N-to-sRGB Mapping for Single-Sensor Multispectral Imaging

〇Yusuke Monno, Masayuki Tanaka and Masatoshi Okutomi

Tokyo Institute of Technology

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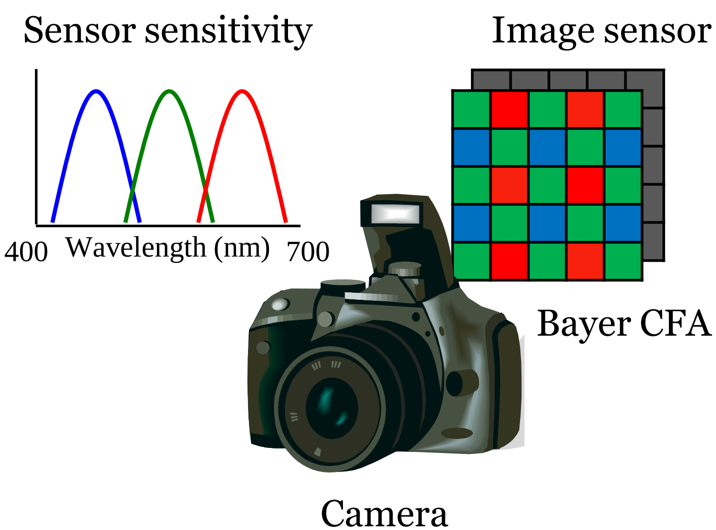
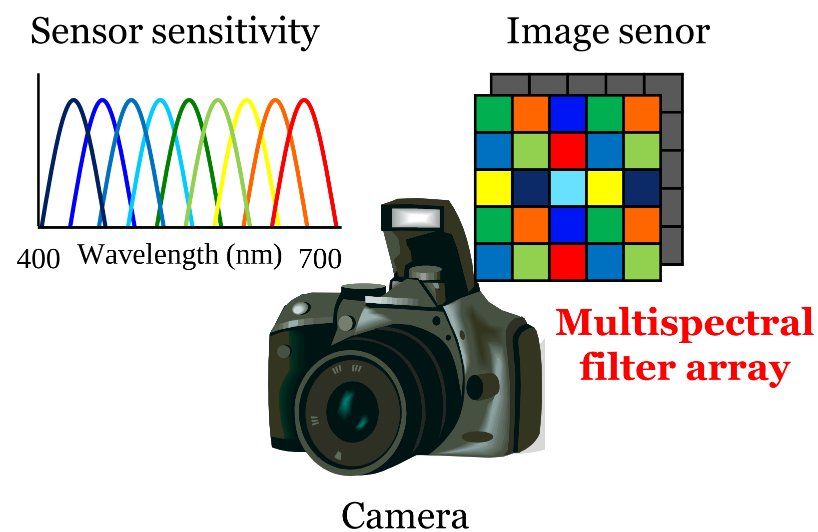
Background

- **Single-sensor multispectral imaging has received increasing attention.**
  - ✓ low cost and compact



Single-sensor color imaging

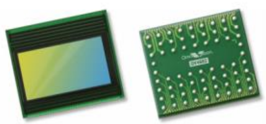


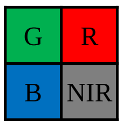
Single-sensor multispectral imaging

Real Products

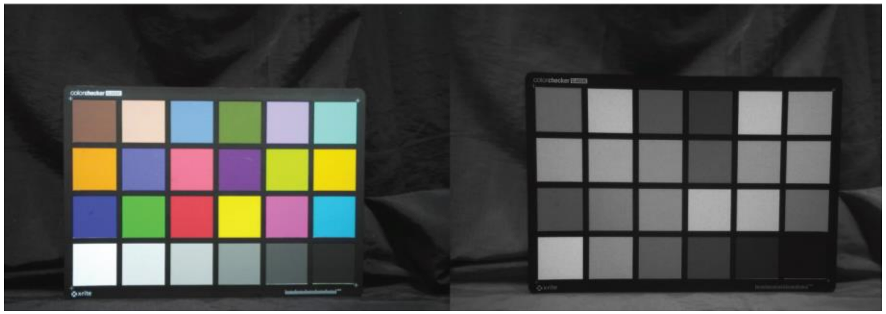
- **It is becoming possible to manufacture a new image sensor for multispectral imaging.**

OmniVision **RGB-NIR** sensor



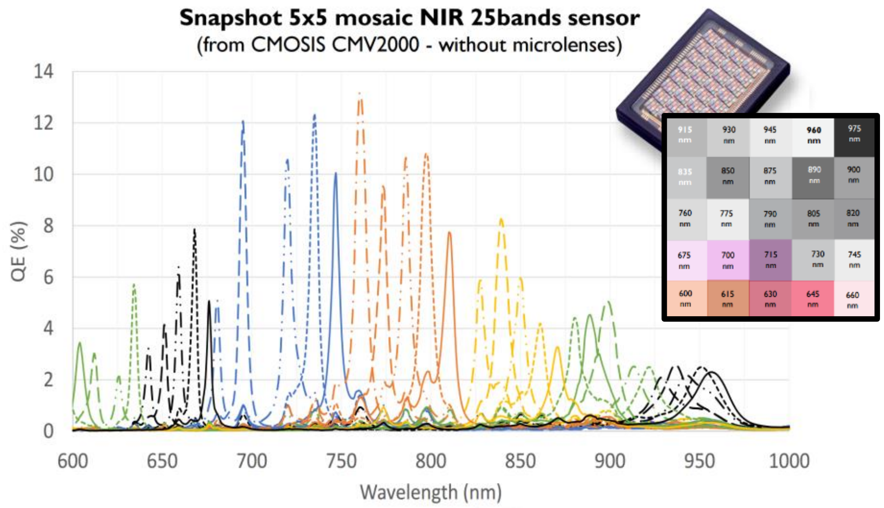


OV4682 4MP product brief



http://www.ovt.com/products/sensor.php?id=145

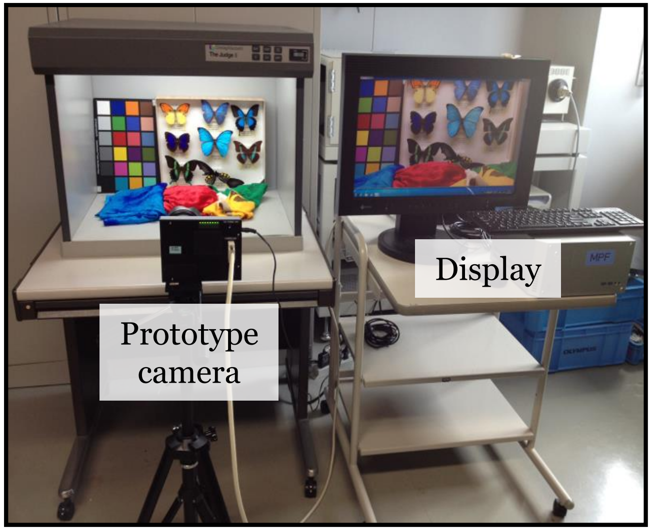
IMEC **hyperspectral** sensor

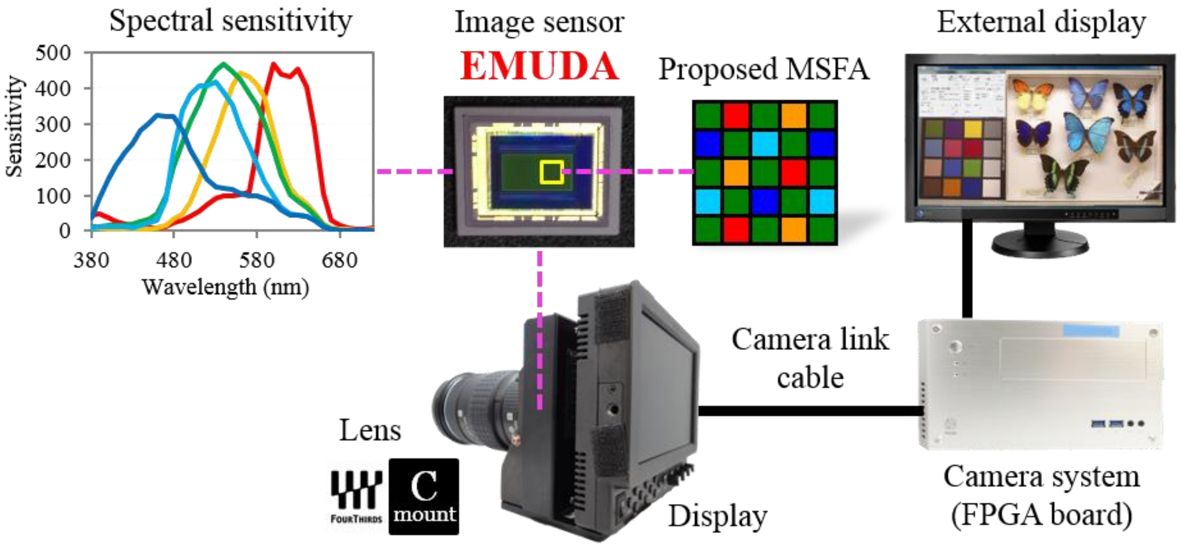


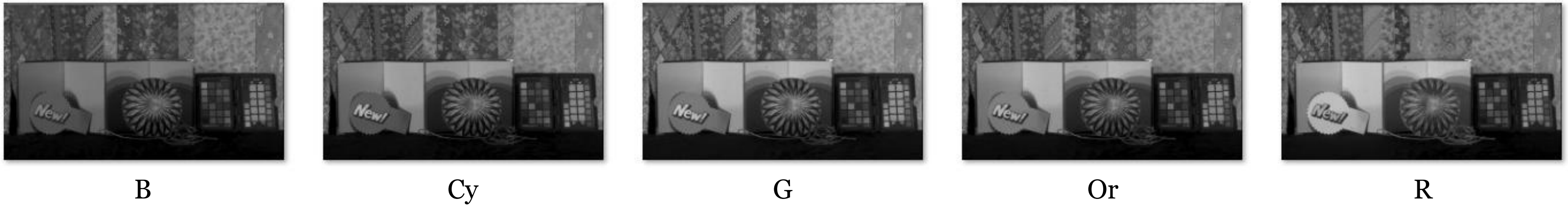
http://www2.imec.be/content/user/File/Brochures/2015/HSI%20activity.pdf

Our Prototype Camera

- **High-quality real-time 5-band imaging system**





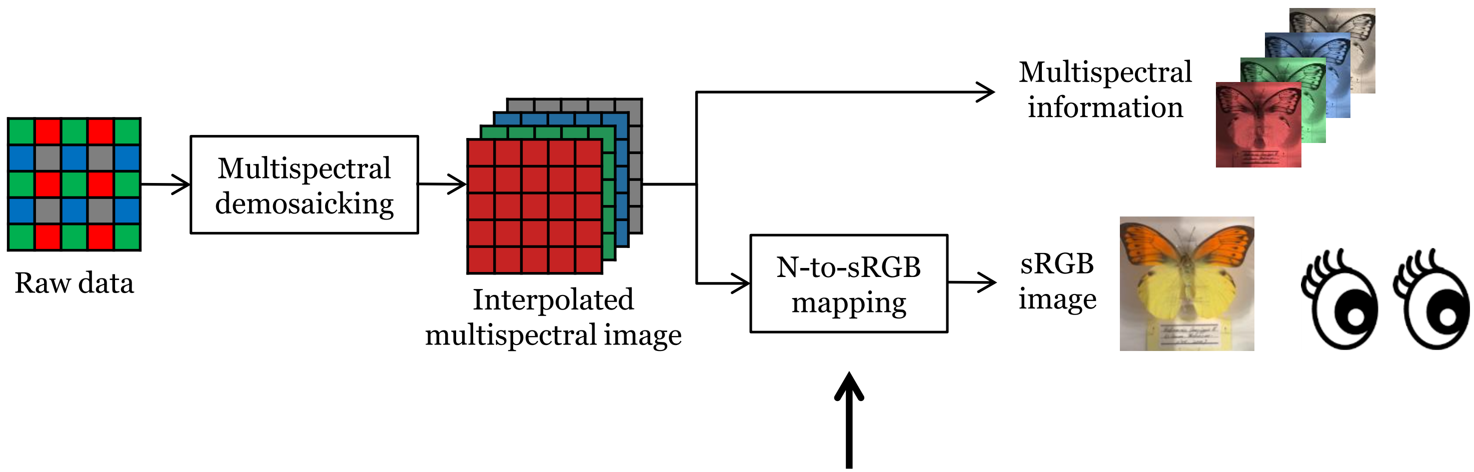


Monno et. al., "A Practical One-Shot Multispectral Imaging System Using a Single Image Sensor," TIP, 2015.

Focus of This Paper

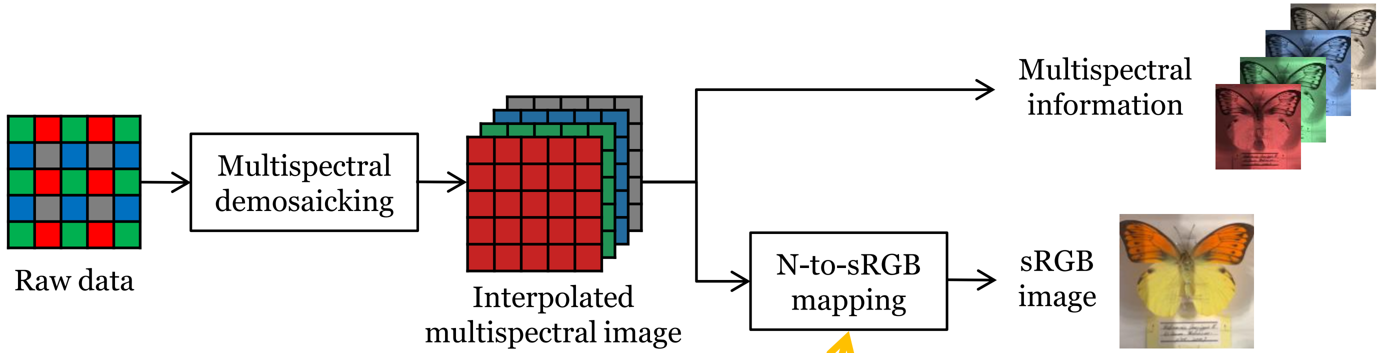
- **"N-to-sRGB" mapping problem in single-sensor multispectral imaging.**

Standard imaging pipeline

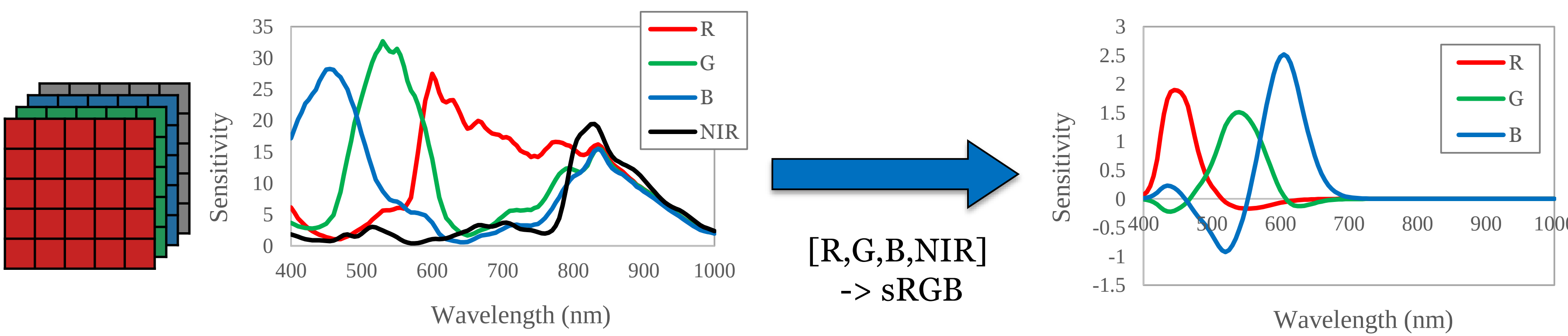


Mapping from N spectral bands to sRGB

Example: [R,G,B,NIR] -> sRGB



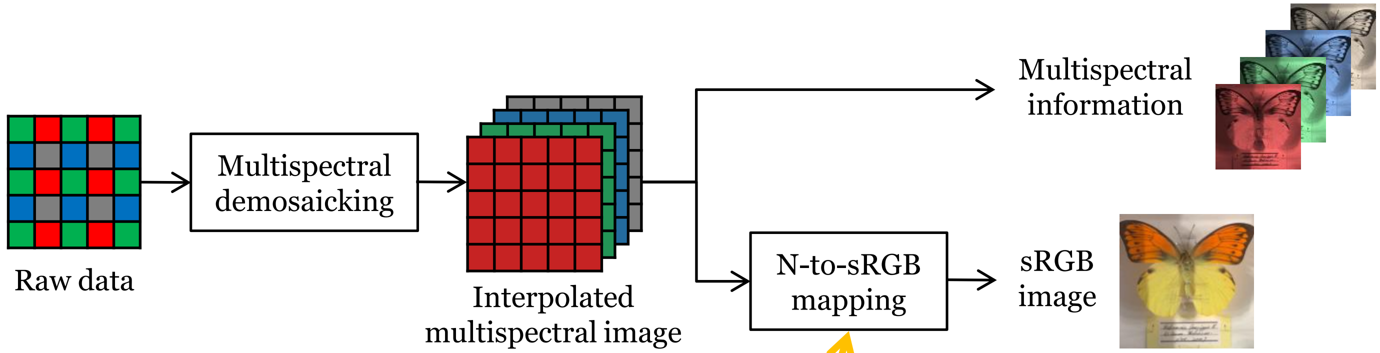
[R,G,B,NIR] -> sRGB (also can be called color correction)



Sensor dependent RGB-NIR space

sRGB space

Example: [R,G,B,NIR] -> sRGB



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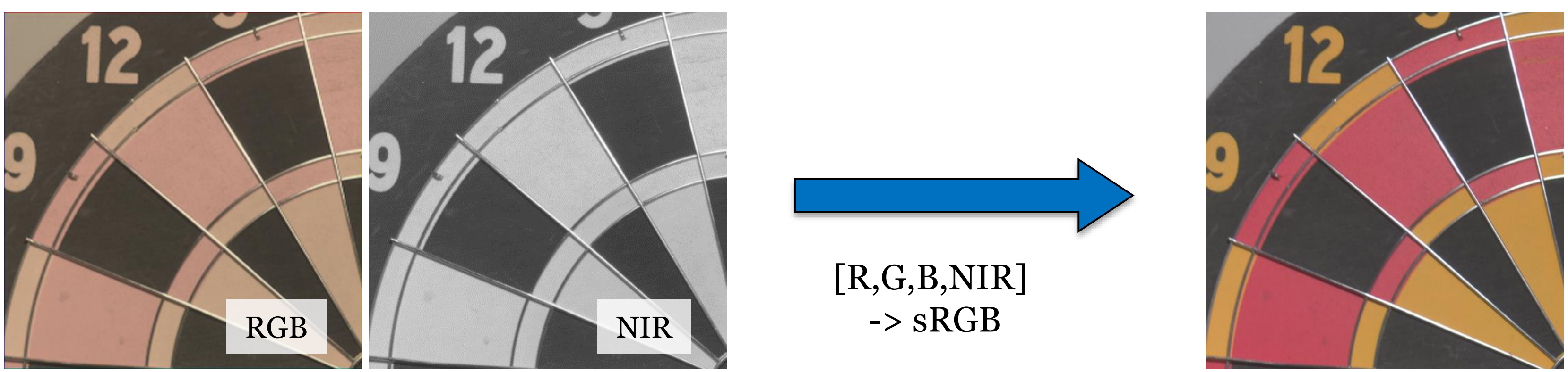


Sensor dependent RGB-NIR space

sRGB space

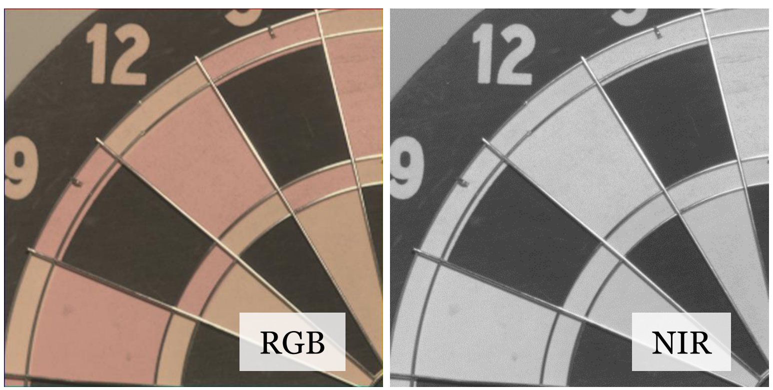
Mapping Algorithms

- Linear mapping
- Polynomial
- Root-polynomial
  (Finlayson et al., TIP2015)

$$\begin{bmatrix} r^s \\ g^s \\ b^s \end{bmatrix} = \begin{bmatrix} m_{11} & m_{12} & m_{13} & m_{14} \\ m_{21} & m_{22} & m_{23} & m_{24} \\ m_{31} & m_{32} & m_{33} & m_{34} \end{bmatrix} \begin{bmatrix} r \\ g \\ b \\ n \end{bmatrix}$$

Target sRGB vector — Mapping matrix $\mathbf{M}$ — Input intensity vector

[R,G,B,NIR] -> sRGB (also can be called color correction)



Sensor dependent RGB-NIR space

[R,G,B,NIR]
-> sRGB

sRGB space

Problem in Single-Sensor Imaging

$$\begin{bmatrix} r^s \\ g^s \\ b^s \end{bmatrix} = \mathbf{M} \begin{bmatrix} r + e_r \\ g + e_g \\ b + e_b \\ n + e_n \end{bmatrix} = \mathbf{M} \begin{bmatrix} r \\ g \\ b \\ n \end{bmatrix} + \mathbf{M} \begin{bmatrix} e_r \\ e_g \\ e_b \\ e_n \end{bmatrix}$$

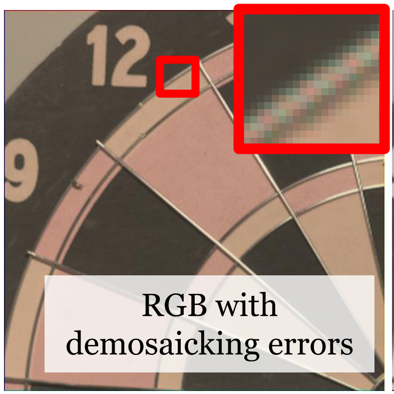
Latent error-free intensities

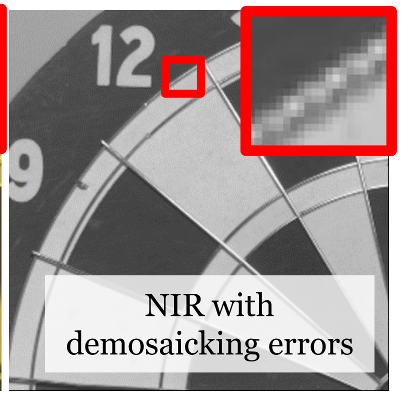
Demosaicking errors

Demosaicking errors are
- **amplified**
- **propagated**

by the mapping.

[R,G,B,NIR] -> sRGB (also can be called color correction)





Sensor dependent RGB-NIR space

[R,G,B,NIR]
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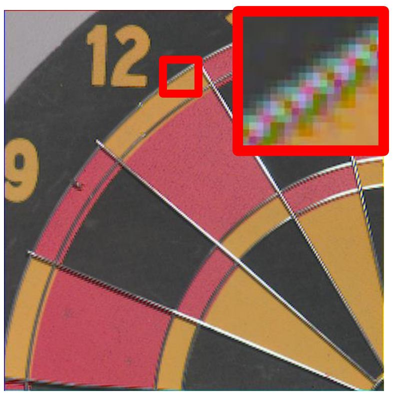


sRGB space

Error Amplification and Propagation

- **Toy example**
  - Only the NIR band contains demosaicking errors.

Error-free sRGB values

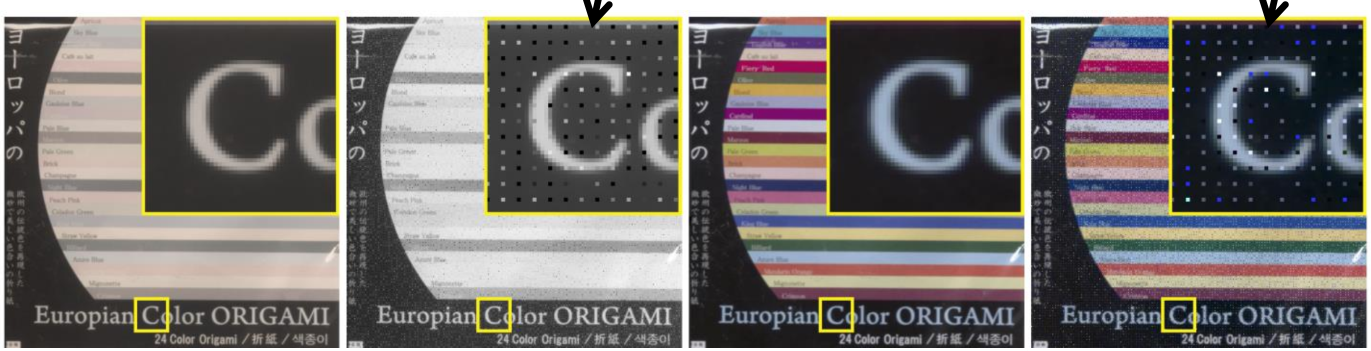
Amplification by large coefficients

$$\begin{bmatrix} r^s \\ g^s \\ b^s \end{bmatrix} = \mathbf{M} \begin{bmatrix} r \\ g \\ b \\ n \end{bmatrix} + \mathbf{M} \begin{bmatrix} 0 \\ 0 \\ 0 \\ e_n \end{bmatrix} = \mathbf{q}_0 + \begin{bmatrix} m_{14} \\ m_{24} \\ m_{34} \end{bmatrix} e_n$$

Propagation of errors in NIR

Errors in NIR

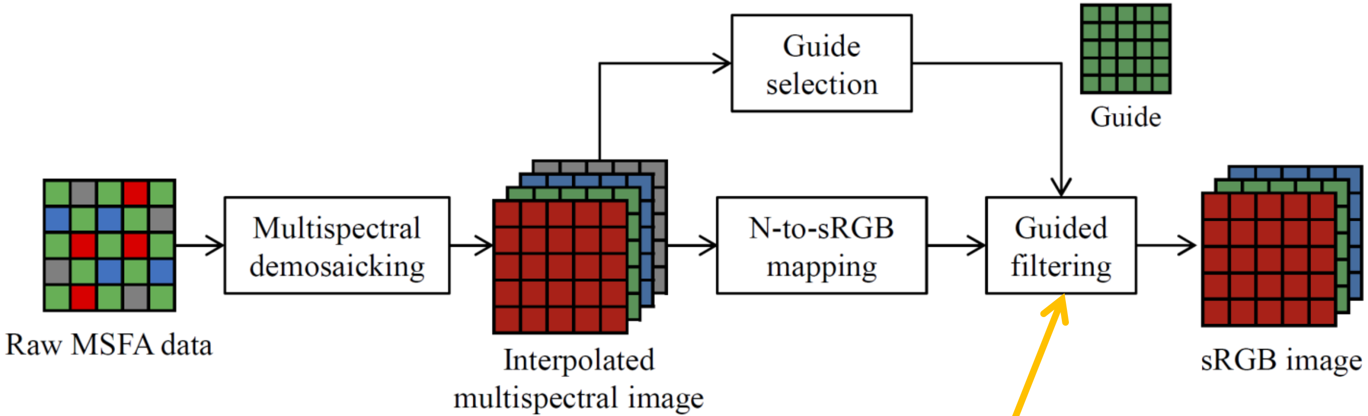
Amplified and propagated



RGB (error-free) NIR with errors Target sRGB Mapped sRGB

Proposed Mapping Pipeline

- **Simple and general pipeline with guided filtering**

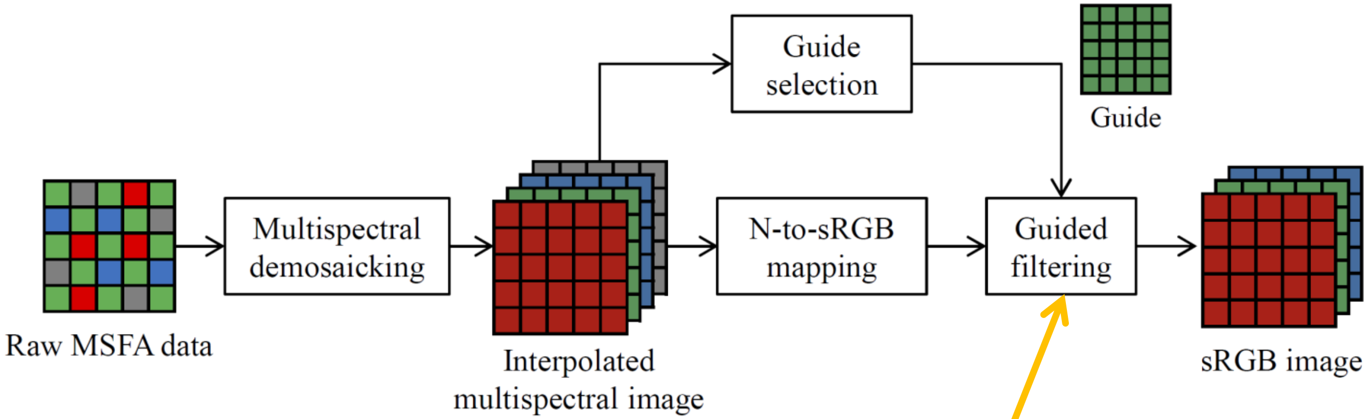


Main idea :

We apply the guided filtering in the mapped sRGB space using **one of input N band images before the error amplification and propagation** as a guide image.

Proposed Mapping Pipeline

- **Simple and general pipeline with guided filtering**



Guided filtering (He et al., PAMI2013)

Guide: One of N band images **before the amplification and propagation.**

Filtering output in a local window : $f_k = \alpha I_k + \beta, \quad \forall k \in \omega$

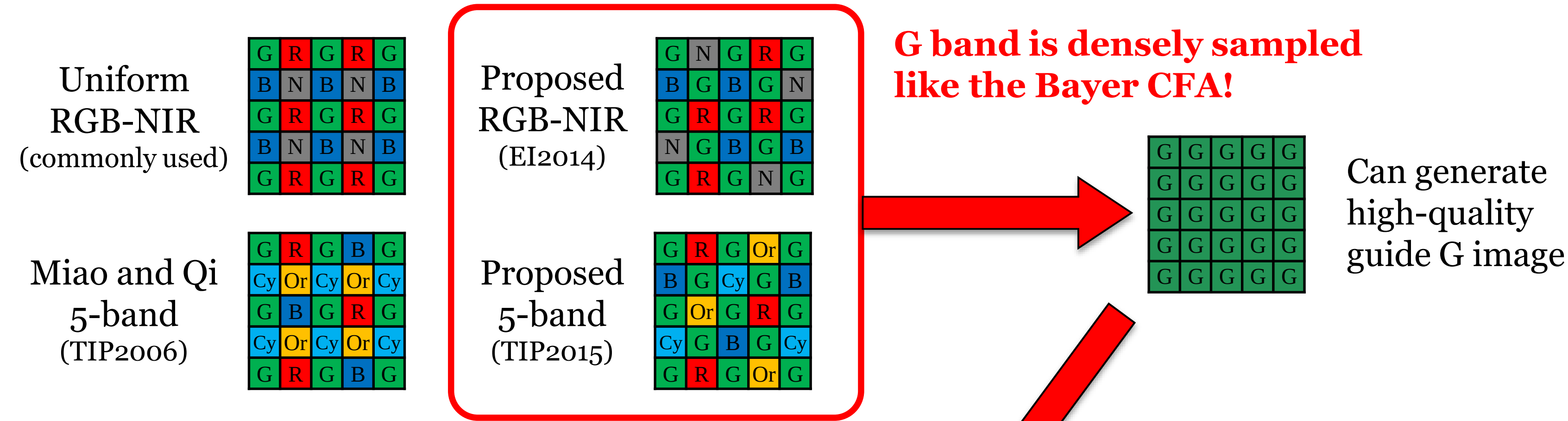
Cost function: $(\alpha, \beta) = \min_{\alpha,\beta} \sum_{k \in \omega} \left(r_k^s - (\alpha I_k + \beta) \right)^2$

Linear transformation of the guide

Input (e.g., R values) **with amplification and propagation.**

Our Motivation

- **Our previously proposed filter array (TIP2015, EI2014)**



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Linear transformation of the guide

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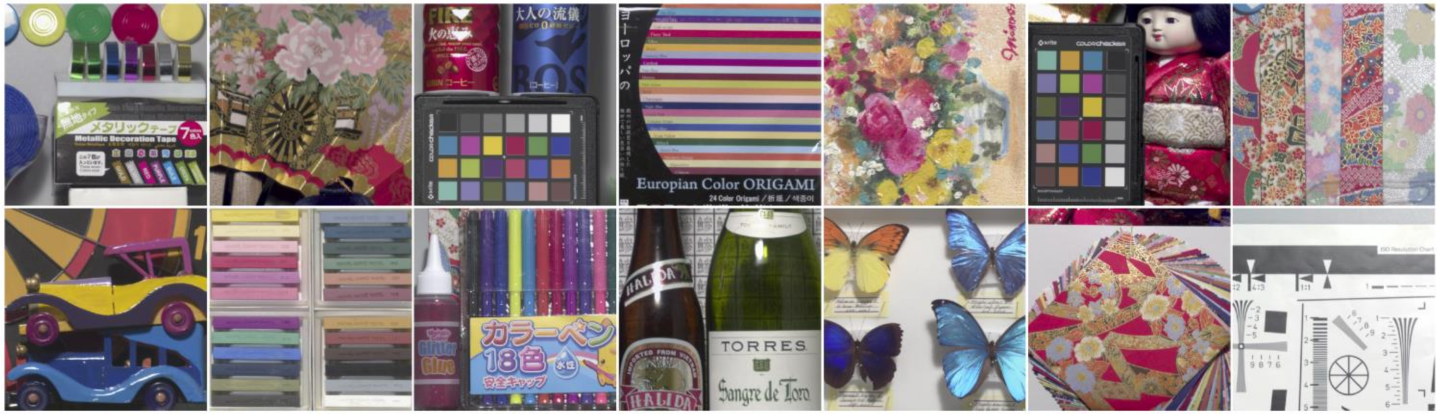
Experimental Setups

- **Hyperspectral image dataset (420nm-1000nm)**
  - Captured using two Varispec filters
    - VIS (420nm-640nm) and SNIR (650nm-1000nm)
  - 512 x 512 pixels
  - 40 scenes
    - 20 scenes for training the mapping matrix
    - 20 scenes for testing



Experimental Setups

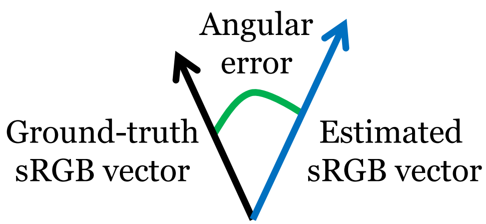
- **Illuminations**
  - Incandescent, diva (Kinoflo), LED, fluorescent, and daylight
- **Filter arrays**
  - RGB-NIR: Uniform, our proposed
  - 5-band: Miao and Qi, our proposed
- **Mapping algorithms**
  - Linear, polynomial, and root-polynomial (Finlayson et al., TIP2015)
- **Implementation of the guided filtering**
  - Guide image: G band for all filter arrays
  - Window size: 5x5, smoothness parameter: 1e-10 (to avoid zero division)
  - Three lines in MATLAB implementation if we use the author's code

Example code

```
sR = guidedfilter(Guide, sR_mapped, window radius = 2, eps = 1e-10);
sG = guidedfilter(Guide, sG_mapped, window radius = 2, eps = 1e-10);
sB = guidedfilter(Guide, sB_mapped, window radius = 2, eps = 1e-10);
```

Results: Numerical Evaluation

- **Comparison of angular errors**



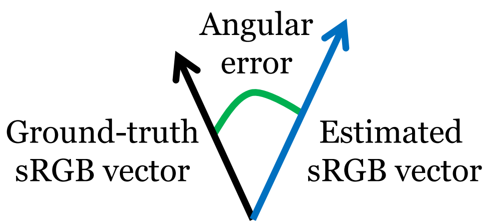
100 scenes
(20 test scenes
x 5 illuminations)

Filter type	Pattern	Mapping	Guided filtering	Average	Median	95 percentile
RGB-NIR	Uniform G R G R G B N B N B G R G R G B N B N B G R G R G	Linear	No	7.57	4.62	18.25
			Proposed	5.17	3.17	13.36
		Polynomial	No	7.29	4.41	17.67
			Proposed	**4.92**	**2.97**	**11.83**
		Root-polynomial	No	7.73	4.87	18.46
			Proposed	5.35	3.31	13.36
	Proposed G N G R G B G B G N G R G R G N G B G B G R G N G	Linear	No	4.41	3.17	10.49
			Proposed	3.99	**2.92**	9.35
		Polynomial	No	4.06	3.07	9.00
			Proposed	**3.66**	2.94	**7.55**
		Root-polynomial	No	4.35	3.35	9.02
			Proposed	3.91	3.12	7.87
5band	Miao and Qi G R G B G Cy Or Cy Or Cy G B G R G Cy Or Cy Or Cy G R G B G	Linear	No	6.63	6.37	10.55
			Proposed	4.74	4.59	7.26
		Polynomial	No	7.00	6.89	10.39
			Proposed	6.48	6.31	9.45
		Root-polynomial	No	5.09	4.79	8.46
			Proposed	**4.02**	**3.74**	**6.43**
	Proposed G R G Or G B G Cy G B G Or G R G Cy G B G Cy G R G Or G	Linear	No	4.22	4.07	7.08
			Proposed	3.47	3.27	5.84
		Polynomial	No	3.96	3.40	7.72
			Proposed	3.41	2.82	6.56
		Root-polynomial	No	3.32	3.03	6.04
			Proposed	**2.83**	**2.52**	**5.11**

Improved the mapping accuracy for all filter arrays and algorithms.

Results: Numerical Evaluation

- ## Comparison of angular errors



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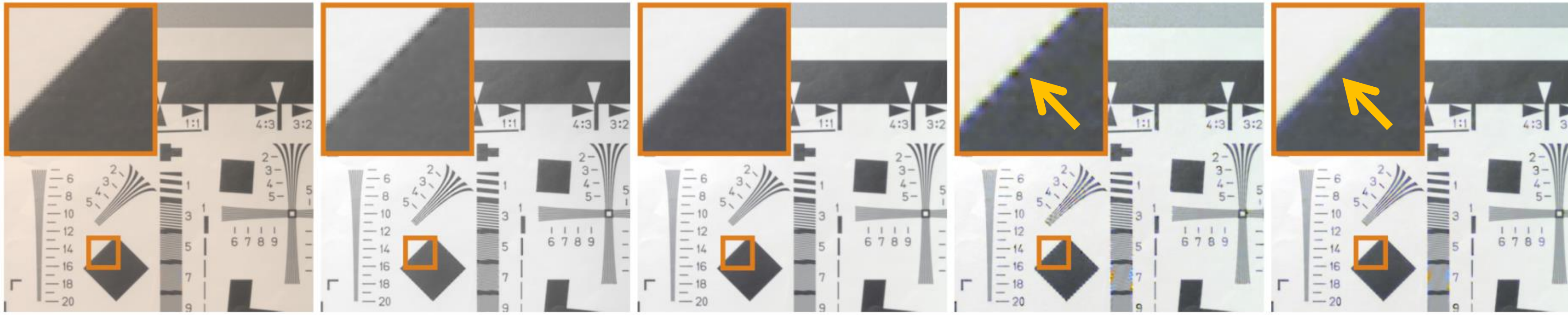
Our proposed filter arrays give the better performance

Results: Visual Comparison

- **Uniform RGB-NIR filter array (Polynomial)**

Input RGB | Input NIR | Ground truth | Without GF | **Proposed**

- **Our RGB-NIR filter array (Polynomial)**



Input RGB | Input NIR | Ground truth | Without GF | **Proposed**

Results: Visual Comparison

- **Miao and Qi 5-band filter array (Root-polynomial)**

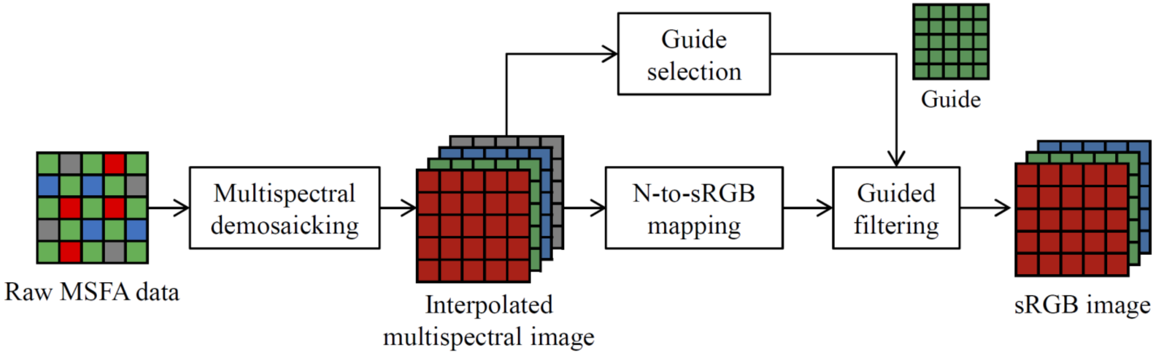
Input 5 band data | Ground truth | Without GF | **Proposed**

- **Our 5-band filter array (Root-polynomial)**

Input 5 band data | Ground truth | Without GF | **Proposed**

Conclusion and Future Work

- **Conclusion**
  - We have proposed a simple but effective pipeline of N-to-sRGB mapping with guided filtering in single-sensor multispectral imaging



- **Future work**
  - Consideration of noise effects

End

Thank you for your attention !