Compact Low-Cost Hyperspectral Imaging via Angular-to-Spectral Diversity Conversion

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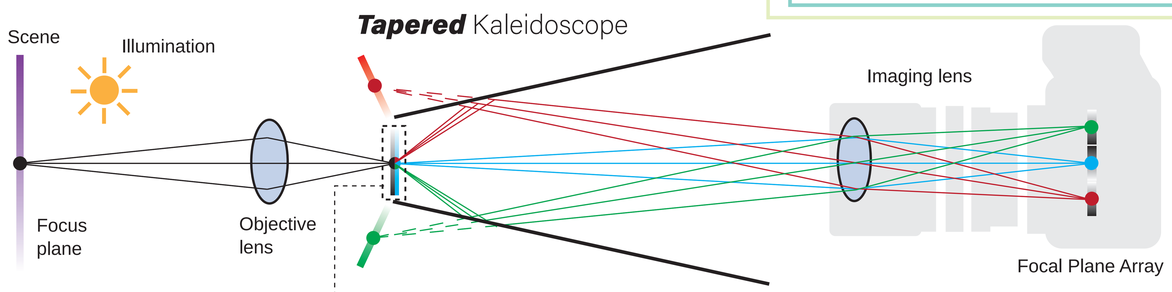
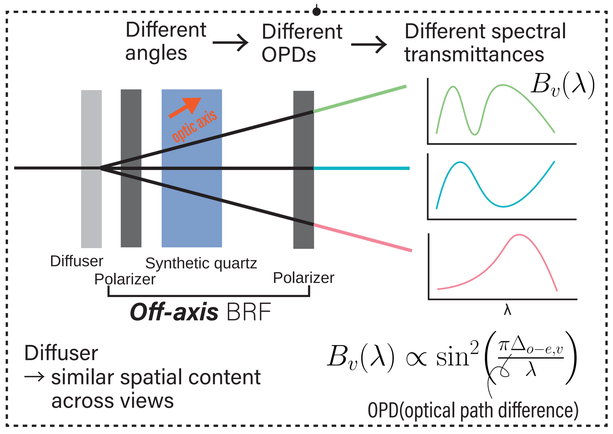
Challenge

Snapshot Hyperspectral Imaging (=HSI from a single exposure)
→ Hard to achieve **compact + low-cost + stable** at the same time

Optics



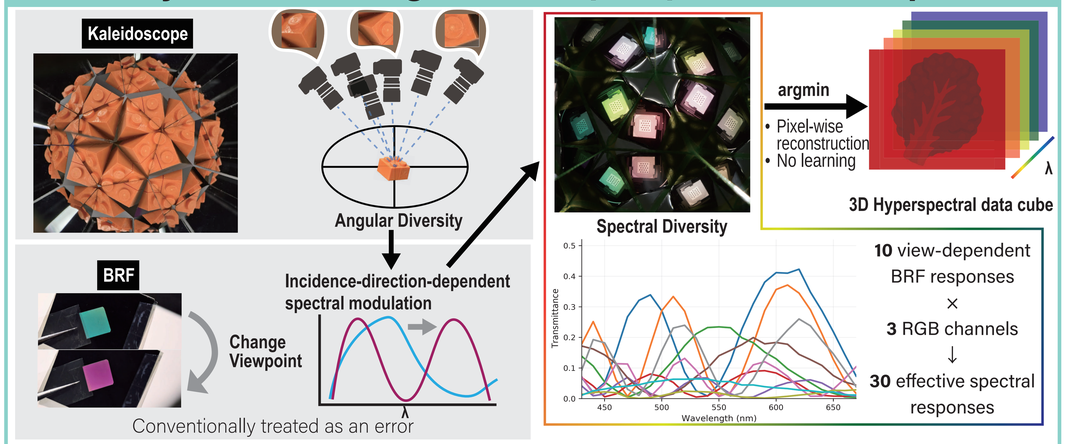


Diffuser
→ similar spatial content across views

$$B_v(\lambda) \propto \sin^2\left(\frac{\pi \Delta_{o-e,v}}{\lambda}\right)$$

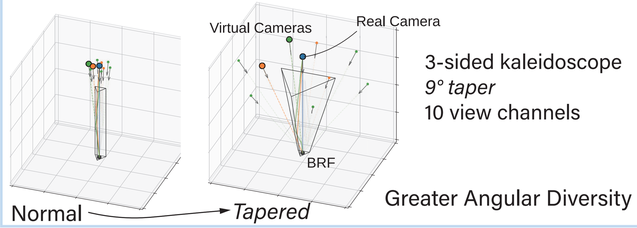
OPD(optical path difference)

Key Idea: Birefringent Filter (BRF) × Kaleidoscope



▪ Kaleidoscope-induced angular diversity is converted into spectral diversity by the BRF's incidence-direction dependence.

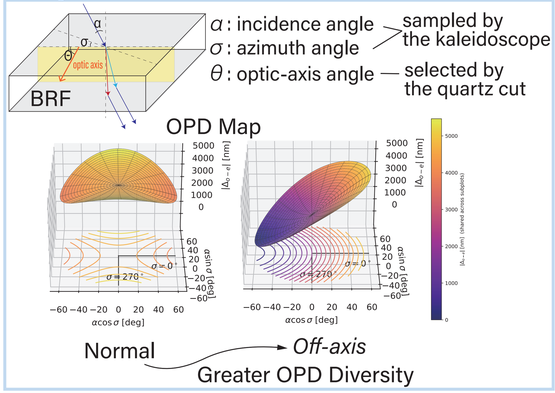
Why a *Tapered* Kaleidoscope?



3-sided kaleidoscope
9° taper
10 view channels

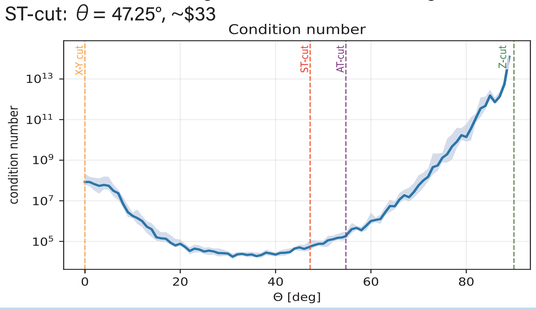
Greater Angular Diversity

Why an *Off-Axis* BRF?



How to Select θ ?

Synthetic quartz is widely used in frequency-control resonators
→ standard cuts with known optic-axis angles are commercially available
→ choose the cut that gives the best conditioning
ST-cut: θ = 47.25°, ~$33



Model & Reconstruction

$$I_{v,c} = \int_\Lambda \underbrace{l(\lambda)}_{\text{Unknown}} \underbrace{s(\lambda)}_{\text{Unknown}} \underbrace{B_v(\lambda)}_{\text{Known/Calibrated}} \underbrace{f^c(\lambda)}_{\text{Unknown}} d\lambda \xrightarrow{\text{Discretize \& Stack}} \mathbf{i} = \mathbf{H}\mathbf{s}$$

$$B_v(\lambda) = B(\lambda; \alpha_v, \sigma_v, \theta) \propto \sin^2\left(\frac{\pi \boldsymbol{\Delta}_{o-e}(\alpha_v, \sigma_v, \theta)}{\lambda}\right)$$

Regularized Non-negative Least Squares

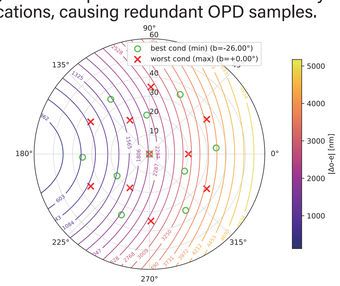
$$\hat{\mathbf{s}} = \arg\min_{\mathbf{s}\geq 0} \|\mathbf{H}\mathbf{s} - \mathbf{i}\|_2^2 + \beta \underbrace{\|\mathbf{D}\mathbf{s}\|_2^2}_{\text{spectral smoothness}}$$

$\mathbf{i} \in \mathbb{R}^{30}$ (10 views×3 RGB)
v: view channel, c: RGB channel

▪ Pixel-wise reconstruction
▪ No learning

Why In-Plane Rotation?

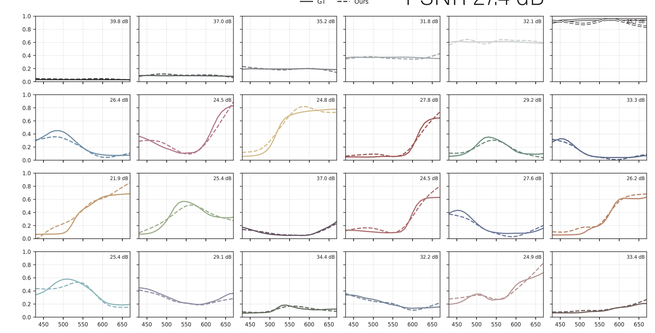
b: BRF in-plane rotation
At b=0°, some sampled directions fall on mirror-symmetric OPD locations, causing redundant OPD samples.



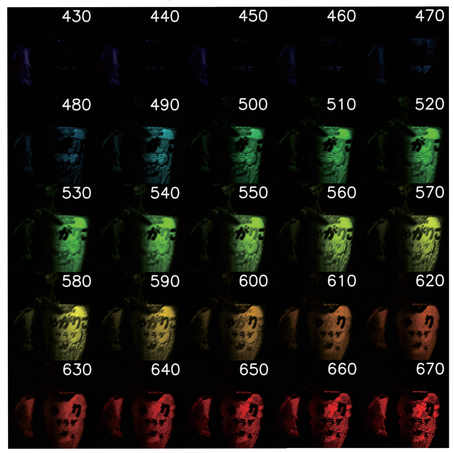
In practice, we use b=20° to avoid the b=0° symmetry.

Results

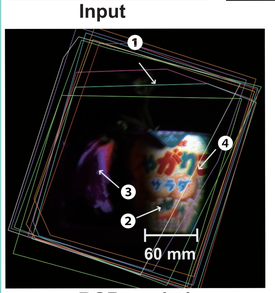
Macbeth ColorChecker — 430-670 nm, 25 bands, PSNR 27.4 dB



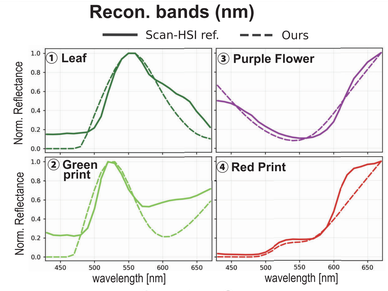
Real-Scene Validation — 0.25 s exposure, ISO 200, F/8



Input — Recon. bands (nm)



RGB rendering



Spectral Curves

Comparison with Low-Cost Snapshot HSI

Exposure-matched synthetic comparison with 3Camera (Oh et al., CVPR'16) and Faced Reflectors (Takatani et al., CVPR'17), using the same reconstructor on synthetic data.