High-fidelity color reproduction and multispectral medical imaging

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High-fidelity color reproduction: Questions

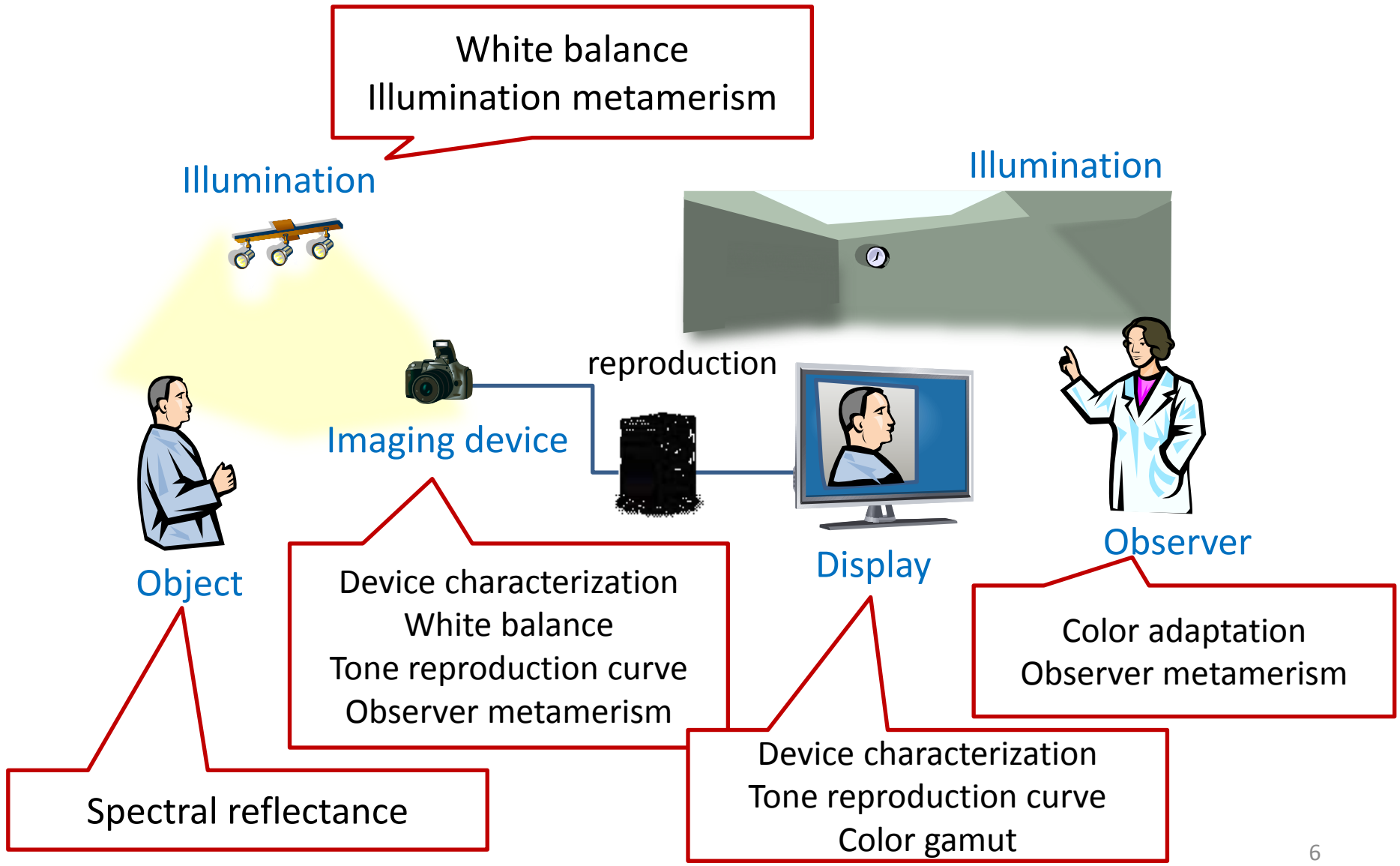
Is “high-fidelity color” significant in medicine?

How is it valuable?

Methodology

- "Multispectral Imaging"
  - Enables extremely high-fidelity color reproduction under different illumination environment.
- Demonstrate "Hi-fi color" to medical doctors. Acquire comments from doctors.
- Experiments:
  - Dermatology (Still image and video)
  - Surgery video
  - Telemedicine
  - Pathology

Issues in color reproduction systems



- **Color reproduction by RGB-based systems**
  - ex. sRGB standard
  - White balance + Device calibration
  - Limited environment
    - Limited object class
      - (considering the statistical characteristics of spectral reflectance)
    - Fixed illumination environments
    - Limited color gamut

- **Color reproduction by multispectral-based systems**
  - Device characterization
  - Higher accuracy and more flexibility
    - Different illumination environments
      - (Illumination spectrum measurement)
    - Arbitrary objects
    - Wider color gamut (device native mode)

Masahiro Yamaguchi, Hideaki Haneishi, Nagaaki Ohyama. Beyond Red-Green-Blue(RGB): Spectrum-Based Color Imaging Technology, Journal of Imaging Science and Technology, Vol. 52, no. 1, pp. 010201-1-15, (2008).

Dermatology (Still Image)

- Captured 16-band multispectral images of cutaneous lesions.
- Reproduced the images on a calibrated monitor.
- Dermatologists visually evaluated the images.

In cooperation with Kagawa Univ. Hospital

Evaluation by dermatologists:

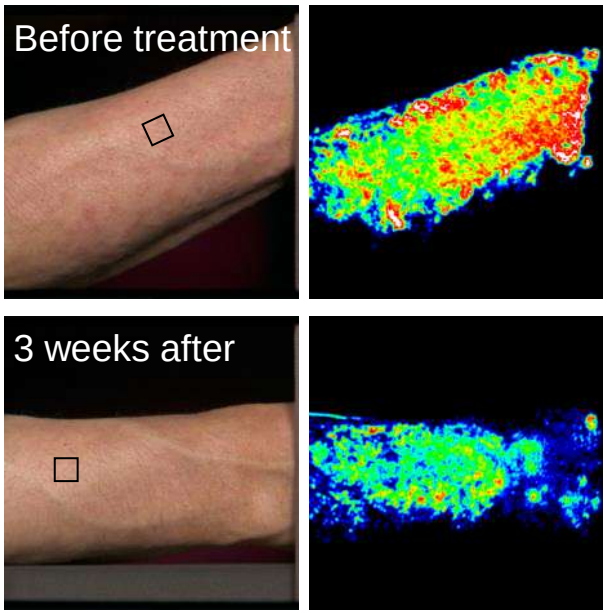
- The reproduced color is very natural
- Even better than reversal slide film
- Faint color variation is clearly reproduced

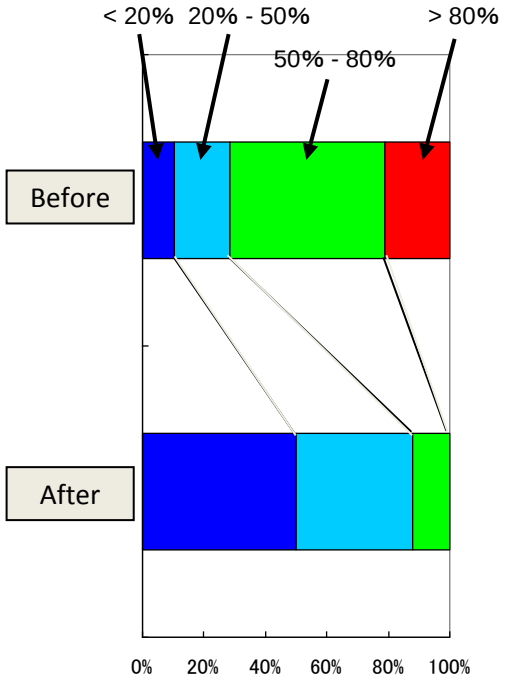
Psoriasis case

Natural color reproduction from 16-band image

Dermatology (Still Image)
Utilizing quantitative color information

Psoriasis: Spectrum-based color enhancement





Quantification of skin lesions

High-fidelity color and Spectral information is also useful for Computer Aided Diagnosis
- Quantification of skin disease
- Assessment of treatment
- Explanation to patient

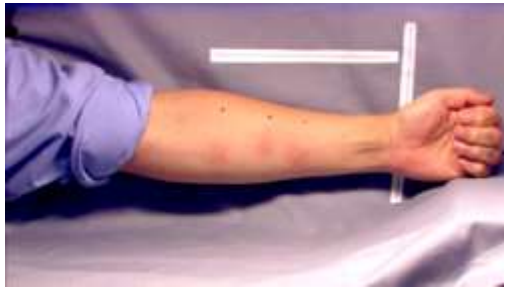
Dermatology (Still Image) Discussions

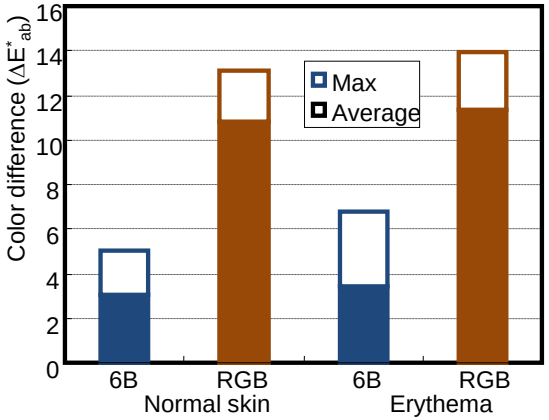
- The accuracy of color reproduction from 3-channel image is worse in some cases;
  - Scleroderma and dermatomyositis give visually apparent color difference
- Hi-fi color reproduction is suitable for case DB, teledermatology…
- High-fidelity reproduction is required for specific types of diseases
  - Dermatomyositis ex. “heliotrope rash,” Pigmented spots ex. nevus spilus
- Possibilities of skin disease quantification or grading using color:
  - Quantitative evaluation: effect of treatment, explanation to patient
  - Identification of inflammatory and immunologic disease: ex. support general physicians
  - Acne grading

Masahiro Yamaguchi, et. al., “Multispectral color imaging for dermatoligy:application in inflammatory and immunologic deseases,” Proc. IS&T/SID 13th Color Imaging Conference, pp. 52-58, (2005).

Dermatology (Video)

- Experiments using 6-band and conventional-RGB HD videos
- Artificial erythema - Simulating typical flare, ex. Urticaria
  - "Prick tests" of histamine, cedar pollen, and mite allergen





Color difference between real skin and reproduced image

- Dermatologists were asked to measure erythema size when it found.
- Real Skin, 6-band, and conventional RGB.
- Result:
  - No significant difference between RGB and 6B systems in Erythema size measurement
  - Oversight in the 3B system (Erythema sizes were not measured)

	6-band HDTV	Conventional HDTV
Oversight	0	8
Total observation (3 dermatologists)	80	60

≅ 13%

Dermatology (Video)
Comments from dermatologists

- The color reproduction by conventional RGB system is not sufficient especially in reddish colors, not suitable for the diagnosis of subtle flare such as measles, virus infection, and drug allergy.
- The image color in 6B system looks natural, and the reddish and yellowish colors can be easily discriminated.
- The profile of the erythema, the dilatation of blood capillary are clearly observed in 6B system.
- Expected applications:
  - Monitoring or recording of surgery
  - The observation of circulatory disorders.
  - The condition and the area of inflammation in inflammatory diseases.
  - Intraepidermal carcinoma, ex., Paget's disease, the subtle color variation is important to determine the extent of tumor.
  - Precancerous skin diseases, which depend on the color appearance of dark or light tan, pink, and red colors.

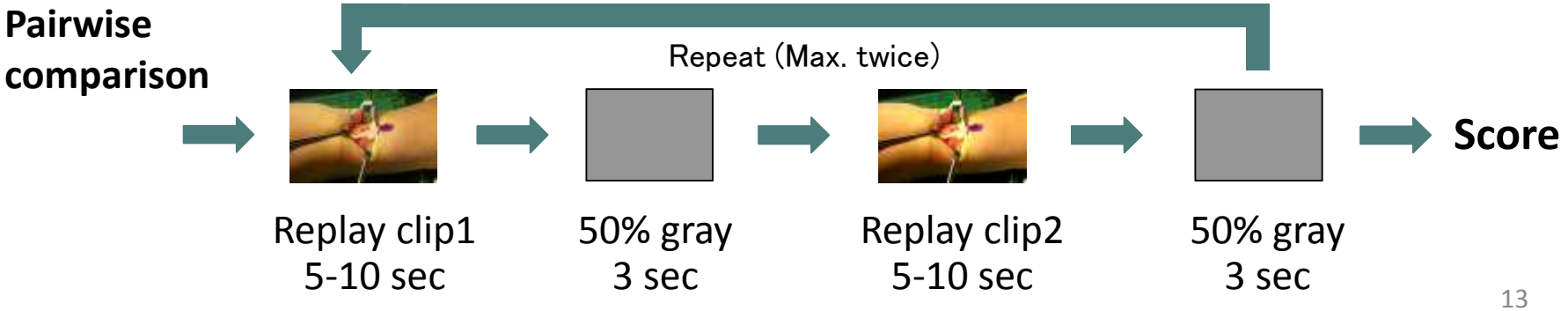
Surgery video

- ✓ OR displays
- ✓ Case archive
- ✓ Conference
- ✓ Education
- ✓ Telementoring
- ✓ Telesurgery

- Reproduced color differs from the original object

  Ex. The region of resection

➔ 6-band video recording and subjective evaluations



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Surgery video
Experimental results and discussions

- The color of blood distributes outside of conventional display color gamut.
- Subjective evaluation by pairwise comparison of 6-band and conventional RGB videos
  - **6-band system is significantly superior in "Color reproducibility," "Fidelity," "Material appearance"**
  - "Grayscale," "Sharpness" "Appropriateness for surgery video" were not clear (Improvement of 6-band camera is required.)
- High-fidelity color video system will be valuable for the case archives, real-time video transmission for remote assistance, laparoscopic surgery, conferences and the educations.

RGB (simulated)

6band

Masahiro Yamaguchi, et. al., "Color reproducibility of skin lesions in multispectral video: Experimental evaluation," 14th Color Imaging Conference, Proc. IS&T/SID 14th Color Imaging Conference, pp. 8-13, (2006).

Videoconference for telemedicine

Demonstration experiment of simulated clinical consultation

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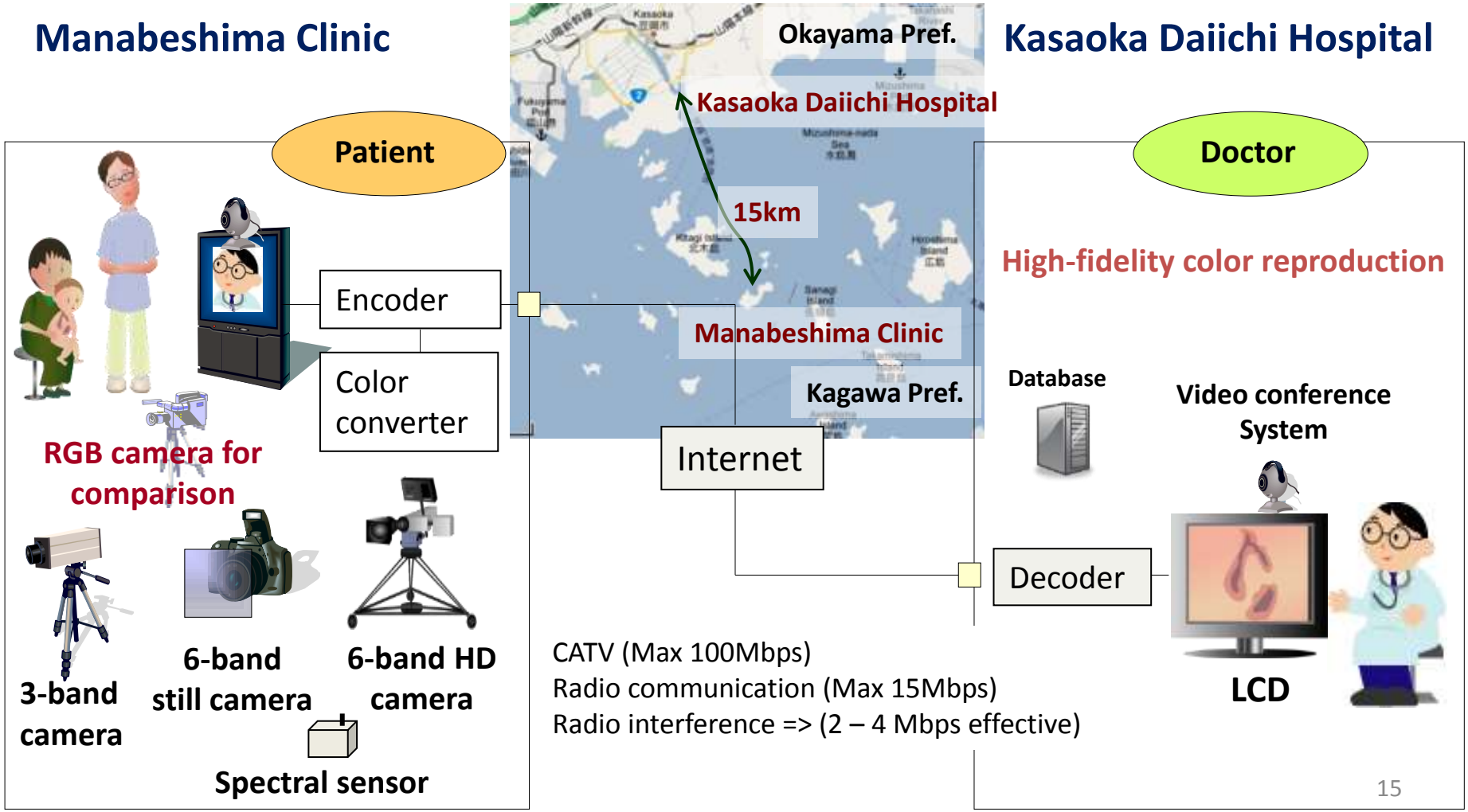
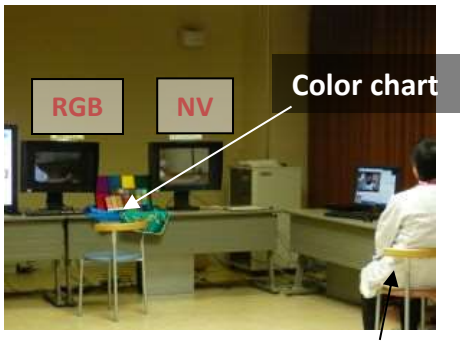


Videoconference for telemedicine Discussions

- Teleconsultation between hospital and clinic in remote island is really needed to improve the patient care in remote island.
- The reality of the reproduced image was highly evaluated by the participated medical doctors.
  - Especially - complexion / skin color.
- The combination of videoconference and high-resolution still image seems to be practical.

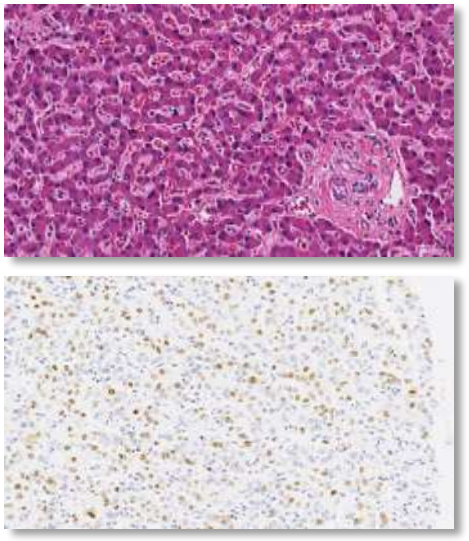
Manabeshima Clinic



Kasaokadaiichi Hospital

Masahiro Yamaguchi, et. al., "Video-Telemedicine with Reliable Color Based on Multispectral Technology," Advances in Telemedicine: Technologies, Enabling Factors and Scenarios, Edited by: Georgi Graschew and Theo A. Roelofs, Intech, (2011).

Digital Pathology



- Color variations in histopathology image
  - Device dependence
  - Staining condition
- Pathologists are forced to compensate such color variations by mental processing.
- Image analysis for computer aided pathology diagnosis
  - Valuable for the decision of treatment.
  - Color correction is one of the key issues

Digital pathology
Color correction experiment

- Device characterization
  - Color calibration slides
    - Color chart slide
    - HE stained mouse embryo
  - Gold standard:
    captured by multispectral microscope
  - Regression model applied.
- Results of color correction

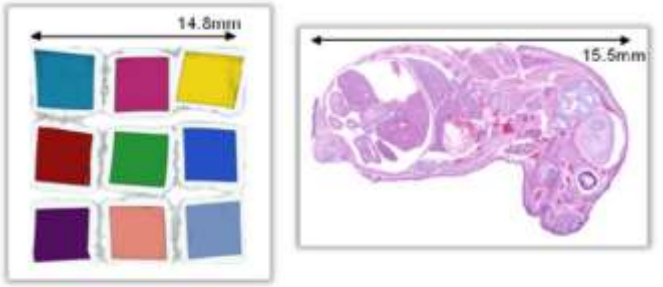
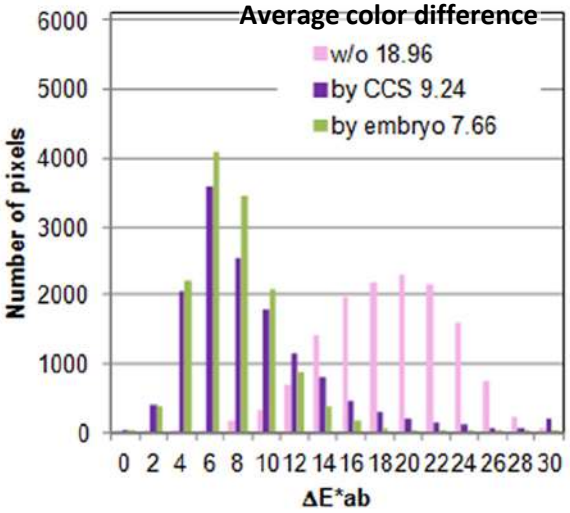
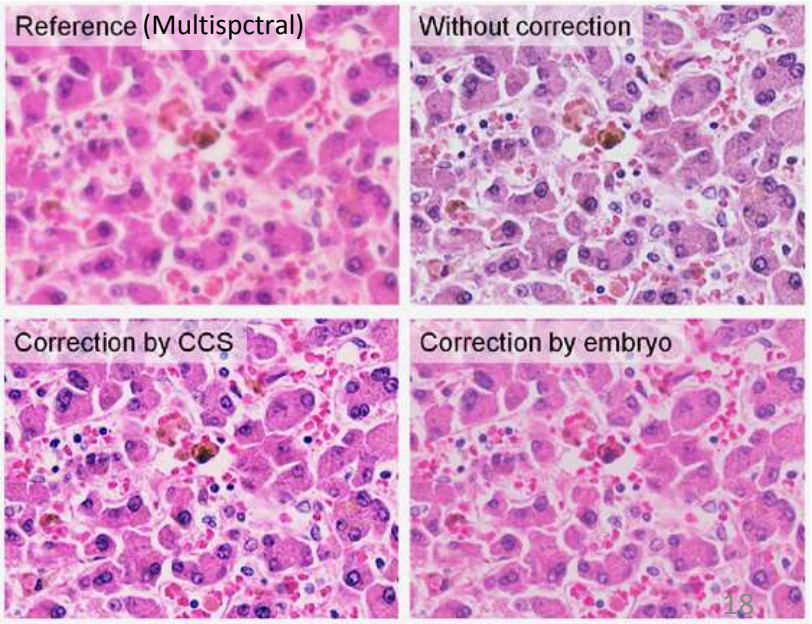


***Figure 1**. A set of calibration slides; MGH color charibration slide (left) and H&E stained mouse embryo slide (right).*

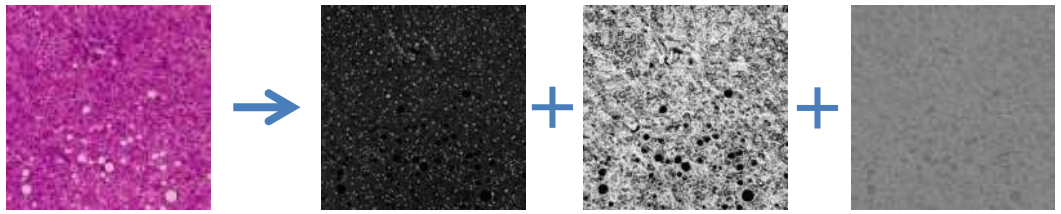




Yuri Murakami, et. al., "Color Correction in Whole Slide Digital Pathology," 20th Color and Imaging Conference, 253-258 (2012)

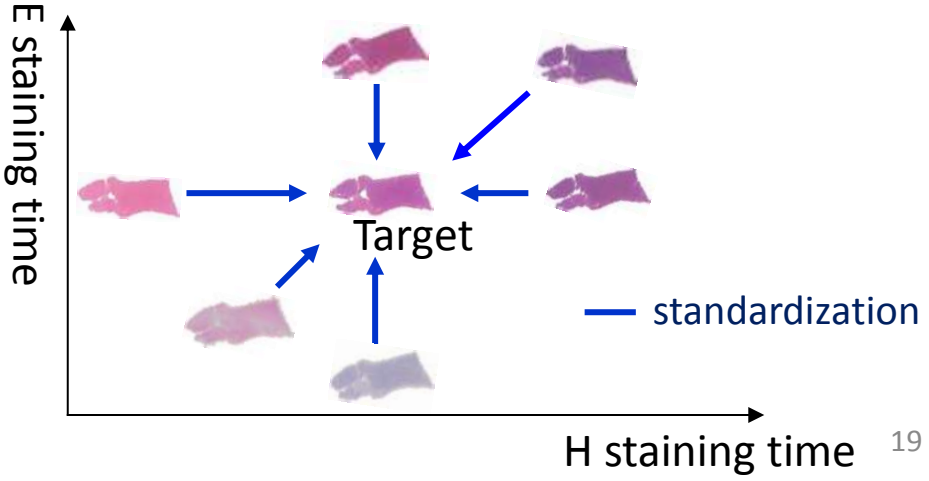
Digital Pathology
Correction of staining variation

- Color unmixing
  - Estimation of dye amount image

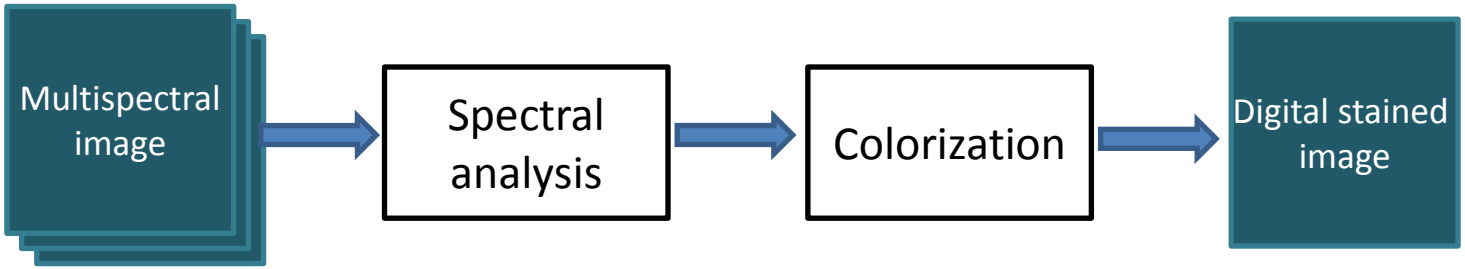


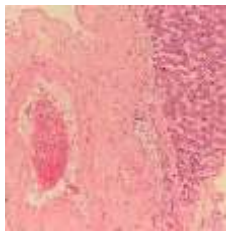
- Adjustment of weighting factors for dye amount images
- Re-mix a color image

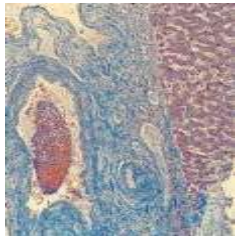
➢ **Standardization of staining condition**

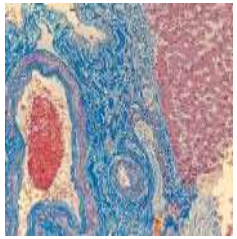


Digital Pathology
Digital staining using multispectral images

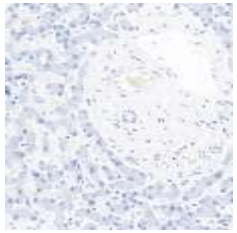


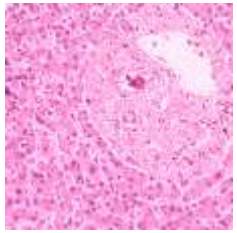

HE

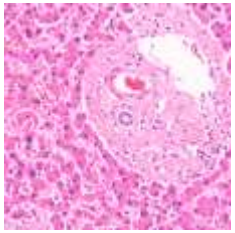

Digital MT from HE

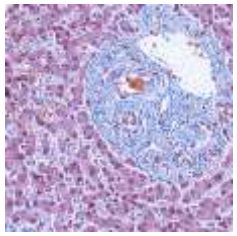

Real MT of serial section

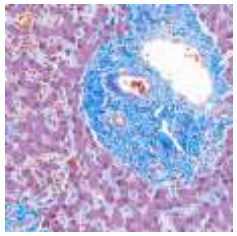
Spectral features used
- Shift of eosin absorption peak
- Attenuation due to scattering


H-only


Digital HE from H-only


Real HE of serial section


Digital MT from H-only

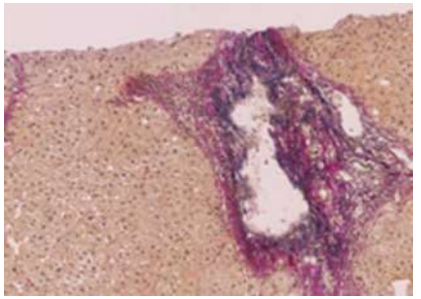

Real MT of serial section

Pinky A. Bautista, et. al., "Digital staining for multispectral images of pathological tissue specimens based on combined classification of spectral transmittance," Computerized Medical Imaging and Graphics, Vol. 29, No. 8, pp. 649-657, (2005).

Digital Pathology
Fibrosis evaluation with color correction

- EVG (Elastica van Gieson) stain
  - Nuclei: black-brown
  - Elastic fiber: black
  - Collagen: Red
  - Cytoplasm and muscles: yellow

→ **Quantification of fibrosis**



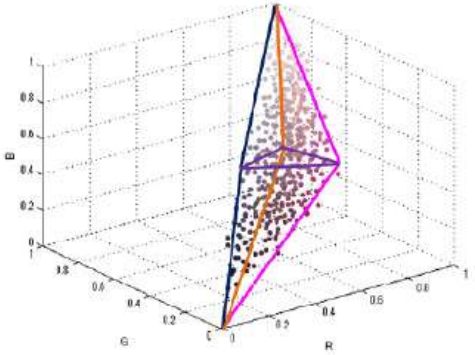


***Figure 10**. Model of color distribution of EVG stained tissue sample, consisting of two triangular pyramids*

- **Color correction**
  - Color gamut of stained image is modeled by tetrahedron
  - Color space is distorted to fit to the gamut of reference image.
  - Colors are sampled from specific region that contains all colors.

In cooperation with Keio Univ., NEC corporation

Yuri Murakami, et. al., "Color Correction in Whole Slide Digital Pathology," 20th Color and Imaging Conference, 253-258 (2012)

Discussions and Summary

- Significance of “high-fidelity color” and “quantitative color”
  - Dermatology
  - Surgery video
  - Teleconsultation
  - Digital pathology
- Not only for telemedicine, but the introduction of digital color imaging technology to visible light images will provide much benefits.
  - Database
  - Quantitative analysis for supporting diagnosis, explanation to patients

What aspect of color is most important for telemedicine: accuracy, consistency or discrimination?

- Accuracy
  - "To be" in near future.
    - Required in the observation of complexion, or face color.
    - Specific types of lesions in dermatology, such as pigmented spots, heliotrope rash of dermatomyositis.
- Discrimination
  - Crucial in many cases of color imaging
    - Evaluation of the area of skin lesion,
    - Visual or automatic measurement of histology or cytology images
    - Decision of resection area based on faint color difference of tumor in surgery operation.
- Consistency
  - Without consistency, the color information is meaningless.

What one step (if any) would you suggest we should take in order to improve the handling of color within your area of expertise?

Methods and Criteria for the color reproduction capabilities of input and display devices

Then users will be able to choose appropriate system for respective purposes.

Acknowledgements

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