Discussion on the workflow of multispectral imaging systems

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Note: this document is prepared only for the base of discussion in the TC0807 and may contain ambiguous or incorrect descriptions. The author would appreciate any corrections or comments on this document.

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Objective of this document

- To make clear the detailed requirements of the multispectral image format, it is important to discuss the workflow of multispectral imaging systems. This document presents the primitives of the multispectral imaging workflow as a base of discussion.
- The presented workflow primitives are still abstract, and the detailed definitions of the primitives are required. The real workflow needs to be the combination of the presented primitives, and the information needed for the image format can be derived from this discussion. These are the issues of further consideration.
Use cases of multispectral images

• Image generation
  – Multispectral Capture
  – Spectral rendering (Computer generated spectral images)

• Image-based measurement
  – Color measurement
  – Spectral measurement
  – Image analysis

• Image processing
  – Image processing without color adjustment (noise reduction, structure enhancement, etc.)
  – Image processing with color adjustment (color enhancement, etc.)

• Color rendering
  – Color rendering (natural)
  – Pseudo-color representation

• Visualization
  – Color reproduction (display)
    • Colorimetric color display
    • Spectral color display
  – Color reproduction (printer)
    • Colorimetric color printing
    • Spectral printing

• Image compression
Multispectral imaging model

- Image generation
  - Captured by a camera or scanner
  - Generated by a computer

- Object
  - Reflection
  - Transmission
  - Emission

- Illuminant

- Spectral separation *
  - Sensor-side *1
  - Illuminant-side *2

- Sensor device profile
  - Spectral sensitivity
  - Tone curve

- CMF (CIE 1931, 1964, etc.)

- Wavelength range
  - Visible, IR, UV

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*1 Sensor-side spectral separation

*2 Illuminant-side spectral separation
Legend

Operation applied to a multispectral image

Numerical data

Multispectral image within the scope of this document

Image data or sampled points out of the scope of this document
Multispectral capture

- **Object**
  - Radiance
  - Reflectance
  - Transmittance

- **Illuminant**
  - Spectral radiance

- **Capturing device**
  - Spectral sensitivity
  - Tone curve
  - Dark current

- **Post-processing (Device correction)**
  - Distortion correction
  - Dark current correction
  - Tone curve correction
  - ...

- **Multispectral image**
  (Original image file)

*Note: The device independent image representation is not efficient in multispectral imaging; The number of bands varies depending on the devices, and the linear encoding may cause the loss of information by the quantization.*
Spectral rendering
(Computer generated spectral images)

Illuminant
- Spectral radiance

Object
- Radiance
- Reflectance
- Transmittance

Spectral rendering software

Image formatting

Multispectral image
(Original image file)

Display device profile

Visualization on display with color adjustment*

Wavelength range, sampling interval
Virtual camera sensitivity
Spectral transform, ex. PCA

*The color image may be visualized on a display during the image generation, but the generated image is considered to be independent on the display device. The display device calibration is performed within the image generation system in most cases.
Color measurement

- Tristimulus values under standard illuminant, i.e., D50 or D65.
- Scene tristimulus values (reflection objects under input illuminant or emissive objects).

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+-----------------+          +-----------------+
| CMF             |          | Tristimulus values |
|                 |          | XYZ, L*a*b*       |
|                 v          v
| Multispectral image (Original image file) | Color estimation |
|                         v
| Device profile          | Spectral reflectance estimation |
|                         | D50 or D65 spectrum       |
|                         | Input illuminant spectrum |
|                         +-----------------+          |
|                         +-----------------+          |
|                         Tristimulus values |
|                         XYZ, L*a*b*     |
| Image or sampled points |
```
Spectral measurement

- Spectral radiance / reflectance / transmittance.
Image processing without color adjustment (noise reduction, structure enhancement, etc.)

- In the image processing operation, such as noise reduction or structure enhancement, the pixel values are modified without the intention of color modification.
- It optionally needs the input device profile.
Image processing with color adjustment
(color enhancement, etc.)

• In the image processing operation with the intention of color modification, such as color enhancement, it optionally assumes an expected visualization condition or a virtual imaging condition.
• Pixel values are modified in the image processing, and another multispectral image is obtained as the output.
• The color adjustment can be done after the conversion to the tristimulus values or the image for visualization, but they are not addressed in this document, because they are covered by the ICC workflow.
**Color rendering**

- Two cases considered:
  - The original multispectral image is persistent, the information on the color reproduction is kept as metadata.
  - Color image is generated, and will be dealt with conventional color management system, such as the format within the ICC workflow, sRGB, adobeRGB, sYCC, sc-RGB, or xvYCC.

### Diagram

- **Multispectral image** (Original or processed image file)
- **Device profile**
- **Input illuminant spectrum**
- **Rendering illuminant spectrum**
- **ICC profile**
- **Color image** ex., XYZ L*a*b*, sRGB
- **Expected visualization condition**
- **Color conversion**
- **CMF**
- **D2C matrix preparation**
- **Color reproduction**
Pseudo-color representation

- Colors are assigned to the image data but it is not intended to reproduce the natural color.
- In the color assignment, the spectral profile of the imaging device is needed in most cases.
- Two cases considered:
  - The original multispectral image is persistent, the information on the color assignment definition is kept as metadata
  - Pseudo-color image is generated, and will be dealt with conventional color management system.
Colorimetric color reproduction (display)

- Reproduction of scene tristimulus values (reflection objects under input illuminant or emissive objects).

*Note: Some extension will be needed for ICC profile specification in the case of multiprimary color displays.
Colorimetric color reproduction (display)

- Reproduction of tristimulus values under a specific rendering illumination.

Multispectral image (Original or processed image file) → Calculation of tristimulus values
- Spectral reflectance/transmittance estimation
- Spectral radiance estimation

Display device correction

Display device-dependent image

Device profile

CMF

Input illuminant spectrum

Rendering illuminant spectrum

Display device profile

ICC profile is applicable*. 
Spectral color reproduction (display)

- Reproduction of approximated spectral radiance using multiprimary color display.
- Optional constraint of colorimetric match.

*Note: Spectral profile of display device needs to be defined for this application.*
Colorimetric color reproduction (printer)

- Reproduction of tristimulus values under a D50 rendering illumination.

Multispectral image (Original or processed image file)

Calculation of tristimulus values
- Spectral reflectance / transmittance estimation
- Spectral radiance estimation

Output device correction

Output device-dependent image

Output device profile

Input illuminant spectrum

D50 illuminant spectrum

CMF

Device profile

ICC profile is applicable.
Spectral color reproduction (printer)

- Reproduction of approximated spectral reflectance.
- Optional constraint of colorimetric match.

*Note: Spectral profile of output device needs to be defined for this application.*
Image compression

- Spectral transform is a key issue in multispectral image compression.
- Two cases considered:
  - Spectral transform is attained in the compression / decompression system.
  - Spectral transform is performed before the compression and after the decompression system.
Examples

• Spectral color reproduction with multiprimary color display

  Multispectral image capture → Image processing without color adjustment → Color rendering (define the rendering illuminant) → Multispectral image with the rendering illuminant spectrum

  ex. noise reduction

  ex. Spectral approximation under the constraint of colorimetric match.

• Colorimetric color printing using multispectral camera or scanner

  Multispectral image capture → Color rendering (D2C transform) → XYZ or L*a*b* image under D50 illuminant → ICC CMM → Printer

  D50 illuminant spectrum

  ICC profile of the printer

  ICC workflow is applied.
Discussion on the scope of multispectral image format

• The spectral profile is a most important in the workflow of multispectral imaging.
• If the definition of spectral profile is available, some conventional image formats that support multichannel images can be employed, ex., TIFF, JPX, HDF
• Importance and simplicity: category 1 > 2 > 3.
  – Category 1
    • Original multispectral image
    • Processed multispectral image
  – Category 2
    • Multispectral image with expected visualization condition
  – Category 3
    • Image data for multichannel display
    • Image data for spectral printing
  Corresponds baseline, advanced, archival in the requirements?
• The comparison with the requirements discussed in this TC is needed.