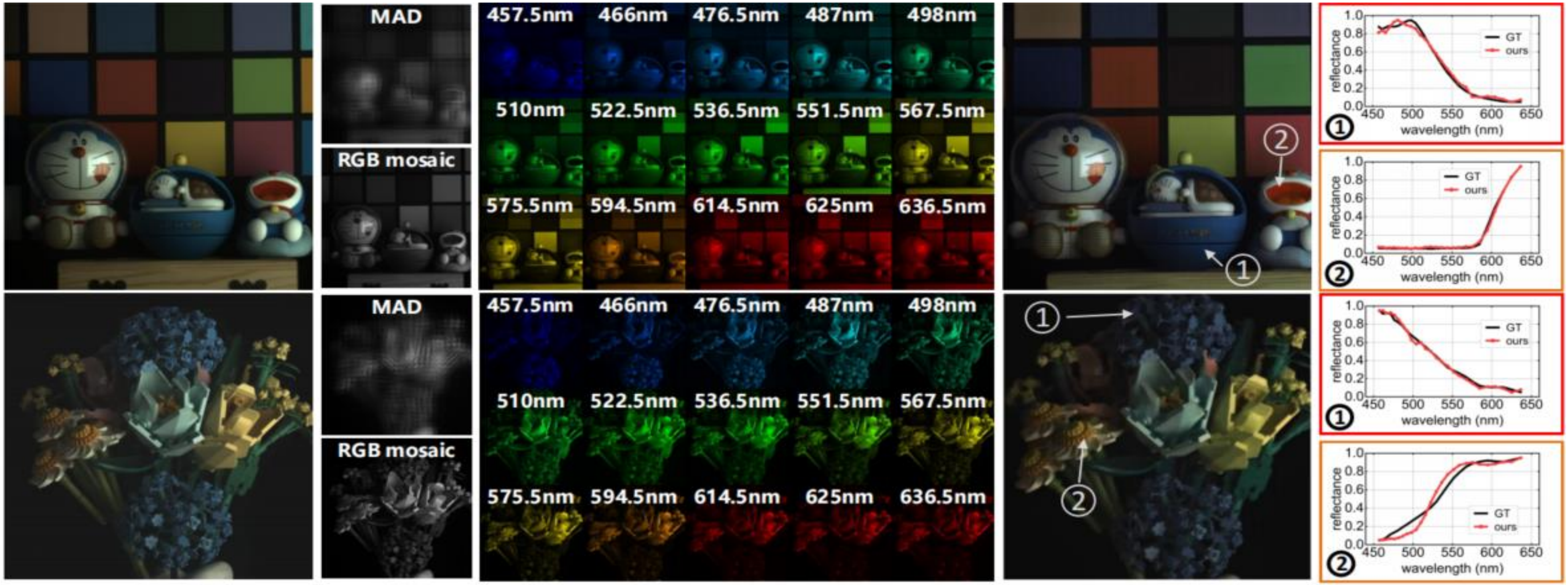
Comparison of system complexity and calibration complexity illustrates the sophistication of PCCADS

Real Reconstruction



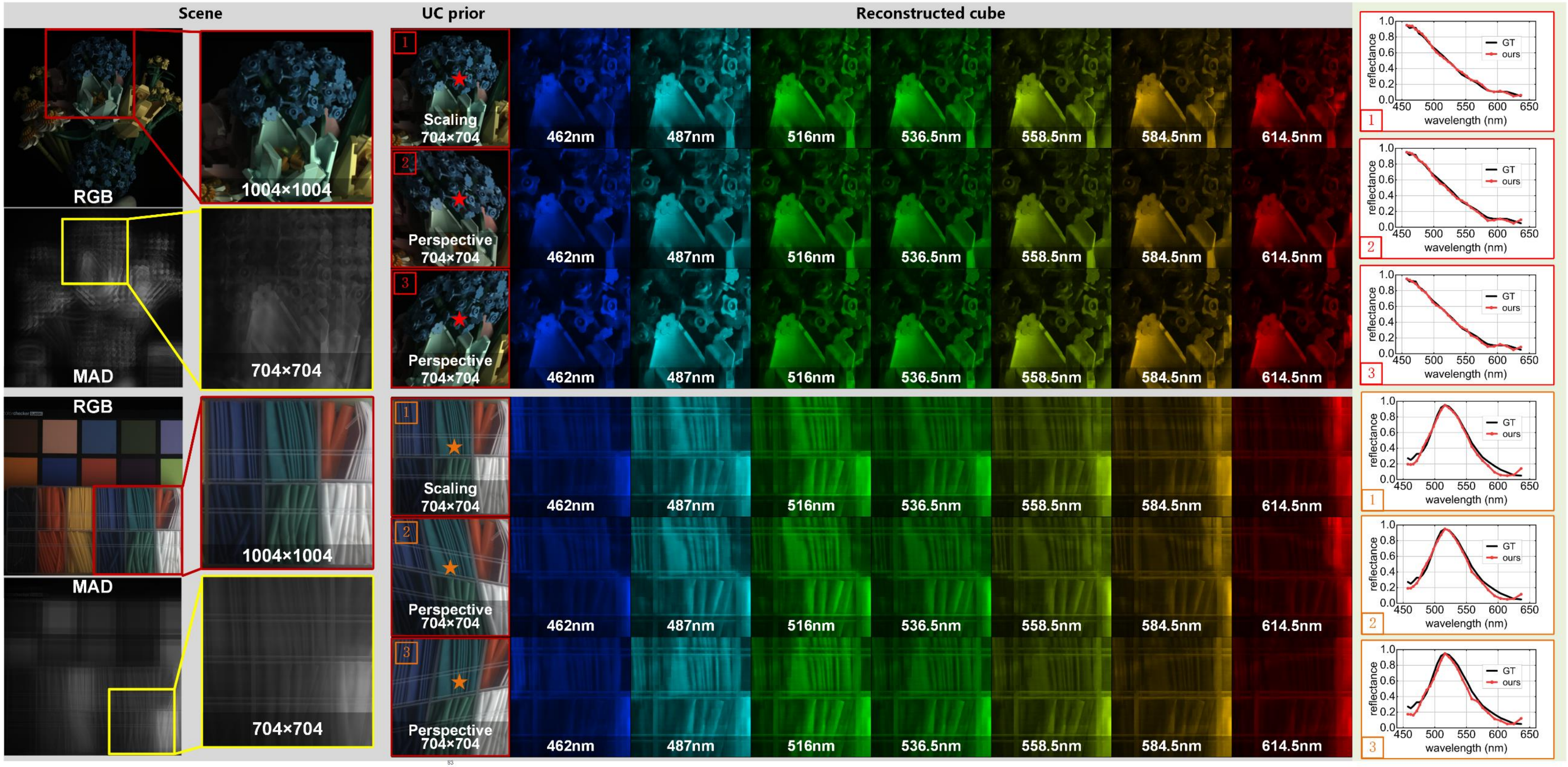
From the reconstruction results for the resolution targets, PCCADIS can recover a resolution level similar to that of RGB direct imaging

Real Reconstruction



With the well-calibrated experimental setup, PCCADIS recovers the spectral details of the scene with a clear spatial structure

Real Reconstruction



Under uncalibrated mode, PCCADIS can reconstruct accurately and stably for different guided images.

Ablation and Analysis

Table 4: Result of ablation on SFEM, L_{UC} and imaging mode

Traning mode	PSNR(dB)	SSIM
SSFCT+L_{UC}(MAD+RGB)	37.38	0.959
SSFCT+L_{Recon}(MAD+RGB)	36.76	0.951
Decoder+L_{Recon}(MAD+RGB)	36.33	0.950
Decoder+L_{Recon}(only RGB)	35.53	0.945

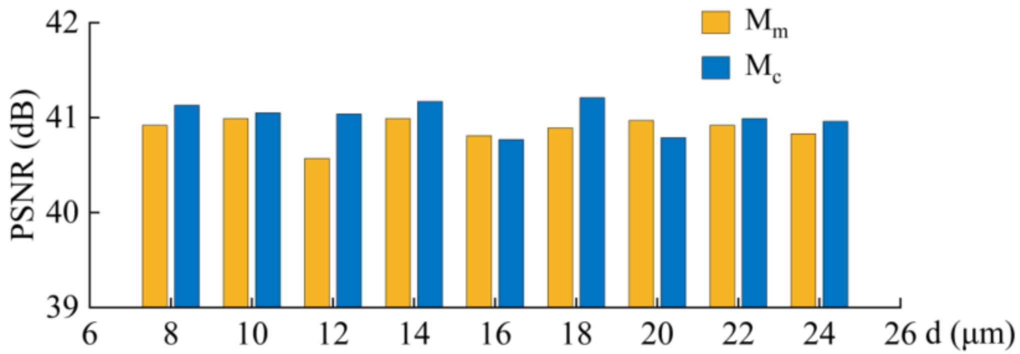


Fig. 8: Influence on PSNR of hole period d.

Table 5: Comparison of light throughput between PCCADIS and ADIS. (LT: light throughput)

Methods	ADIS(M_m)	ADIS(M_c)	Ours(M_m)	Ours(M_c)
LT	$\frac{1}{4}\times\frac{1}{3}$	$\frac{3}{4}\times\frac{1}{3}$	$\frac{1}{2}(\frac{1}{4}+\frac{1}{3})$	$\frac{1}{2}(\frac{3}{4}+\frac{1}{3})$
LT	8.3%	25.0%	29.2%	54.2%

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ECCV

Thanks for your attention!

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