UNIVERSITY OF LIVERPOOL

CIC Workshop 2

Multi-Disciplinary Challenges in the Measurement and Reproduction of Skin Colors

23 October 2015

Welcome

Kaida Xiao
University of Liverpool, UK

Dave Connah
University of Bradford, UK

Skin colour measurement

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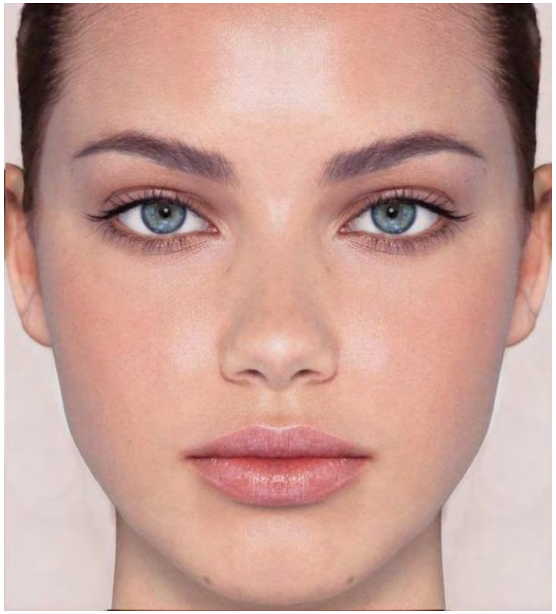
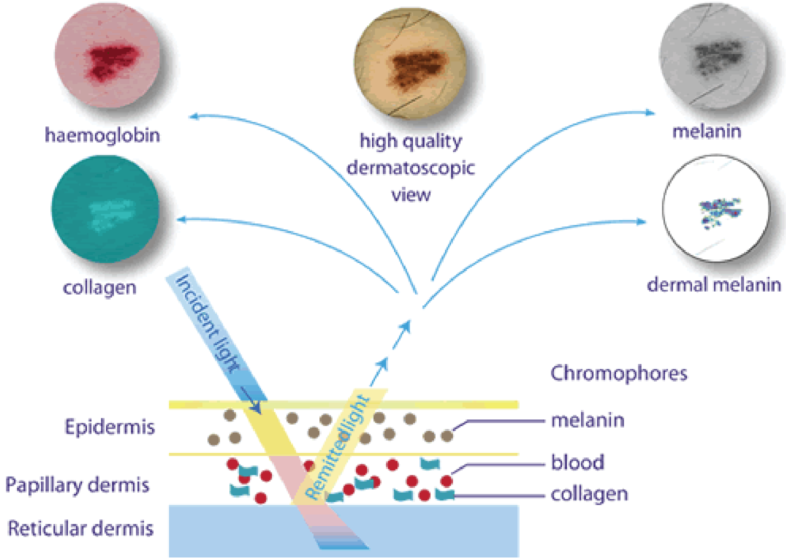


3D shape

Non-uniform colour distribution

Complicated structure



Un-stable

Skin colour measurement

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Skin color database

- **Year Established:** 2013
- **Terms of Reference:**

1. To investigate the uncertainty in skin color measurement and to recommend protocols for good measurement practice.

2. To tabulate skin color measurements that accord with these protocols covering different ethnicity, gender, age and body location.

- **Chair:** K Xiao GB
- **Members:** Paula Alessi US, Peter Bodrogi DE, Francisco Imai US, Peili Sun TW, Suchitra Sueeprasan TH, Wen Luo GB, Esther Perales ES, Changjun Li CN, Mengmeng Wang GB.

ICC Medical Imaging WG

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Medical Imaging Activity: Imaging and reproduction of skin

- Understand the challenges in measurement and reproduction of skin
- Clarify the requirements of different users of skin reflectance data
- Review best practices in skin measurement and reproduction
- Agree a method of estimating skin reflectance from RGB image data
- Develop a publicly accessible database of skin images and skin reflectance data

Project coordinator: Kaida Xiao

International Color Consortium®

Skin colour applications

Simulate what we see

- Skin appearance reproduction
- Skin image rendering
- Skin makeup
- Skin colour detection
- Skin for colour rendering index
- Facial impression
- Medical photography
- Soft tissue prostheses

Skin colour applications

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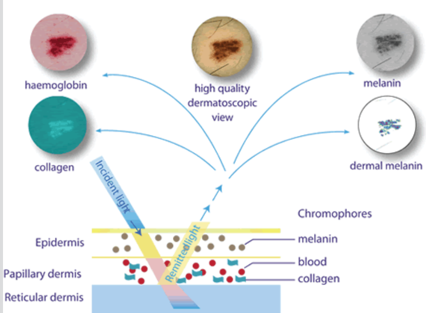
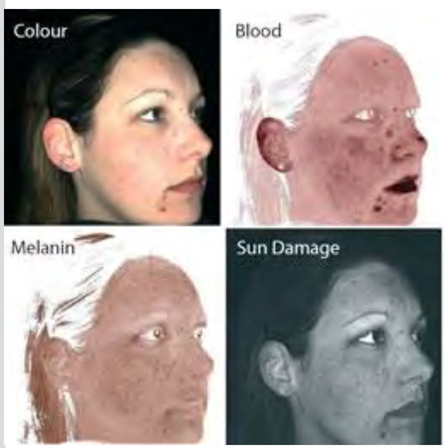
Beyond what we see





Skin chromosphere prediction

- Analysing skin quality
- Detecting various skin diseases
- Monitoring health status
- Evaluating convalescence

Proof for Evolution Psychology

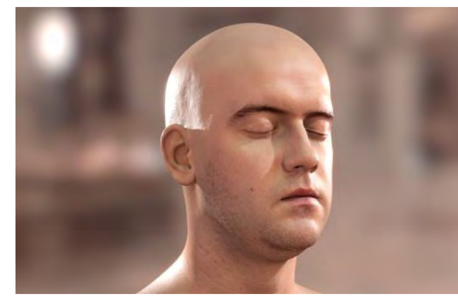
- Sexual dimorphism
- Skin colour discrimination in the human visual system

Skin colour applications

Soft tissue prostheses

- Colour accuracy
- Colour appearance, reflectance

Skin image rendering



- Colour realistic
- BRDF

Medical photography

- Colour reliability
- Colour appearance

Objective of workshop

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- To investigate methods and best practices for skin colour measurement, skin image capture, and reflectance prediction for skin images.
- To explore current and future applications for skin measurement and databases.
- To bridge the gap between skin colour imaging and measurement, with skin colour application in industry and medicine.

Presentations

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9:10 AM Fundamentals of skin color reproduction for tele-medicine

Francisco Imai; Canon USA, USA

9:40 AM A multispectral imaging system for dermatology studies

Wei-Chung Cheng; US Food and Drug Administration, USA

10:10 AM Uncertainty of skin colour measurement and database

Mengmeng Wang; University of Leeds, UK

10:40 AM Coffee break

11:00 AM Skin colour gamut for different ethnic groups

Changjun Li; University of Science and Technology Liaoning, China

11:30 AM Physics and physiologically based skin color image analysis and synthesis

Mai Sugawara and Norimichi Tsumura; Chiba University, Japan

Fundamentals of skin color reproduction for tele-medicine

Workshop on Multi-Disciplinary Challenges in the Measurement and Reproduction of Skin Colors

CIC 2015, Darmstadt, Germany

October 23th 2015

Francisco H. Imai

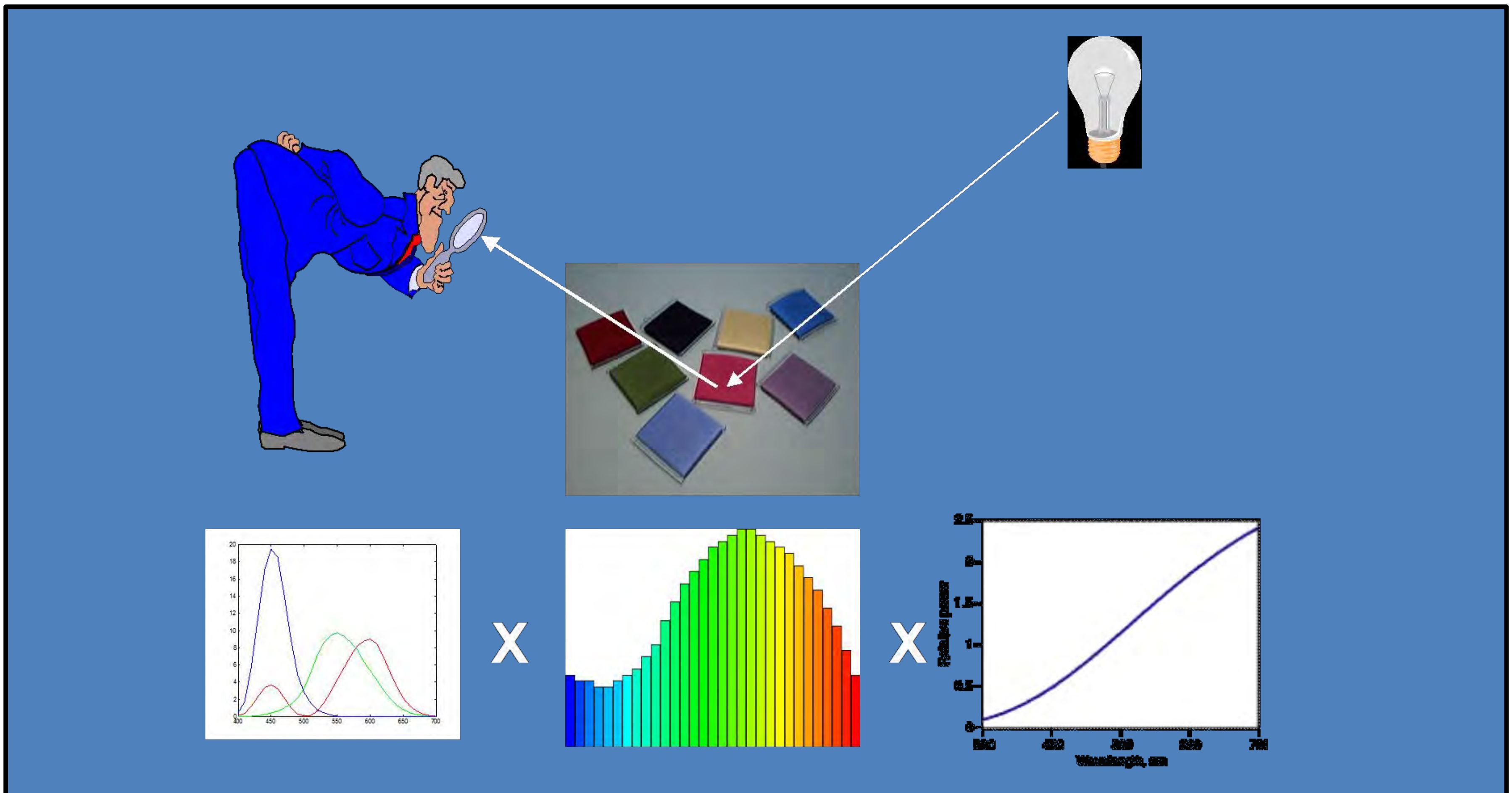
Disclaimer

- This presentation conveys a personal point of view and I am not representing my current or past employers. This presentation is based entirely on publically available material already disclosed by me or by a third party.
- This presentation contains research done in the past at Chiba University and it will focus just on color appearance and spectral reproduction aspects of skin as introduction to other aspects to be discussed this morning in more depth, such as measurement method, measurement uncertainty, color gamut and other aspects of appearance beyond color (e.g. texture and translucency)

Outline

- Spectral imaging
- Skin spectral estimation and image databases
- Adaptive spectral imaging
- Skin color appearance
- Measuring skin color appearance in images

Color perception



Trichromatic Imaging

- Metameric
- Most devices violate Luther condition
- Illuminant change intolerance
- Susceptible to error accumulation in CMS (Color Management System)
- Discards valuable characteristic data at input

Spectral Imaging

- No more standard observer
- Illuminant change easy
- Transcends media
- Input for multi-color output
- Preserves valuable characteristic data
- Increases imaging system complexity

Spectral imaging applications

- Fine arts/museum analysis and archiving
- Medical imaging
- Hi-Fi printing
- Textiles
- Industrial inspection and quality control
- Computer graphics

Spectral imaging principle

Multi-band images $Im = T * Ref$ (Spectral reflectance)

Inverse problem:

$$Ref = T^{-1} * Im$$

Quality of estimation depends on:

- Database (spectral reflectance measurements and multi-band images)
- Quality of transformation

Procedure I
System design

1. Selection of digital camera system
   a. Quantum efficiency (spectral sensitivity)
   b. Linearity
   c. Bit depth
   d. CCD imaging size
   e. Noise characteristics
   f. Infra-red cut-off wavelength
2. Selection on filtering
   a. Narrow-band
      I. Liquid-crystal tunable filter
      II. Interference filters
   b. Wide-band   I. Filter design
3. Considerations about illumination
   a. Spectral power distribution (smoothness, noise, temporal stability)
   b. Diffuse x spot light

Procedure II
Imaging

01. Selection of calibration target
02. Measure spectral reflectances of calibration target
03. Set-up camera, illumination and target
04. Check for light space uniformity
05. Exposure metering for each filter/channel (aperture and speed). Special attention to clipping
06. Imaging calibration target
07. Imaging gray uniform card (flat fielding)
08. Imaging dark current (shutter closed / caps on)
09. Correct each image based on camera set-up
10. Register images if it is necessary

Procedure III
Transformation and Evaluation

1. Create digital masks for the uniform color patches
2. Use the masks to extract the camera signals
3. Build a transformation from camera signals to measured reflectance spectra:
    - Pseudo-inverse
    - Eigenvectors
    - Smooth inverse
    - Wiener filtering
4. Evaluate the transformation for the verification targets
    - Objective metrics (CIEDE2000, RMS, Metameric Index)
    - Curve comparison plots (between measured and estimation)
    - Subjective evaluations for pictorial images

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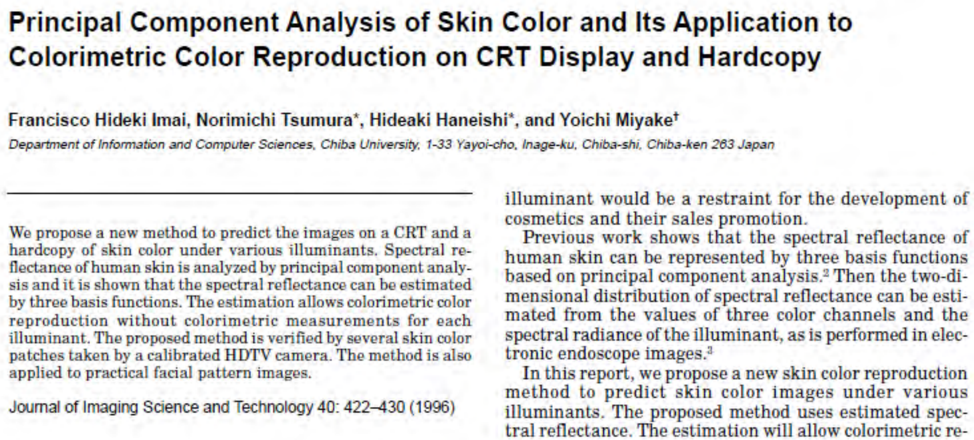
Skin spectral estimation



Principal Component Analysis of Skin Color and Its Application to Colorimetric Color Reproduction on CRT Display and Hardcopy

Francisco Hideki Imai, Norimichi Tsumura*, Hideaki Haneishi*, and Yoichi Miyake†
Department of Information and Computer Sciences, Chiba University, 1-33 Yayoi-cho, Inage-ku, Chiba-shi, Chiba-ken 263 Japan

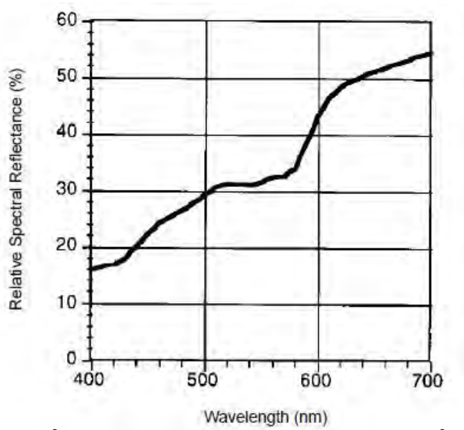
We propose a new method to predict the images on a CRT and a hardcopy of skin color under various illuminants. Spectral reflectance of human skin is analyzed by principal component analysis and it is shown that the spectral reflectance can be estimated by three basis functions. The estimation allows colorimetric color reproduction without colorimetric measurements for each illuminant. The proposed method is verified by several skin color patches taken by a calibrated HDTV camera. The method is also applied to practical facial pattern images.

Journal of Imaging Science and Technology 40: 422–430 (1996)

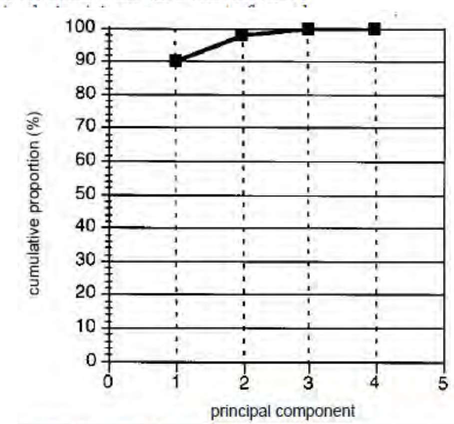
illuminant would be a restraint for the development of cosmetics and their sales promotion.

Previous work shows that the spectral reflectance of human skin can be represented by three basis functions based on principal component analysis.[2] Then the two-dimensional distribution of spectral reflectance can be estimated from the values of three color channels and the spectral radiance of the illuminant, as is performed in electronic endoscope images.[3]

In this report, we propose a new skin color reproduction method to predict skin color images under various illuminants. The proposed method uses estimated spectral reflectance. The estimation will allow colorimetric re-



- Skin spectra is smooth

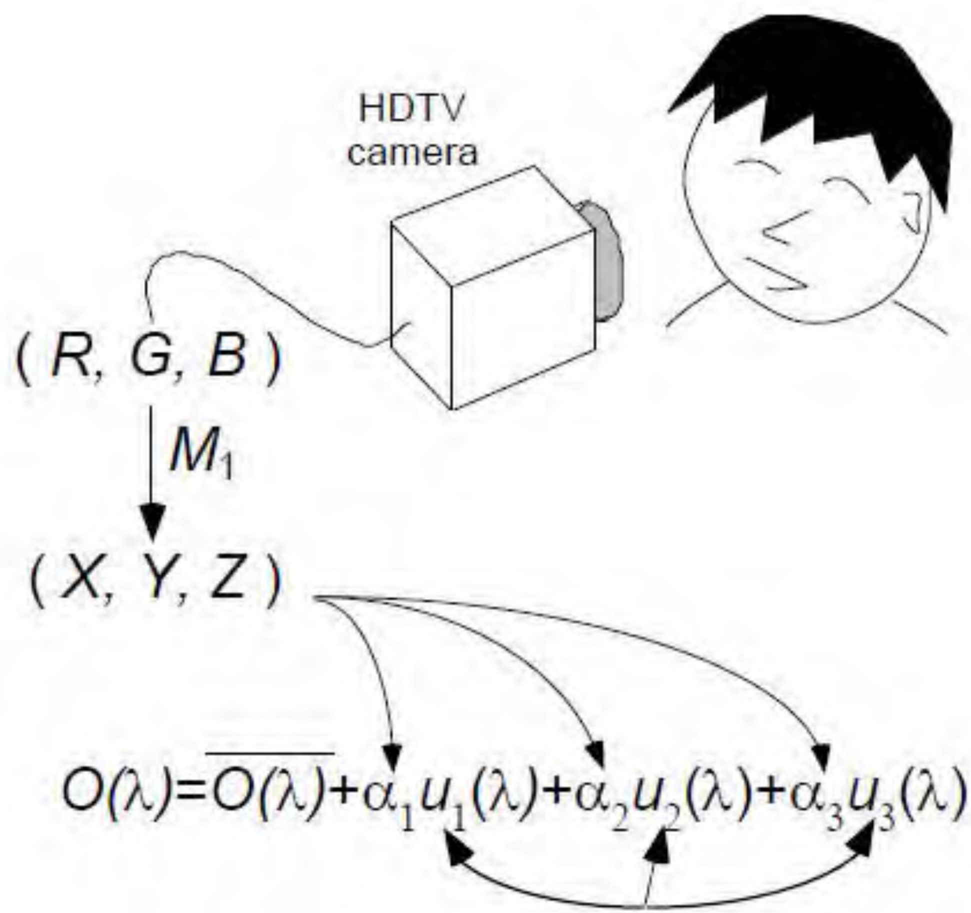


- 3basis vectors are sufficient for reconstruction

Conclusion: 3-band camera (RGB) can give signals to estimate coefficients of 3 basis functions to reconstruct skin spectra

Reference: Imai et al., Journal of Imaging Science and Technology 40, 422-430 (1996)

Spectral estimation



Reference: Ph.D. Thesis - **www.cis.rit.edu/people/staff/imai/PhDThesis.pdf**

Spectral decomposition

- Extend Wyszecki hypothesis to any arbitrary detector (not just human eye)

  Detection component $\boldsymbol{D} = [\boldsymbol{R}] * \boldsymbol{Spec}$; *and*

  Residual components $\boldsymbol{Res} = (\boldsymbol{I} - [\boldsymbol{T}]) * \boldsymbol{Spec}$ or $\boldsymbol{Res} = \boldsymbol{Spec} - \boldsymbol{D}$

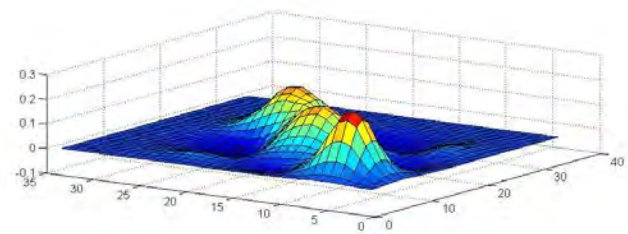
  where ***I*** is an *m* by *m* identity matrix

  $$[\boldsymbol{T}] = \boldsymbol{W} * (\boldsymbol{W}' * \boldsymbol{W})^{-1} * \boldsymbol{W}',$$

  where ***W*** is an *m* by 3 matrix of detection weights that were calculated as a product between the normalized spectral-power distribution ***S*** of a selected illuminant and the detector spectral sensitivities ***Dec***

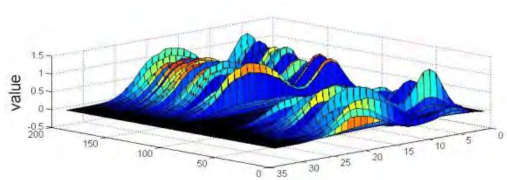
  W' denotes the transpose matrix of ***W***; and where the superscript $^{-1}$ denotes an inverse matrix.

Use of signatures derived by both detection and residual components for material identification

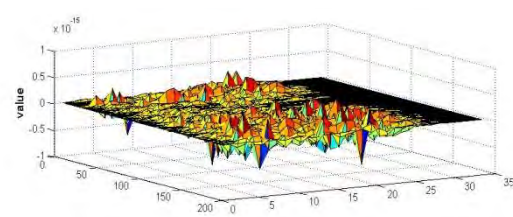


Matrix [R]

Detection



Residual



AIC 2013
SCAD 2013

Skin reflectance image database - 1

International Symposium on Multispectral Imaging and Color Reproduction for Digital Archives 117
October 21-22 1999 Keyaki Hall, Chiba University, Chiba, Japan

Lippmann2000: A Spectral Image Database Under Construction

LCTF + Film

Mitchell R. Rosen and Xiao-Yun (Willie) Jiang*

Munsell Color Science Laboratory
Rochester Institute of Technology

Fig. 6. Converted golf bag cart used as brace for head during 16 exposures.

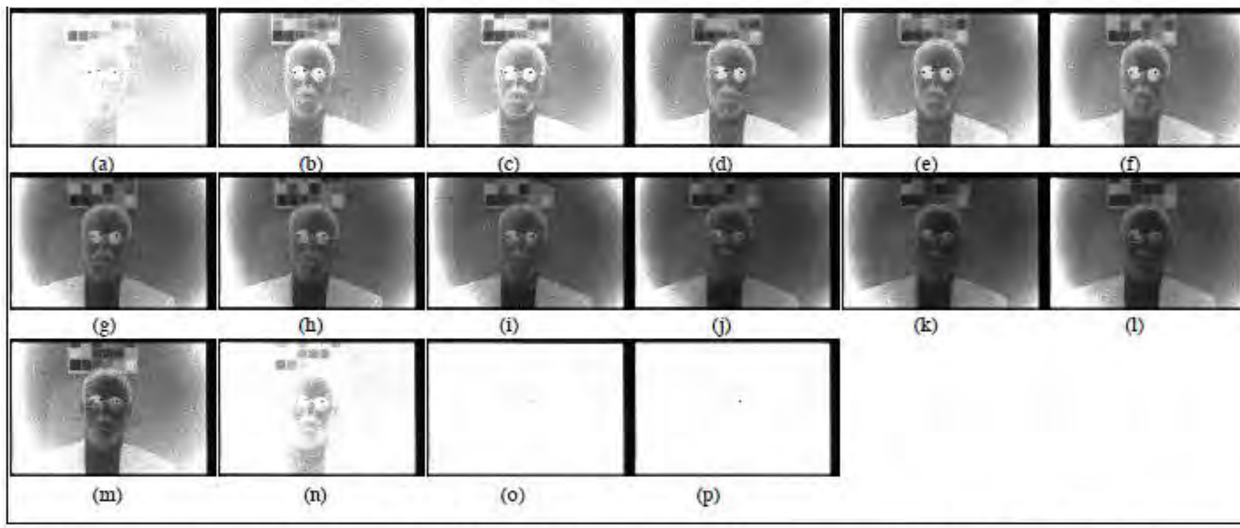


Fig. 4. Our model, Professor Roy Berns, sits for 16 separate exposures. He does a remarkably good job at not moving. His head is braced by a converted golf bag cart. To accommodate flash recharge, approximately 15-25 seconds lapses between exposures. Flash intensity has been calibrated to the combination of filter efficiency and film sensitivity for each filter bandpass. Nominal center wavelengths passed by the tunable filter: (a) 410nm, (b) 430nm, (c) 450nm, (d) 470nm, (e) 490nm, (f) 510nm, (g) 530nm, (h) 550nm, (i) 570nm, (j) 590nm, (k) 610nm, (l) 630nm, (m) 650nm, (n) 670nm, (o) 690nm, (p) 710nm. Film sensitivity and filter efficiency plummet at approximately 670nm. Last three frames (longest wavelengths) flash intensity turned to maximum giving Professor Berns a suntan. 12-bit scans of negatives produce usable data in long wavelengths. Bright spots on sunglasses can be seen in the illustrations of exposures (o) and (p) above.

Reference: Rosen and Jiang, Proc. of Int. Symposium on multispectral imaging, 117-122 (1999)

Skin reflectance image database - 2

RGB digital camera + absorption filters

JOURNAL OF IMAGING SCIENCE AND TECHNOLOGY® • Volume 46, Number 6, November/December 2002

A New Procedure for Capturing Spectral Images of Human Portraiture

Qun Sun, Mark D. Fairchild
Munsell Color Science Laboratory, Chester F. Carlson Center for Imaging Science
Rochester Institute of Technology, 54 Lomb Memorial Dr., Rochester, NY 14623-5604/USA

Statistical Characterization of Face Spectral Reflectances and Its Application to Human Portraiture Spectral Estimation

Qun Sun▲ and Mark D. Fairchild▲
Munsell Color Science Laboratory, Chester F. Carlson Center for Imaging Science, Rochester Institute of Technology, Rochester, New York

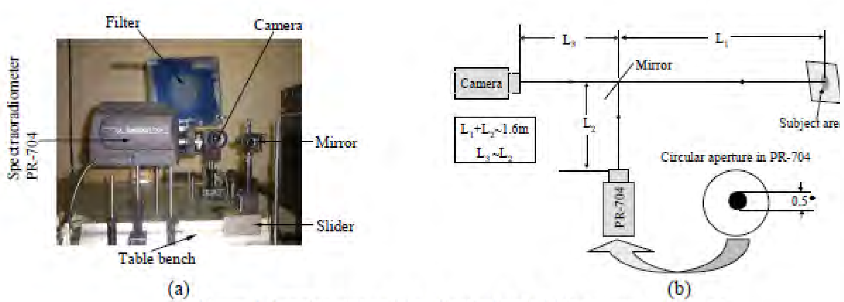


Figure 1. Imaging system (a) and optical path (b) for system calibration.

Figure 3.Samples of original images and estimated spectral images for display. (a) Caucasian subject. Images from top to bottom are R, G and B channel images respectively. Images from left to right are original image without filter, original image with filter, 3P7T image, 3P17T image and 6P7T image. (b) Black subject. The same image arrangement as (a).

References:

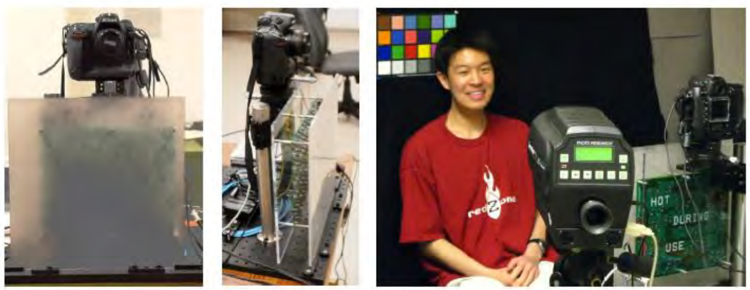
- Sun and Fairchild, Proc. of AIC (2001)
- Sun and Fairchild, JIST 6, 498-506 (2002)

Skin reflectance image database - 3

RGB digital camera + LED illumination

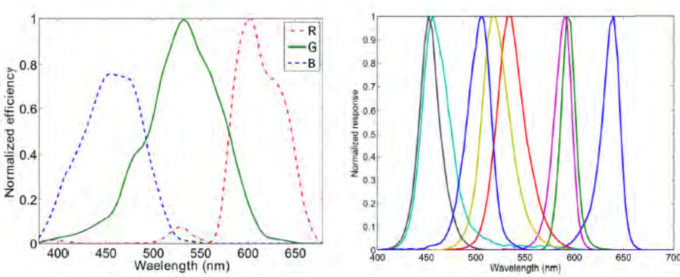
An LED-based lighting system for acquiring multispectral scenes

Manu Parmar[a*], Steven Lansel[b], Joyce Farrell[b]
[a]Qualcomm MEMS Technologies, San Jose, CA-95134, USA;
[b]Electrical Engineering Dept., Stanford University, Stanford, CA-94305, USA



(a) (b) (c)

Figure 5. (a) Front view of the LED lighting system with camera (Nikon D2xs) (b) side-view (c) The system in use for image acquisition.



(a) (b)

Figure 3. (a) Normalized spectral efficiencies of the RGB filters of the Nikon D2xs camera with the Nikon Nikkor 50 mm lens at *f/4* (b) The normalized responses of the 8 different light and camera-filter combinations of the LED lighting system that give useful signal.

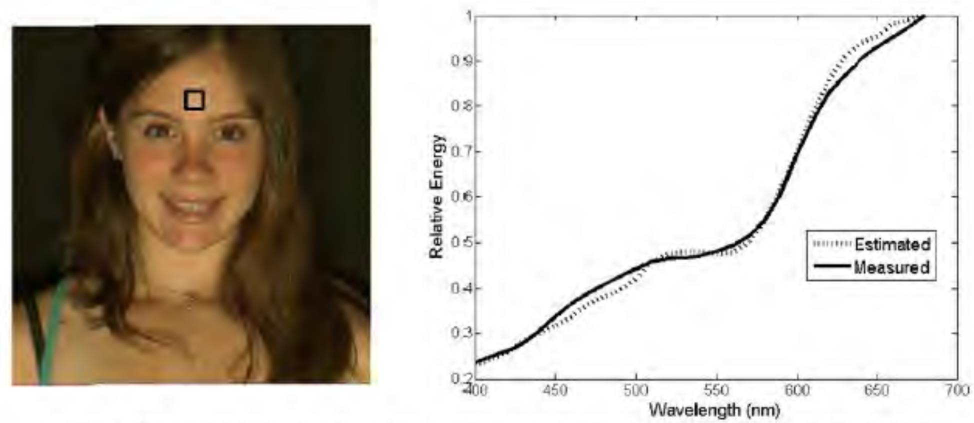


Figure 7. The spectral image of a female face is rendered by summing the energy in long-, middle- and short-visible wavebands and assigning these to the R, G and B primaries, respectively. The graph compares the measured and estimated spectral reflectance of a region selected from her forehead (demarcated with a rectangle).

Reference:

Digital Photography VIII, edited by Sebastiano Battiato, Brian G. Rodricks, Nitin Sampat, Francisco H. Imai, Feng Xiao, Proc. of SPIE-IS&T Electronic Imaging, SPIE Vol. 8299, 82990P · © 2012 SPIE-IS&T · CCC code: 0277-786X/12/$18 · doi: 10.1117/12.912513

SPIE-IS&T/ Vol. 8299 82990P-1

Skin reflectance image database - 4

Hyperspectral imaging

A collection of hyperspectral images for imaging systems research

Torbjørn Skauli[a,b], Joyce Farrell[*a]
[a]Stanford Center for Image Systems Engineering, Stanford CA, USA;
[b]Norwegian Defence Research Establishment, P. O. Box 25, 2027 Kjeller, Norway

Table 1. Basic specifications for the HySpex cameras used to record the images.

	HySpex VNIR-1600		HySpex SWIR-320m-e	
Spectral range	400-1000 nm		9700-2500	
Spectral sampling	3.7 nm		6 nm	
No. of bands	160		256	
Angular field of view	17 degrees		13.5 degrees	
Spatial resolution along FOV	0.185 mrad		0.74 mrad	
Spatial resolution across FOV	0.37 mrad		0.74 mrad	
No. of pixels along FOV	1600		320	
Closeup lens	1 m	3 m	1 m	3 m
Field of view	0.30 m	0.90 m	0.23 m	0.68 m
Spatial sampling along FOV	0.2 mm	0.6 mm	0.7 mm	2 mm
Depth of focus	7 mm	67 mm	28 mm	255 mm

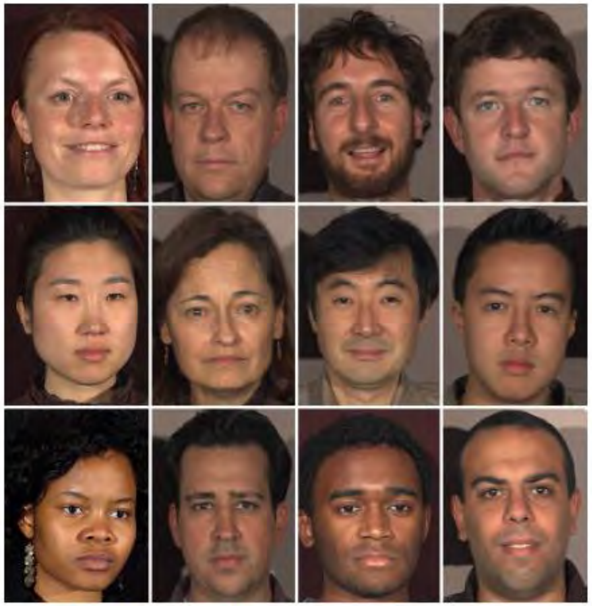


Figure 3. Samples taken from the face database. Although the faces were illuminated by studio tungsten lamps, the faces are shown here rendered under D65.

Digital Photography IX, edited by Nitin Sampat, Sebastiano Battiato, Proc. of SPIE-IS&T Electronic Imaging, SPIE Vol. 8660, 86600C · © 2013 SPIE-IS&T · CCC code: 0277-786/13/$18 · doi: 10.1117/12.2007097

Reference:

Outline

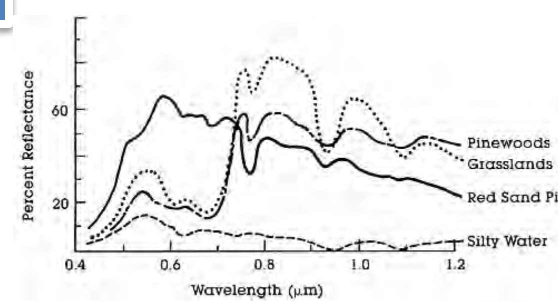
- ❖ Spectral imaging
- ❖ Skin spectral estimation and image databases
- ❖ Adaptive spectral imaging
- ❖ Skin color appearance
- ❖ Measuring skin color appearance in images

Time Multiplexing Multispectral Camera

For static scenes only

Calculations

Spectral reflectance



Multiple-channel captures

- Example: Nuance FX, CRI Inc.
  - Time multiplexing (high quality images may take up to 30 seconds)

Note: Slide prepared by Andy Lin (Stanford) for CIC19 presentation (2011)

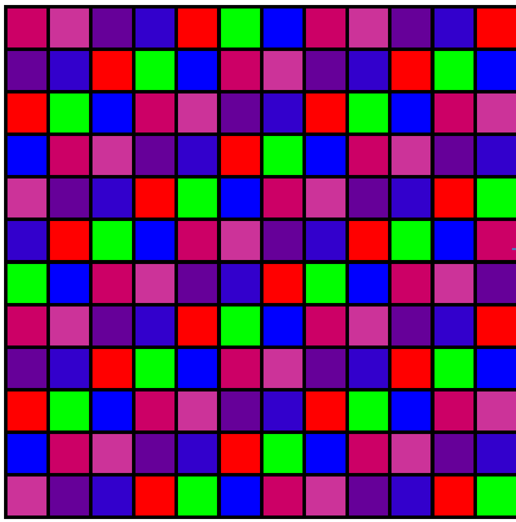
Time Multiplexing Multispectral Camera: Issues with non-static scene capture

Note: Slide prepared by Andy Lin (Stanford) for CIC19 presentation (2011)

Red: unusable regions due to movement

Spectral images from Chakrabarti and Zickler (Harvard University)

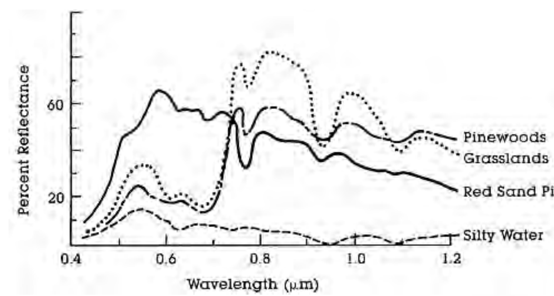
Color Filter Array (CFA) Demosaicing Multispectral Camera



Calculations

Faster capture sacrificing
Spatial resolution

Spectral reflectance



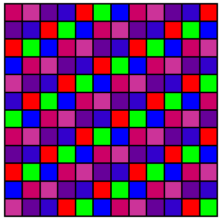
- Example: Canon Expo 50 megapixel camera
  - Medium format camera
  - 6-channel CFA, demosaicing

Note: Slide prepared by Andy Lin (Stanford) for CIC19 presentation (2011)

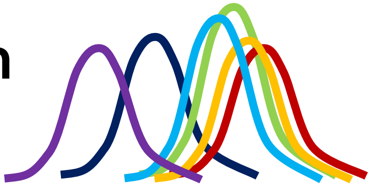
Alternative adaptive systems

- Time multiplexing
  - Fixed exposure duration

- CFA
  - Miao et. al demosaicing



- **Tunable sensor**
  - **Adaptive filter configuration selection**
  - **More accurate than CFA with 2-shots**
  - **As accurate as time multiplexing and much faster**



More details in: A. Lin, **F. H. Imai**, Efficient spectral imaging based on imaging systems with scene adaptaion using tuanble color pixels, *Proc. of 19th IS&T/SID Color and Imaging Conference,* 2011, pp. 332-338.

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Color appearance

JOURNAL OF IMAGING SCIENCE AND TECHNOLOGY • Volume 41, Number 2, March/April 1997

Prediction of Color Reproduction for Skin Color Under Different Illuminants Based on Color Appearance Models

Francisco Hideki Imai, Norimichi Tsumura*, Hideaki Haneishi*, and Yoichi Miyake*
Department of Information and Computer Sciences, Chiba University, 1-33 Yayoi-cho, Inage-ku, Chiba-shi, Chiba-ken 263, Japan, Tel & Fax: +81-43-290-3262, e-mail: imai @ icsd6.tj.chiba-u.ac.jp

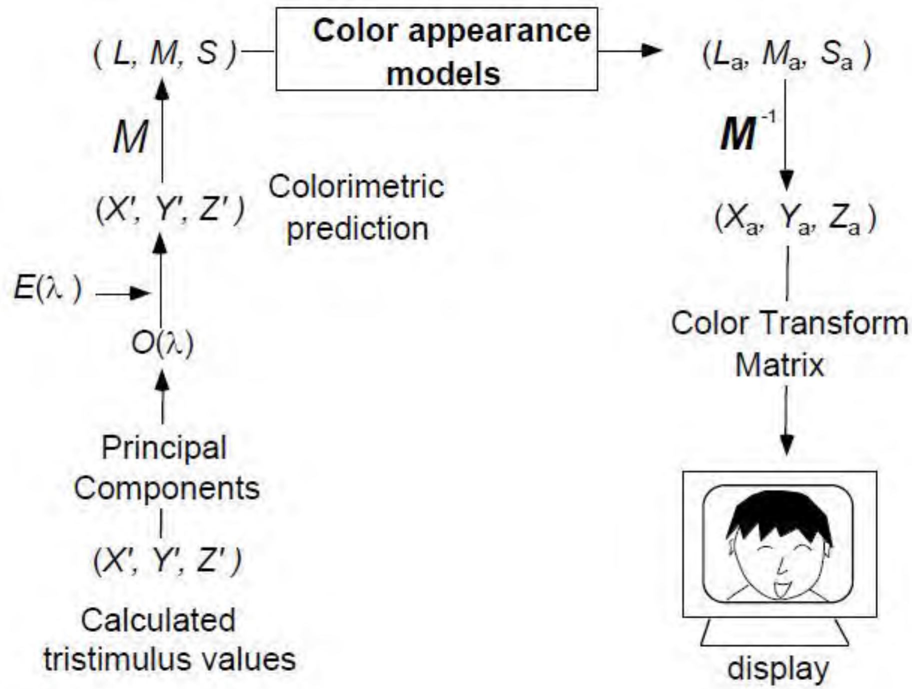
JOURNAL OF IMAGING SCIENCE AND TECHNOLOGY • Volume 42, Number 3, May/June 1998

Improvement of Incomplete Chromatic Adaptation Model for Facial Pattern Images

Francisco Hideki Imai*‡, Norimichi Tsumura*, Hideaki Haneishi*, and Yoichi Miyake†
Department of Information and Computer Sciences, Chiba University, 1-33 Yayoi-cho, Inage-ku, Chiba-shi, 263 Japan

We improved the incomplete chromatic adaptation model proposed by Fairchild to reproduce facial pattern images under various illuminants. We introduced weighting coefficients in the modified fundamental chromaticities of the adapting stimulus used in the Fairchild model to improve the color reproduction. Psychophysical experiments using memory matching technique were performed to select the optimum weighting coefficients of adapting stimulus for facial pattern images. The improved model with the optimum coefficients was compared with other color appearance models, von Kries, RLAB, LLAB, and colorimetric color reproduction under three illuminants; illuminant A (2837 K), Daylight (6047 K) and Cool White (3957 K). As a result, it was shown that the improved model performed significantly well for facial pattern images if compared with other models.

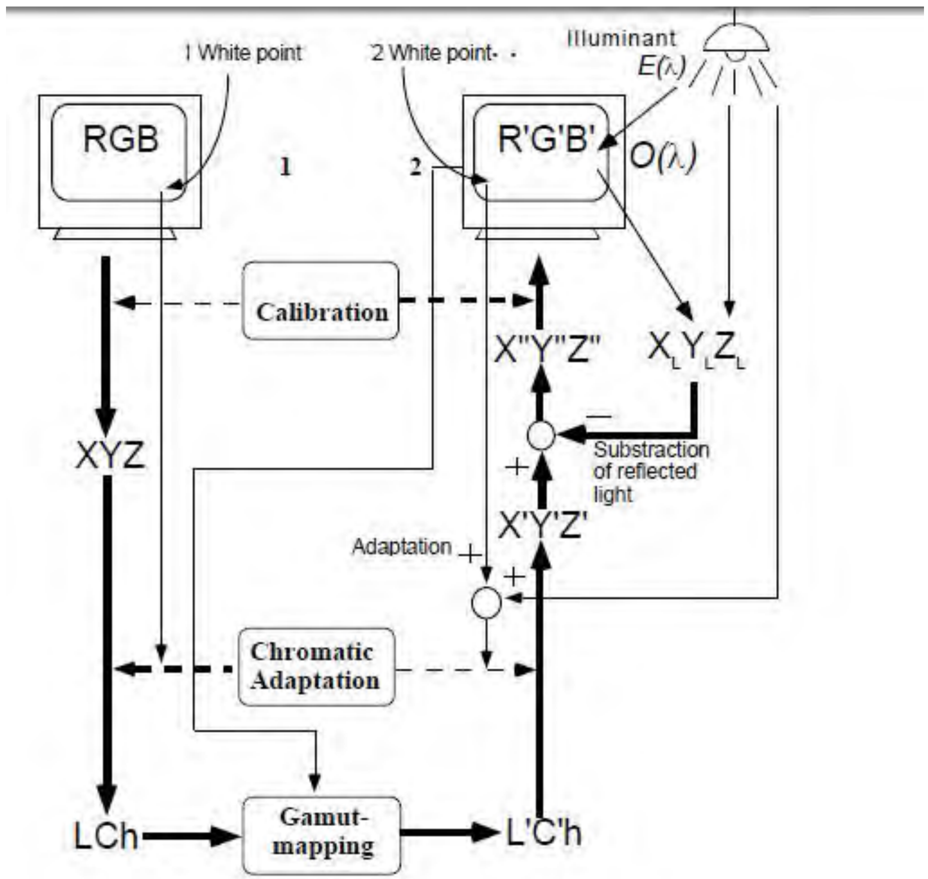
Journal of Imaging Science and Technology 42: 264–268 (1998)



F. H. Imai, N. Tsumura, H. Haneishi and Y. Miyake, Improvement of incomplete chromatic adaptation model for facial pattern images, *J. Imaging Sci. Technol.* **42,** 264-268 (1998).
F. H. Imai, N. Tsumura, H. Haneishi and Y. Miyake, Prediction of color reproduction for skin color under different illuminants based on the color appearance models, *J. Imaging Sci. Technol.* **41**, 166-173 (1997).

Ph.D. Thesis - **www.cis.rit.edu/people/staff/imai/PhDThesis.pdf**

How to preserve color appearance across media



Reference: Ph.D. Thesis - **www.cis.rit.edu/people/staff/imai/PhDThesis.pdf**

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Perceptual metric for color appearance

$$d = \left\{ \begin{bmatrix} \Delta L & \Delta C & \Delta h \end{bmatrix} \begin{bmatrix} 0.2047 & -0.0630 & -0.1071 \\ -0.0630 & 0.1247 & 0.1556 \\ -0.1071 & 0.1556 & 0.9530 \end{bmatrix} \begin{bmatrix} \Delta L \\ \Delta C \\ \Delta h \end{bmatrix} \right\}^{\frac{1}{2}}.$$

F. H. Imai, N. Tsumura and Y. Miyake, Perceptual color difference metric for complex images based on Mahalanobis distance, *J. Electronic Imaging* **10**, 385-393 (2001).

Reference: Ph.D. Thesis - **www.cis.rit.edu/people/staff/imai/PhDThesis.pdf**

Summary

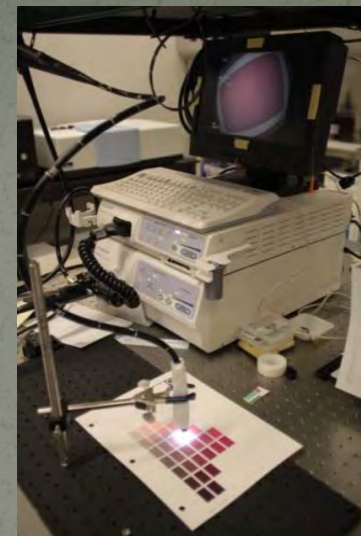
- The quality of the spectral estimation depends on the quality of database and mathematical transformation from captured channels to spectra
- Material detection can be done by decomposing spectra
- For visible skin spectral estimation, 3 channels (RGB) is sufficient
- There are multiple ways to capture skin spectral images:
  - RGB + LCTF
  - RGB + absorption filter
  - RGB + LED lights
  - Hyperspectral images
- There is a need to come with appropriate metrics for skin color appearance

A Multispectral Imaging System for Dermatology Studies

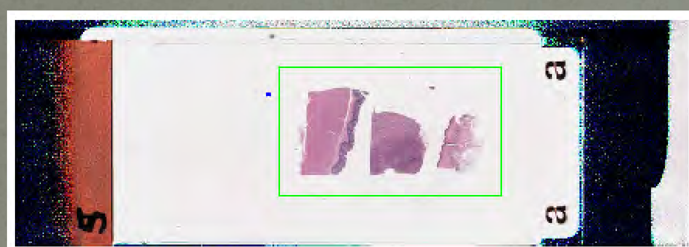
Wei-Chung Cheng
US Food and Drug Administration
Center for Devices and Radiological Health

23rd Color and Imaging Conference
Workshop 2: Multi-Disciplinary Challenges in the Measurement and Reproduction of Skin Colors
10-23-2015

US FDA and Color Research



- US FDA regulates medical imaging devices including
  - Microscope-based: whole-slide imaging system
  - Endoscope-based: flexible and capsule endoscopes
  - X-ray-based: FFDM, tomosynthesis, CT
  - Dermatology, US, MR, PET, gamma-ray, etc.
- Mission
  - Conduct scientific research in support of regulatory decision making

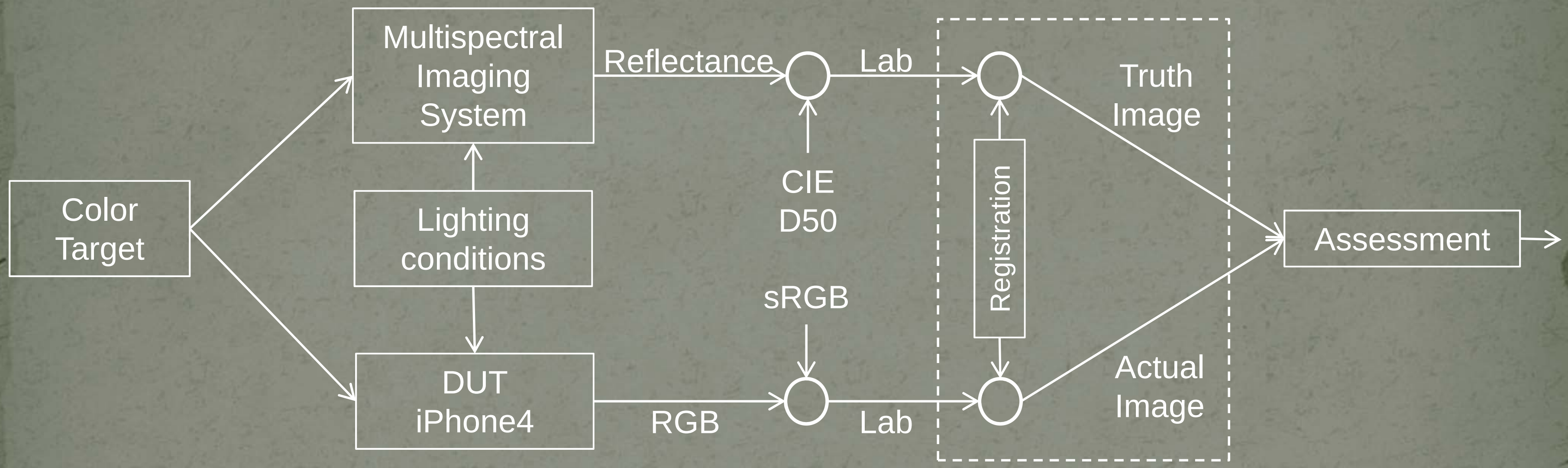


- Disclosures
  - The mention of commercial products herein is not to be construed as either an actual or implied endorsement of such products by the Department of Health and Human Services

Motivation

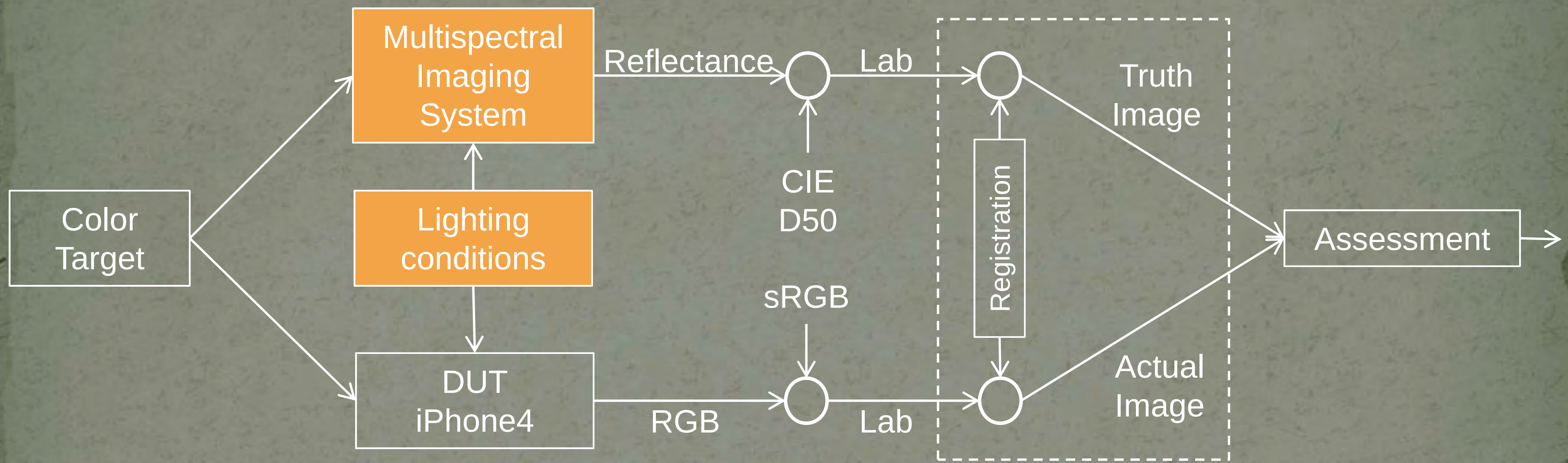
- Telemedicine is promoted by advance in Internet, imaging technologies, and portable electronics
- Dermatology devices do not require special light source or optics
- Mobile apps on various phones for imaging and viewing skin conditions
- Research question: Are these devices safe and effective?

Evaluation Framework



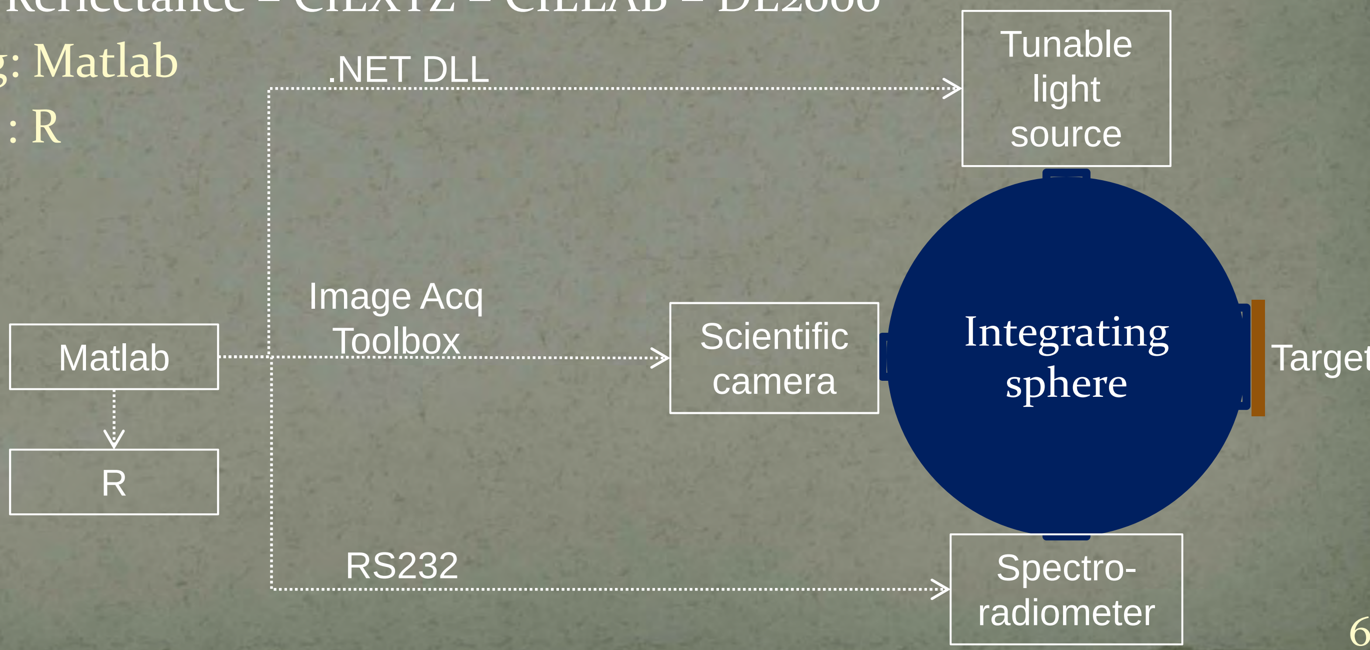
- Project goals
  - A tool for measuring skin reflectance in high resolution
  - A framework for testing mobile cameras in dermatology applications
- Outline
  - Multispectral imaging system
  - Color target
  - Mobile camera
  - Assessment methods

1. Multispectral Imaging System



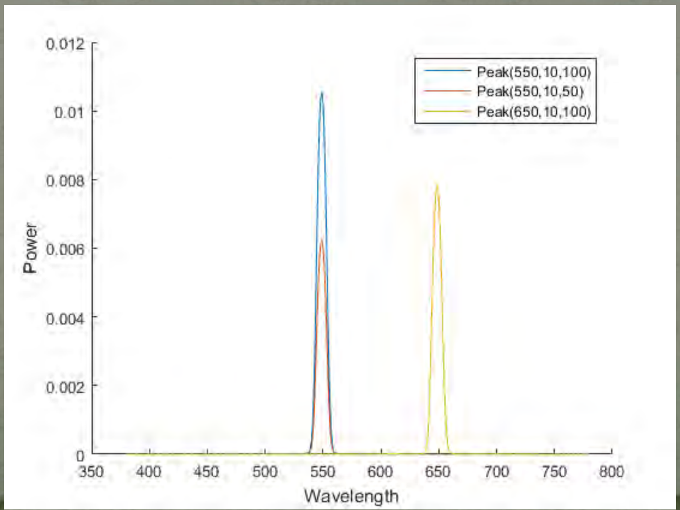
Multispectral Imaging System

- Hardware components
  - Tunable light source: Generate single-wavelength light
  - Integrating sphere: Diffuse light evenly
  - Scientific camera: Detect luminance reflected from subject
  - Spectroradiometer: Verify light spectrum
- Software components
  - Data conversion: Matlab, vectorized conversion
    - Pixel – Reflectance – CIEXYZ – CIELAB – DE2000
  - Interfacing: Matlab
  - Optimizer : R



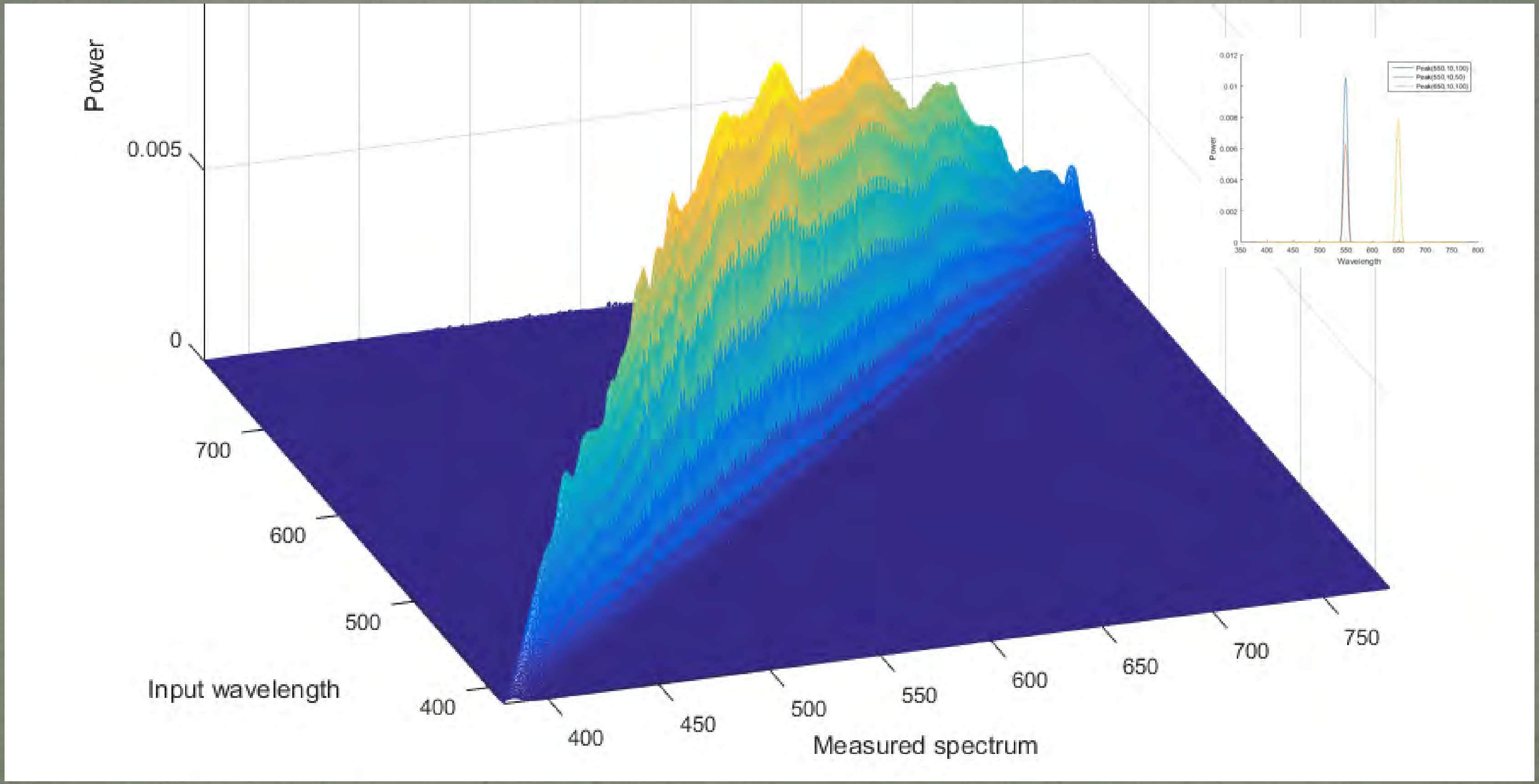
Tunable Light Source

- Gooch-Hausego OL490
  - Xenon lamp
    - Light dispersed by a slit
  - Tunable filter
    - TI digital micromirror device (DMD)
      - DLP technology used by projector displays
      - Each DMD is a fast light switch; intensity controlled by modulating duty cycle
  - 1024 programmable columns of DMDs for wavelength from 380 to 780 nm
  - Software interface
    - High-level API to generate a Peak(wavelength, bandwidth, intensity)



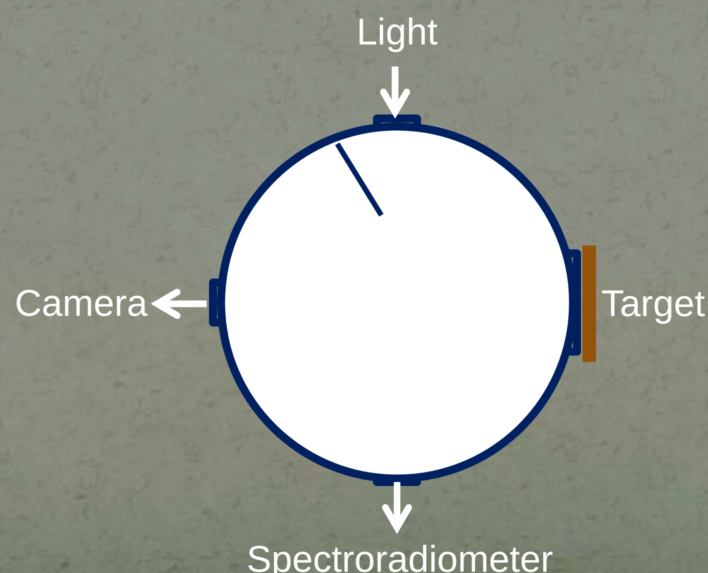
Tunable Light Source Characterization

- Peak(wavelength=380:780, bandwidth=10, intensity=100)
- Spectra between 380 and 780 nm @ 1 nm measured by CS2000
- Spectral errors within 1-2 nm



Integrating Sphere

- 6", 4-port integrating sphere (Labsphere 4P-GPS-060-SF)
- 4 ports: target (2.5"), camera (1"), light (1"), and spectroradiometer (1")
- Coating: Spectraflect, ~98% reflectance for VIS band
- 6" diameter: object distance for camera
- Uniform light field on the target plane
  - Flat-field correction not required, but very shallow depth of field
  - Holder to press target
- Diffused illumination/zero-degree measurement geometry (d/0°)

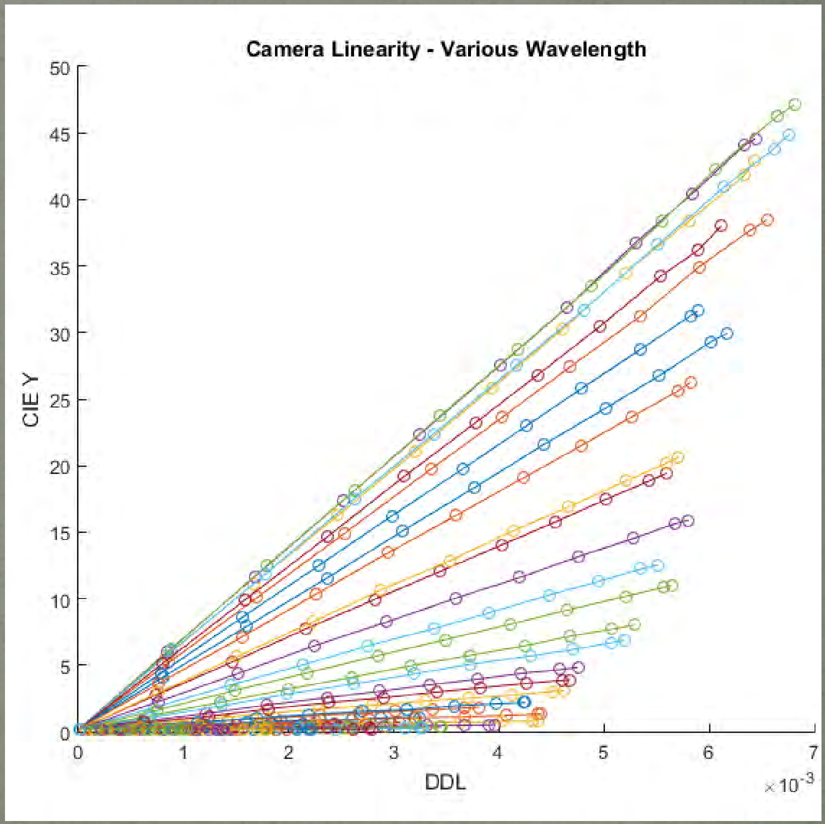


Scientific Camera

- Requirements
  - Linearity: used as a light detector; gamma = 1
  - Consistency: temporal and spatial
  - Controllability: need to fix behavior (exposure, framerate, mode, etc.)
  - Speed: avoid human motion across 41 shots; use smaller image size to reduce data transfer time
- Point Grey Grasshopper Firewire Gras03k2M-C
  - 640*480 pixels, Mono-16, 200 fps
- Lens
  - Tamron 12 mm/f1.4 for CCTV cameras, C-mount
  - Aperture, f4
    - Tradeoff between depth of field and noise induced by low light
  - Veiling glare not noticeable

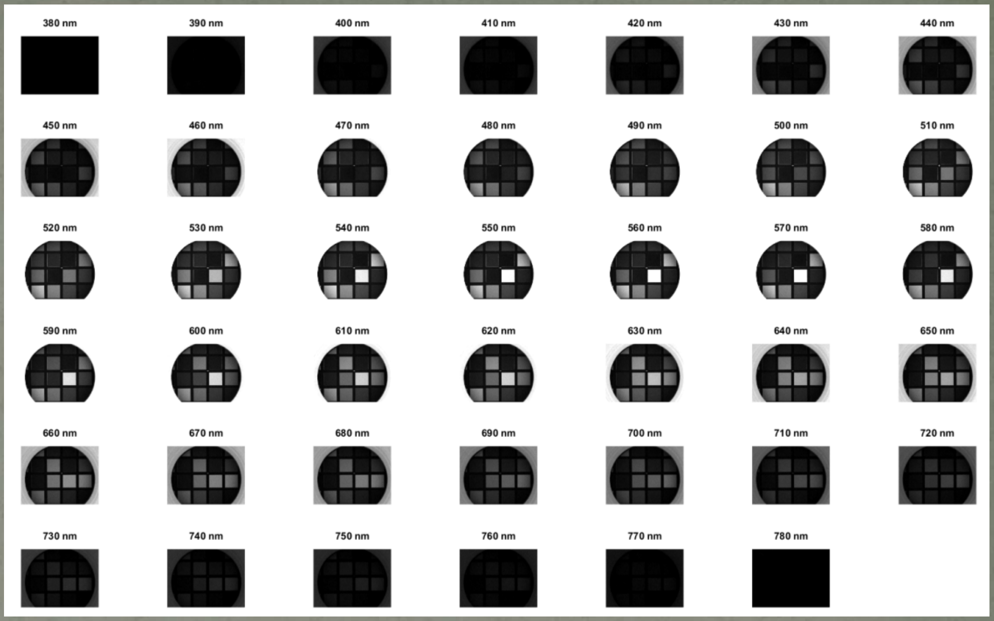
Camera Linearity Test

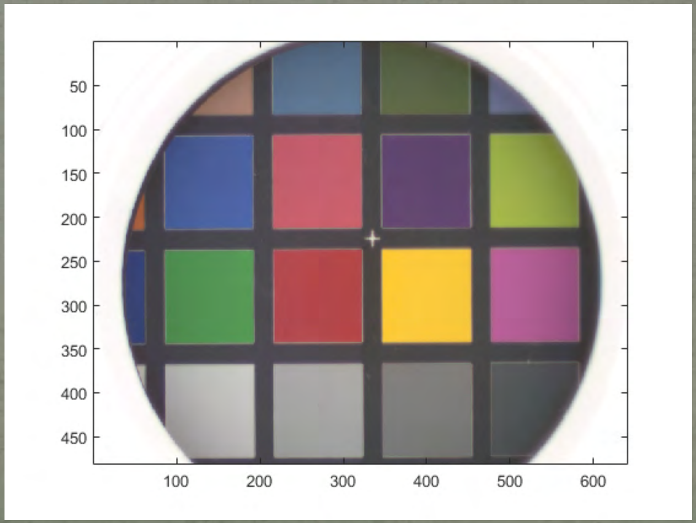
- Modulate light intensity from 0, 10%, 20%,… 100%
- Measure luminance in CIE Y
- Measure camera response in DDL
- Camera response is linear
- Light is not



Workflow

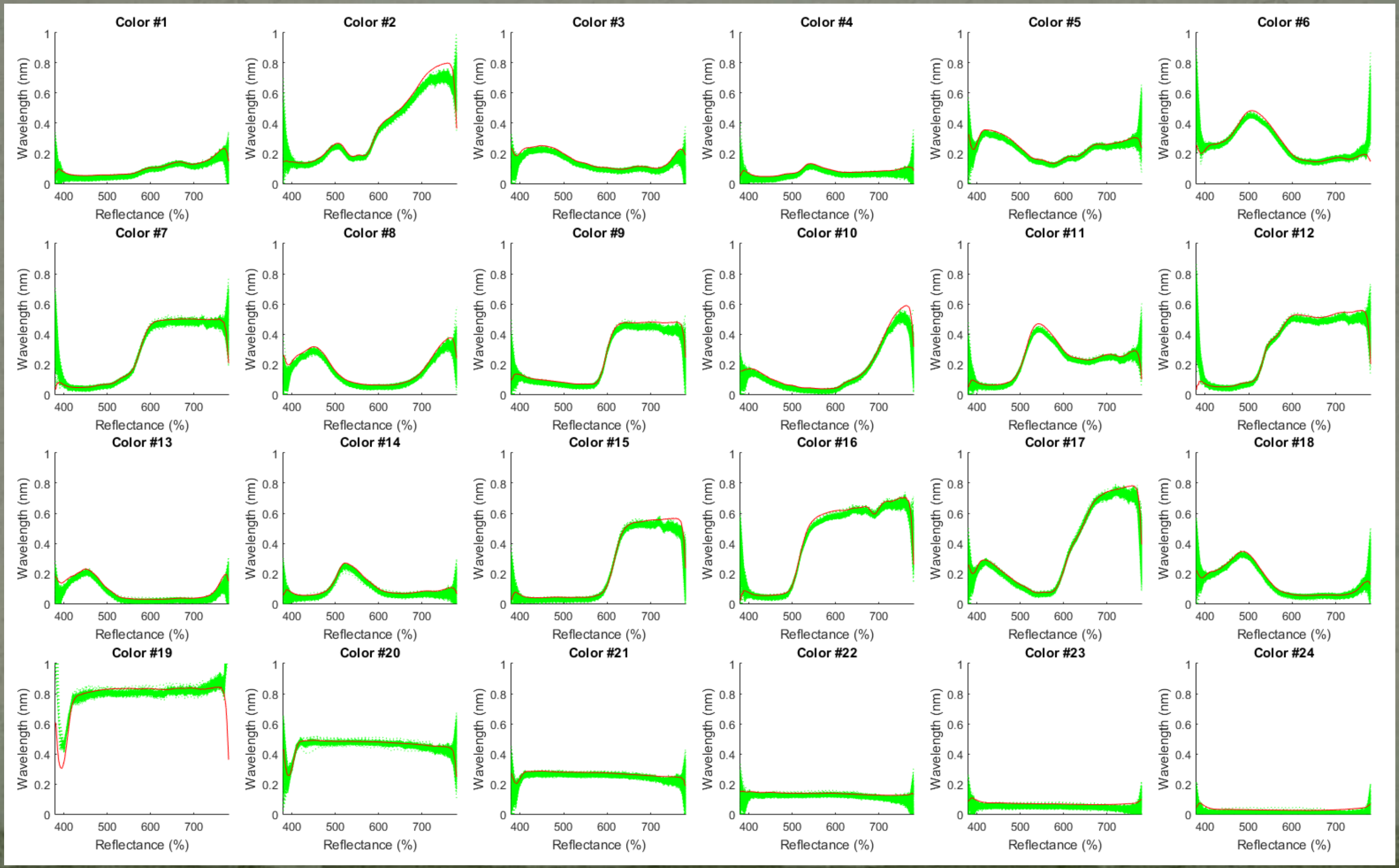
- Light control
  - 41 bands: 380:10:780 nm
- Obtain pixel data
- Calculate reflectance
  - Reflectance = pixel / white
- Add illuminant
  - SPD = Reflectance * D50
- Calculate CIEXYZ
- Calculate CIELAB
- Simulate sRGB image





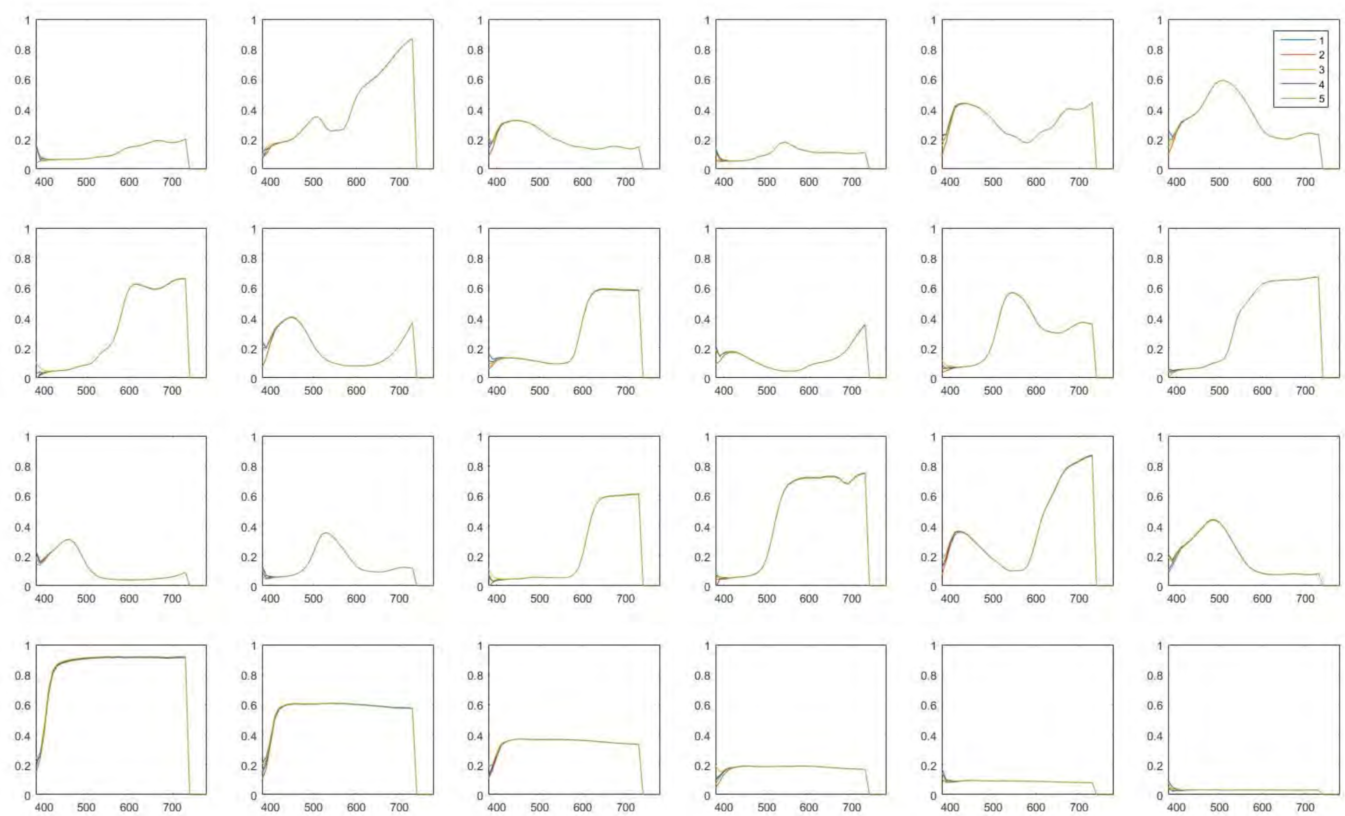
Spectral Accuracy

- 24 patches from ColorChecker
  - Red curve: Spectroradiometer PR730 + SpectraWin
  - Green curves: 400 samples from our MIS
    - Uniformity of patches, unstable camera response at tails

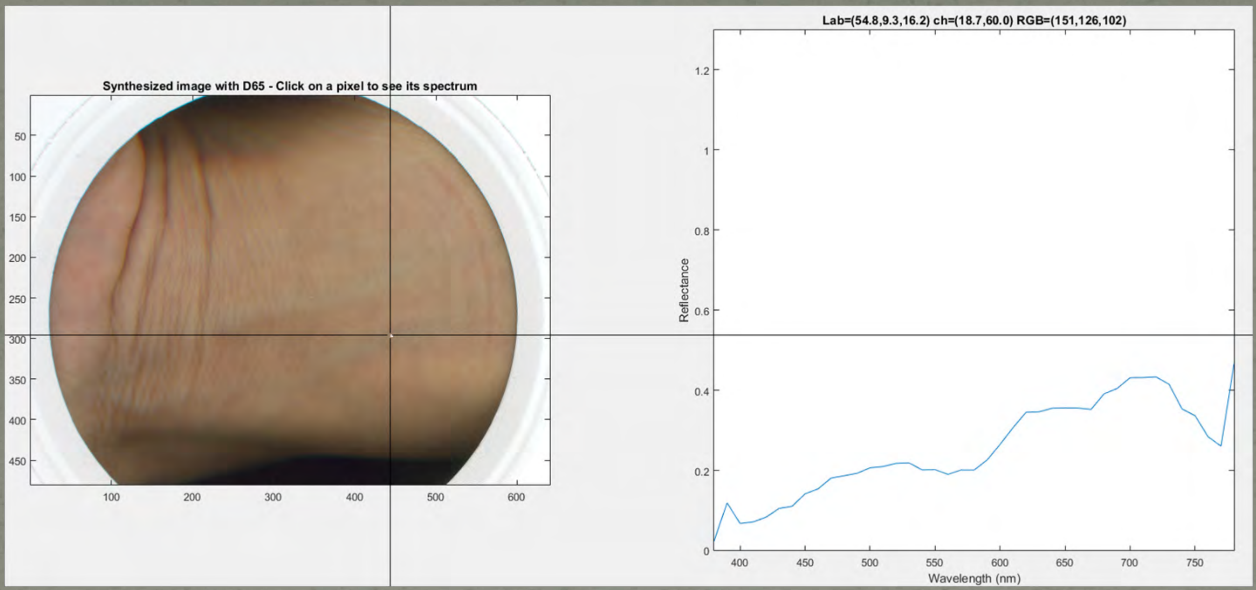


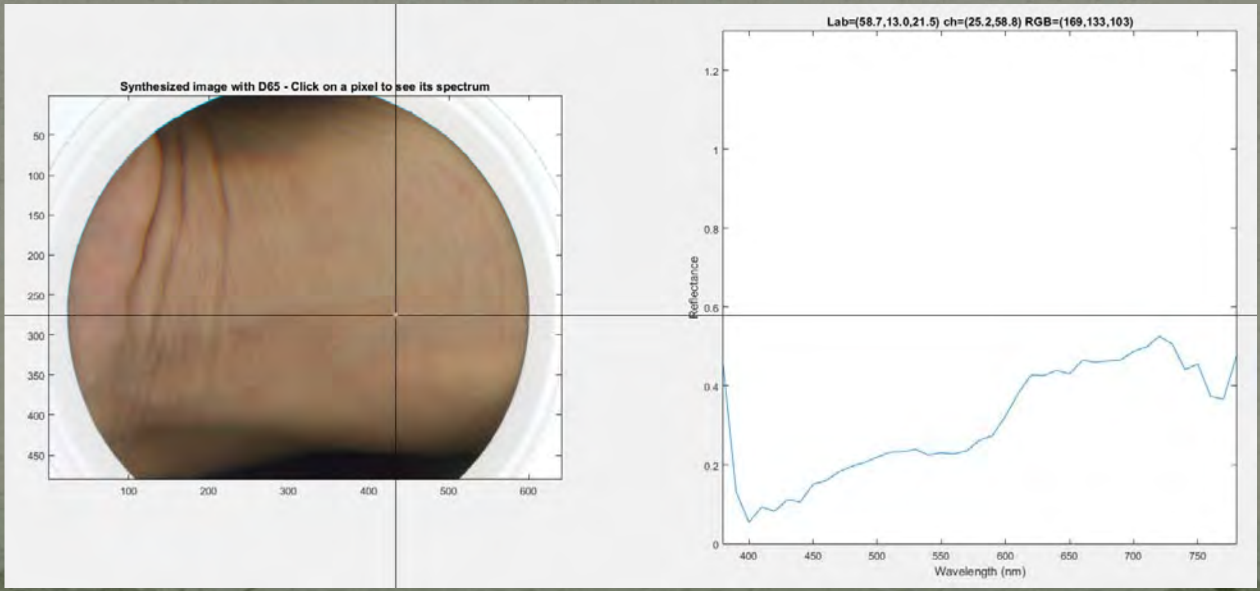
Temporal Consistency

- 5 measurements



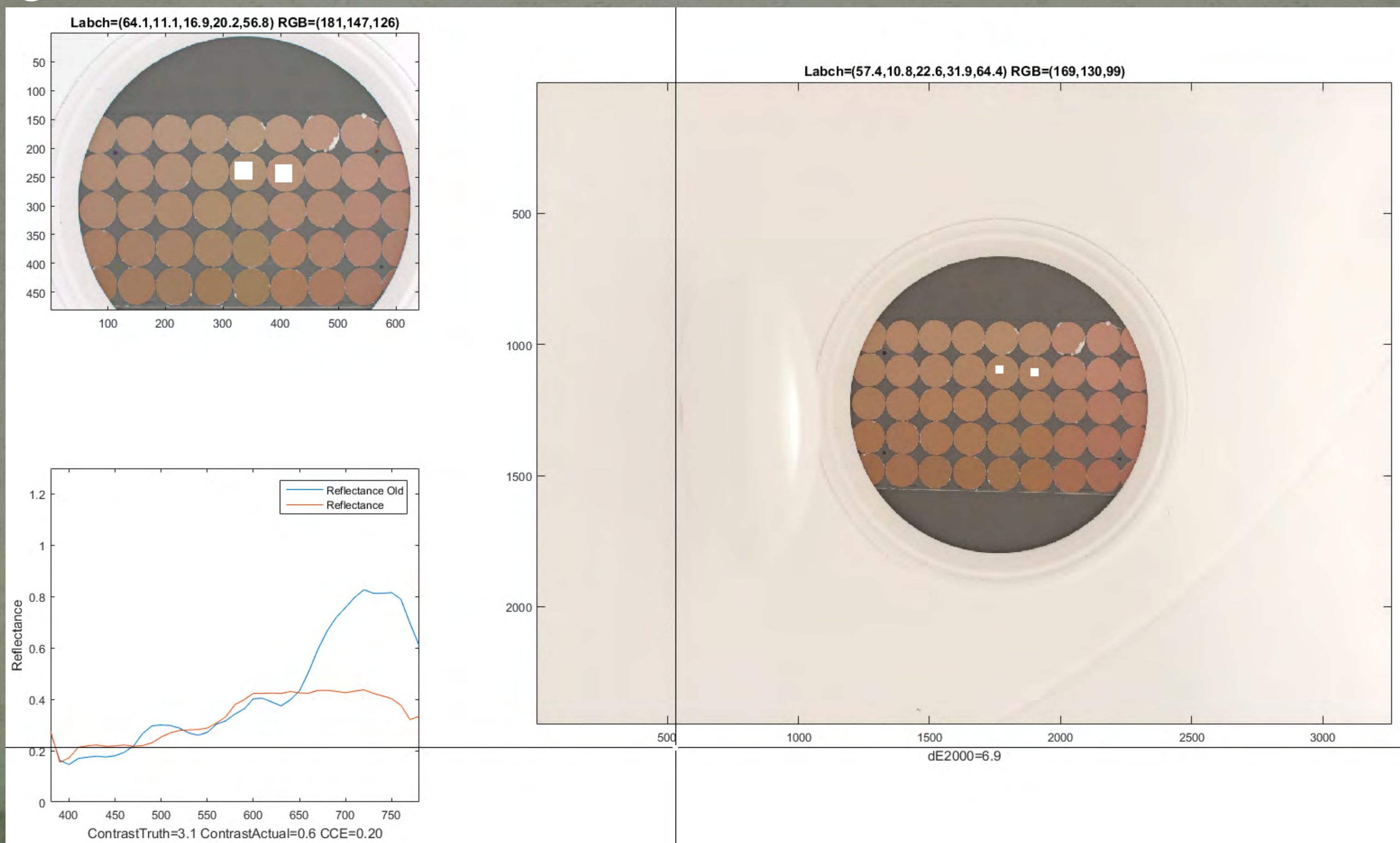
GUI – Color_Picker



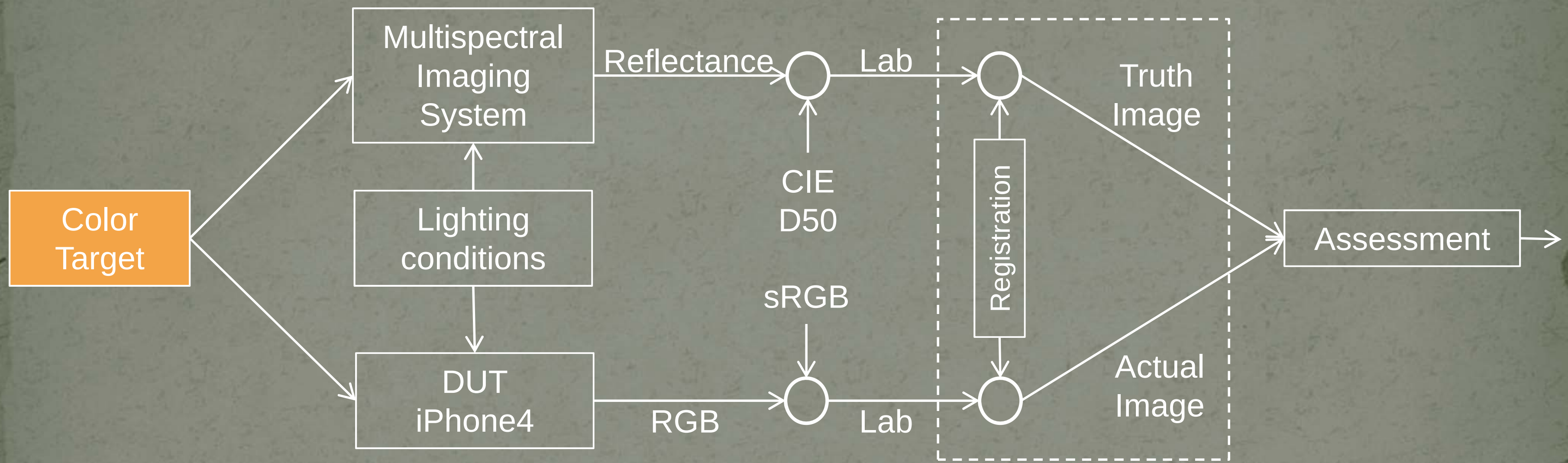


GUI – Truth vs. Actual

- White squares – registration of two user-selected points
- Left: Truth – reflectance, CIE LABCH, sRGB, color difference between 2 pairs, and their ratio
- Right: Camera – CIE LABCH, sRGB, color difference from truth

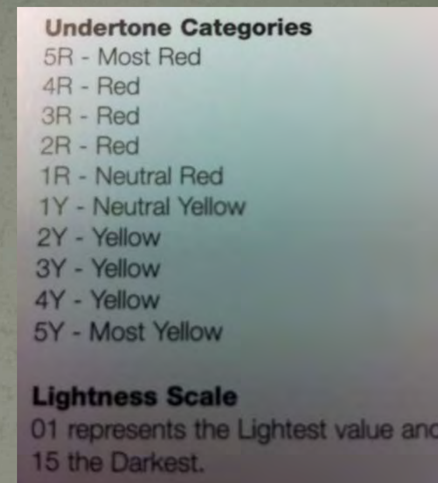


2. Skin Color Target



Color Target

- Requirements
  - Consistent and reproducible
  - Representative color patches in small differences
  - Imaged by one shot to avoid camera control variability
- Pantone SkinTone Guide
  - Designed for visual color matching
  - 3Y08: “3Y”=Hue, “08”=Lightness
  - 110 patches in 10 hue categories and 15 lightness scales

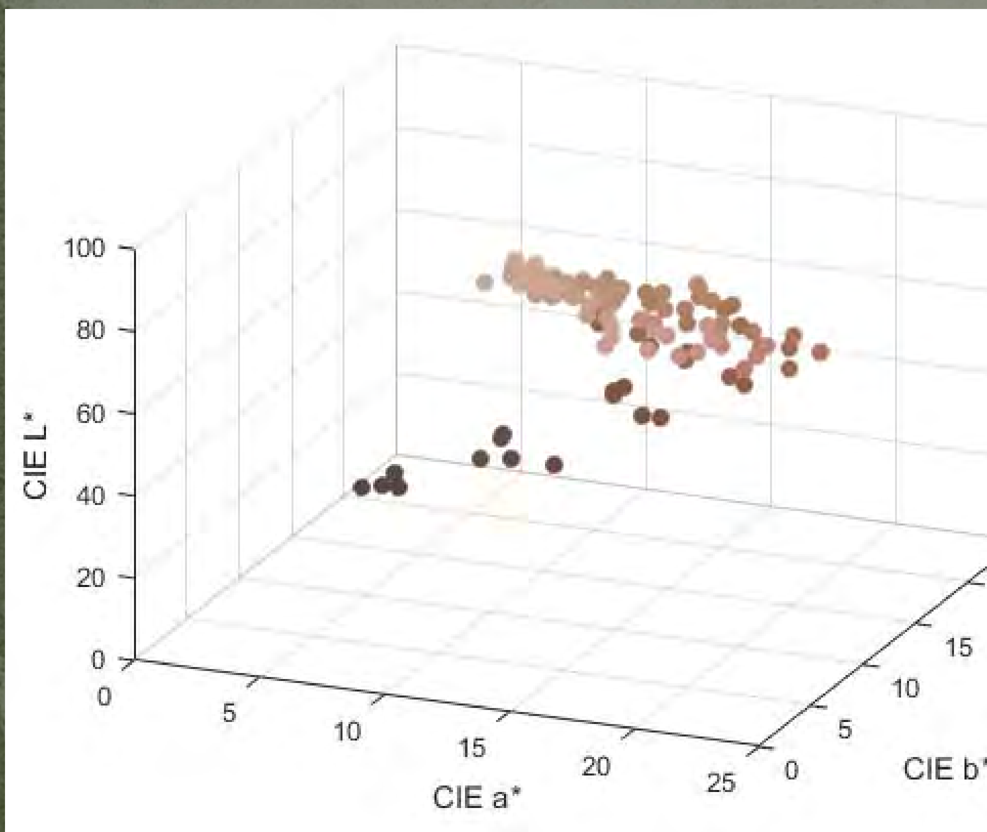


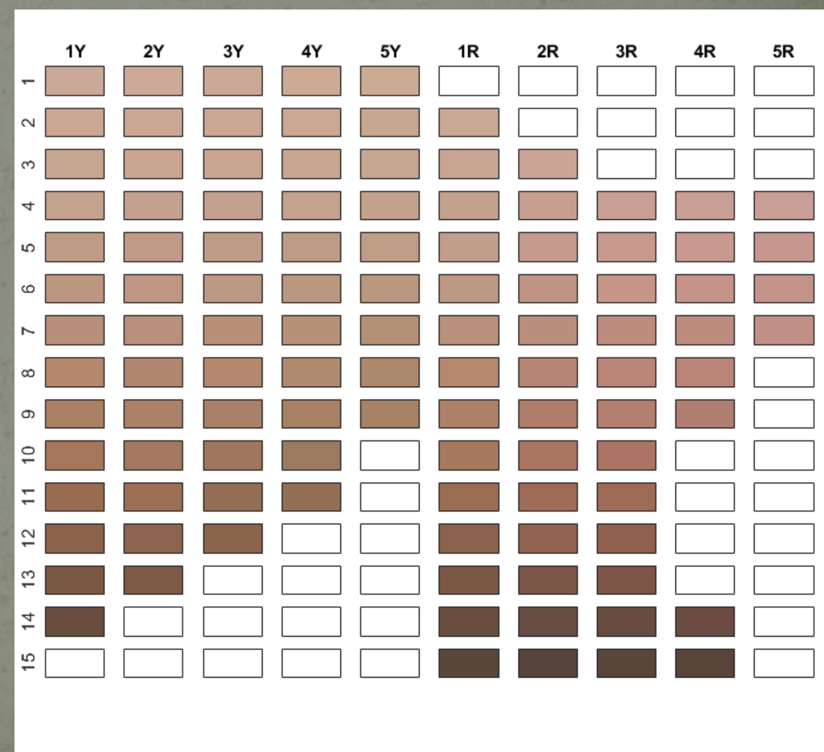
Undertone Categories
5R - Most Red
4R - Red
3R - Red
2R - Red
1R - Neutral Red
1Y - Neutral Yellow
2Y - Yellow
3Y - Yellow
4Y - Yellow
5Y - Most Yellow

Lightness Scale
01 represents the Lightest value and 15 the Darkest.

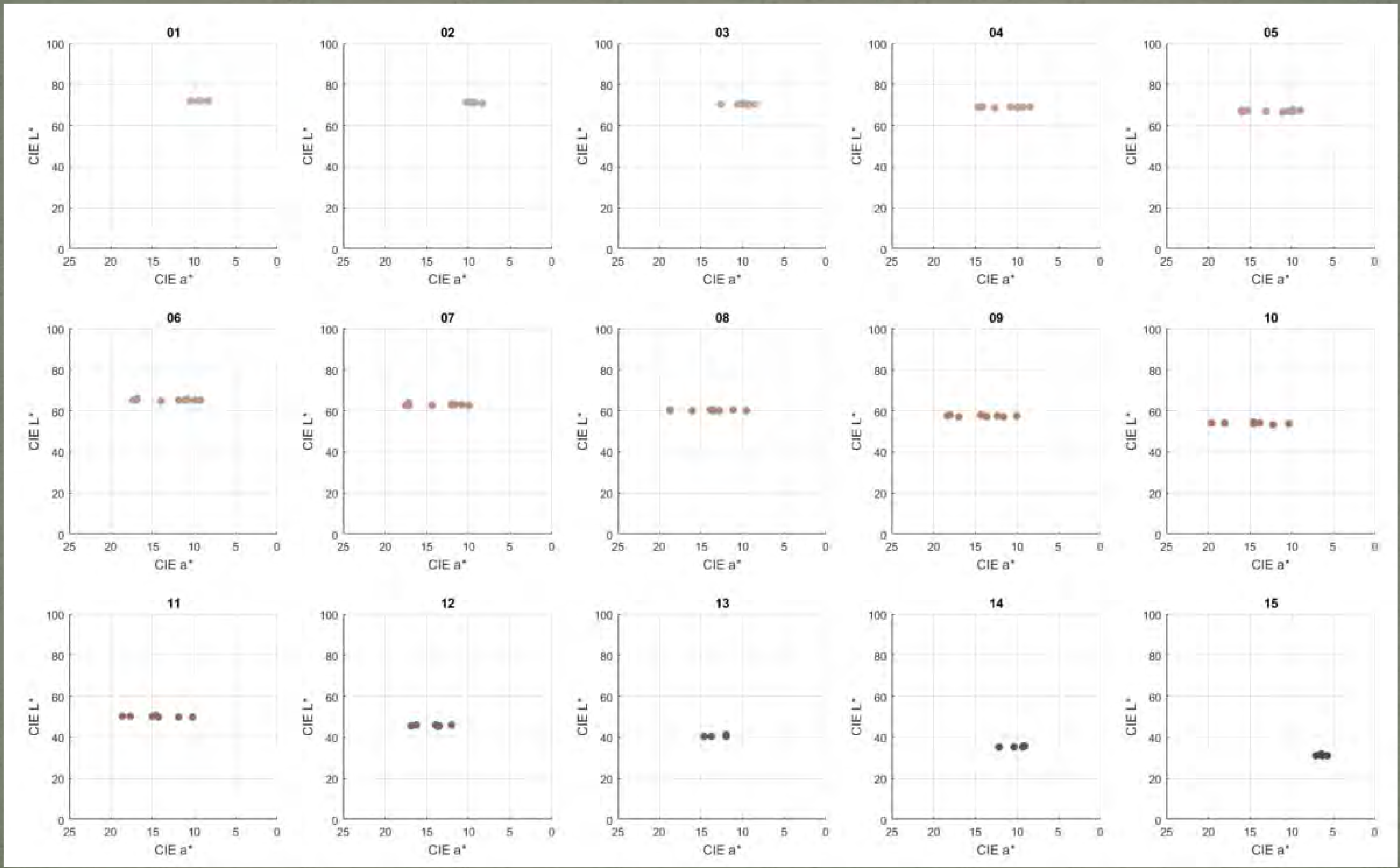
SkinTone Measurement

- CIE L*a*b*
  - Reflectance measured by spectrophotometer CM700d
  - Illuminant CIE D50 to calculate CIELAB
  - Simulated color in sRGB



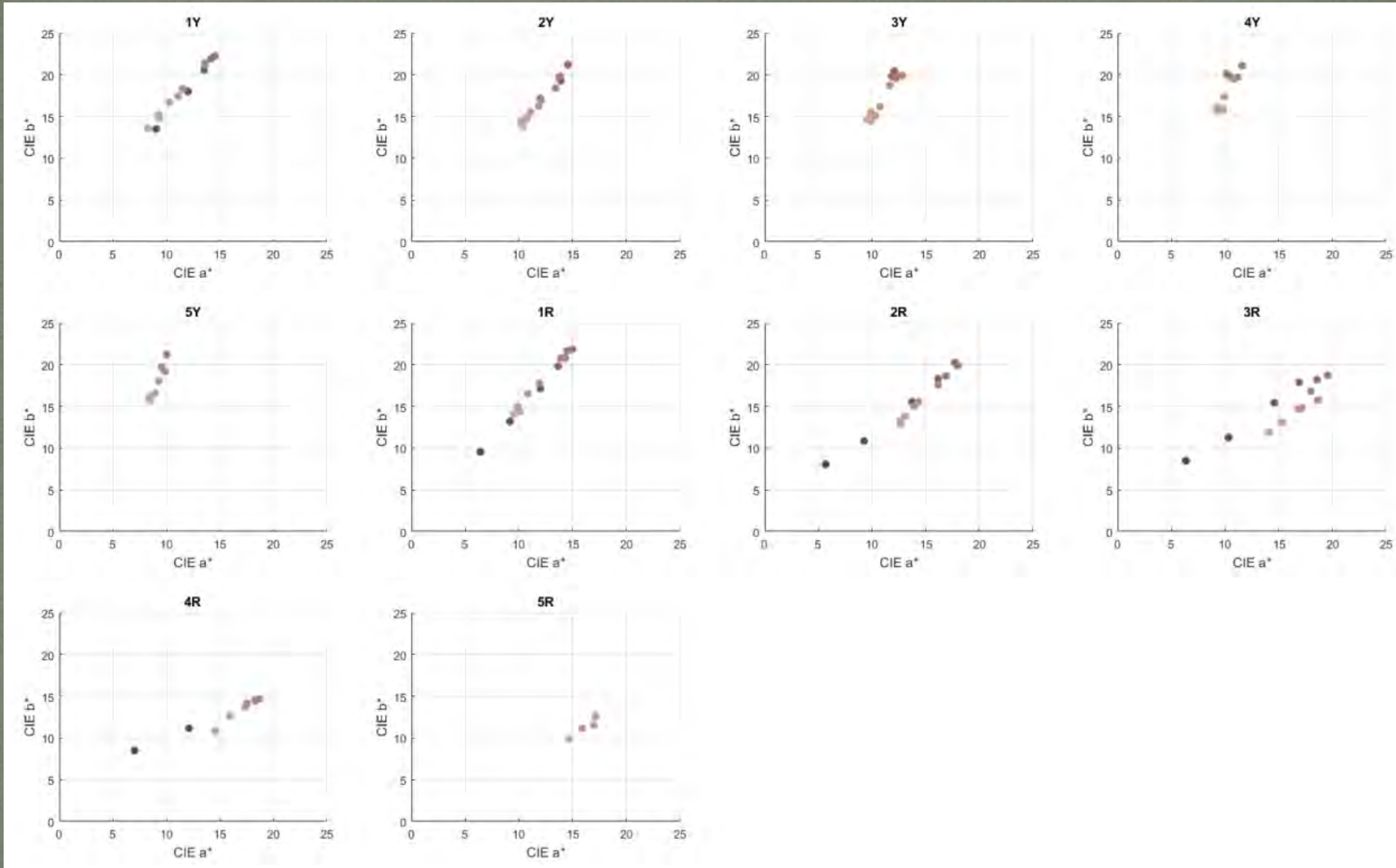


SkinTone Measurement – by Lightness



- SkinTone lightness aligned with CIE L*

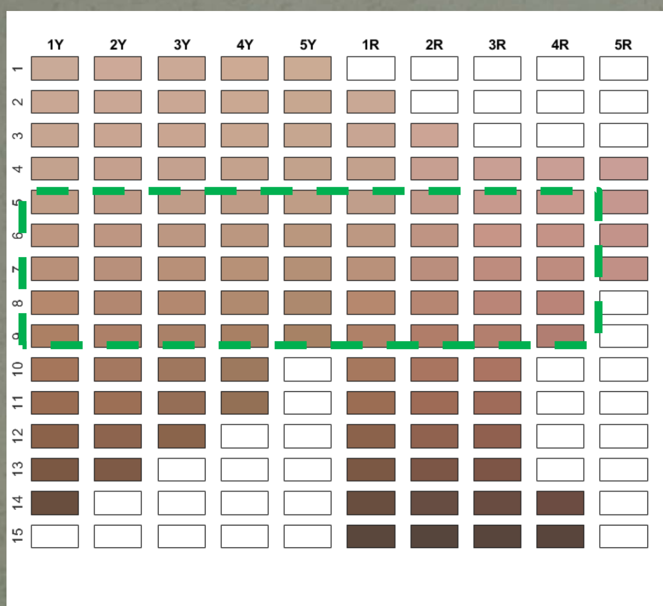
SkinTone Measurement – by Hue

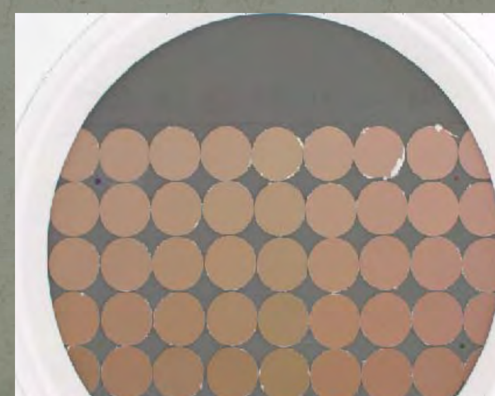


- SkinTone hue in-plane in CIELAB but different from CIE Hue_ab
- Chroma varies

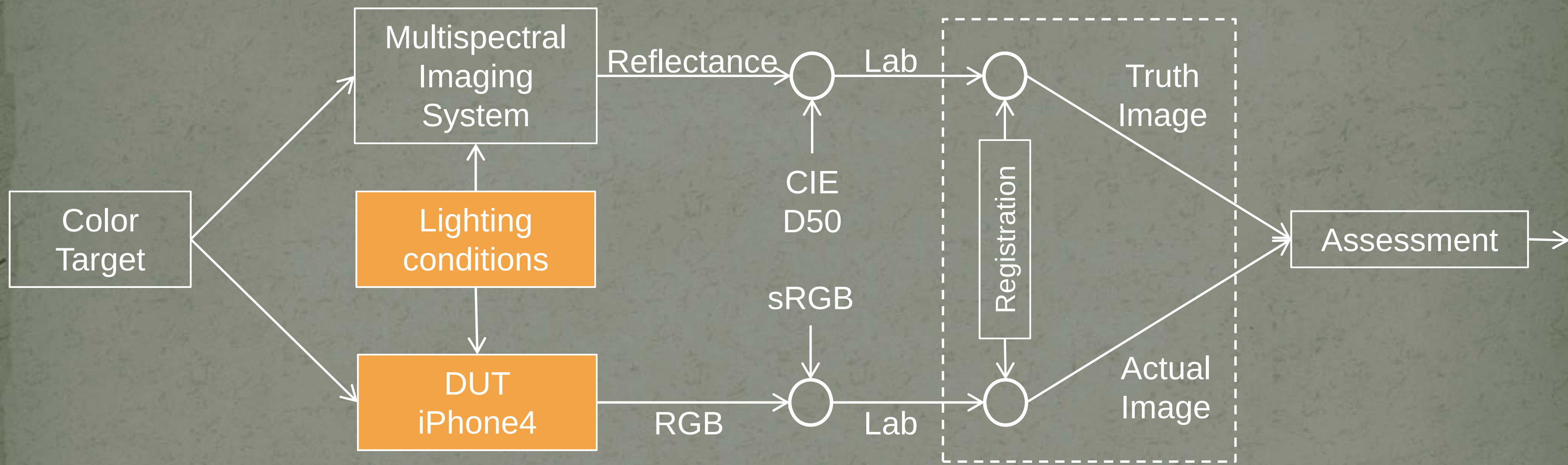
Color Target

- To fit the field of view of the multispectral imaging system
  - 35 patches: [2Y 3Y 4Y 5Y 1R 2R 3R] x [05 06 07 08 09]
  - Circles cut by a 3-hole puncher
  - Arranged by lightness and hue
  - Glued on a 18% photographic graycard
  - 4 color markers for registration
  - Mount in a lens filter



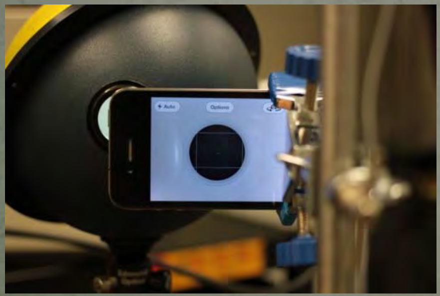


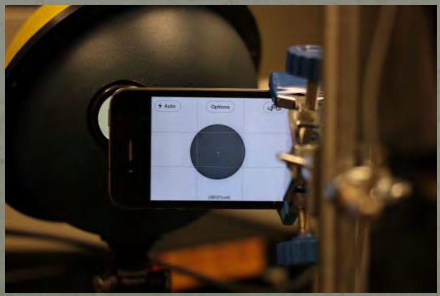
3. Mobile Camera

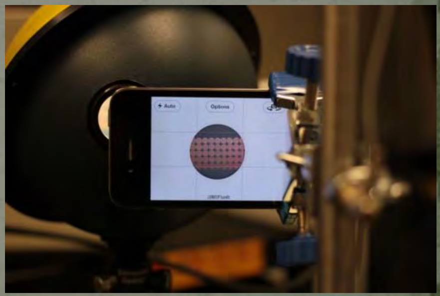


Mobile Phone Camera

- Use the same lighting geometry as MIS
  - Use tunable light source to simulate CIE D50
- Limited user control in mobile phone cameras
  - Exposure, white balance, and focus need to be controlled
- Method
  - Gray target for controlling auto-exposure and auto-focus (AE/AF)
    - 18% photographic graycard with texture
  - Use AE/AF lock
    - Compose for gray target
    - Activate AE/AF lock
    - Replace with skin color target

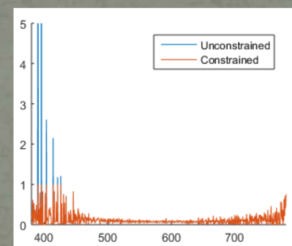


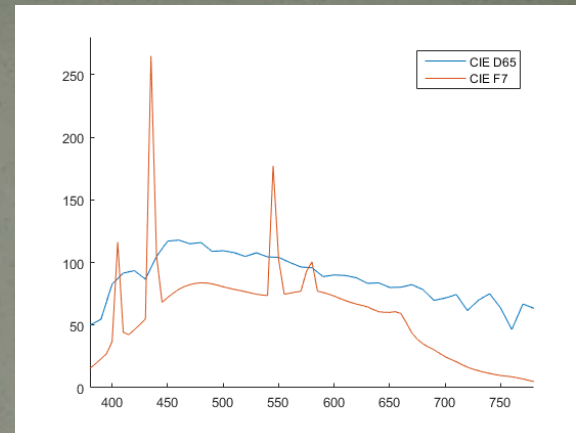


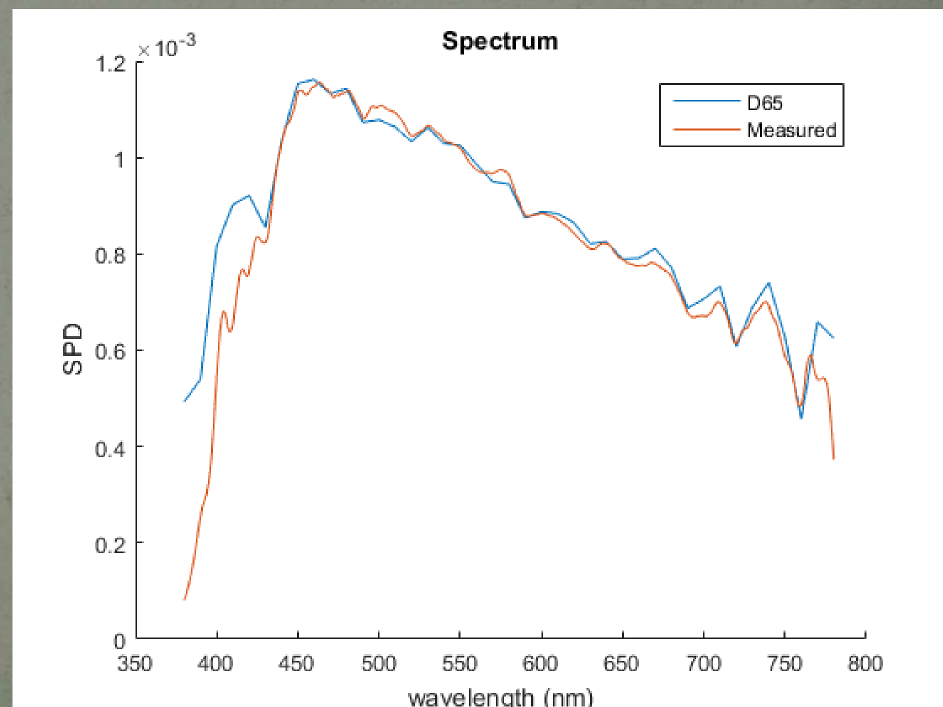


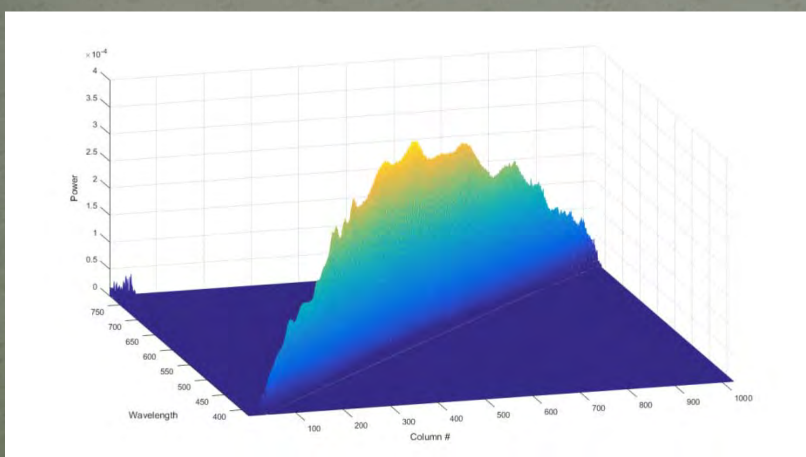
Light Source Simulation

- To simulate CIE D65 illuminant
  - Light booth (~CIE F7) is not accurate
- Reuse tunable light source
  - Column-level characterization
  - Inverse transformation
  - R, optim(), ‘L-BFGS-B’, lb=0
  - Scale/clip column assignment
  - Measured CCT=6443K

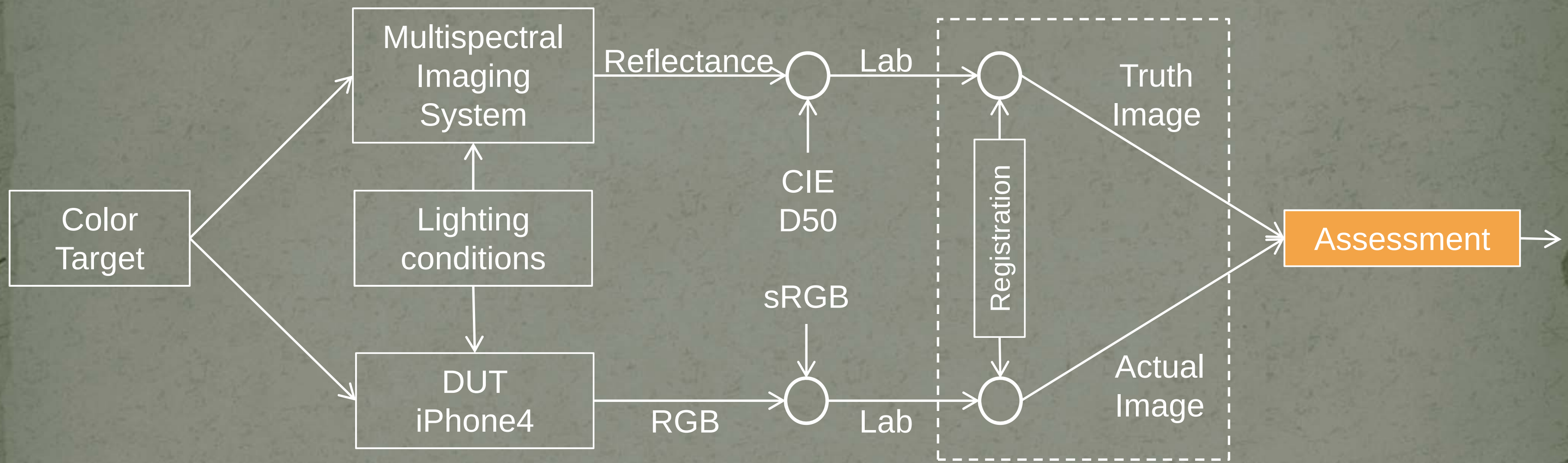








4. Assessment Methods



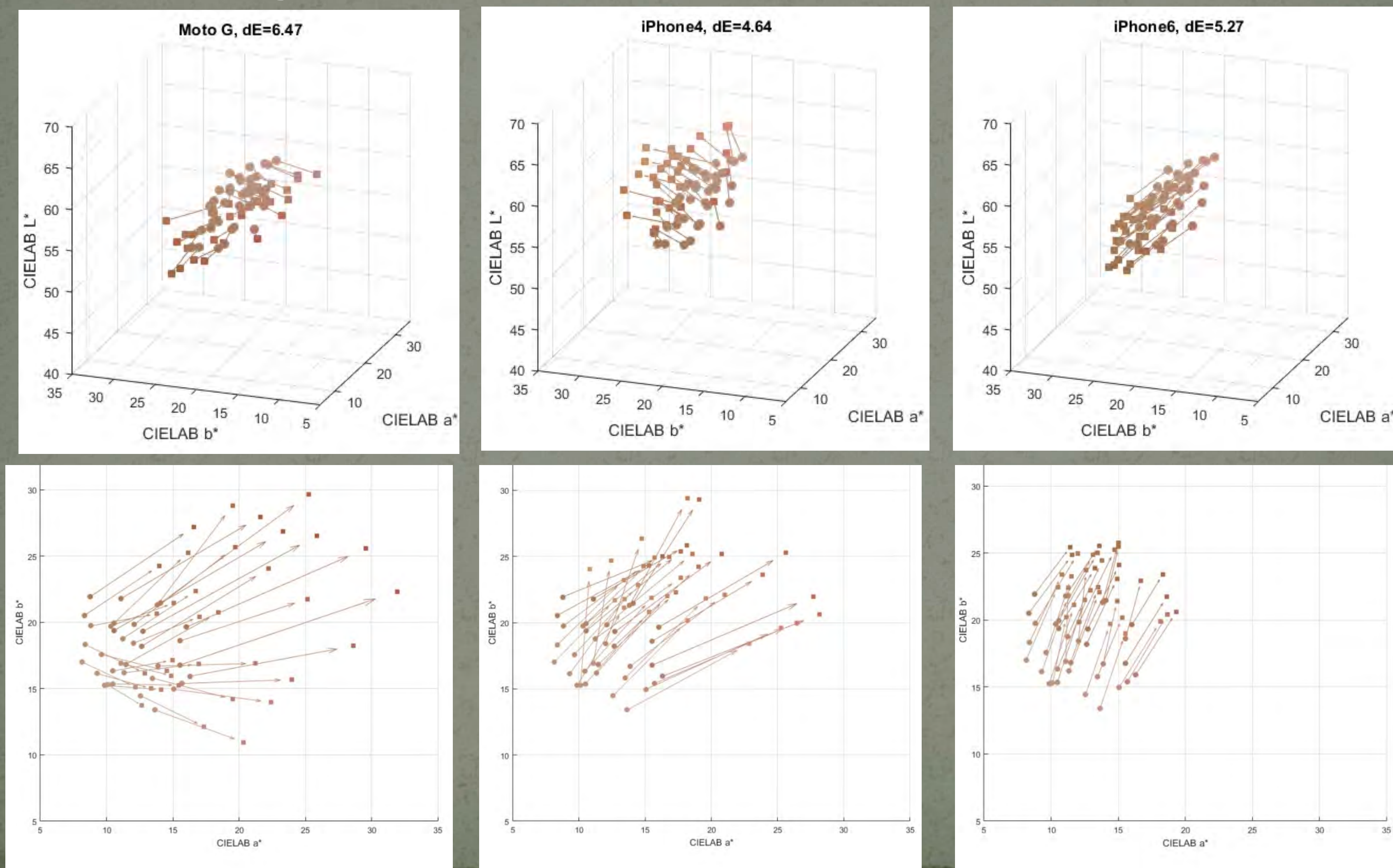
Assessment

- Methods
  - Absolute error (color difference)
  - Relative error (difference of color difference)
  - Ordering error (concordance in ordering of lightness, hue, and chroma)

- Mobile cameras
  - iPhone 4, iOS 6.1.3
  - iPhone 6, iOS 8.3
  - Moto G, 1st Generation, Android

Color Difference From Truth

- dE2000: iPhone4 < iPhone6 < Moto G (circle=truth, square=camera)
- Consistency of error direction: iPhone6 > iPhone4 > Moto G

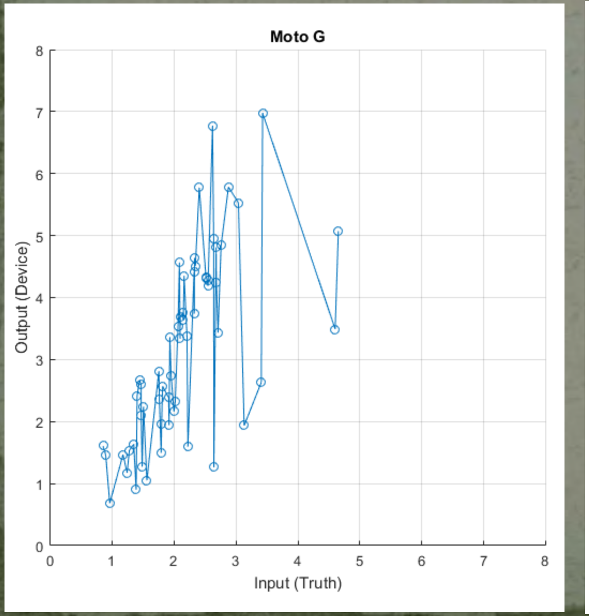


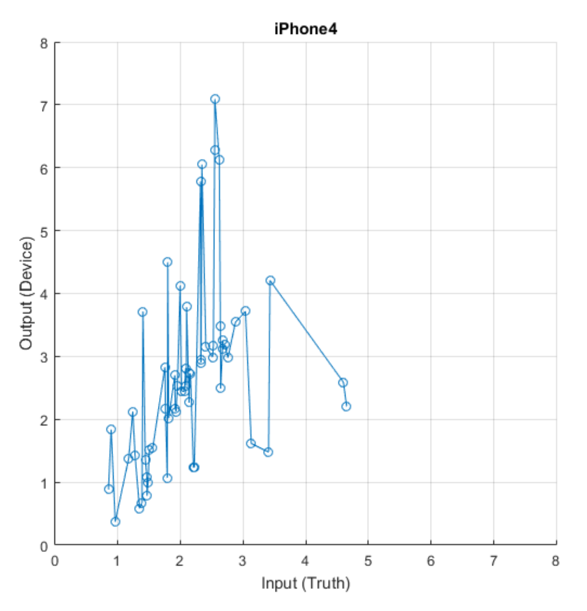
Color Contrast Enhancement

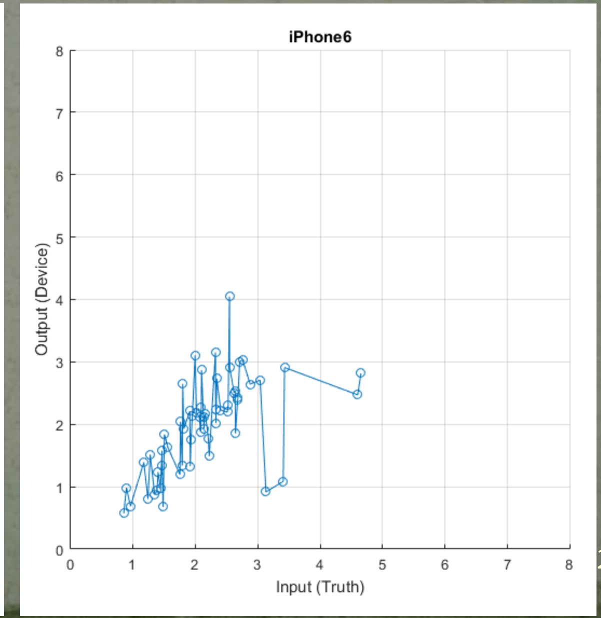
- CCE = ΔE_camera/ΔE_truth
- Whether the color difference can be reproduced (e.g., endoscopy)
- For detectable threshold t
  - Count dots in area x>t, y<t (detectable but not properly reproduced)

	Moto G	iPhone4	iPhone6
t=2	3	3	8
t=3	2	4	6

- CCE: Moto G > iPhone4 > iPhone6

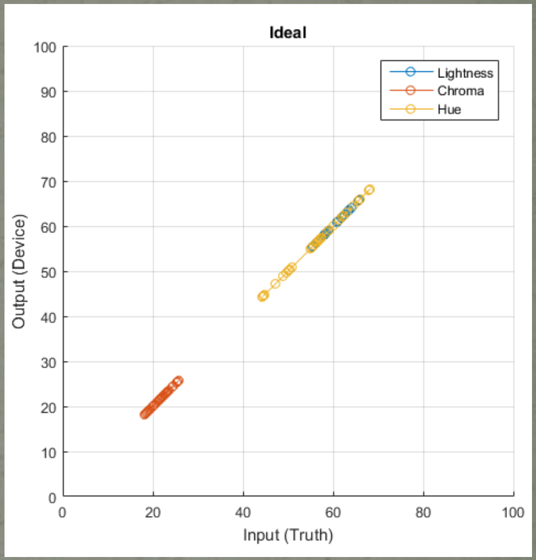


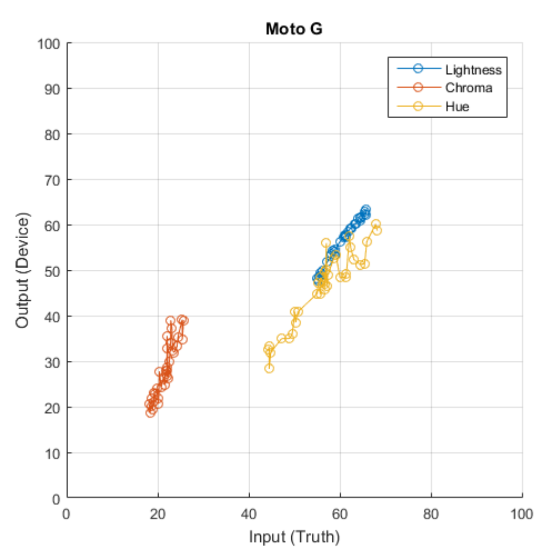


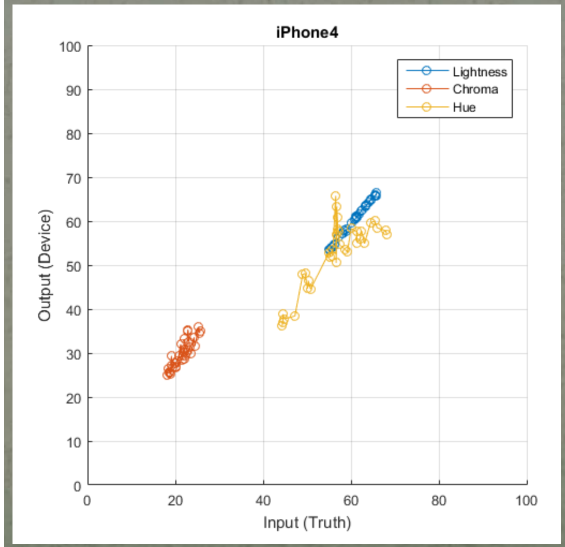


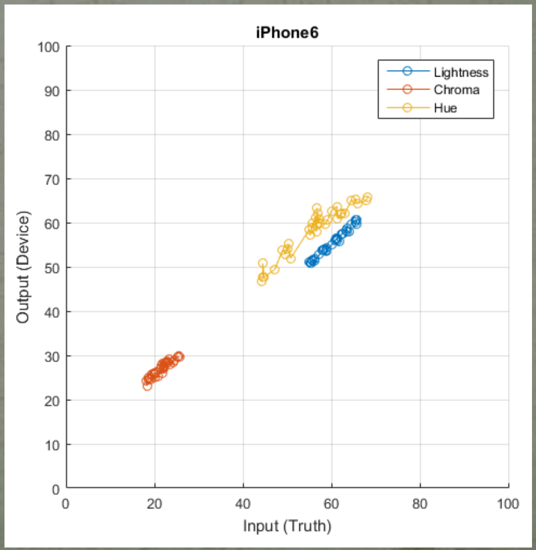
Color Ordering Consistency

- Concordance of ordering in either lightness, chroma, or hue
- Lightness: in-order and properly reproduced for all devices
- Chroma: out-of-order and enhanced
  - Moto G > iPhone4 > iPhone6
- Hue: iPhone6 to yellow; others to red
  - Excessive errors for some patches









Conclusions

- US FDA regulates color medical imaging devices
- Evaluation framework for assessing devices imaging reflective surface
- Multispectral imaging system for obtaining the truth
- CIE D50 reproduced by tunable light source
- Skin color target based on Pantone SkinTone patches
- Evaluate absolute color difference in dE2000
- Evaluate difference of color differences
- Evaluate color ordering of lightness, hue, and chroma
- Choose mobile camera according to applications
- Future work
  - Multispectral imaging system for microscopy
  - Evaluate whole-slide imaging devices
  - Improve FDA Technical Performance Assessment Guidance for WSI systems

Thank You

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UNCERTAINTY OF SKIN COLOUR MEASUREMENT AND DATABASE

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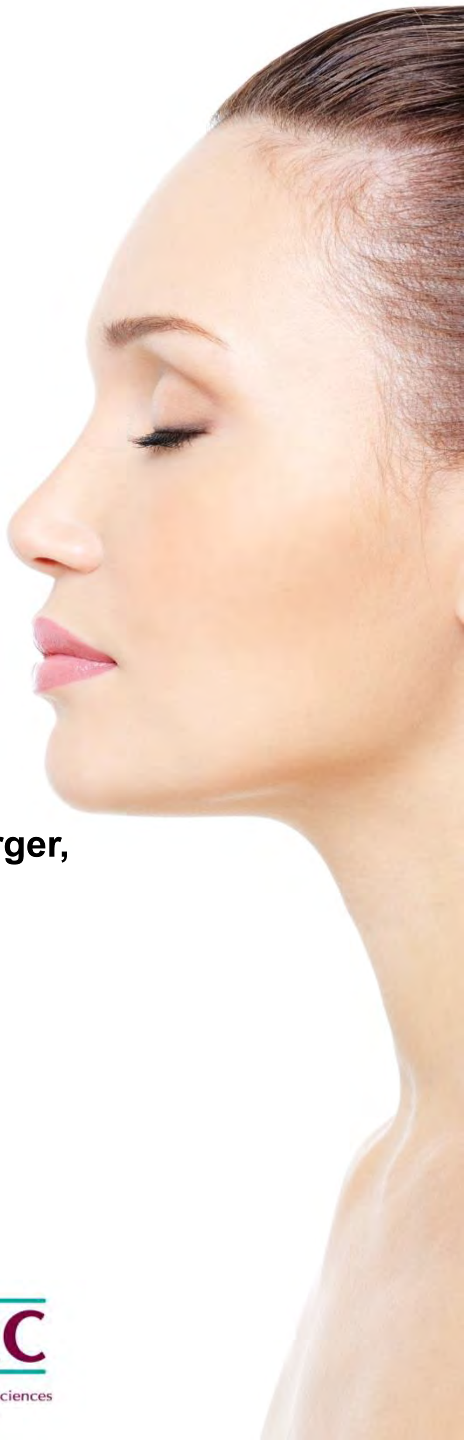
UNIVERSITY OF LEEDS
UNIVERSITY OF LIVERPOOL

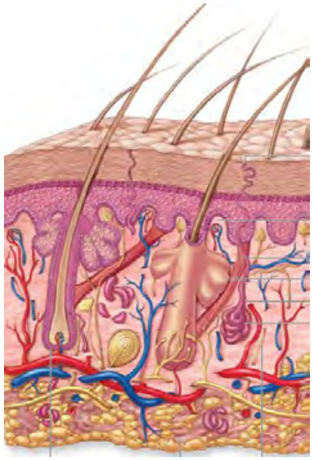
EPSRC
Engineering and Physical Sciences Research Council



Outline

- Introduce LLSC database
- Methodology
  - Short-term repeatability
  - The colour shift
- Uncertainty tests of the instruments
  - Skin colour measurement uncertainty by using spectrophotometer and tele-spectroradiometer.
- LLSC skin colour database
  - The repeatability of the measurements
  - The colour shift between ethnicities, instruments
  - Whiteness and darkness scale

Introduction



- **Skin colour is widely needed**

  by cosmetic industry, dermatologist…..

- **Human skin is a multilayer soft tissue**

- **The measurement results can affected by:**
  - pressures, measurement area sizes…
  - measurement instruments (i.e. spectrophotometer (SP), tele-spectroradiometer (TSR))

- **Today's focus:**
  - Find a suitable setting of each instrument for skin colour data collection
  - Build a skin colour database contain different instruments measurement result

SKIN COLOUR DATA COLLECTION

About LLSC database

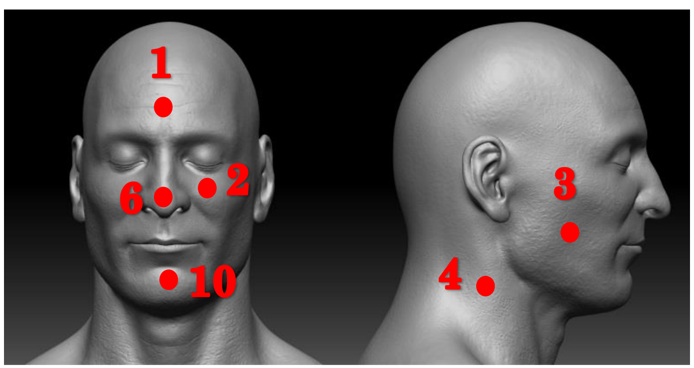
- The Leeds Liverpool Skin Colour (LLSC) database contain:
  - Digital facial image (Nikon D7000)
  - Reflectance gained by PR650 and CM700d
  - Visual assessment results from 3 observers by using Pantone Skintone chart
  - 3D image gained by 3dMD

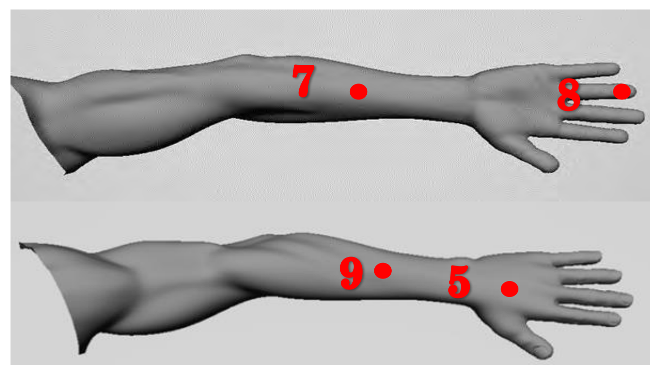




Skin colour data collection

- 188 subjects were measured: 86 Oriental, 79 Caucasian, 13 South Asian and 10 African.
- 5 images of each participants
- Location 1-10 measured by CM700d
- Location 1-5 measured by PR650
- Each location measured 3 times (each instrument)
- Location 1-4 examined by visual assessment (3 Observer)





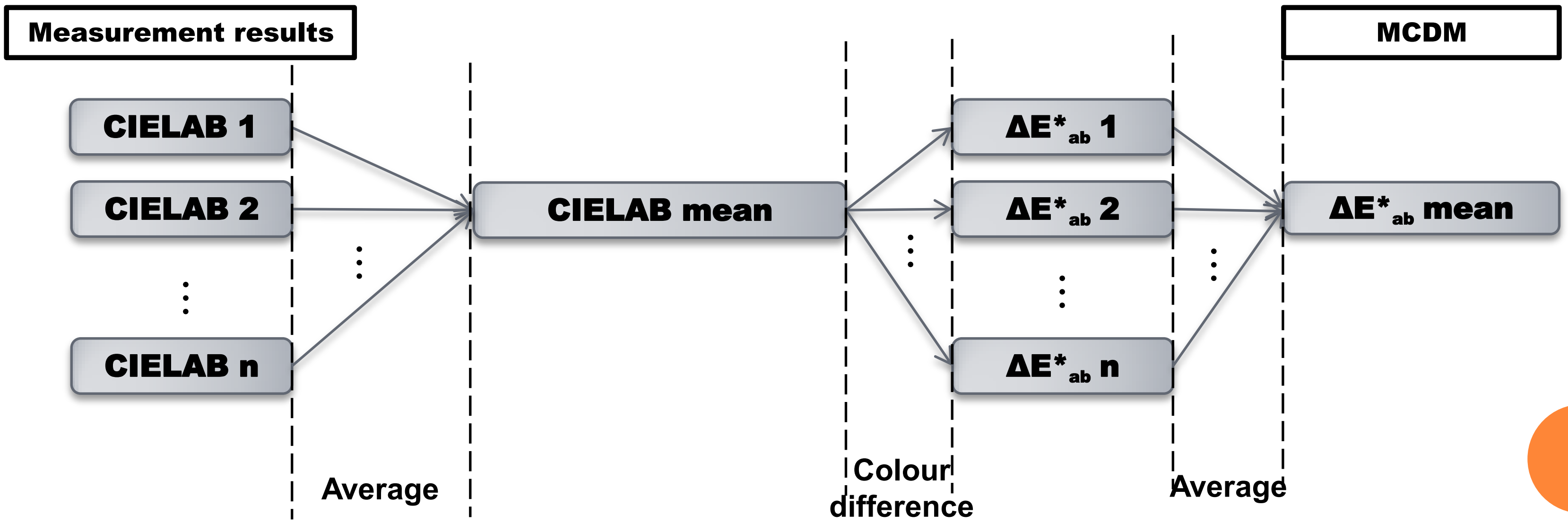
1.forehead (FH), 2. cheekbone (CB), 3. cheek, 4. neck, 5. back of hand (BH), 6. nose tip (NT), 7. inner forearm (IF), 8 fingertip (FT), 9. outer forearm (OF) and 10. chin

METHODOLOGY

- All measurement results were recorded in terms of CIELAB (D65, 2 degree observer)

- **Short-term repeatability**

Mean Colour Difference of the Mean (MCDM) was used to determine the short-term repeatability



Methodology

- **Colour shift of different measurement methods**
  - Plots of mean CIELAB on a*b* and $L^*C^*_{ab}$ plane.
  - Colour difference between different settings of same instrument
  - Colour difference between two instruments' different setting

Uncertainty tests of the instruments

Instruments

- SP: Konica Minolta CM700d spectrophotometer (CM700d)
- TSR: Photo Research inc. PR-650 SpectraScan (PR650)
- Light booth: Verivide® (D65, diffuse illumiation)

(a) (b) (c)

measurement facilities : (a) CM700d (b) PR650 (c) VeriVide light booth

UNCERTAINTY TESTS OF THE INSTRUMENTS
MEASUREMENT UNCERTAINTY

CM700d

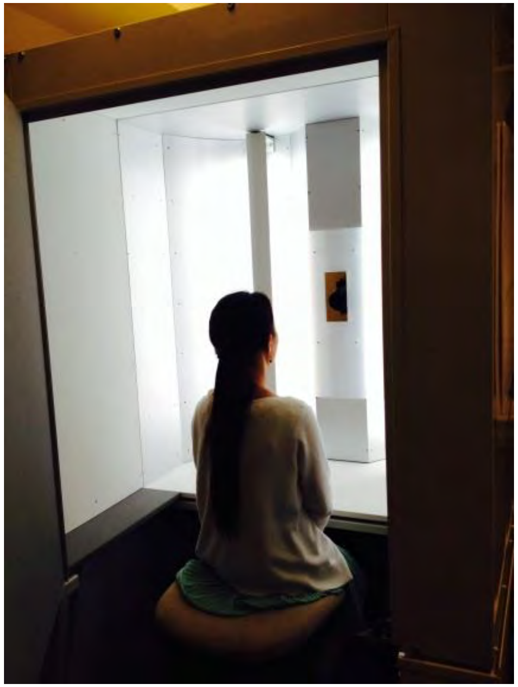
- Three sets of settings
  - Two different aperture sizes :
    - SAV , Φ 3 mm
    - MAV, Φ 8 mm
  - Two different pressure levels :
    - with plate in front (LP)
    - without plate in front (HP)
  - Two repeatability measurement methods:
    - continuous repeatability measurement (CT)
    - consecutive repeatability measurement (CS)

(a) (b) (c) (d)

CM700d masks: (a) MAVLP (b) MAVHP (c) SAVLP (d) SAVHP

PR650

- Two measurement distances of the
  - 57.5 cm (P1)
  - 77.5 cm (P2)

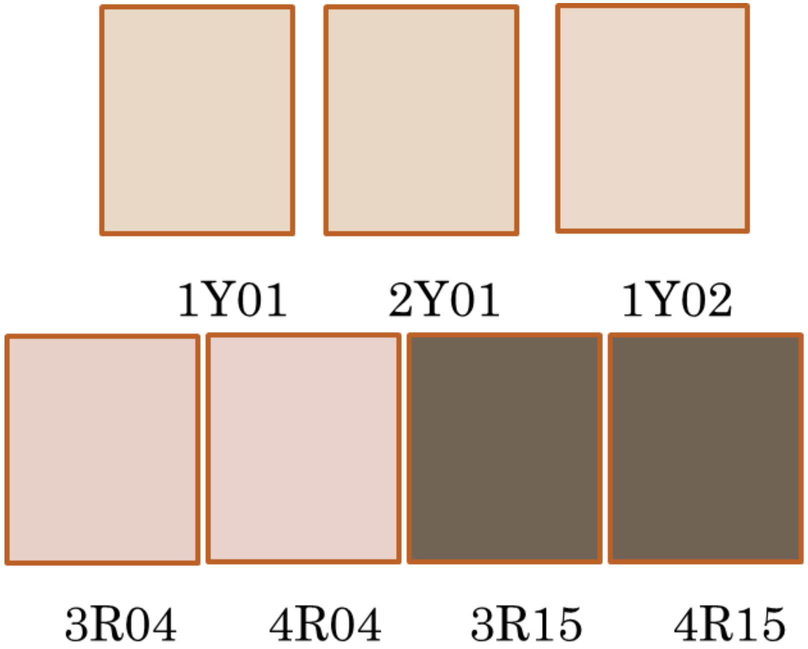


Uncertainty tests of the instruments
Measurement

- **Test 1:**

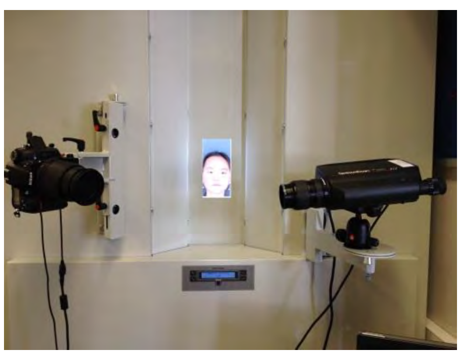
Seven skin colour patches (from Pantone Skintone chart) were measured

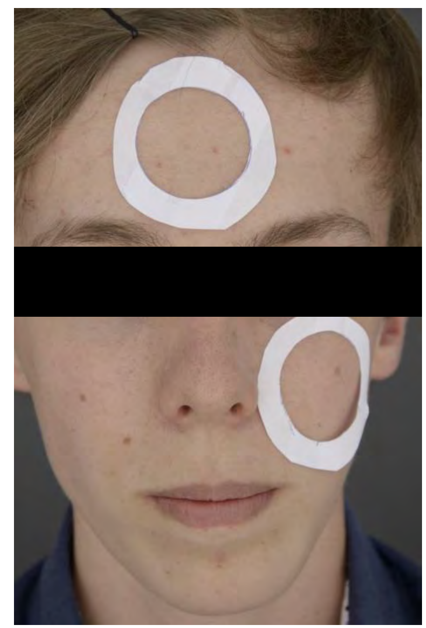
Pantone Skintone chart



Uncertainty tests of the instruments
Measurement

- **Test 2**
  - Two facial locations (forehead and cheek bone) of 11 subjects (7 Caucasians, 3 Oriental and 1 South-Asian) were measured
  - Each location was measured 5 times under different settings





Uncertainty tests of the instruments

Measurement results

Short-term repeatability

- **Short-term repeatability**
  - Higher variability in measurements of human skin vary compared to measuring a skintone chart
  - **PR650**: no significant affection from measurement distance
  - **CM700d**: different aperture sizes and pressures resulted in similar measurement error; continuous repeatability was worse than consecutive repeatability.

Table 1- measurement results from Test 1

Mean MCDM (ΔE*ab) of	PR650	CM700d
Pantone Skintone chart	0.085	0.065

Table 2- measurement results from Test 2

	PR650		CM700d					
Mean MCDM (ΔE^*_{ab}) of	Different distances		Repeatability Measures		Different Pressures		Different Aperture Size	
	P 1	P 2	CT	CS	LP	HP	MAV	SAV
Human skin measurements	0.51	0.53	0.37	0.63	0.34	0.40	0.35	0.39

Uncertainty tests of the instruments

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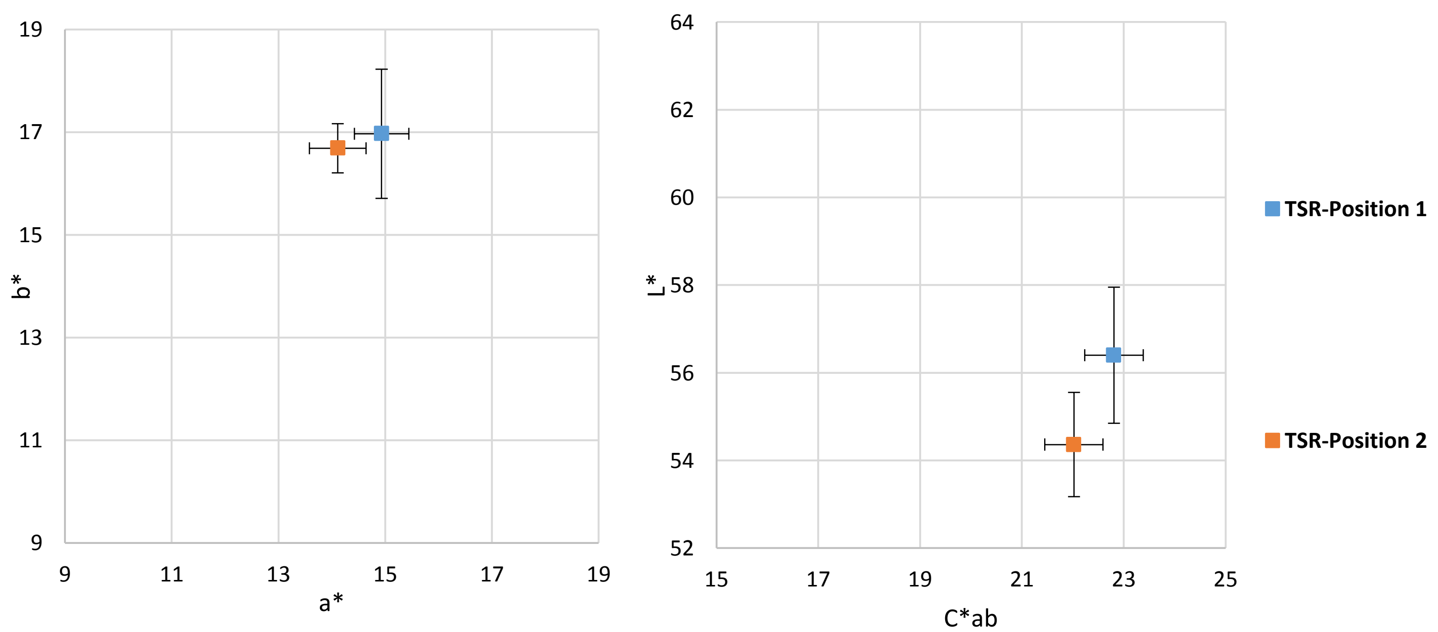
Uncertainty tests of the instruments

Measurement results

Colour shift-TSR's different setting

- **For PR650**

Measurement at P1 had a **higher lightness and chroma** value and **appear redder** than the measurement at P2.

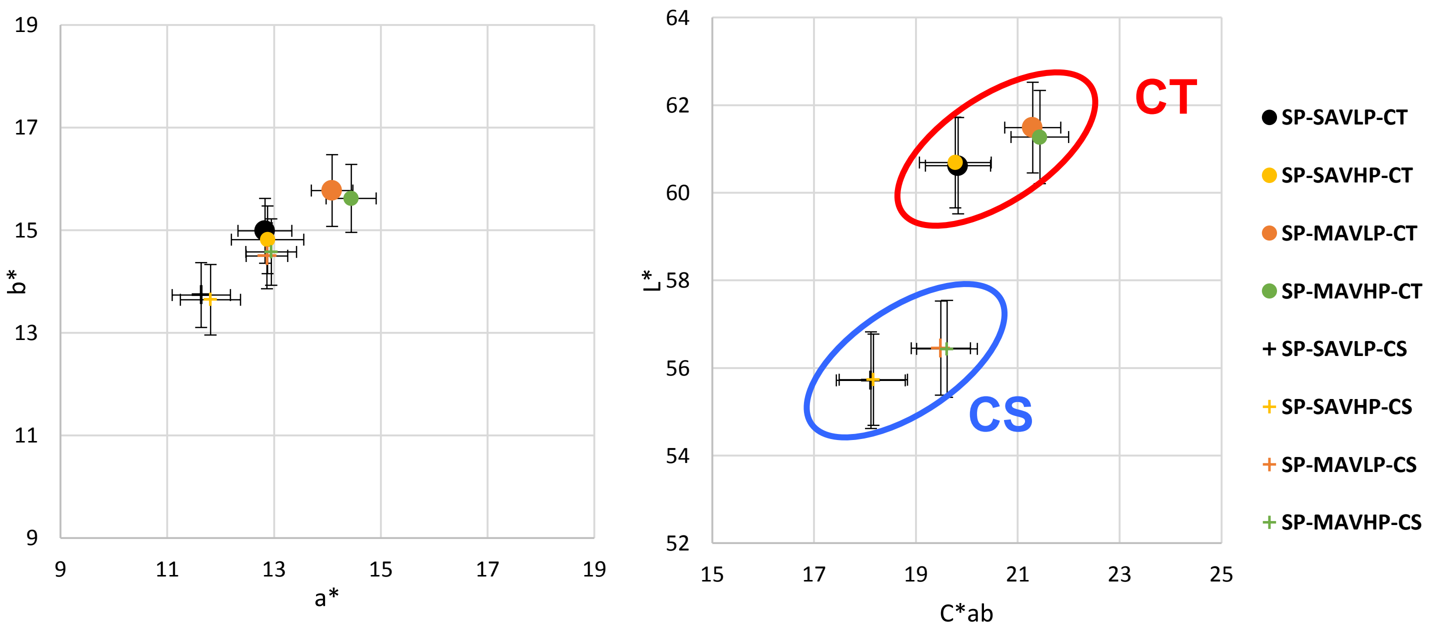


Uncertainty tests of the instruments

Measurement Results And Analysis

colour shift-SP's different setting

- **For CM700d**
  - The pressure has little effect on lightness and chroma.
  - Different mask sizes changed the colour appearance:
    - MAV measurements were higher in chroma and lightness compared to SAV.
  - CT versus CS also affects colour appearance:
    - CS results in higher lightness and chroma, hue angles preserved.
  - Field size and consecutive vs continuous measurements, affect the resulting colour values.

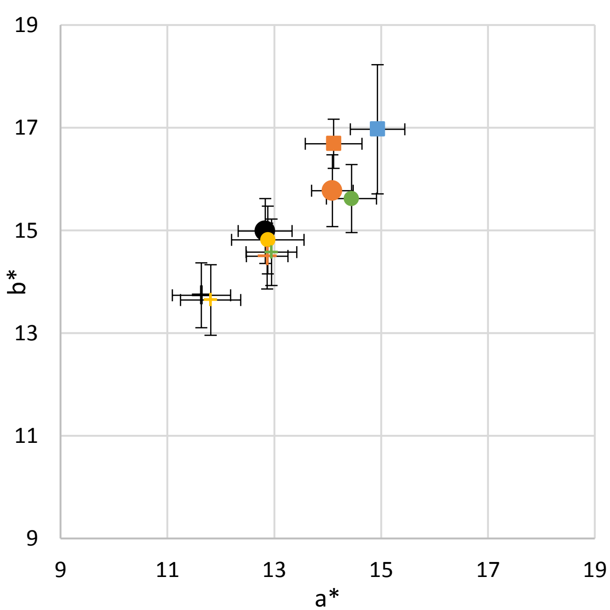


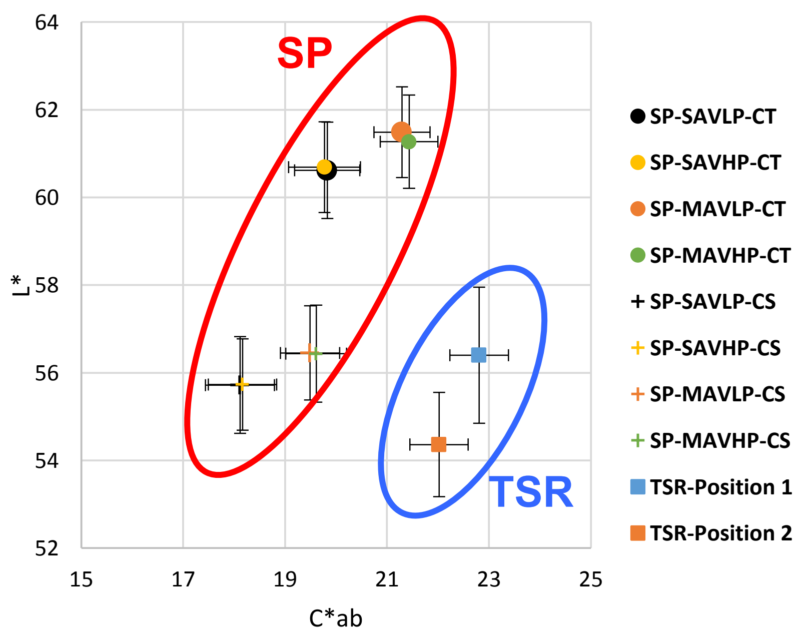
Uncertainty tests of the instruments

Measurement results

Colour shift between these two instruments

- For PR650 and CM700d
  - The measurement results from two instruments were different





Uncertainty tests of the instruments

Measurement results

Colour shift

- **Colour difference between same instrument's different settings:**
  - The greater effect of field size on variability than pressure, reasonable pressures on the skin do not significantly affect the measured colour values.
- **Colour difference between two instruments with different settings :**
  - the larger aperture size masks resulted in the better agreement
  - the differences between two instruments partly driven by the field size difference.

Measurement instrument(s)	Comparison across:	Mean Colour Difference (ΔE^*_{ab})
PR650	**P 1 and P 2**	2.79
CM700d	**LPMAV and LPSAV**	2.48
	HPMAV and HPSAV	3.04
	MAV-HP and MAV- LP	0.88
	SAV-HP and SAV-LP	1.82
PR650 and CM700d	**PR650 and CM700d (SAVLP)**	3.49
	PR650 and CM700d (MAVLP)	2.57
	PR650 and CM700d (SAVHP)	4.02
	PR650 and CM700d (MAVHP)	2.69

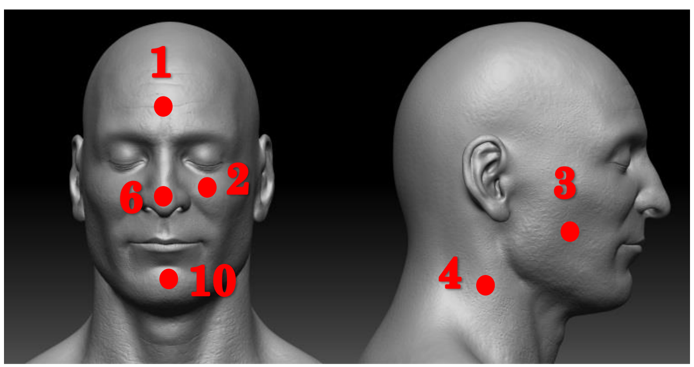
Uncertainty tests of the instruments
Summary

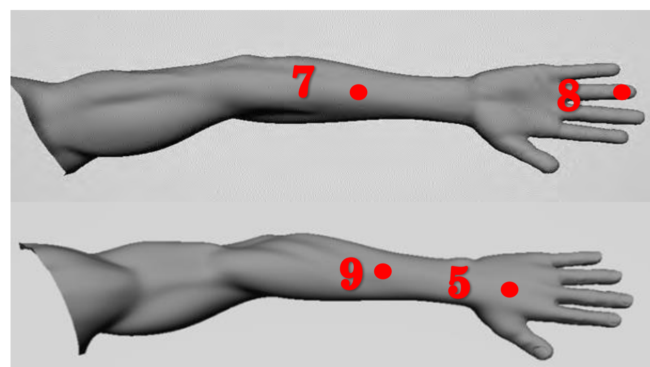
- **Different pressures and measurement field sizes will not affect the short-term repeatability significantly**.
- **For SP :**
  - short-term repeatability is greatly affected by the measurement method: CT yield more repeatable results CS.
- **Colour shifts were found significantly form different measurement distances (TSR) and the field size (SP):**
  - A large field size is associated with a higher chroma and lightness, but the hue angles is not affected.

- **For the skin colour data collection we selected:**
  - PR650: measured at P1
  - CM700d: use MAVLP and SAVLP

Skin colour database

- 188 subjects were measured: 86 Oriental, 79 Caucasian, 13 South Asian and 10 African.
- Location 1-10 measured by CM700d
- Location 1-5 measured by PR650
- Each location measured 3 times (each instrument)





1.forehead (FH), 2. cheekbone (CB), 3. cheek, 4. neck, 5. back of hand (BH), 6. nose tip (NT), 7. inner forearm (IF), 8 fingertip (FT), 9. outer forearm (OF) and 10. chin

LLSC SKIN COLOUR DATABASE

MEASUREMENT RESULT

SHORT-TERM REPEATABILITY

Table 3- measurement results from CM700d

	FH	CB	cheek	neck	BH	inner forearm	outer forearm	chin	nose tip	finger	mean
Oriental	0.42	0.38	0.36	0.40	0.24	0.22	0.20	0.60	0.79	0.67	0.43
Caucasian	0.42	0.46	0.42	0.55	0.28	0.21	0.18	0.59	0.86	0.86	0.48
South Asian	0.40	0.76	0.34	0.41	0.26	0.13	0.19	0.46	0.63	0.77	0.43
African	0.17	0.18	0.23	0.23	0.19	0.09	0.11	0.24	0.29	0.75	0.25
Mean	0.35	0.44	0.34	0.40	0.24	0.16	0.17	0.47	0.64	0.76	-
MCDM of CM700d	-	-	-	-	-	-	-	-	-	-	0.40

Table 4- measurement results from PR650

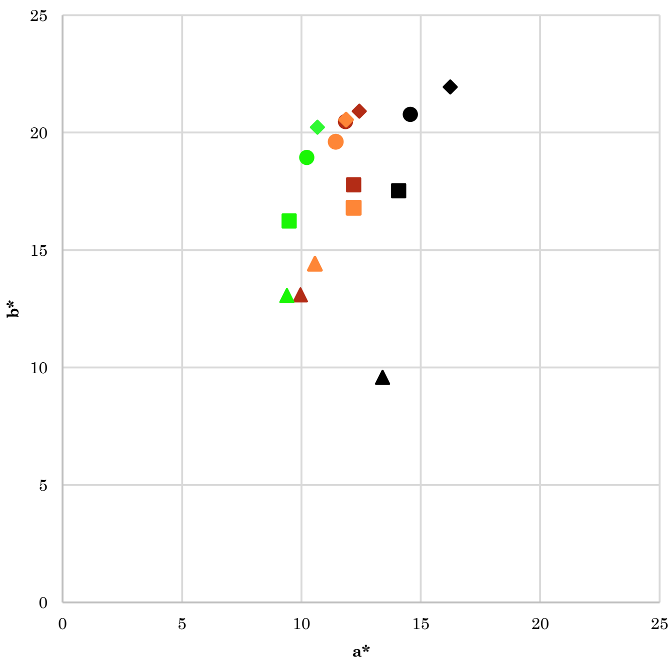
	FH	CB	cheek	neck	BH	mean
Oriental	0.33	0.76	0.87	0.98	0.63	0.71
Caucasian	0.47	0.80	1.04	1.13	1.01	0.89
South Asian	0.40	0.66	0.99	0.72	1.04	0.76
African	0.75	0.55	2.30	0.78	0.62	1.00
Mean	0.49	0.69	1.30	0.90	0.82	-
MCDM of PR650	-	-	-	-	-	0.84

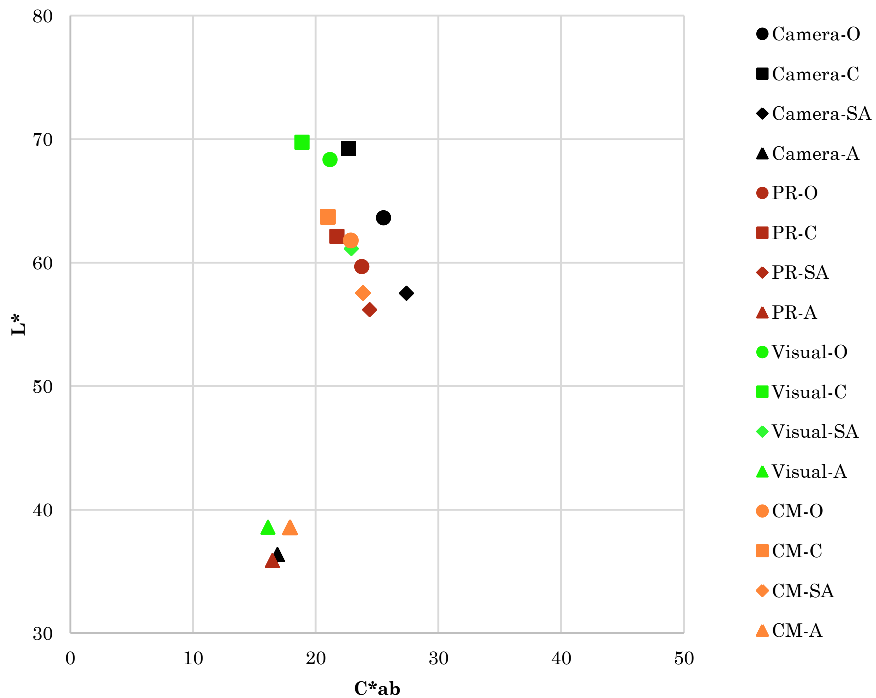
LLSC SKIN COLOUR DATABASE

MEASUREMENT RESULT

COLOUR SHIFT

- The camera gave the most colourful and more reddish result
- visual assessment gave results in the highest lightness and appear to be the yellowest
- The TSR and SP have good agreement in hue angle
- The results from SP have higher lightness than TSR





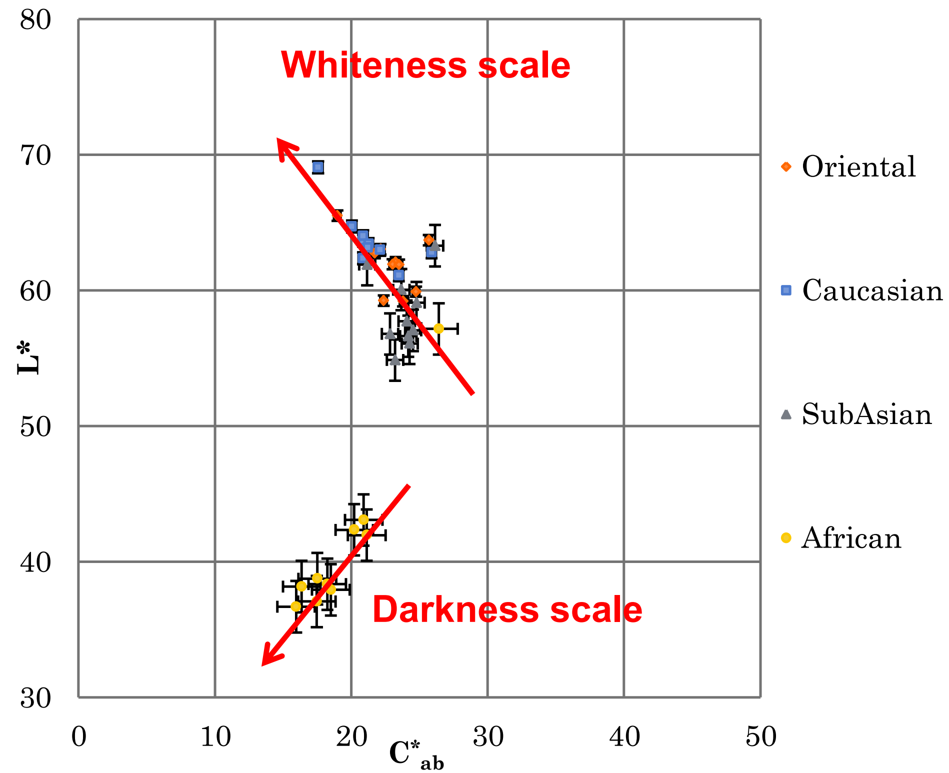
LLSC SKIN COLOUR DATABASE

MEASUREMENT RESULT

WHITENESS DIRECTION AND DARKNESS DIRECTION

SP's results as an example

- For the Caucasian and Oriental, the lighter skin colours are less colourful, appeared 'whiter', as defined by the distance closer to a neutral white.
- For the African, the darker colours also appear less colourful, appeared 'blacker', as defined by the distance closer to a neutral black.
- For the South Asian, the variation is only in lightness, not in chroma direction.



Conclusion

- **Through the uncertainty test select out the measurement methods**

- **The short-term repeatability of the collected skin colour data:**
  - Different instrument the repeatability was different
  - The short-term repeatability varied in location and ethnicities
  - The CM700d is more repeatable than the PR650

- **The colour shift:**
  - The results from PR650 and CM700d were similar. CM700d's measurement results slightly higher in lightness
  - Camera and Visual assessment gave more colorful and higher lightness results.

- **A whiteness and a darkness scale were found in $L^*C^*_{ab}$ plane**

Thank you

Skin Gamut

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University of Science and Technology Liaoning

遼寧科技大學
University of Science and Technology LiaoNing

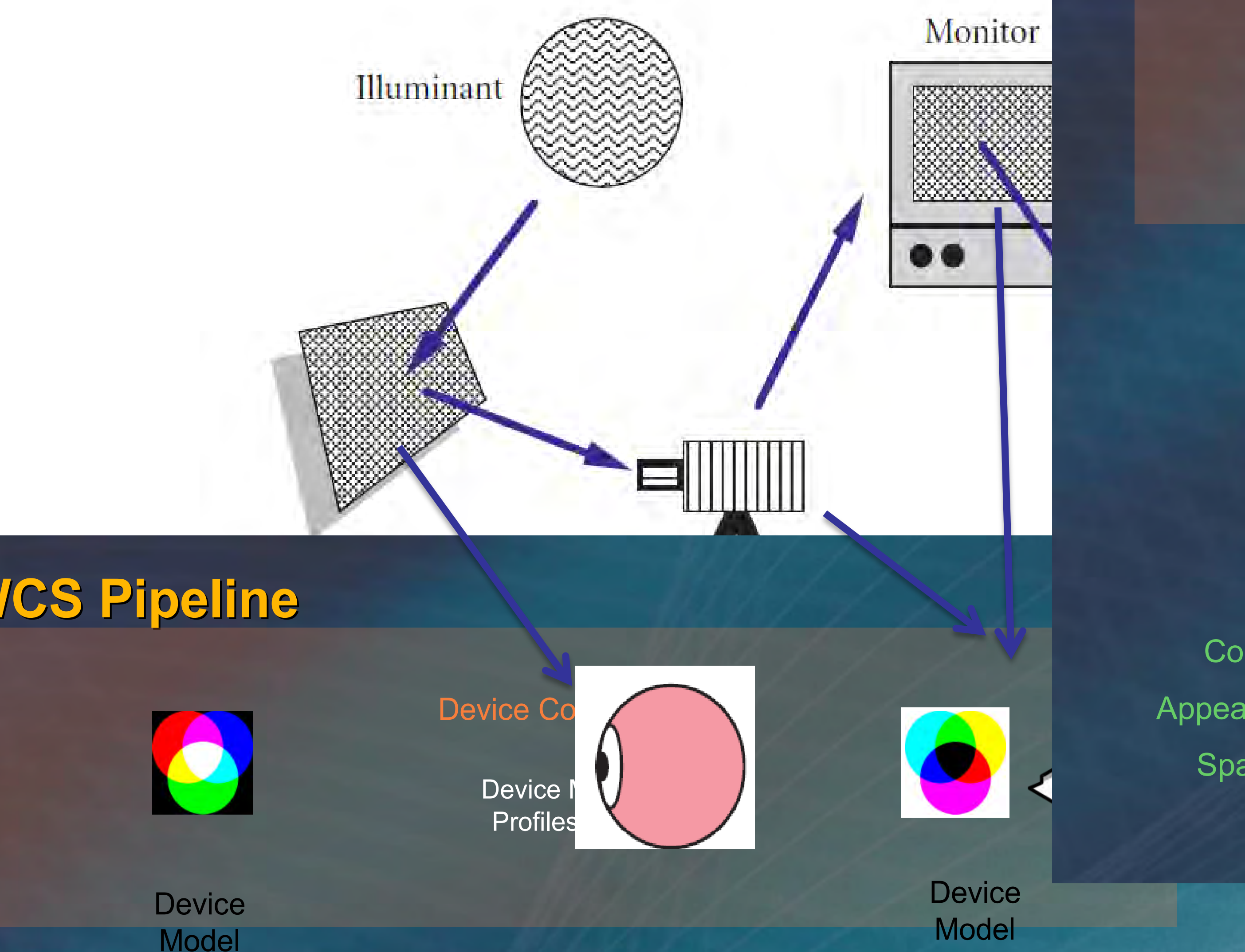
Outline

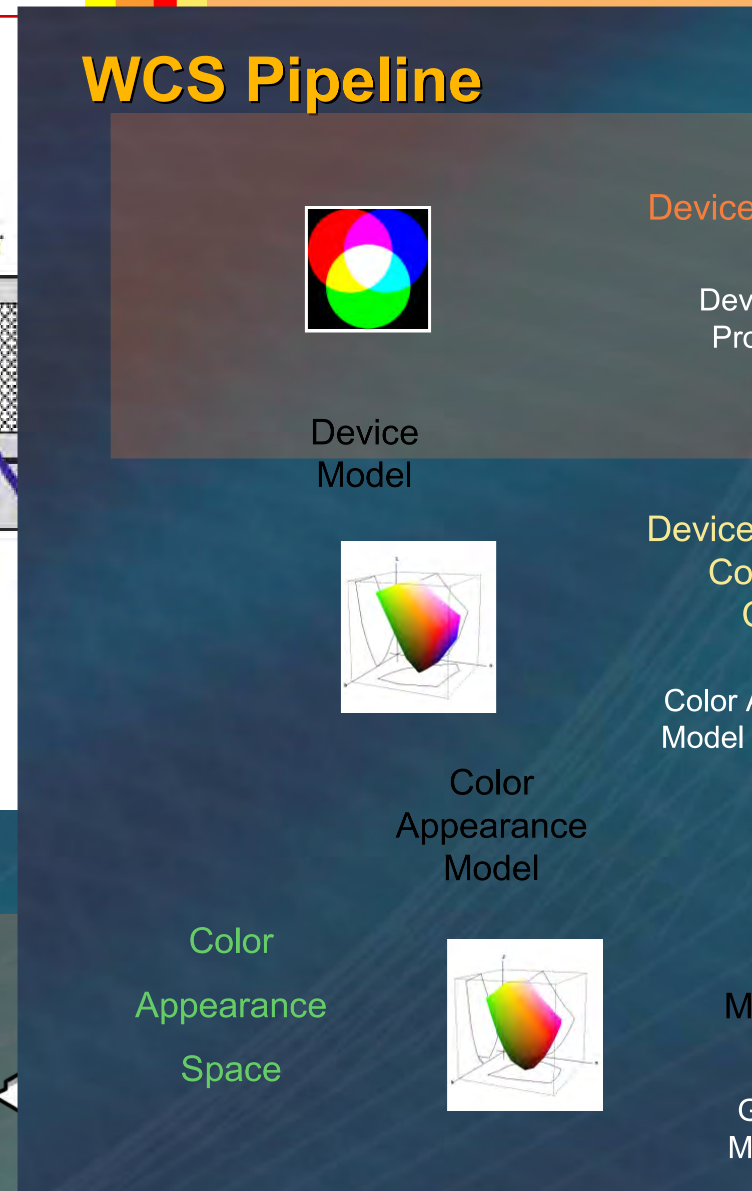
- Surface Colour Gamut
  - Why do we need a colour gamut?
  - Available Gamuts
- Skin Gamut
  - How to define skin gamut?
  - Ethnic Skin Gamut
- Conclusions

Surface Colour Gamut

Why do we need a gamut?

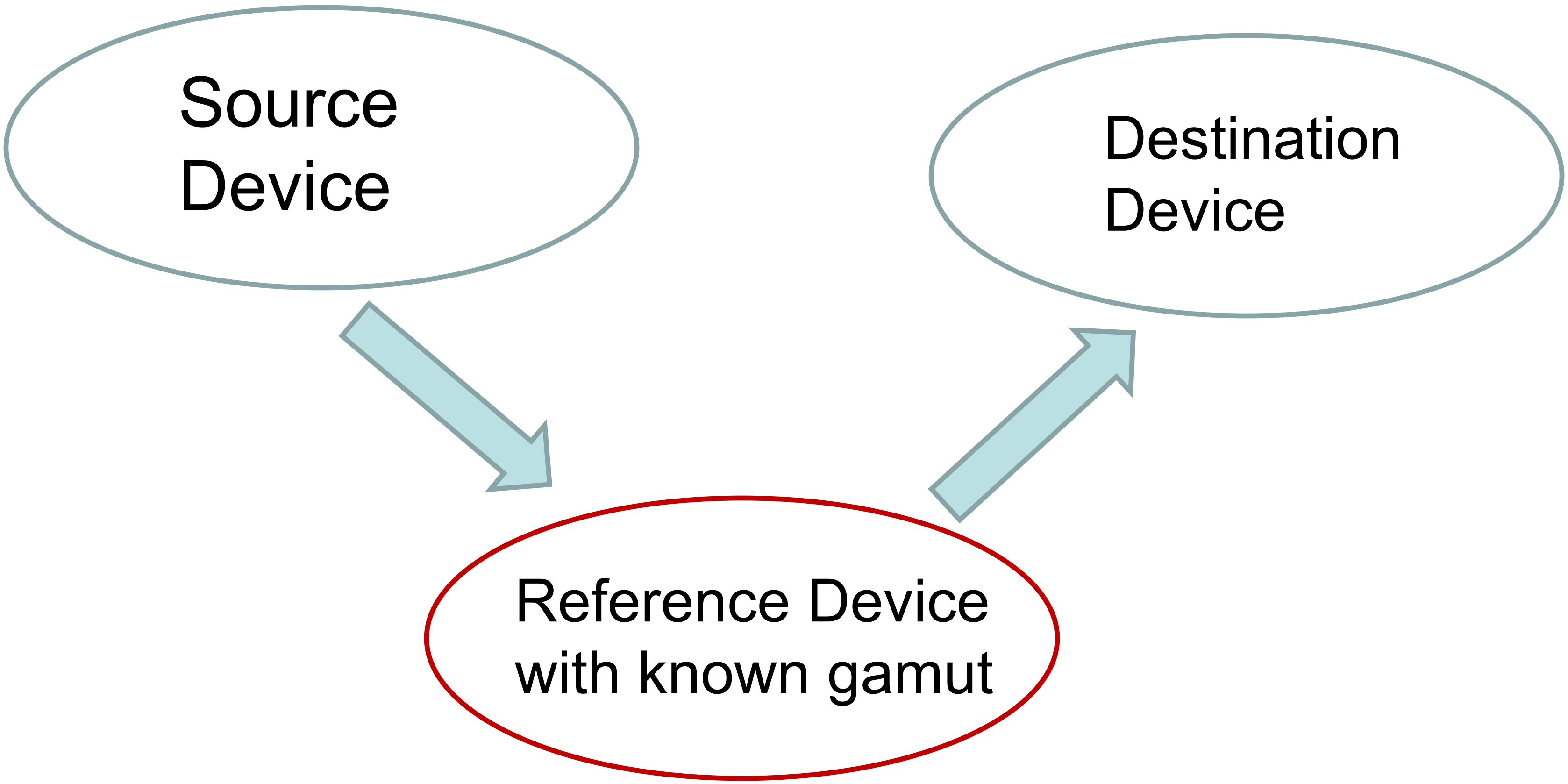
Colour Image Reproduction





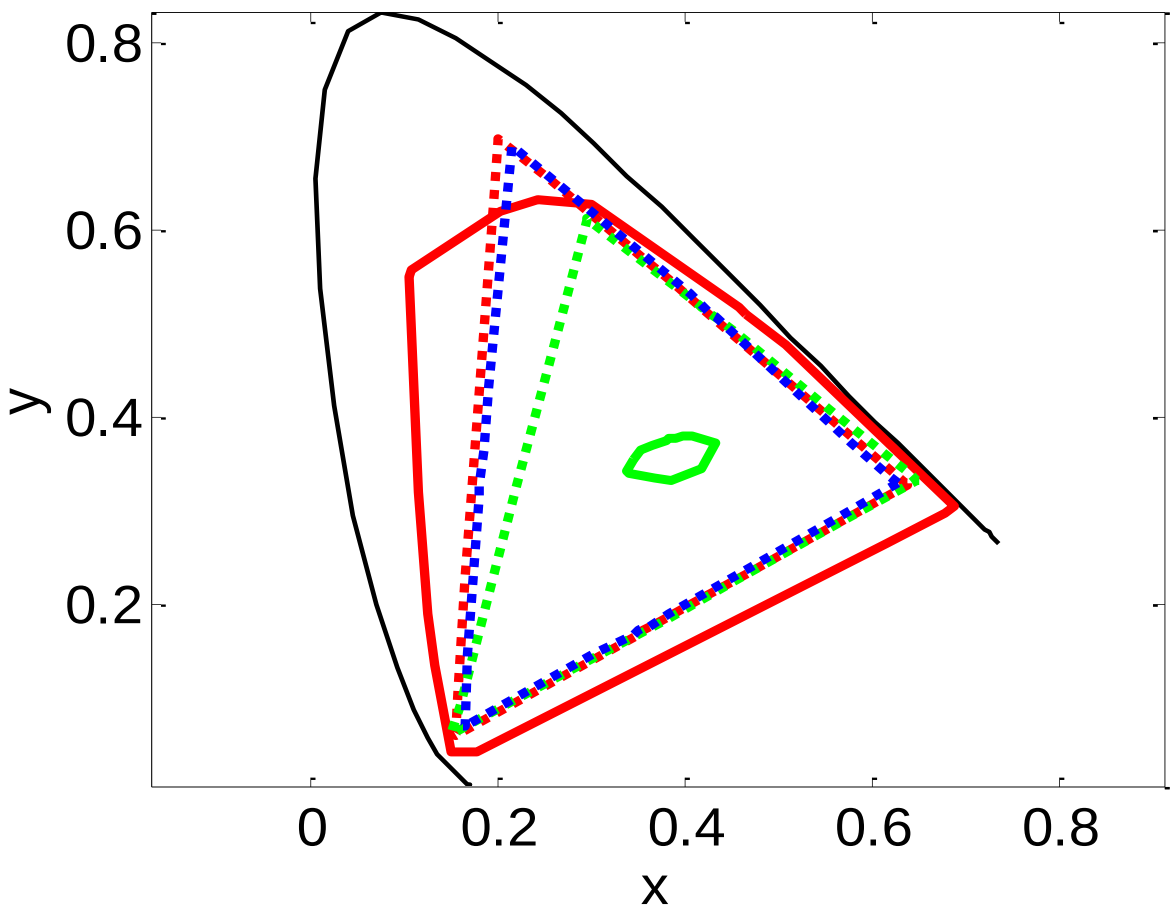
Why do we need a gamut?

Colour Image Reproduction



Why do we need a gamut?

Device evaluations



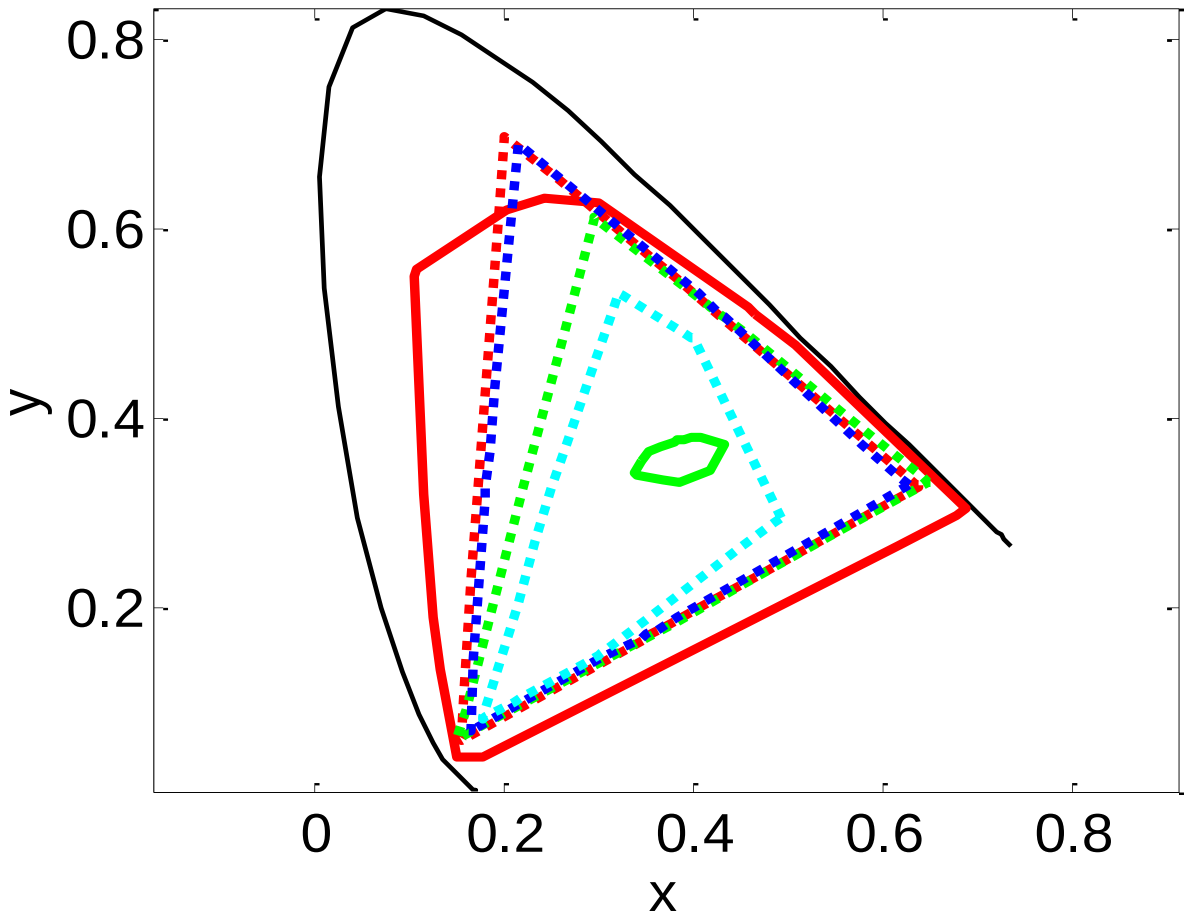
Triangles are three different display;

Red closed curve is the surface colour gamut;

Green closed curve is the skin colour gamut

Why do we need a gamut?

Device evaluations



Triangles are three different high end display;

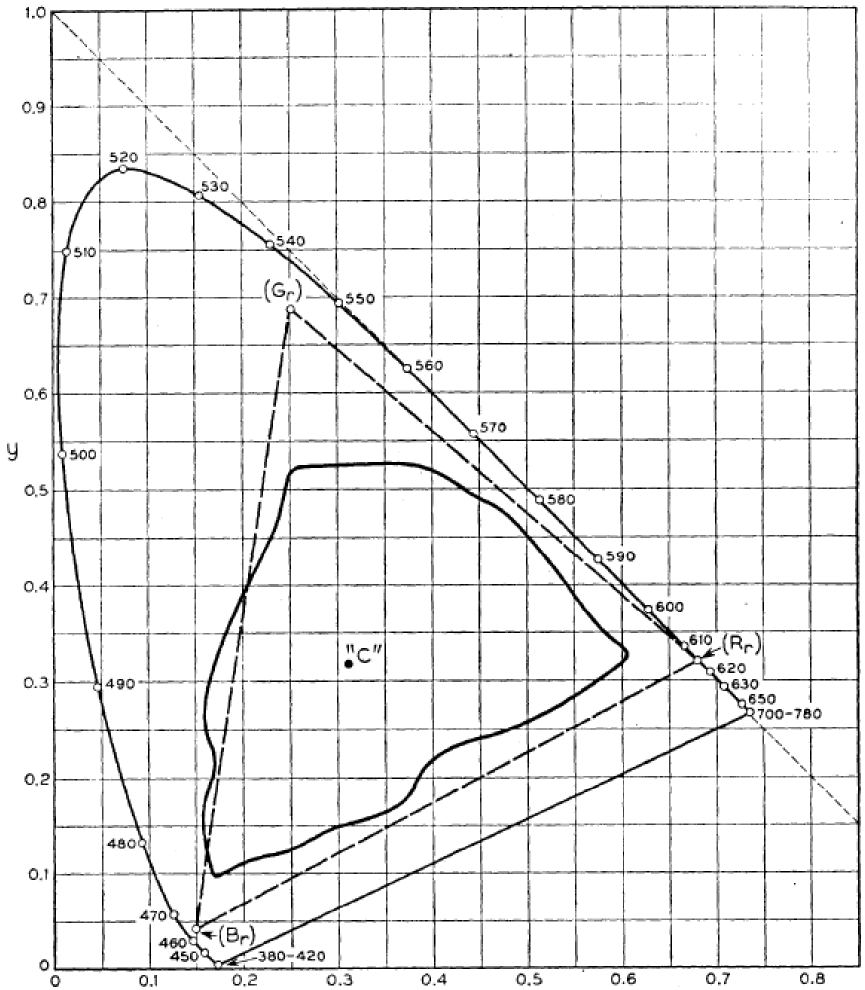
Dotted cyan curve is a low end display;

Red closed curve is the surface colour gamut;

Green closed curve is the skin colour gamut

Avalable Gamuts

2D Gamut



The Wintringham Gamut （1951）

–Locus of extreme purities of pigments, dyes, and inks for Illuminant *C*.
C=Illuminant *C*.
(R_r), (G_r), (B_r) =receiver primaries.

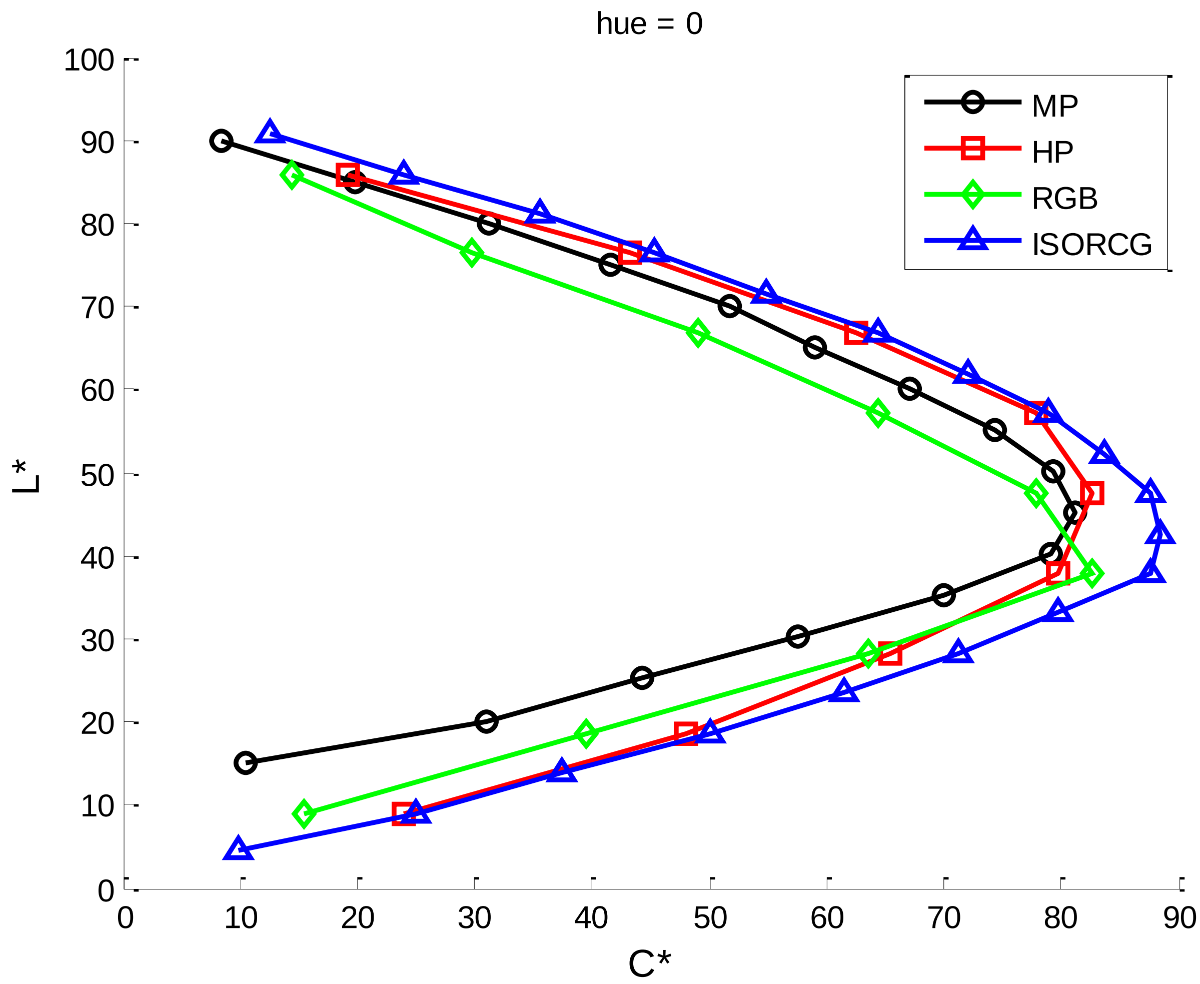
3D Surface Colour Gamut

3D gamut is defined in terms of L,C and h under certain illuminant

	15	20	25	…	80	85	90
0°	10	30	43	…	30	19	8
10°	15	30	45	…	30	18	7
20°	14	34	49	…	30	19	9
…	…	…	…	…	…	…	…
330°	20	50	72	…	27	18	9
340°	26	49	63	…	28	16	4
350°	15	37	52	…	30	17	6

L (row of column headers); C (table values); h (column of row labels)

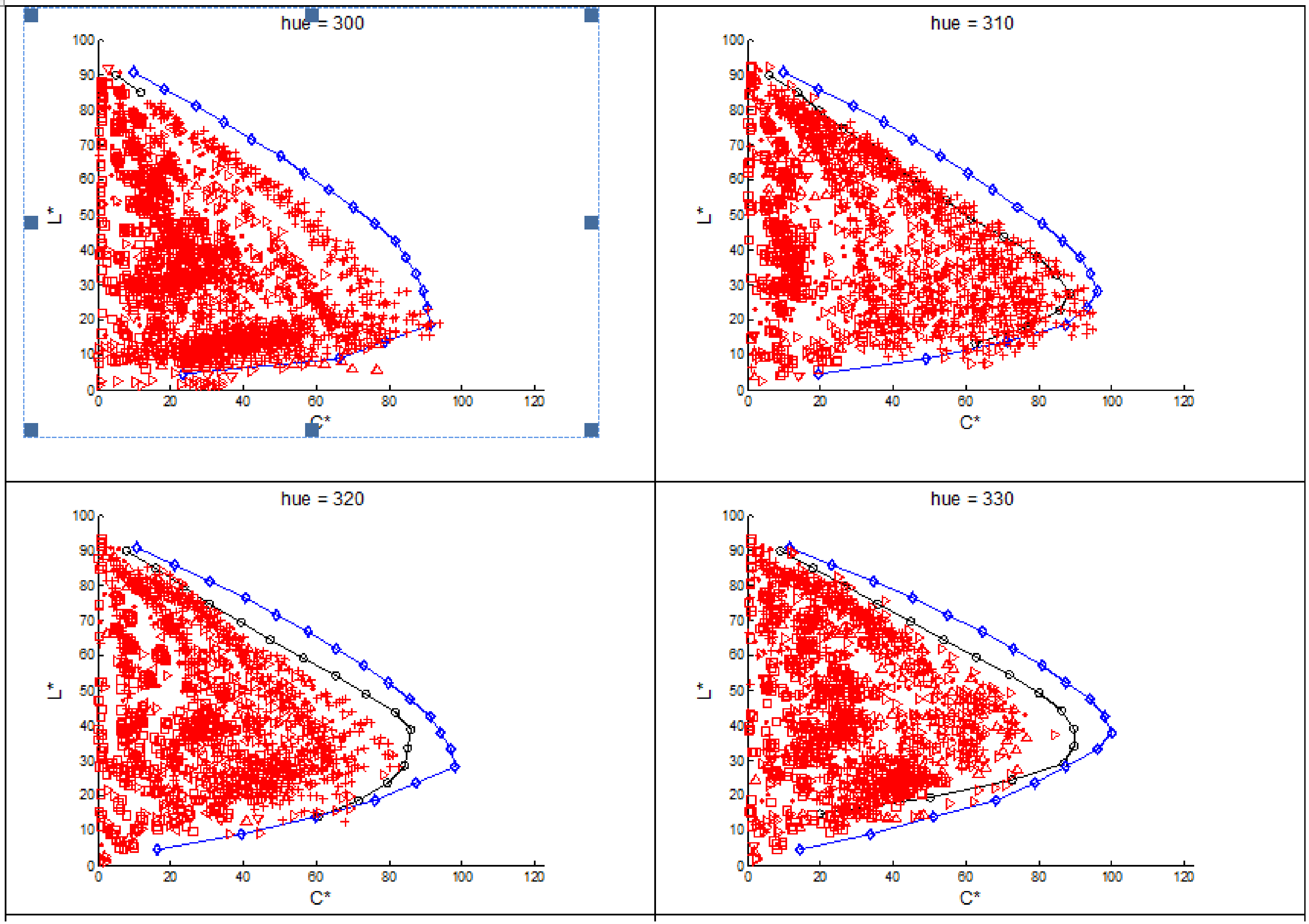
3D Surface Colour Gamut



Pointer: 1980 (ILL C)

ISO RCG: 2007 (D50)

3D Surface Colour Gamut



ISO: blue ;

Pointer: black;

Real data: colour dots

Skin Gamut

How to define the Skin gamut?

Depend on the applications. Here I quote* the skin gamut is needed for:

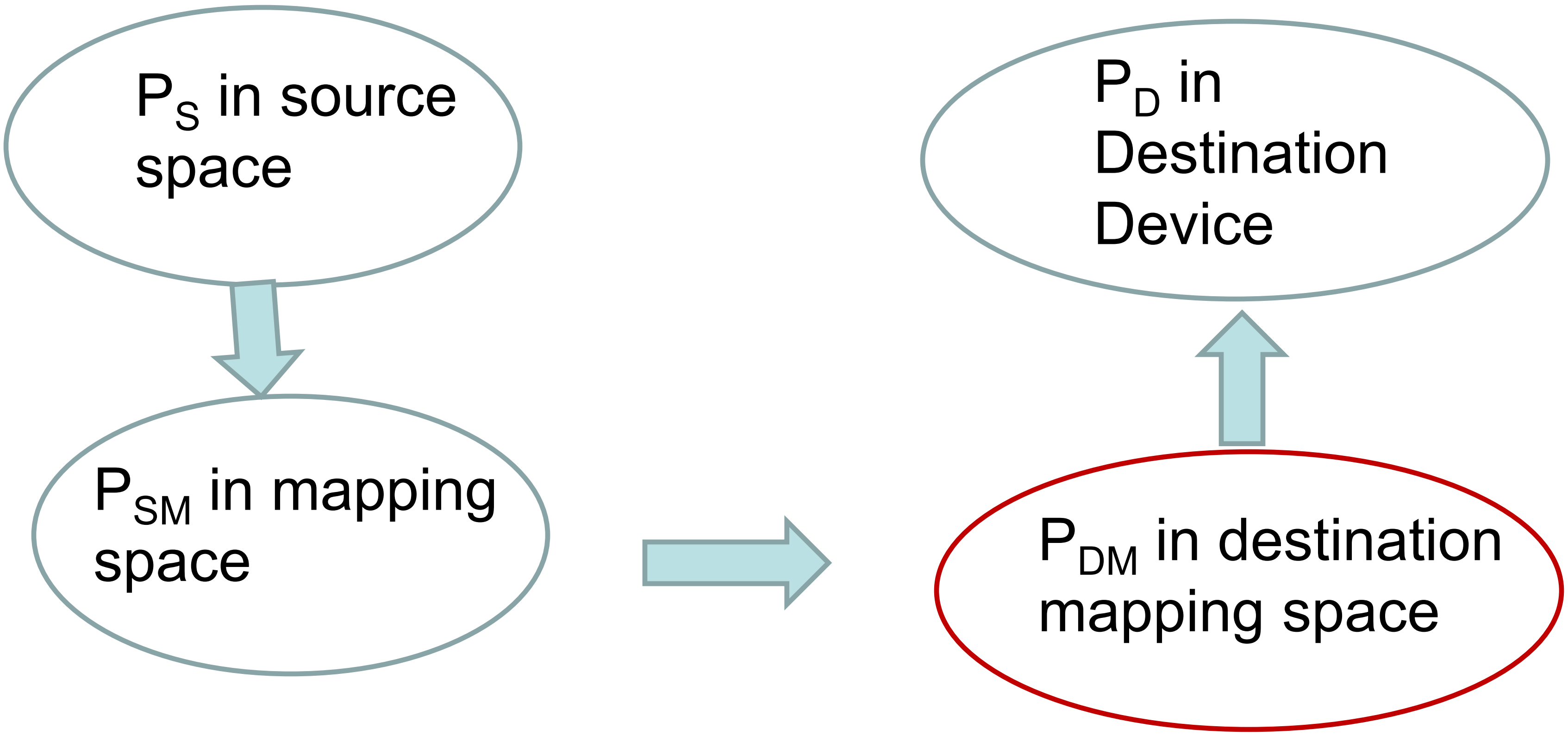
1. To investigate the accuracy of reproduction of skin colours including skin affected by medical conditions on displays used in medical imaging.

2. To apply the findings in recommending optimal workflow and viewing conditions for dermatology images viewed on LCDs.

* Dr Efthimia Bilissi (E.Bilissi02@westminster.ac.uk)
Imaging Technology Research Group, University of Westminster

How to define skin gamut?

For Colour Image Reproduction



For example in L,C.h, keep (or transform h to the destination h range), then consider map L,C in source mapping space into L,C plane in destination mapping space with the same (or transformed) h

Skin gamut

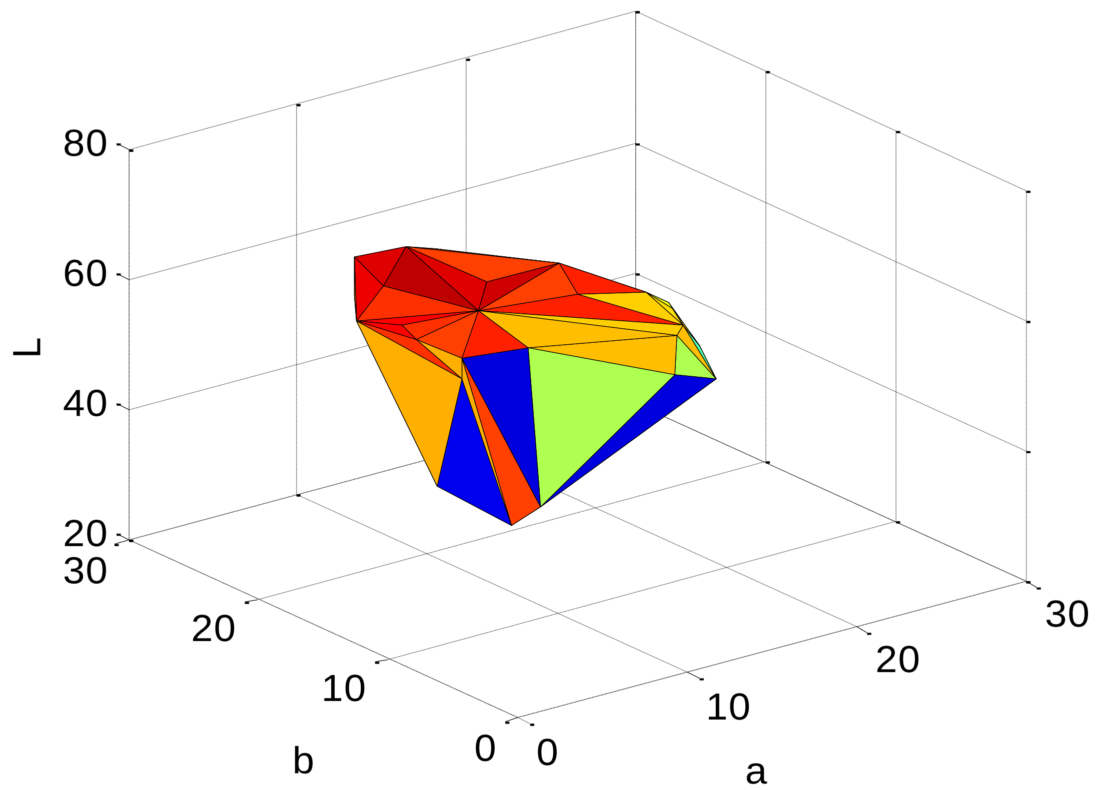
Data:

Four ethnic skin reflectance data: Chinese (807); Caucasian (552); Middle East (595); Thailand (1704); Total: 3658

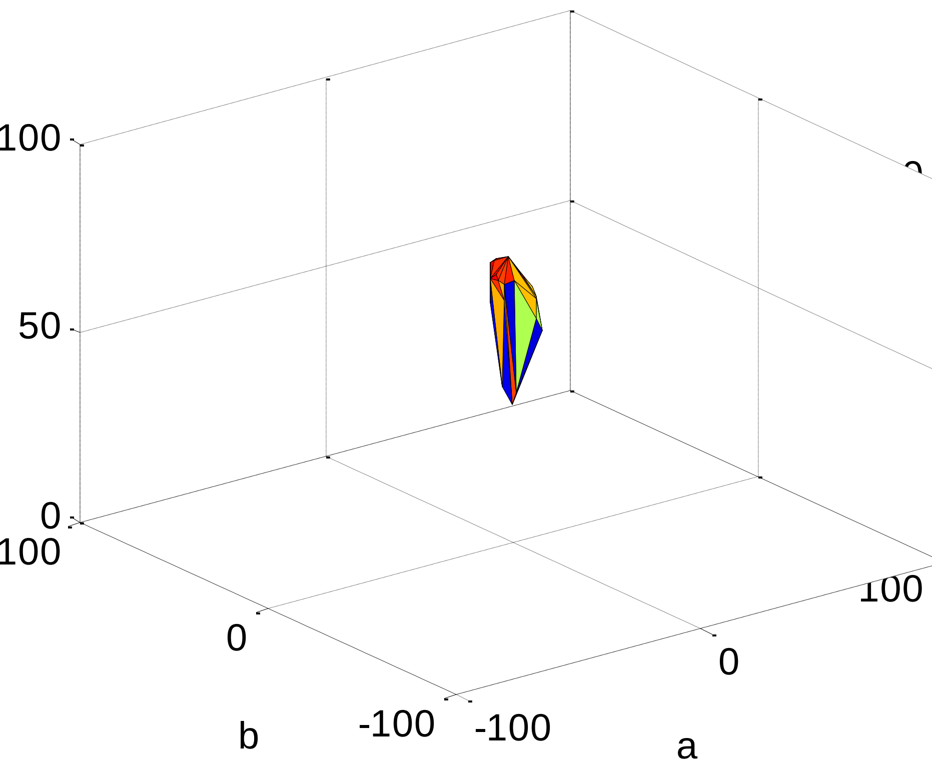
Statistical Information in CIELAB space (D65/31)

	min	mean	max
L	31.9	59.0	73.3
a	1.9	9.6	22.5
b	6.7	16.7	22.7
C	8.5	19.5	27.3
h	26.3	60.4	82.7

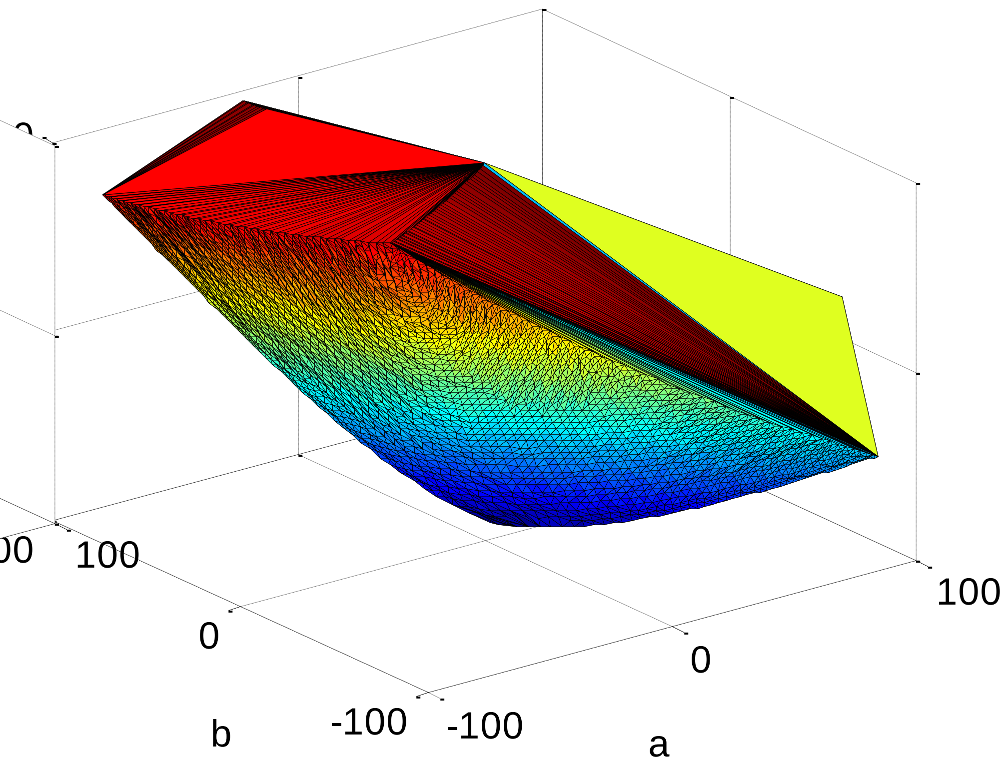
Skin gamut



Skin gamut

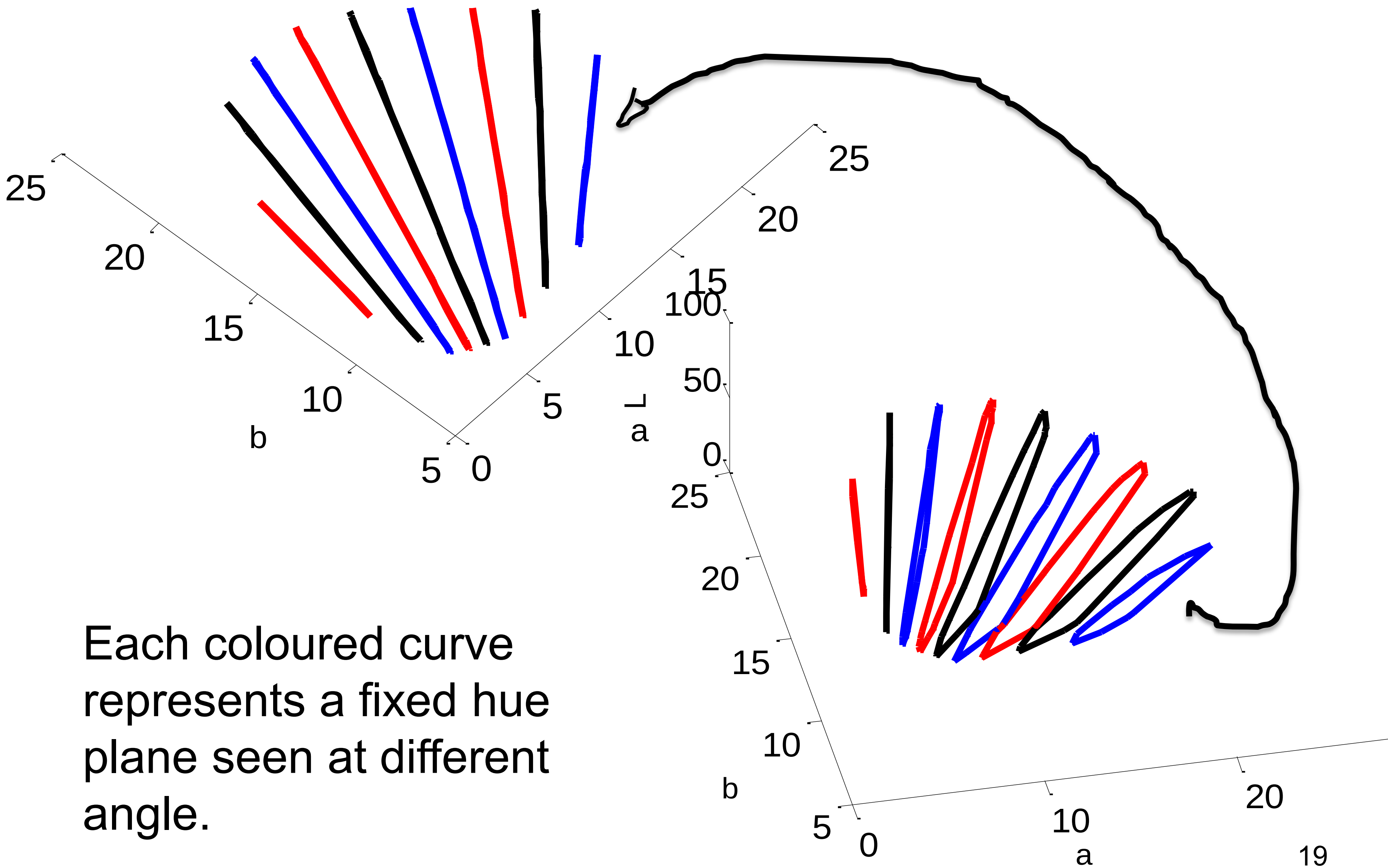


Gamut of skin



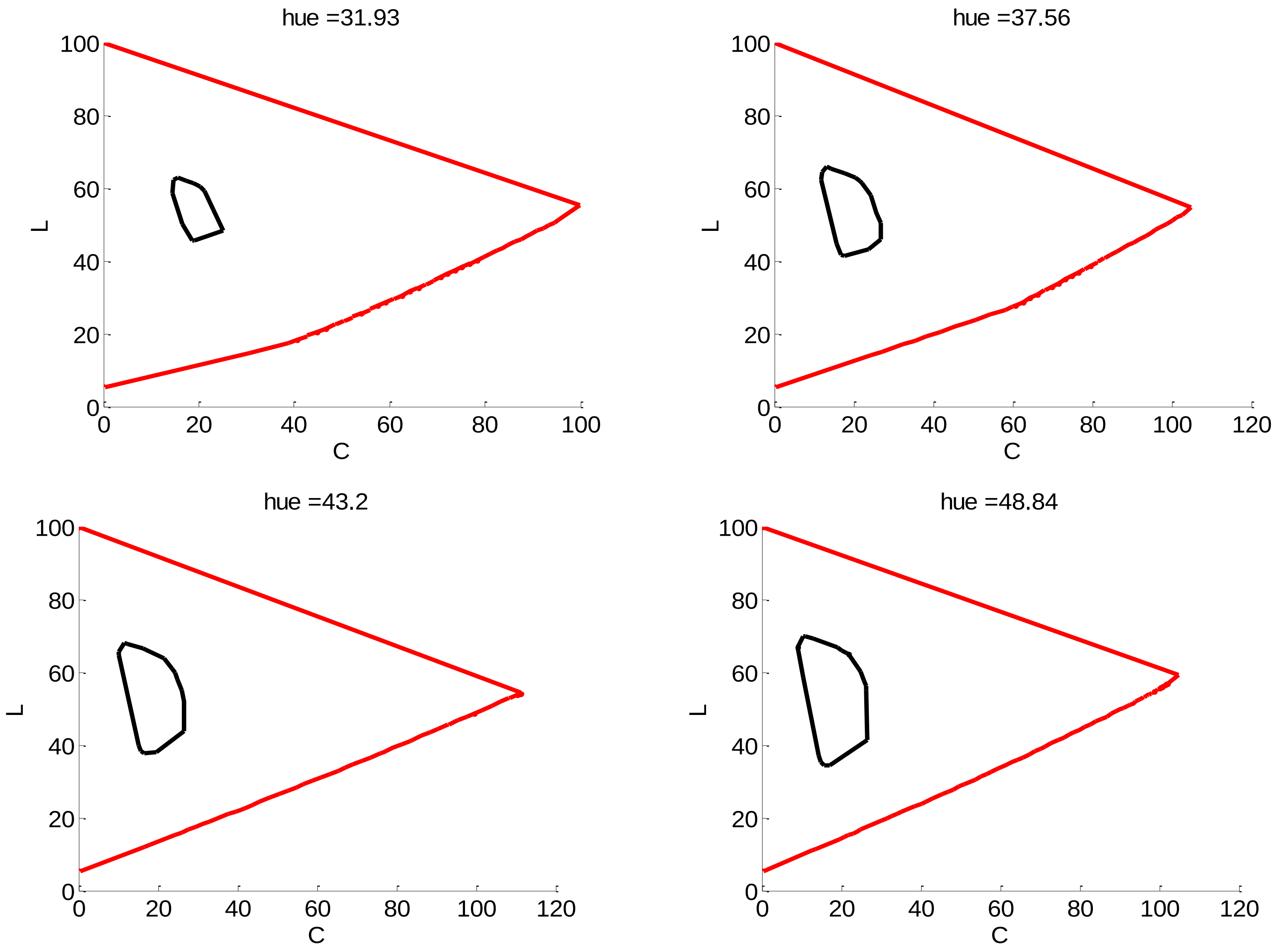
Gamut of a medical display

Skin Gamut

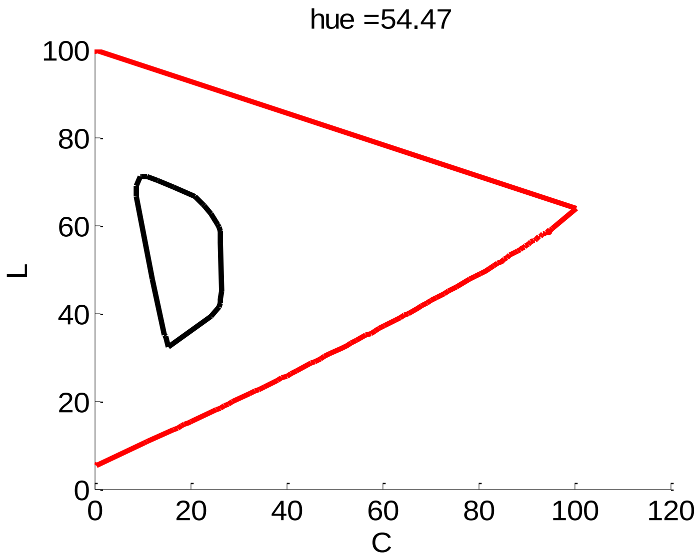


Each coloured curve represents a fixed hue plane seen at different angle.

Skin Gamut



Skin Gamut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100
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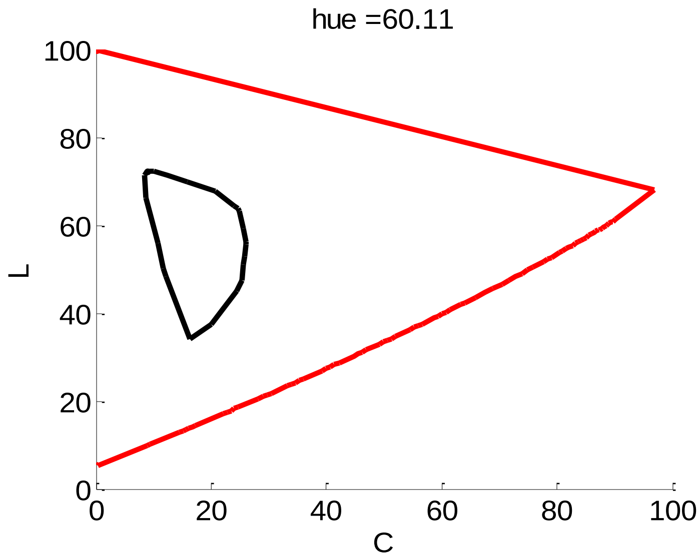
60
40
20
0
L
0
20
40
60
80
100
120
C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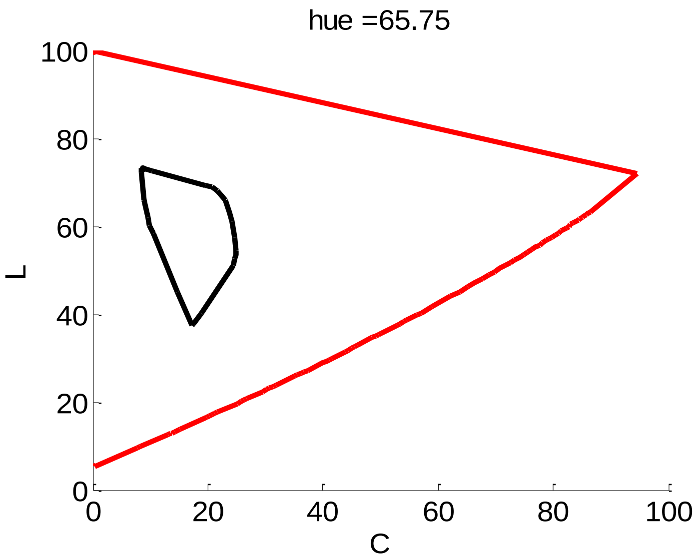
0
20
40
60
80
100
C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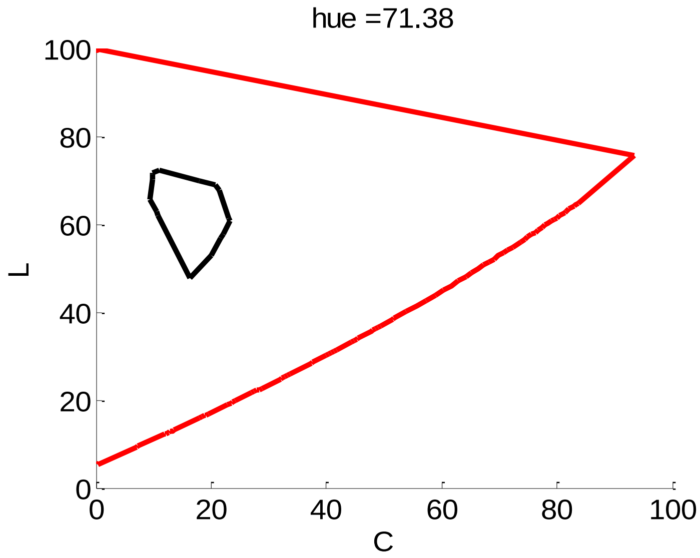
100
C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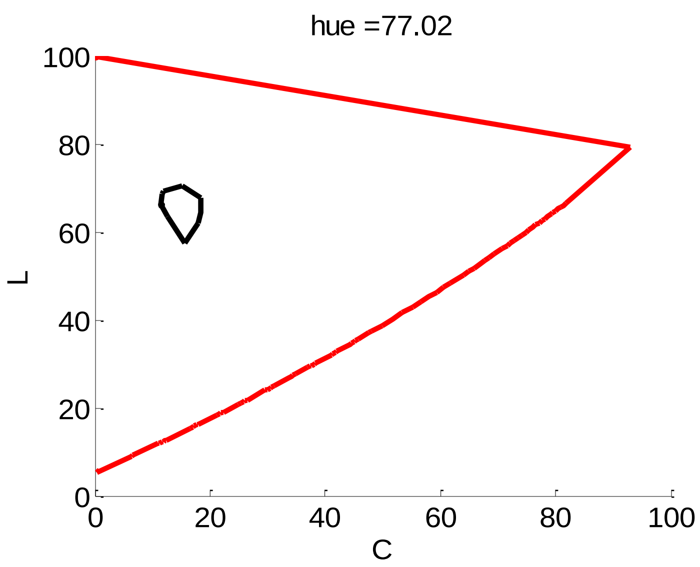
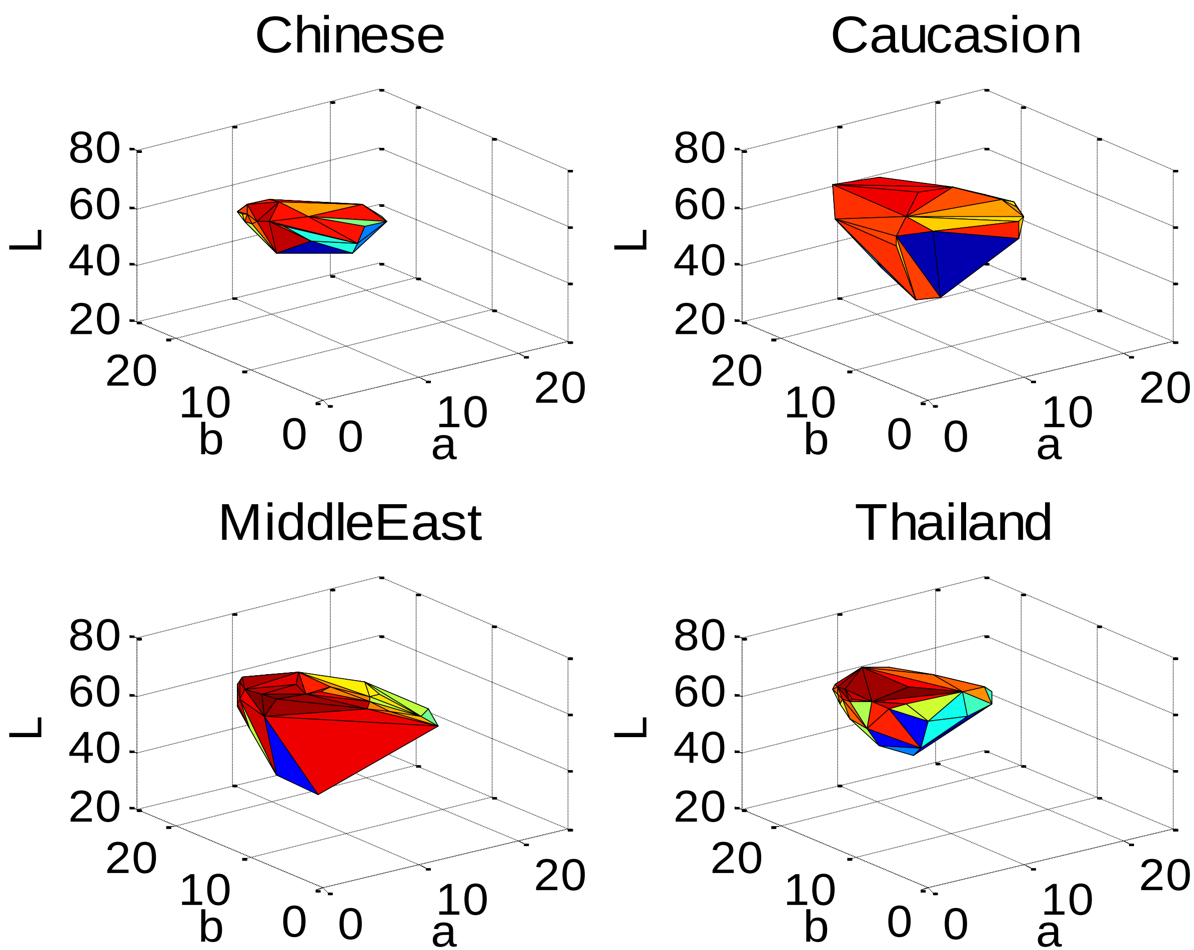
L
0
20
40
60
80
100
C

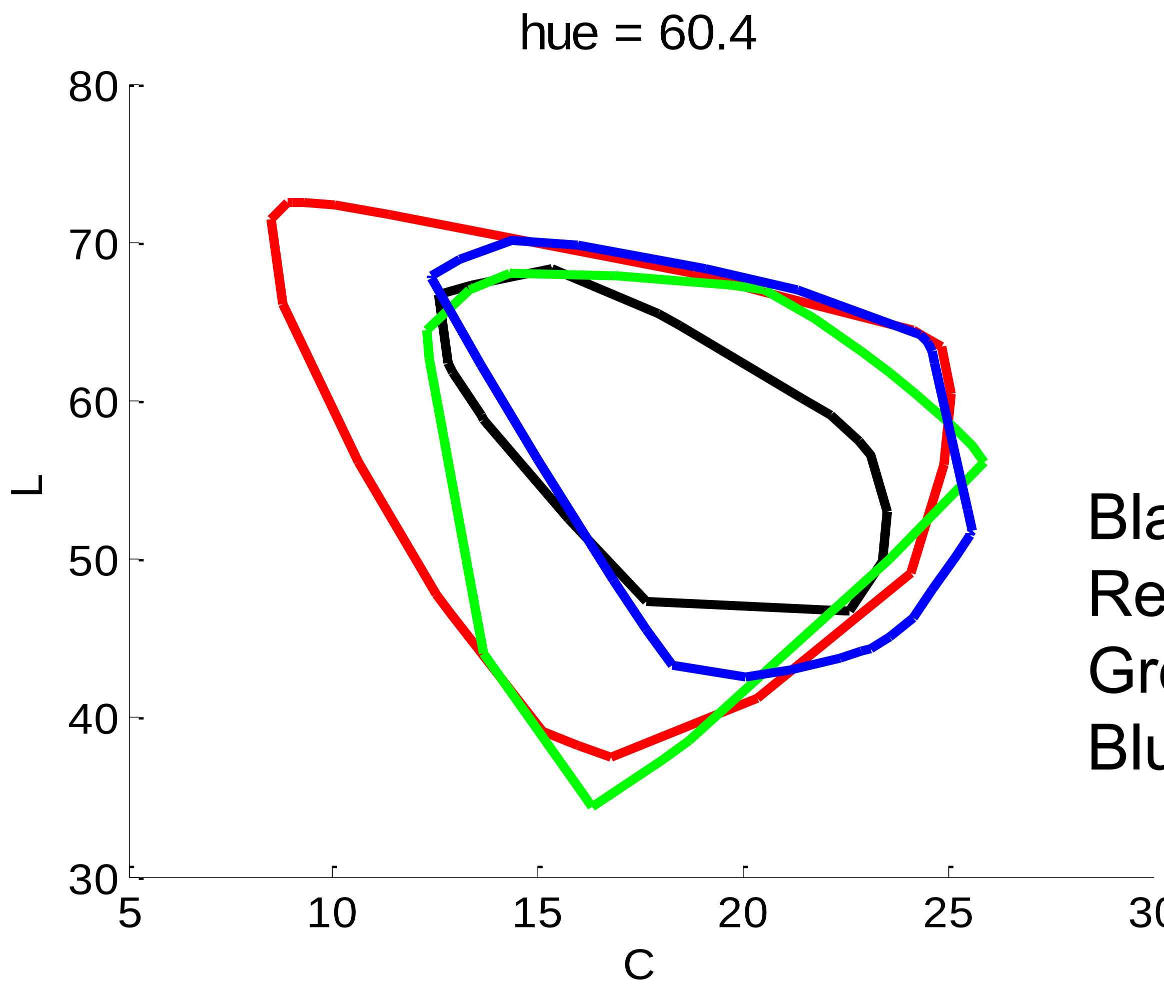
Skin Gamut



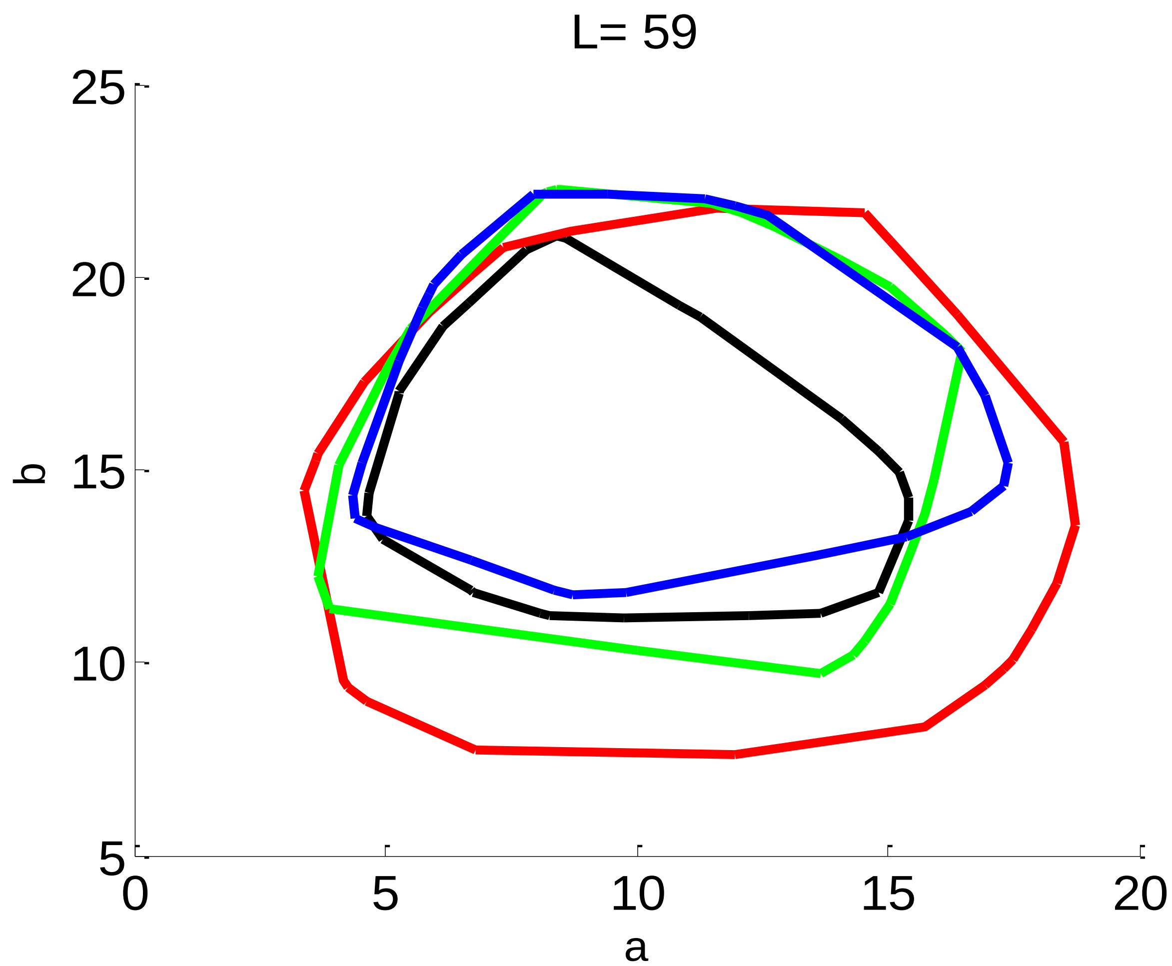
Ethnic Skin Gamut Difference



Ethnic Skin Gamut Difference



Black: Chinese
Red: Caucasian
Green: Middle East
Blue: Thailand



Black: Chinese
Red: Caucasian
Green: Middle East
Blue: Thailand

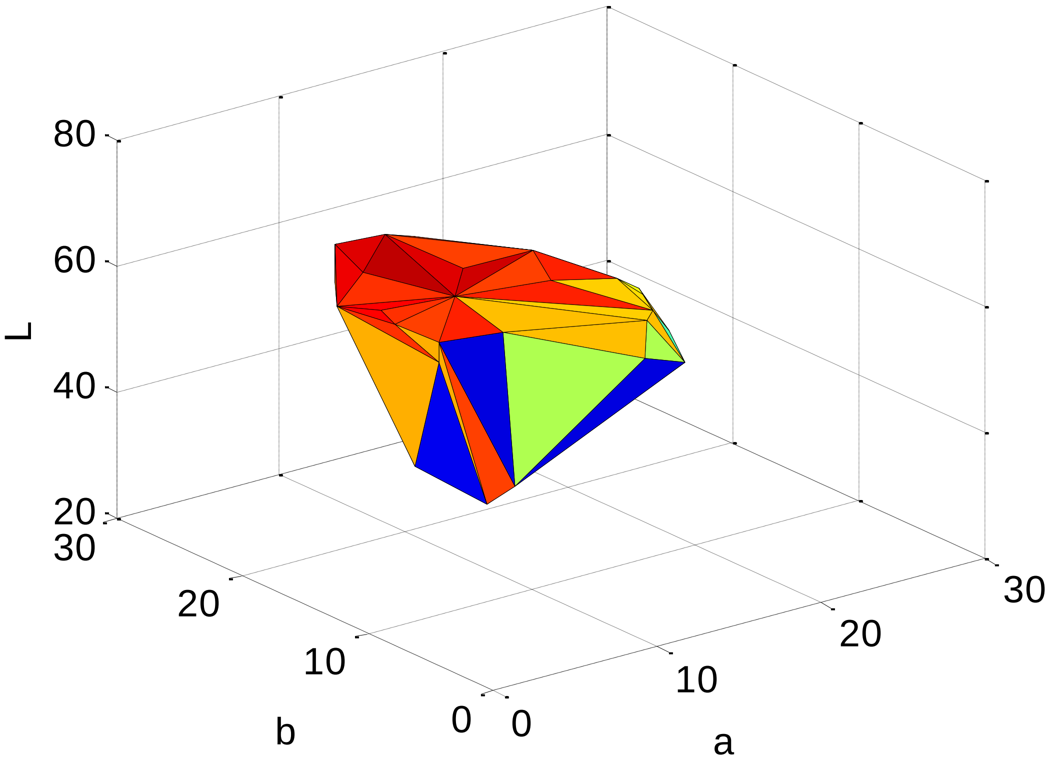
Conclusions

We have the method for getting the boundary :

1. under any illuminant

2. under any orthogonal colour space

3. with different aspects



Conclusions

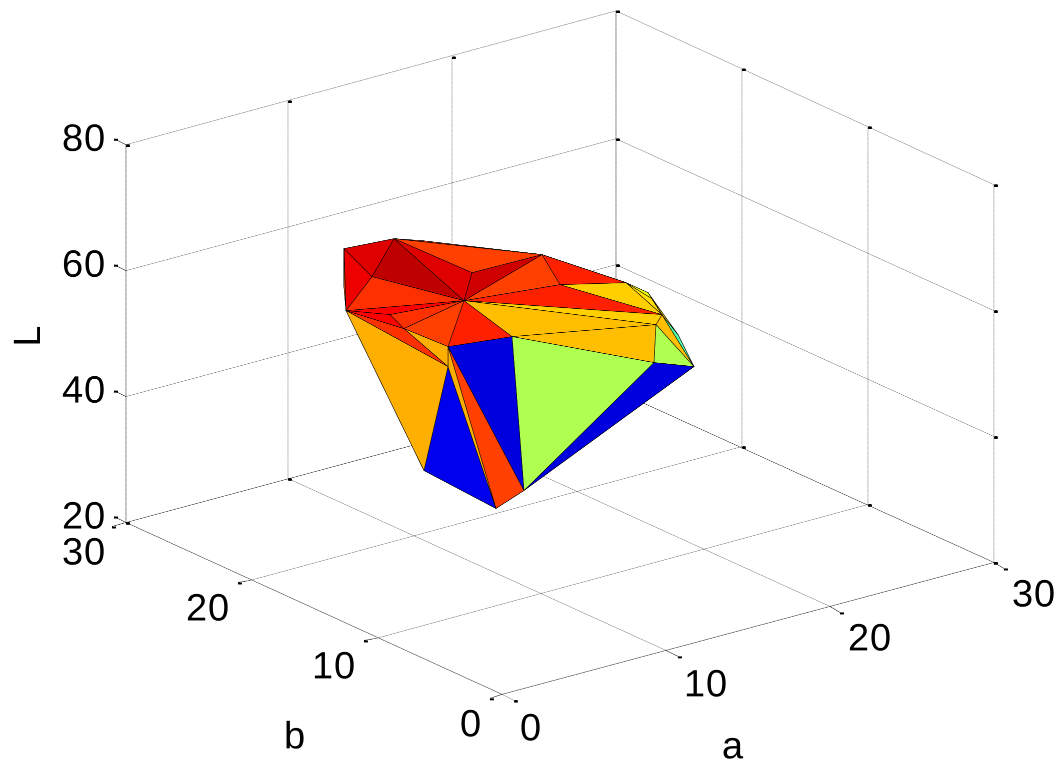
For example in CIELAB space:

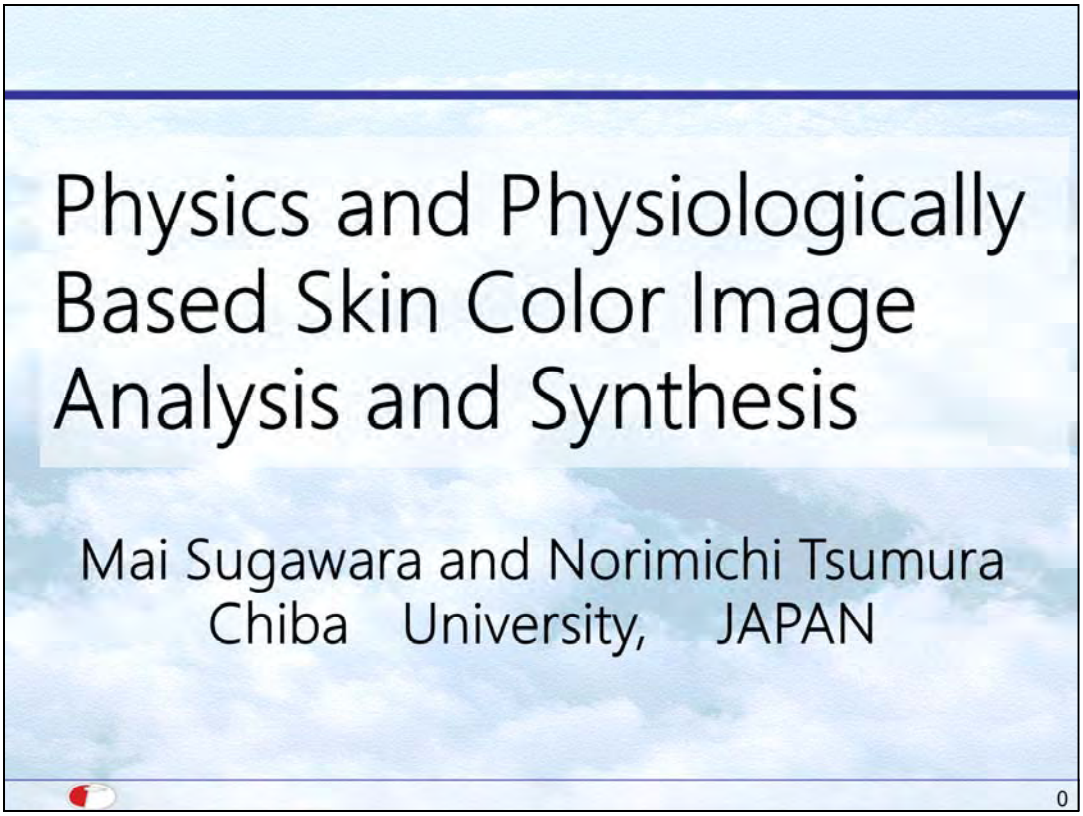
Fix L, in terms of a and b

Fix hue, in terms of C and L

Fix a, in terms of L and b

Fix b, in terms of a and L

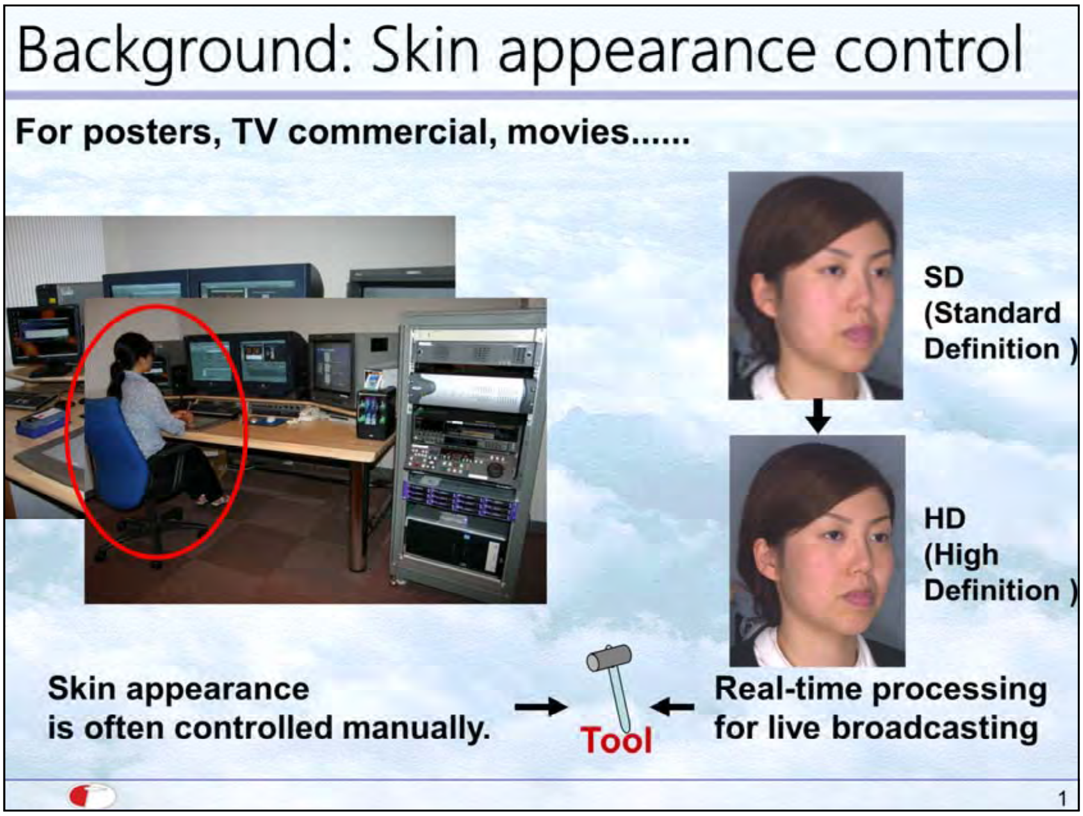




Thank you very much. Mr. Chairman.

(The title of our talk is

“Physics and Physiologically Based Skin Color Image Analysis and Synthesis ”
)



In the reproduction of human skin images in
posters, TV commercials, movies and other media,

skin appearance is often controlled manually
by an experienced operator in a time consuming process.

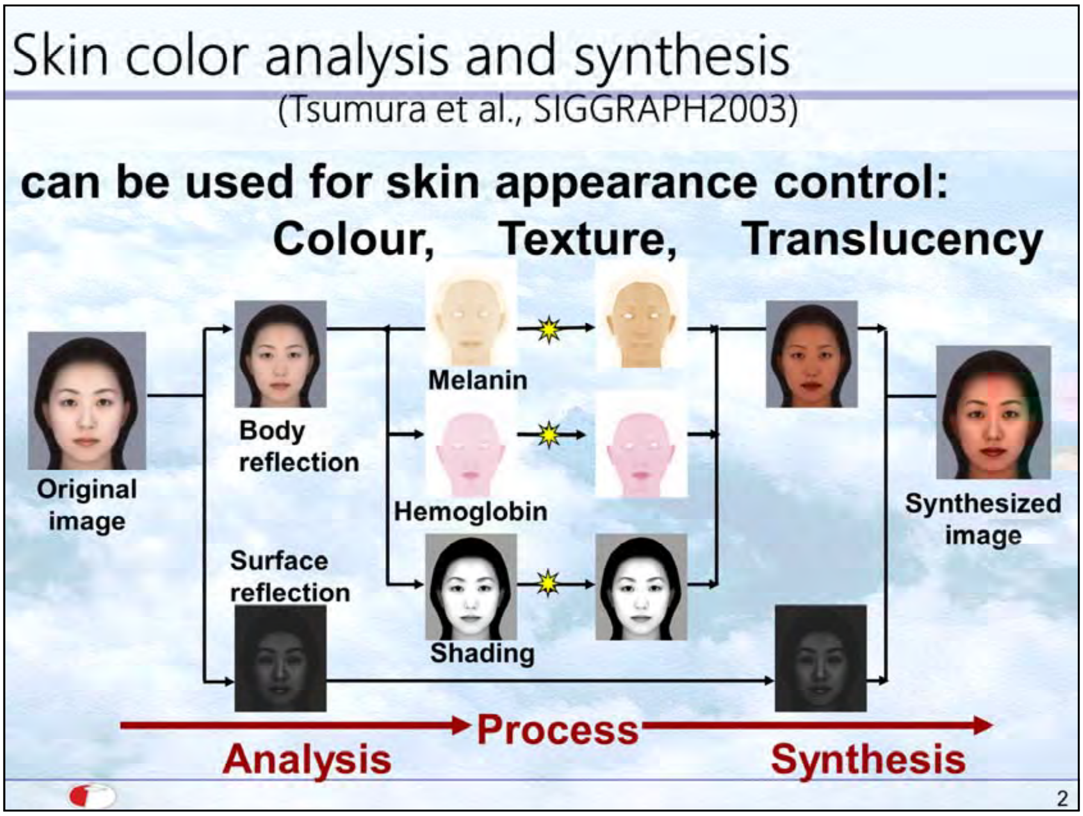
An useful tool is expected to control the appearance
to accelerate this reproduction processes

AND

The recent spread of high-definition imaging system gives a great influence
to the entertainment world, such as actors, actresses, and newscasters,

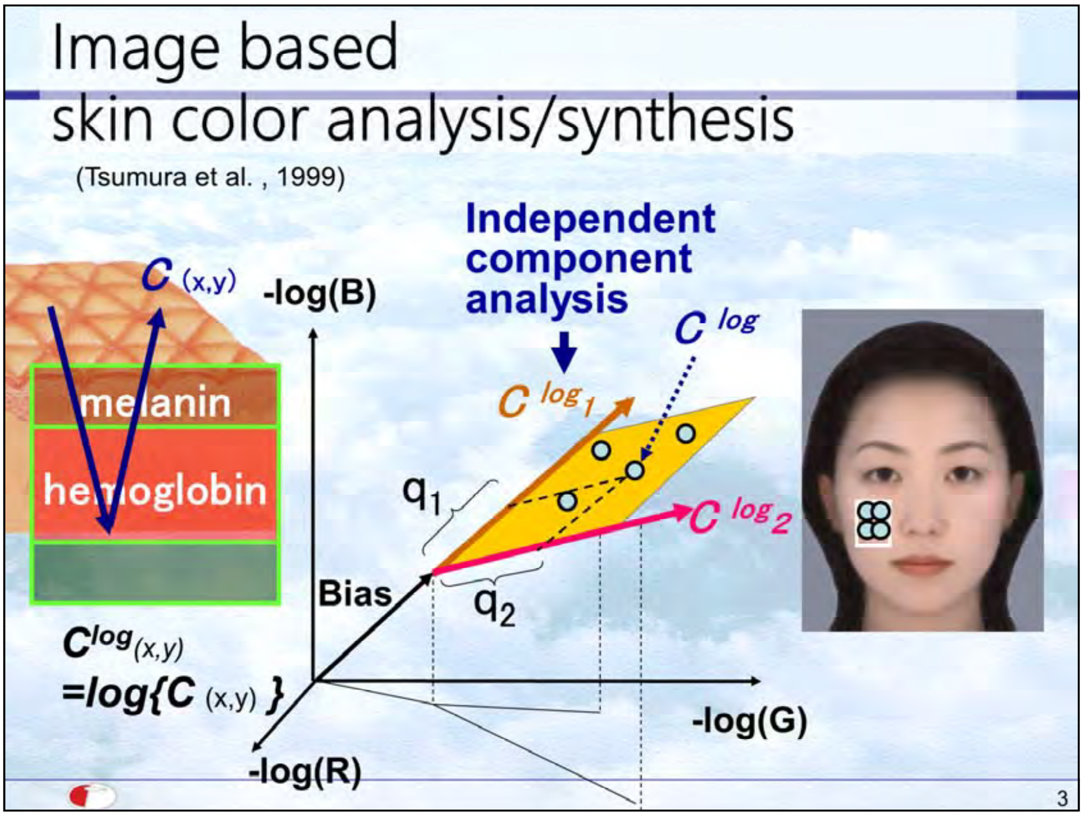
This is because that the skin appearance can be seen in great detail by high-definition imaging systems.

Therefore, A tool for controlling the skin appearance by real-time processing
is necessary for live broadcasting.



Skin color analysis and synthesis can be used for skin appearance control. The major attributes of skin appearance control are Colour, Texture, and translucency.

The component maps are separated from a facial image like these. Physiologically based image processing could be applied to the components to control the physiologically meaningful change of skin.



By extracting a pixel from an image, and creating an RGB plot in minus log, that is density space ,the plots will make a two-dimensional plane spanned by color vectors of hemoglobin and melanin components.

Skin color is constructed form melanin in epidermis and hemoglobin in dermis.

The light is reflected like this.

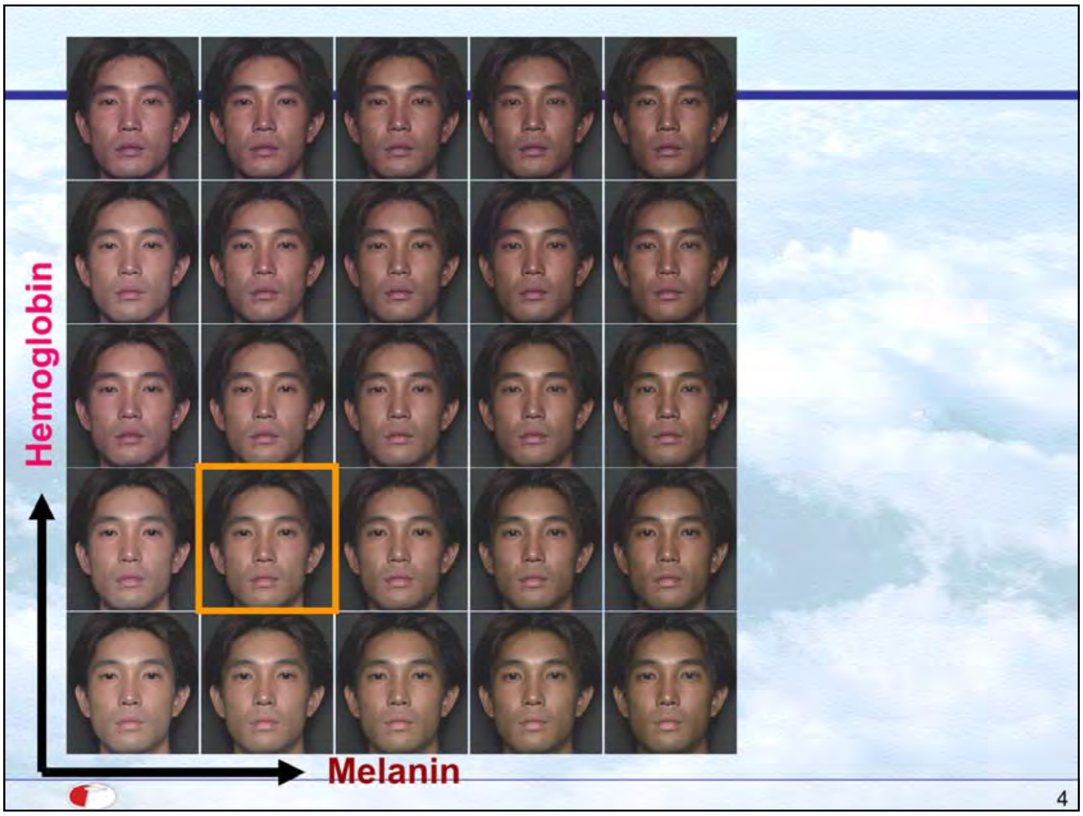
You can think the reflected light is a kind to "multiplication" between the transmittance of melanin layer and transmittance of hemoglobin layer.

As you know, if you take a logarithm to "multiplication", it will be the summation in density space.

Therefore skin color can be described by the weighted summation of melanin vector and hemoglobin vector in density space.

The melanin vector and hemoglobin vector are extracted by independent component analysis.

After the separation, we can change the amount of pigments, and synthesize the various skin colors.



Let me show you the synthesized images in 1999.
This is an original image.

To this direction, we changed the melanin components.
The face seems getting sun-tan.

And decrease.

To this direction, we increased the hemoglobin components.
The face seems getting drunken.

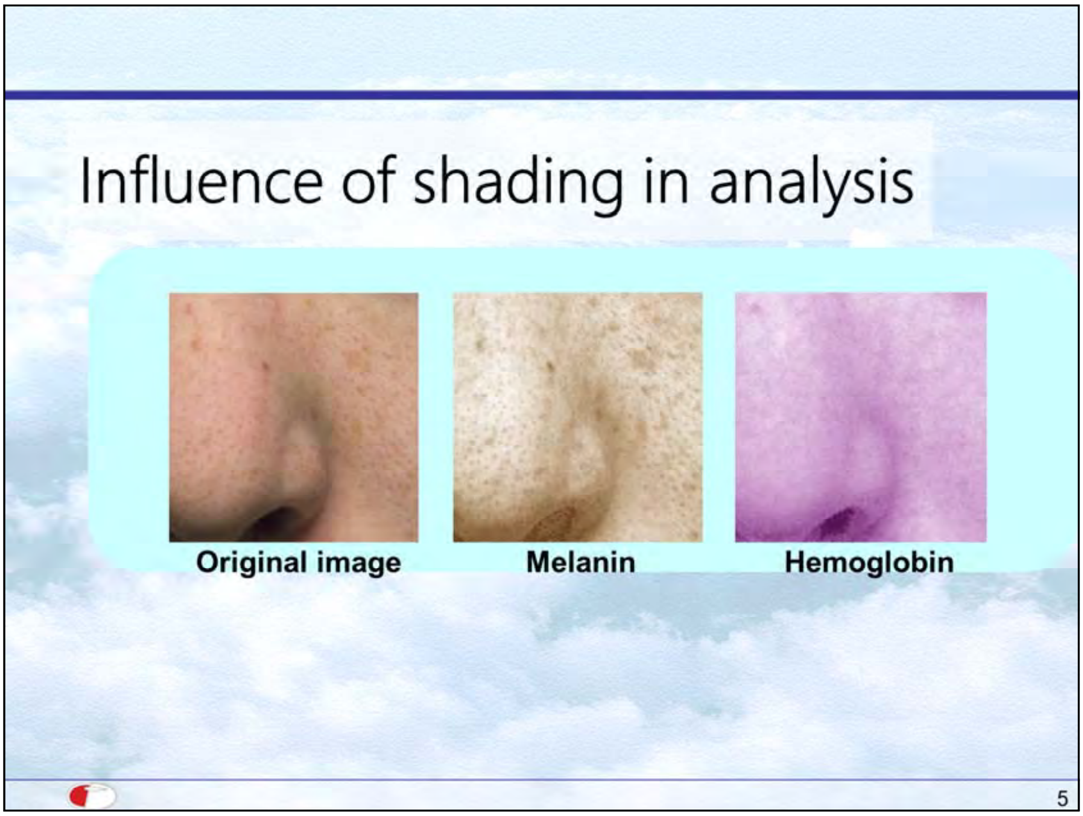
And decrease

And

To this direction, it's a kind of drinking beer on the beach.

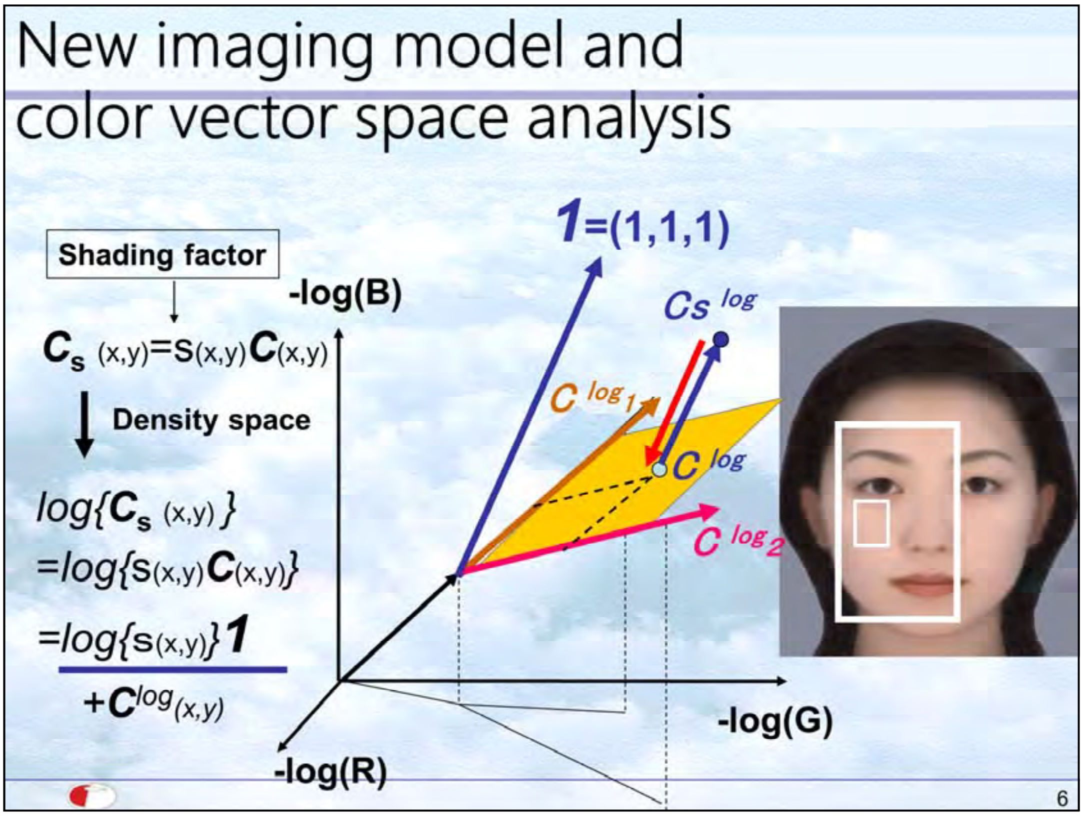
However, in this method, we still have these three problems for practical use.

Shading is increased in the synthesis.



Let me show the problems in detail.

Frist, from these figures, you can see the influence of shading in the analysis.
Shading by nose is mistakenly extracted as an increase of pigmentation.
In correct separation, “nose” should not be recognized.



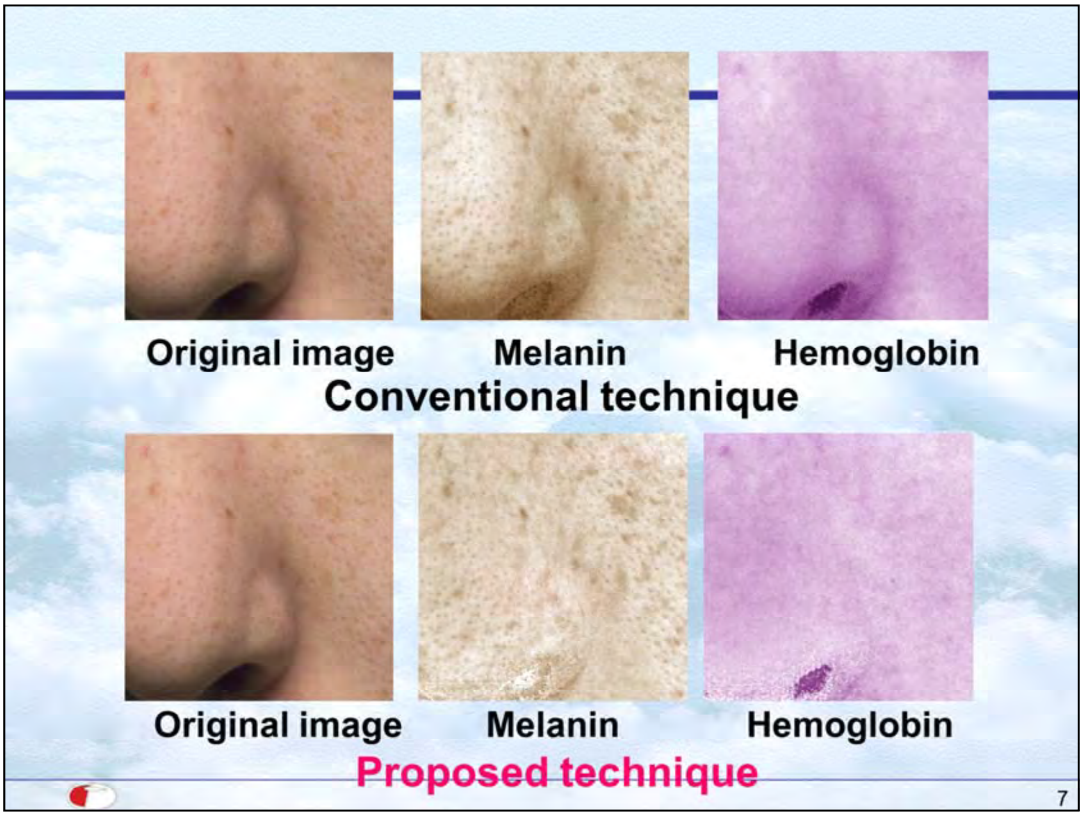
When the entire face is processed,
As you can see, shading becomes a factor.

This “s” is the shading factor, which will change in each pixel.

If you take a logarithm to this equation,
you can see that the vector of shading factor is to the vector of (1,1,1).

Therefore, as shown in this figure,
the point of the original color values is moved to this along the vector (1,1,1) by shading.

To remove the shading, the observed color is projected
onto the skin color plane along the shading vector.



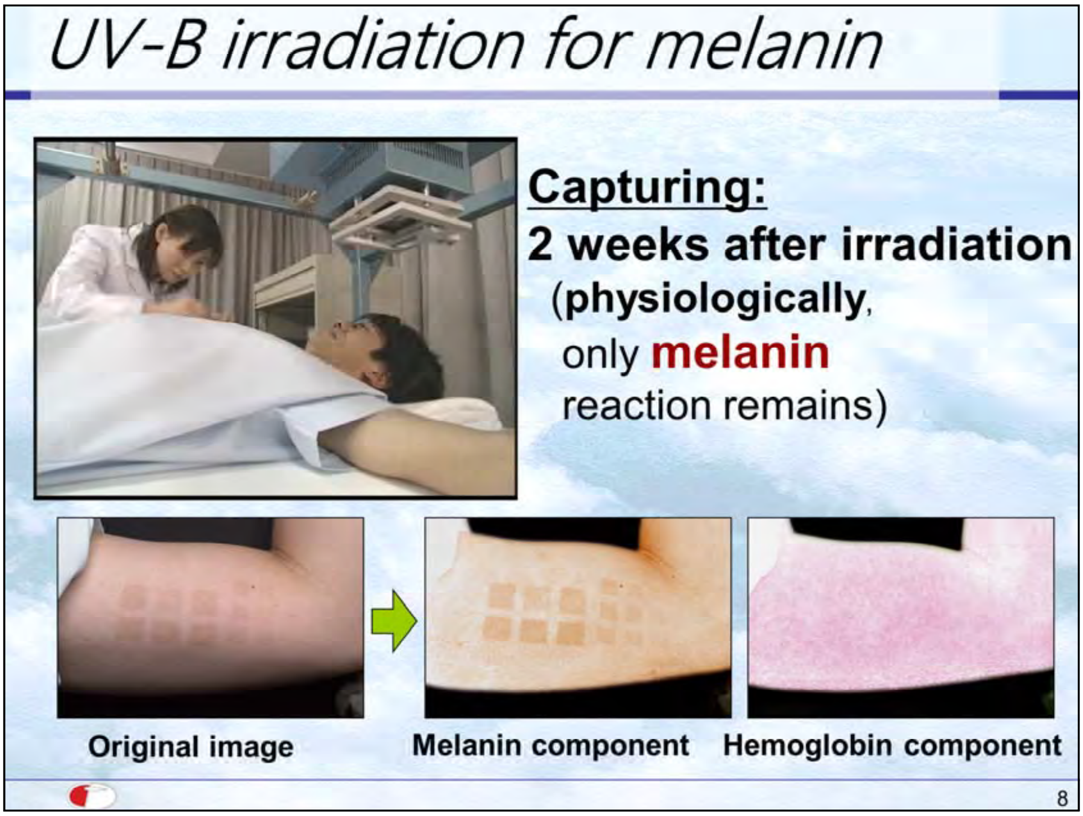
OK. These are previous results.
You can see nose.

These are results by the proposed technique.

You can see that the shading is removed. Nose can not be recognized.

On this stage, we can use this technique for practical use.

We can also say that this is a kind of technique of “inverse lighting”.

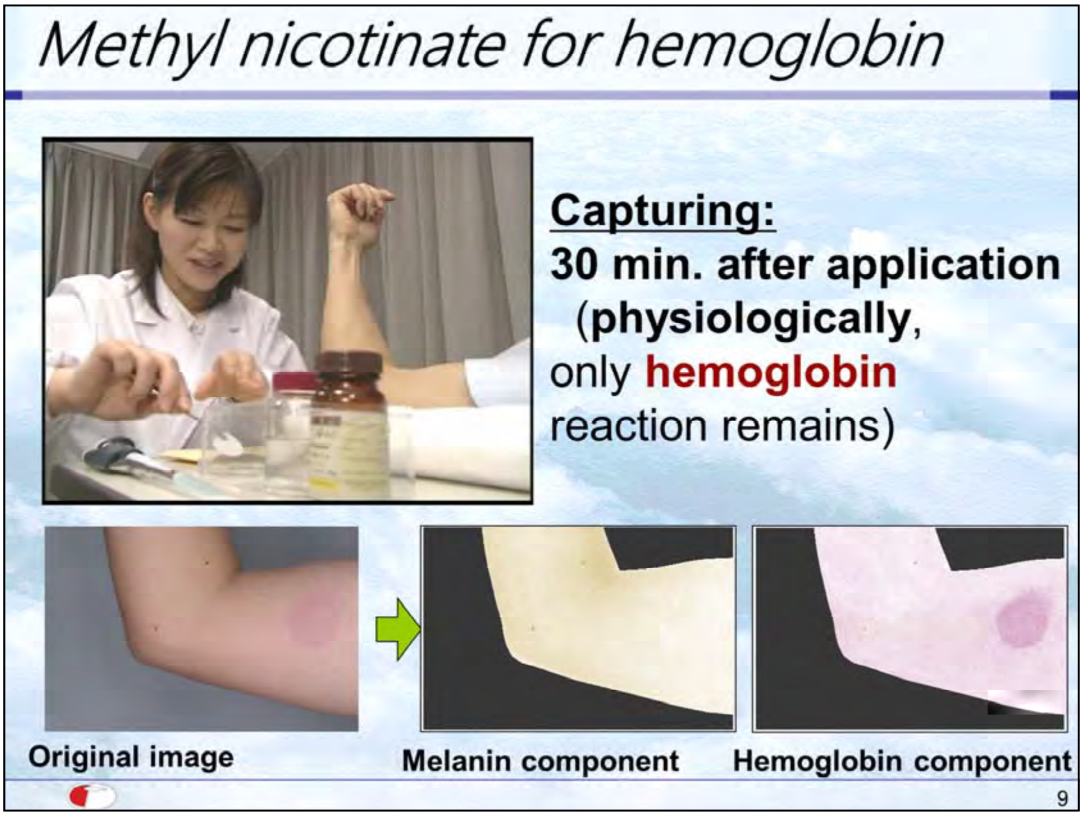


We used the proposed method to analyze rectangular areas of skin two weeks after Ultra Violet irradiation.
This is because we know that physiologically only melanin reaction remains two weeks after irradiation.

You can see that rectangular pattern appeared only on the melanin image.

You can also see that the shading is also removed.

Now, we cay say that our technique is valid for melanin extraction.

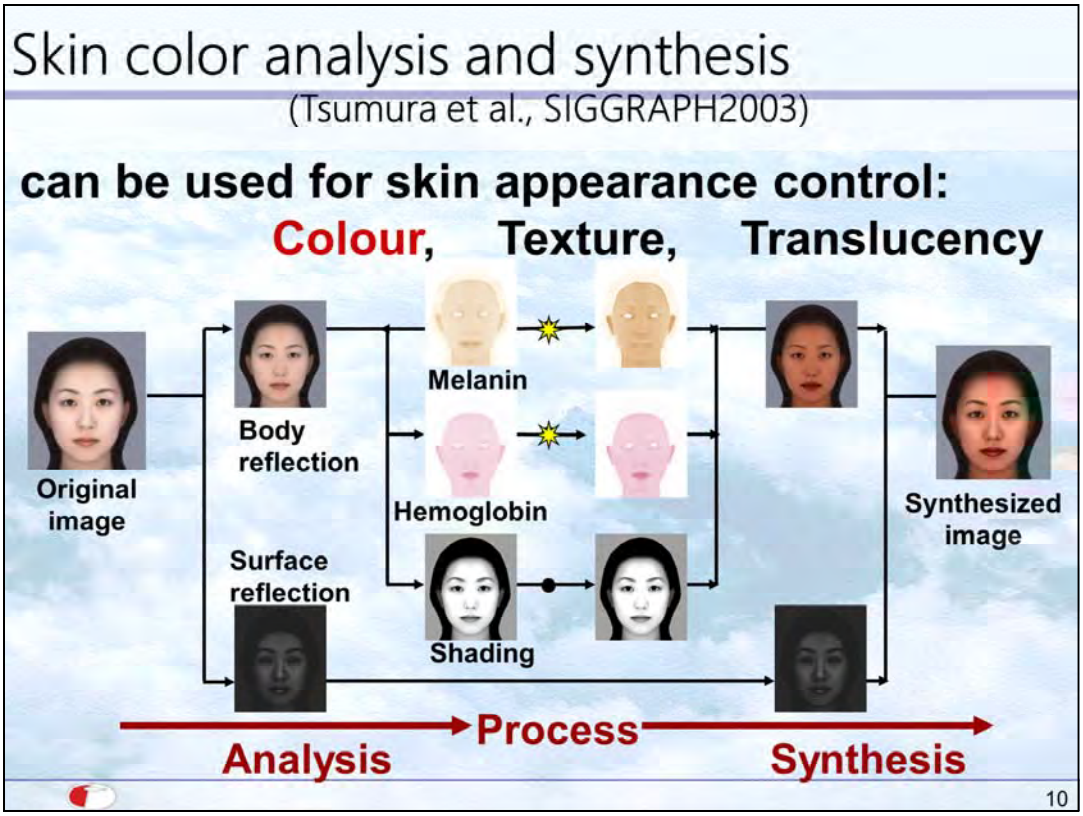


We also stimulated blood flow in a circler portion of skin
by applying methyl nicotinate.

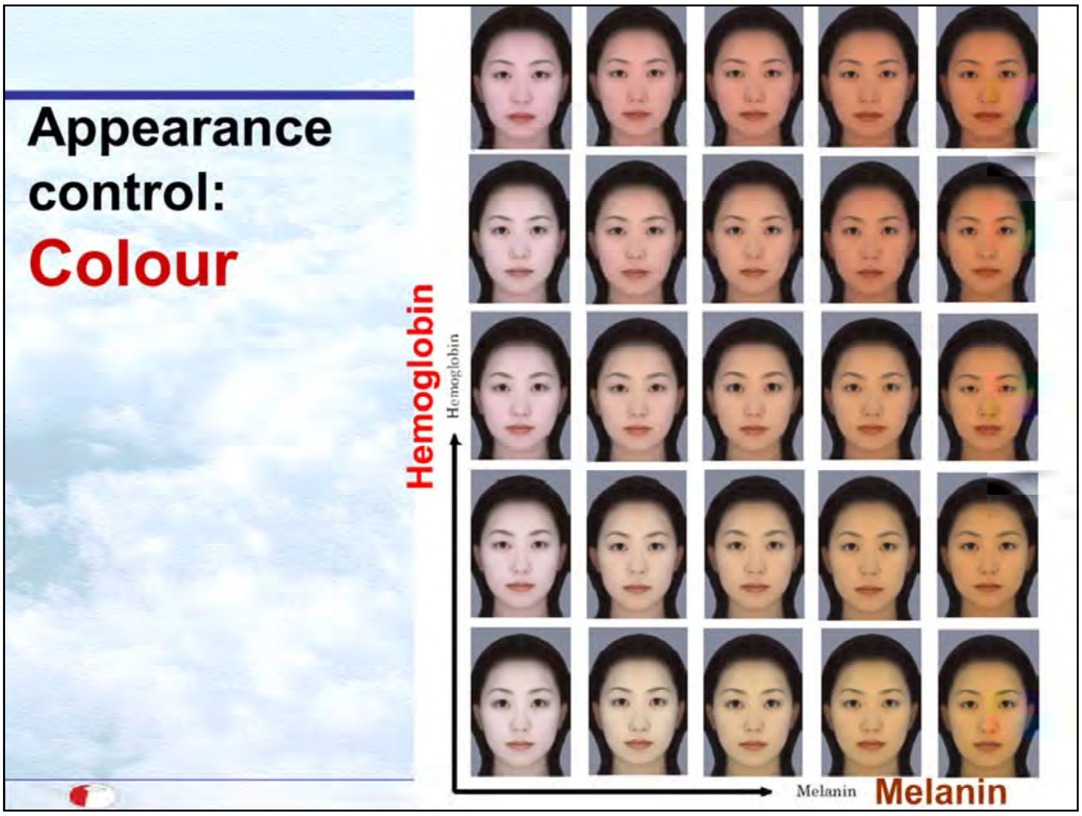
This is because we know that physiologically only hemoglobin reaction remain.

You can see that the circler pattern is appeared only on the hemoglobin image.

Now, we cay say that our technique is valid for hemoglobin extraction.

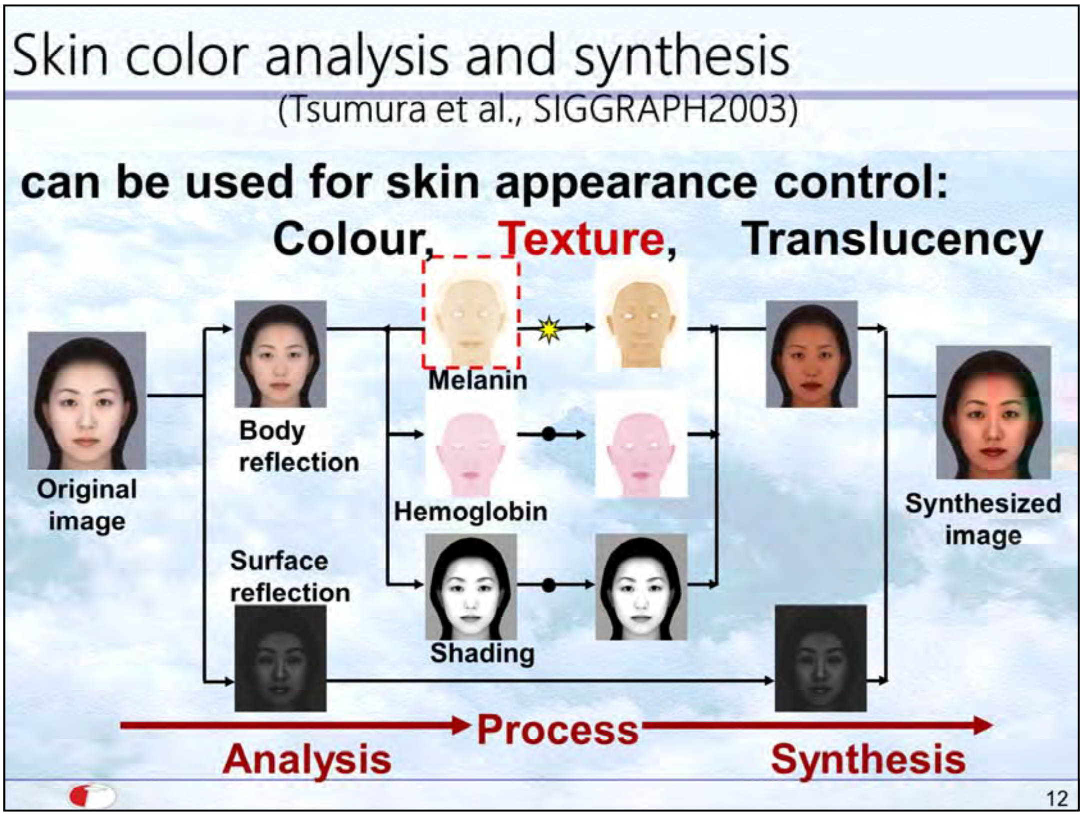


Next, I will show you the improved results of synthesis by the proposed technique.

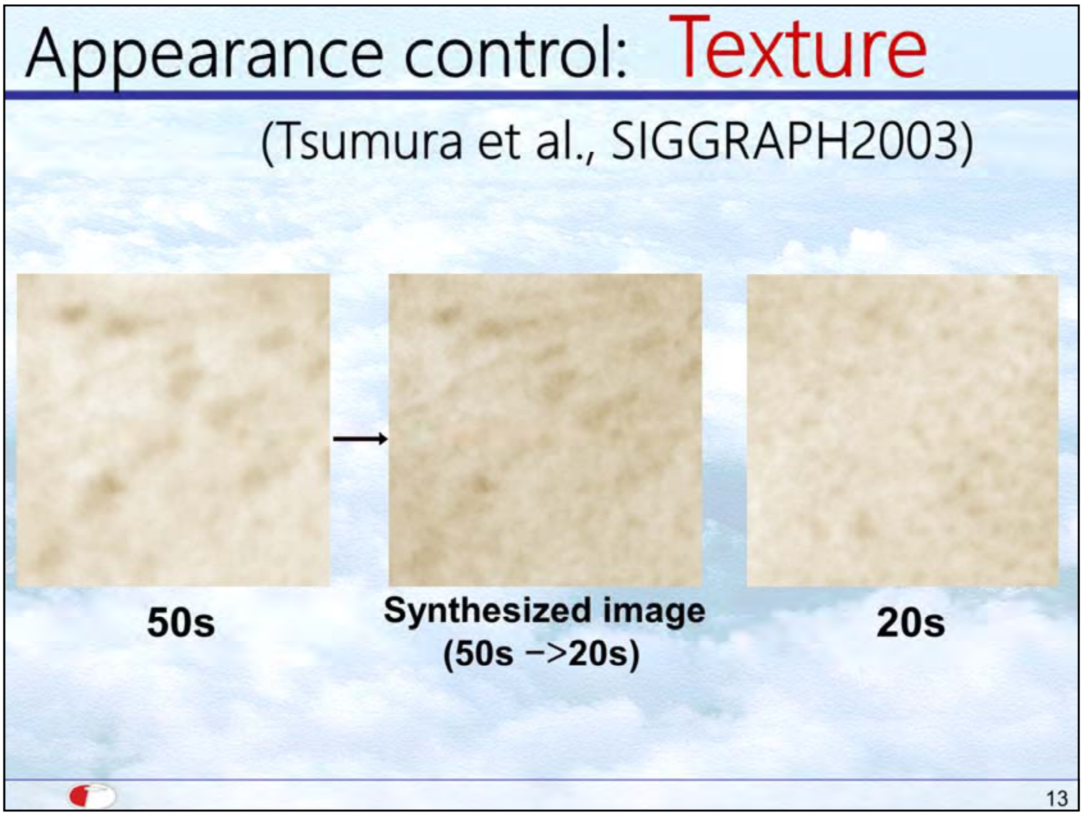


These are improved synthesized images.

Compared to the previous images,
you can see the color is changed much more realistically,
and shading is not mistakenly changed, compared to the previous.



Next, let's move to the issue of texture.



You can see the melanin texture will change by aging from 20 year-old to 50 year-old.

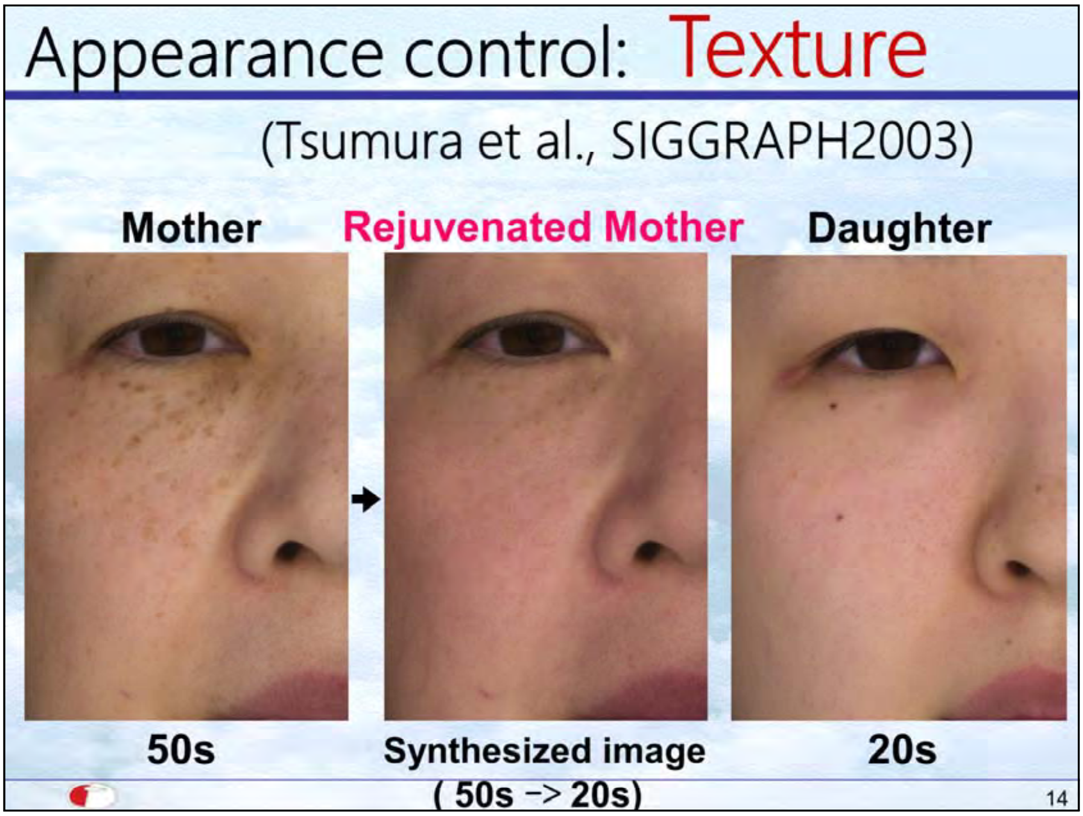
For the issue of texture change,
We used the "well-known" texture synthesis and analysis technique
to analyze and synthesize for physiologically based image processing
of skin pigment texture.

This is the melanin texture of a 50 year-old woman

And, this is the melanin texture of a 20 year-old woman

This is the result of synthesis.

You can see that
the texture of 50 year-old is changed to be like a texture of 20 year-old
keeping the original distribution of pigments.



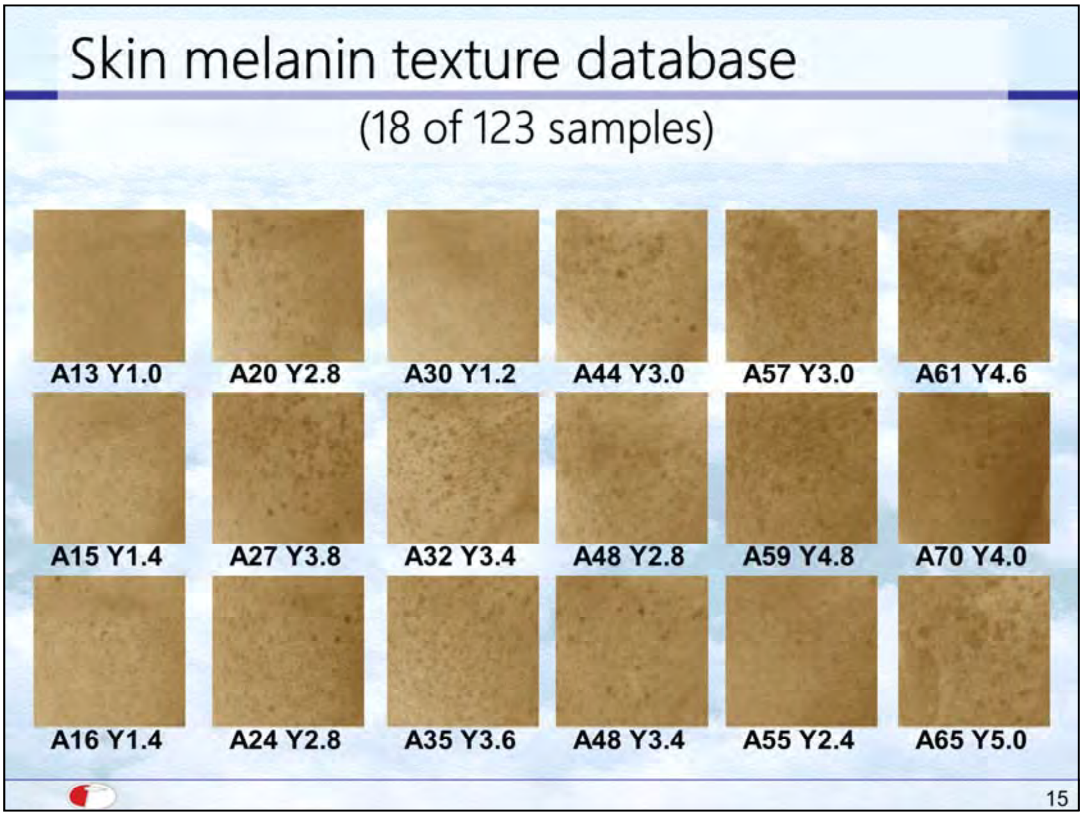
We also applied this technique to the entire face.

So, we can say that
this is the rejuvenated mother by our technique.

We asked her daughter to come.

.

You can see.



We have already mentioned that physiologically based image processing could be applied to the components to control the physiologically meaningful change of skin.

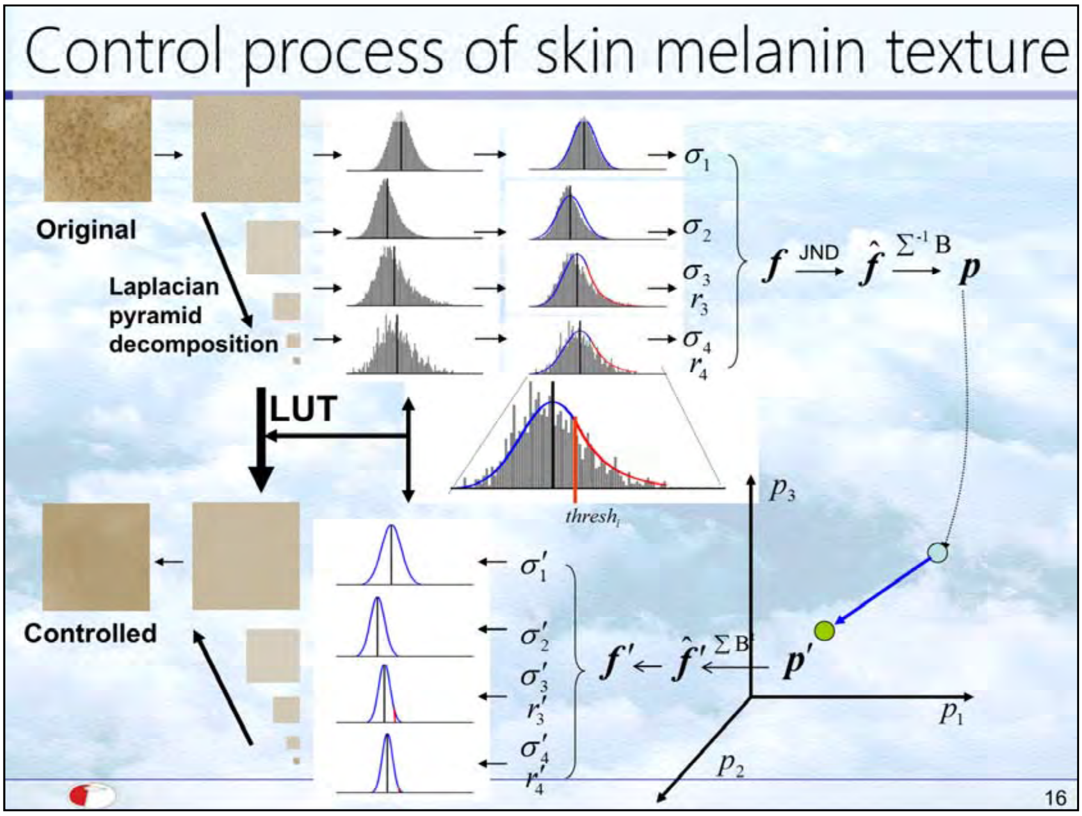
However, we just increase or decrease the component homogeneously or transfer the texture into another

Next,

continual texture control of skin is achieved by Data-driven physiological model of skin texture

based on the analysis of 123 skin textures in our database for physiologically meaningful change of texture

This figure shows examples of the melanin texture in the texture database.



This figure shows an overview of the process to control the skin melanin texture.
The input texture is decomposed into layers by the Laplacian pyramid method.

The feature vector f is extracted to represent the histograms of the layers by using the parameters of the Gaussian and exponential distributions.

Principal component analysis is applied to the feature vectors of 123 samples of the

melanin texture from our own database to extract the physiologically plausible space of changes.

The obtained principal component vector p is shifted in the principal space to control the melanin texture.

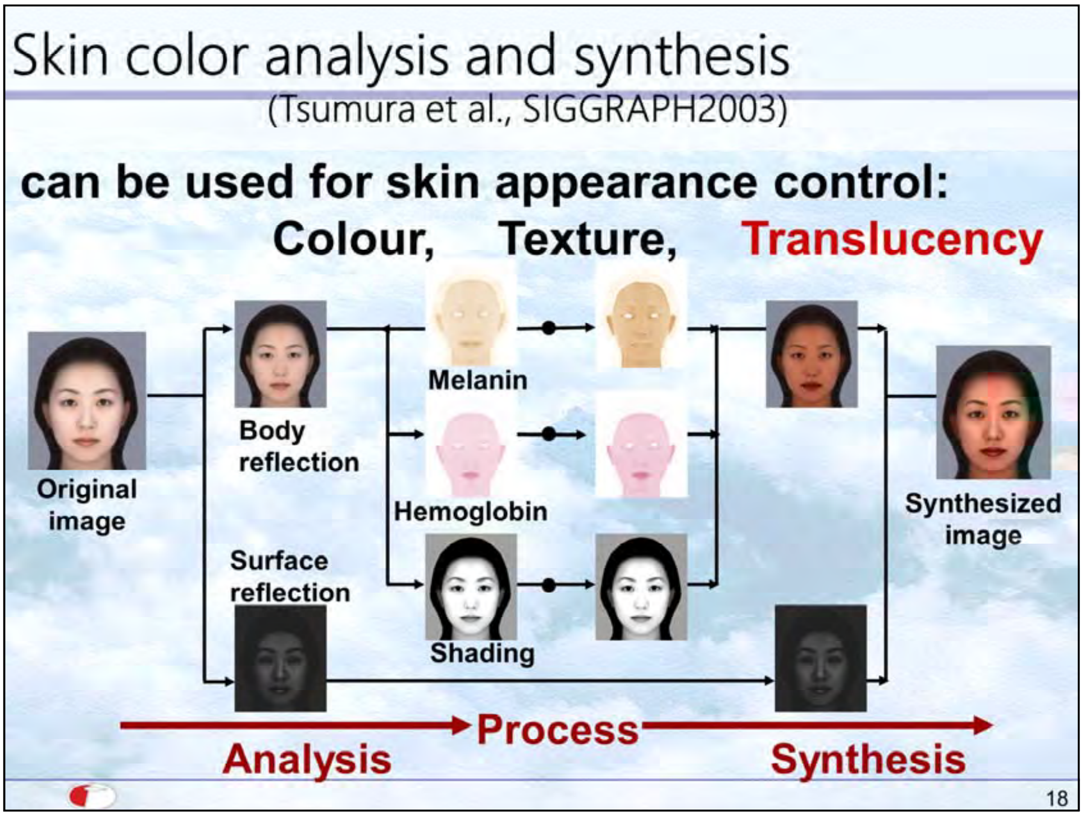
The shifted vector is inversely transformed into histograms of the layers.

The pixel values at each layer of the input texture are transformed by a lookup table created for matching the original histograms and the transformed histograms synthesized by the shifted feature vector.

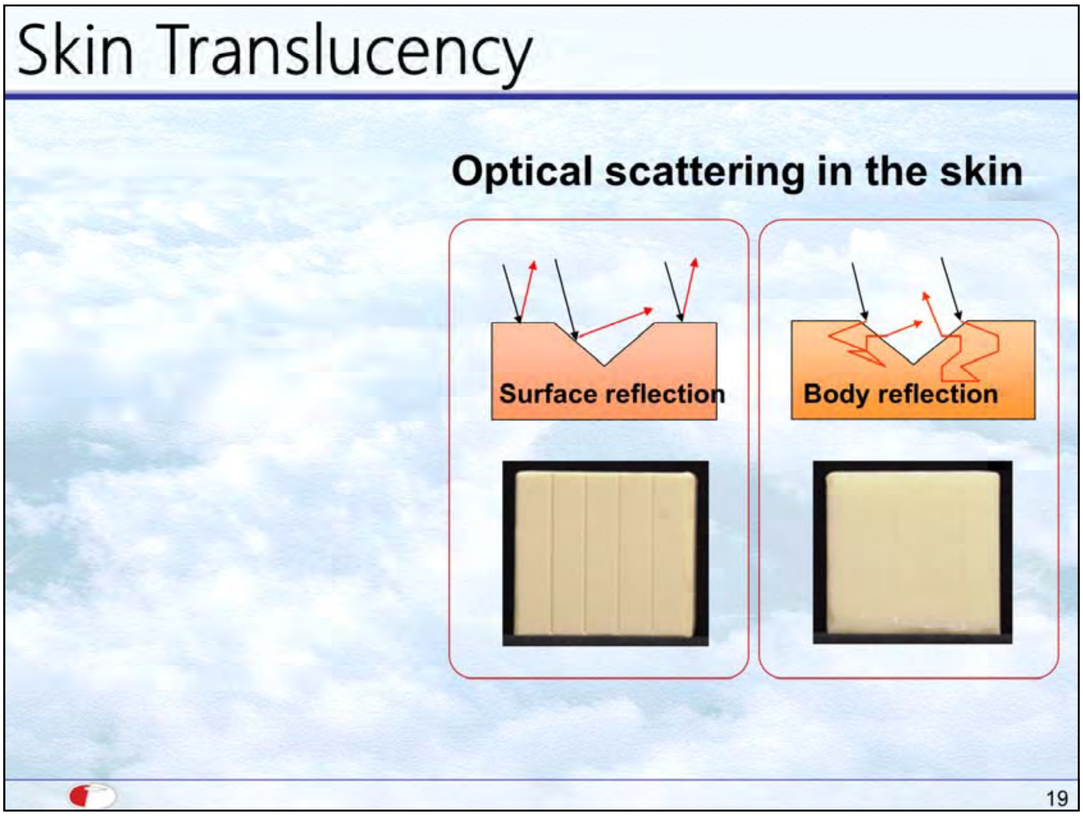
The transformed layers compose the synthesized texture.

This principal space is constructed based on the texture database.

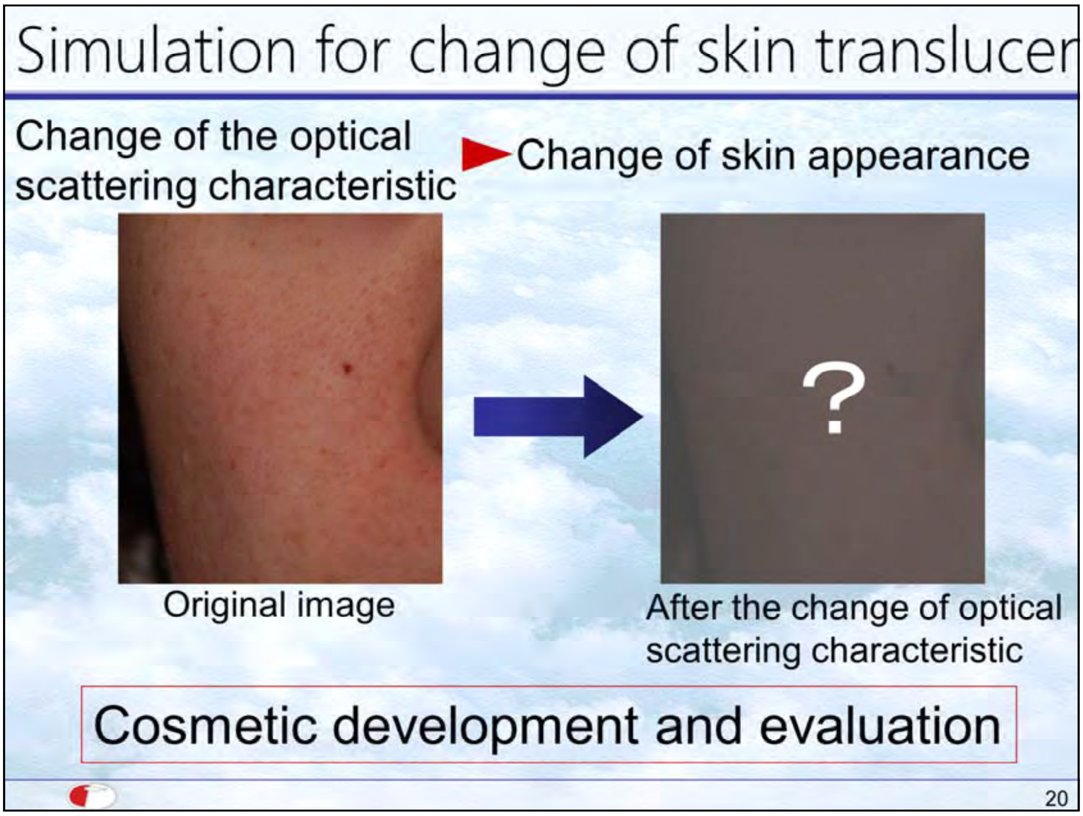
If the original image is like this. A few blotches.
We can increase and decrease these blotches like this.



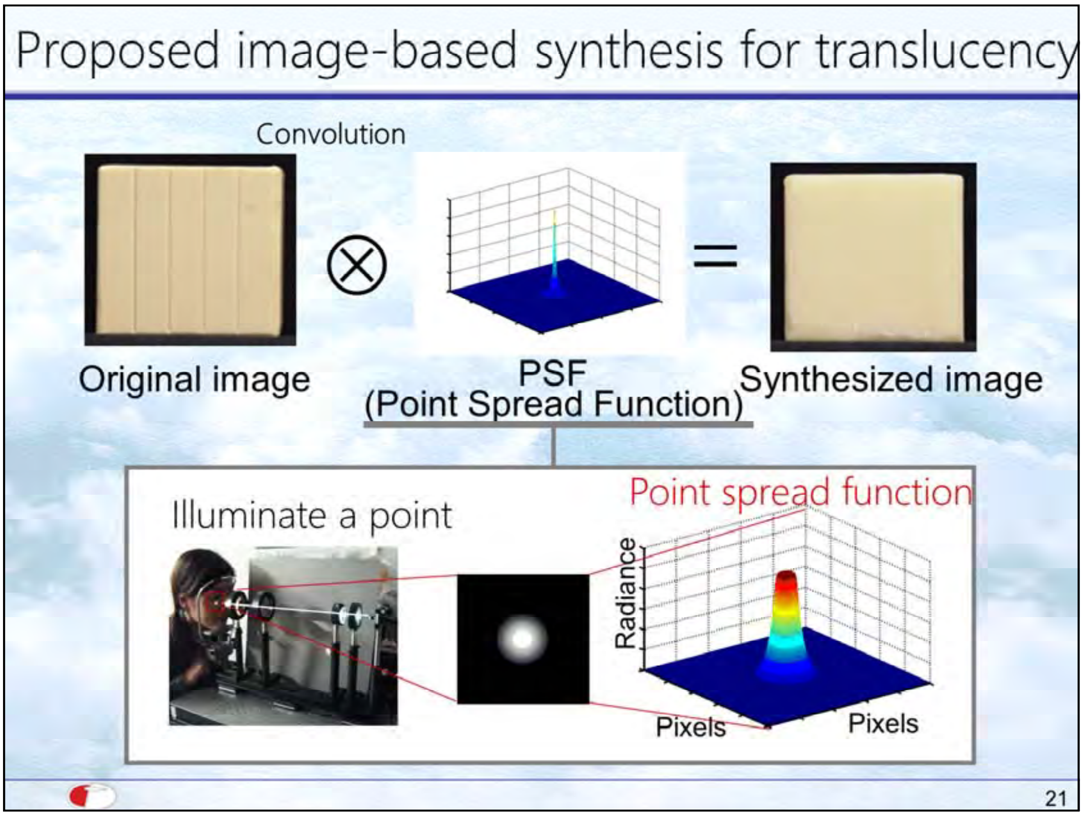
Next, we will propose the simple technique to control the skin translucency.



The skin translucency is caused by optical scattering in the skin. Please see these samples. These have the same 3 dimensional shape. However, by the difference of optical scattering in the media, you can see the change of translucency.



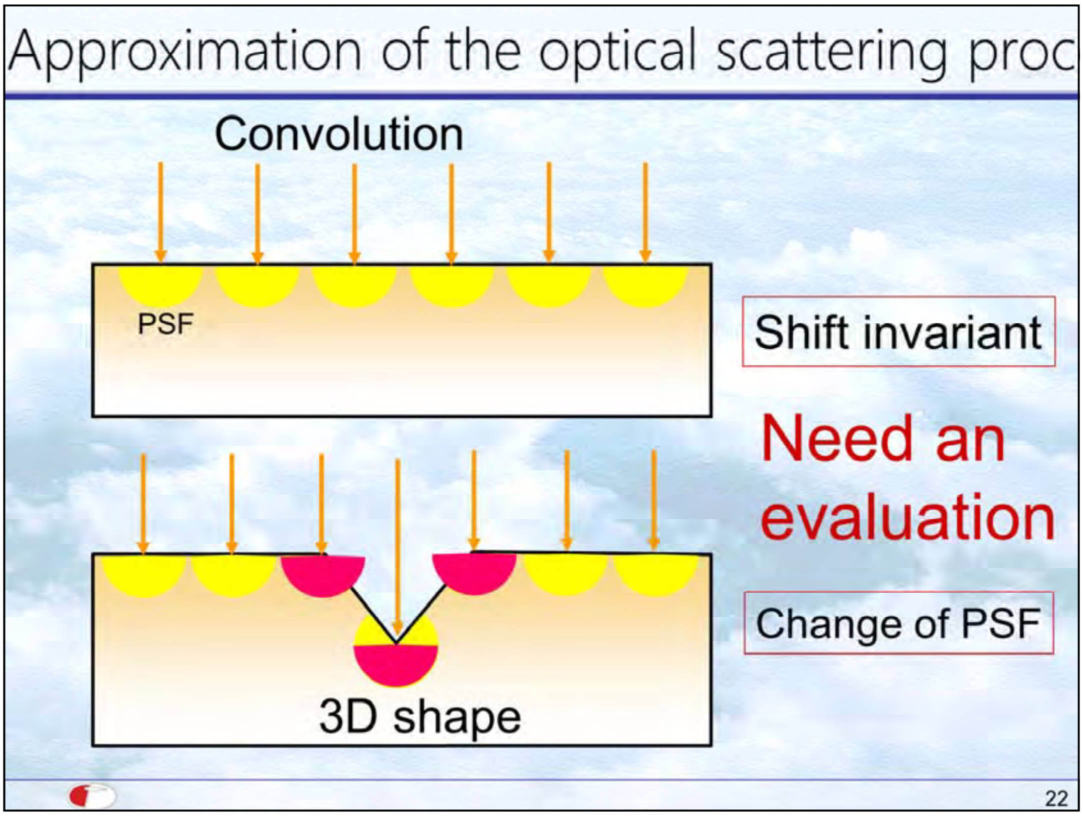
Simulation for change of skin translucency is expected to be developed for cosmetic development and evaluation.



Proposed technique is very simple.

Just, perform convolution of the Point Spread Function to the original shaded image.

Point Spread Function is measured by projecting the points (delta function) on the medium and capture the spread in the medium.

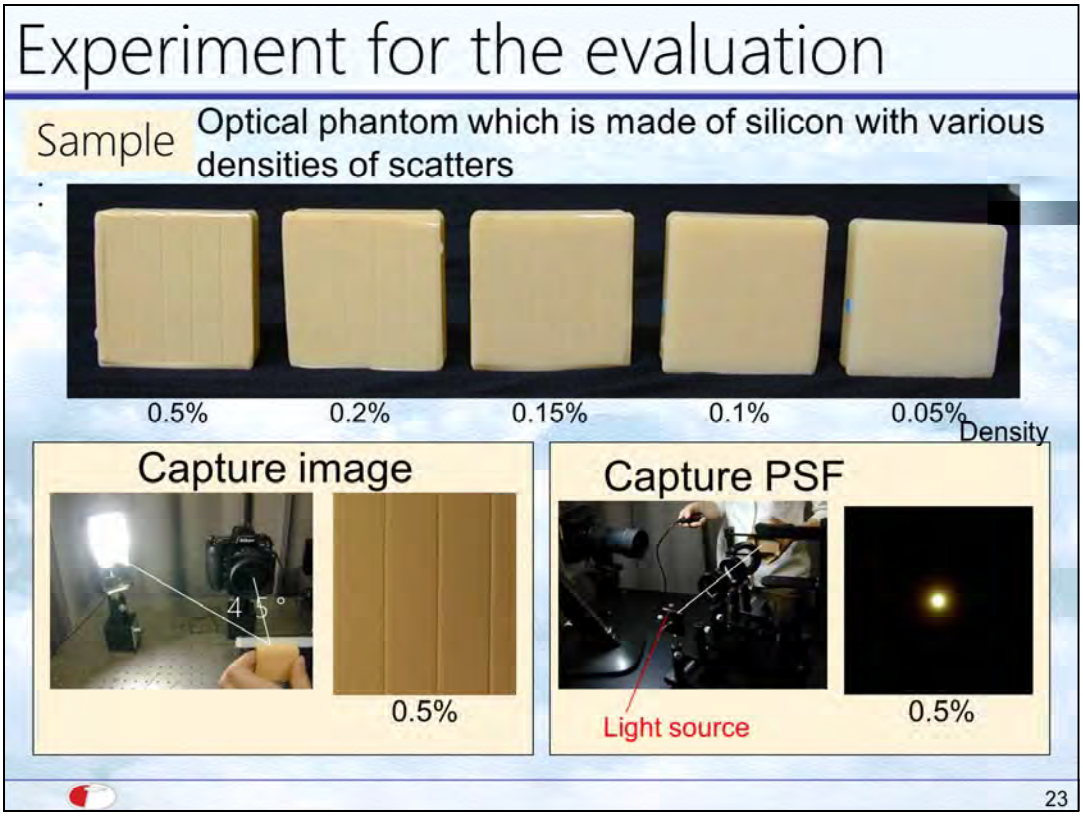


Proposed technique is very simple.

The" convolution " is approximation of optical scattering based on the shift invariant property of the scattering in the flat homogeneous media

However, real media is not flat like this.
In this case, Point Spread Function is shift variant.

We need to confirm that if this approximation is valid in real sample.



So, we have prepared the optical phantom which is made of silicon with various densities of scatters.

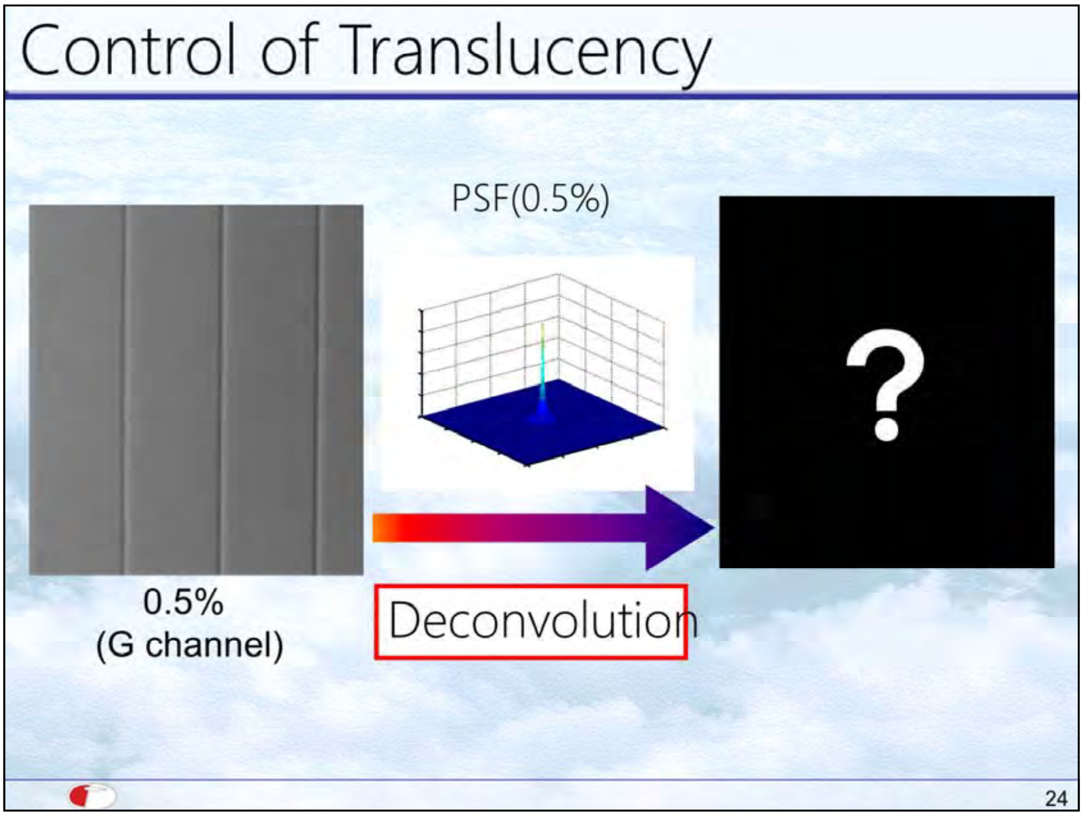
There are gutters in each phantom, those are same shape each other.

This is the phantom of 0.5% scatter in the media, you can see the change of translucency

You can imagine this gutter is a kind of wrinkle in the skin.

We captured the image of the phantoms by illuminating it from 45 degree.

We also captured the image of Point Spread Function by using the half mirror.



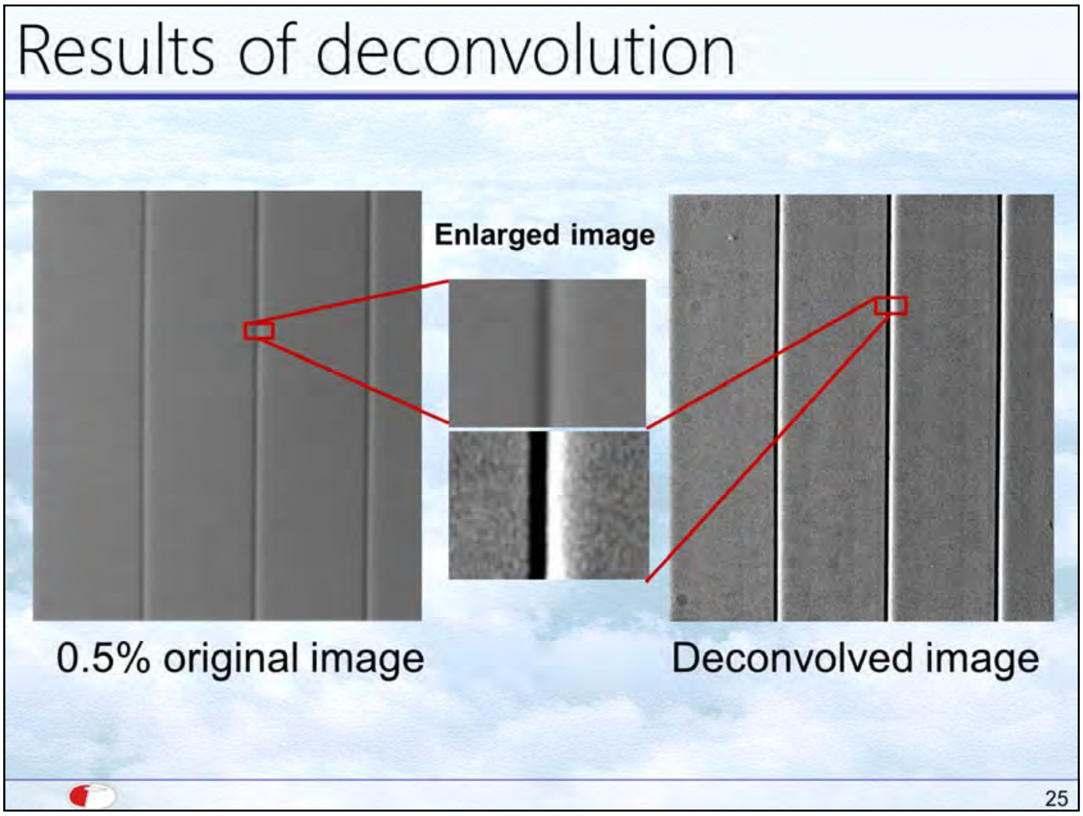
Let me show you an example of the proposed method.

This is the real image of 0.5% scatters phantom.

We also have Point Spread Function for this sample.

If we apply the "de-convolution" of this Point Spread Function from this image.

We are expecting the effect of optical scattering is reduced to be delta function.



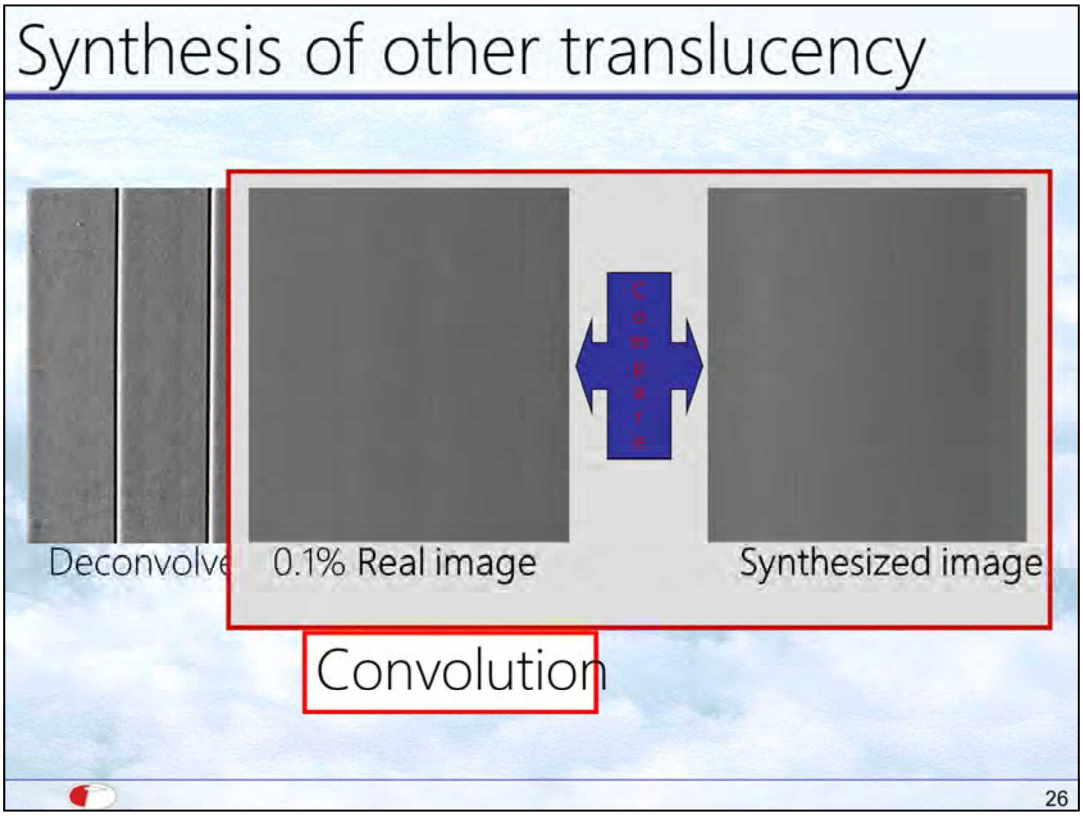
OK. This is a original image
And, this is a de-convolved image.

Here are enlarged images.

You can see that the translucency is controlled realstically.

This image looks plastic.

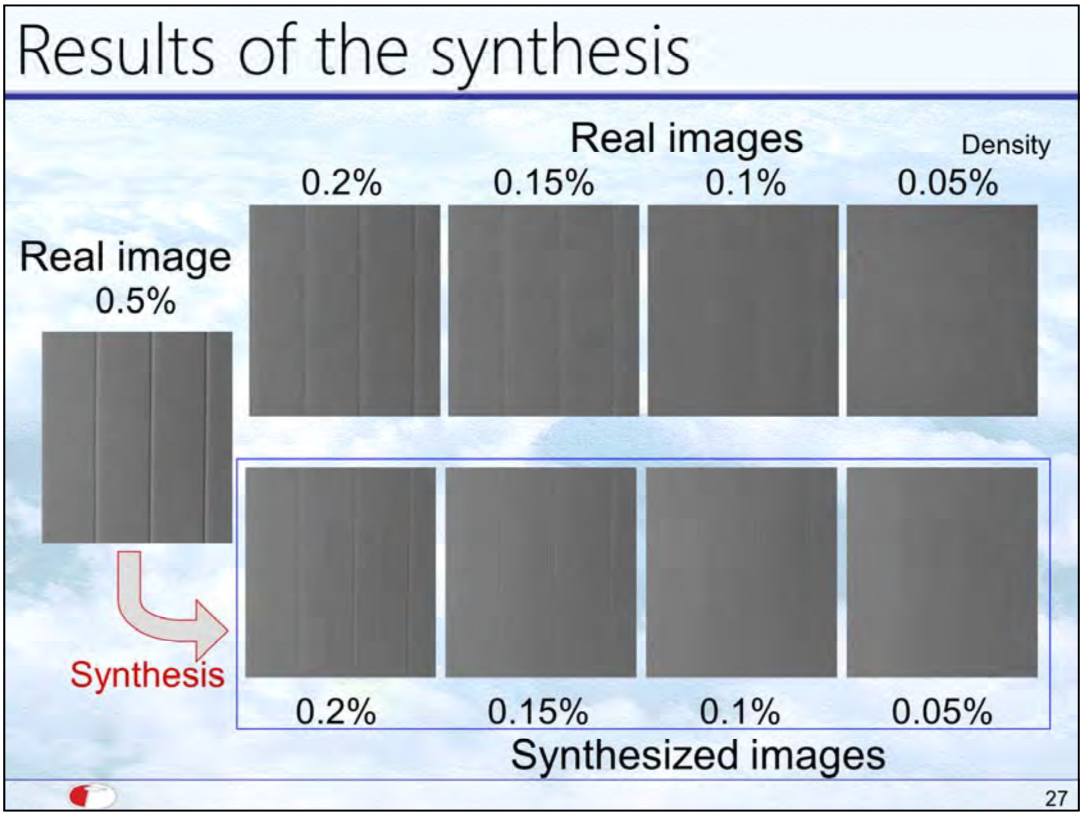
The region is black, because this region is not illuminated from 45 degree of illumination.



Synthesis of other translucency is very easy by using the deconvolved image.

By applying the PSF you want, you can get the synthesized image.

It is necessary to compare the image from real phantom and synthesized image since the approximation of shift invariant should be confirmed if it is valid for real samples.

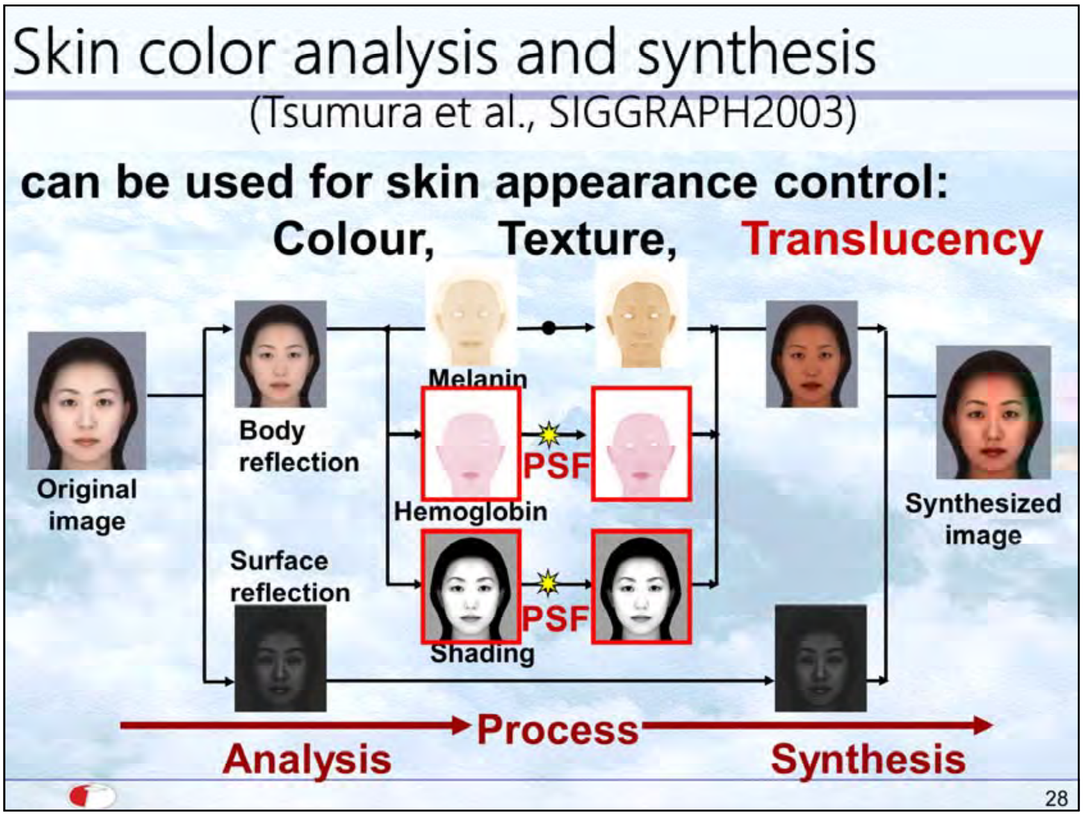


Here is the results of the synthesis.

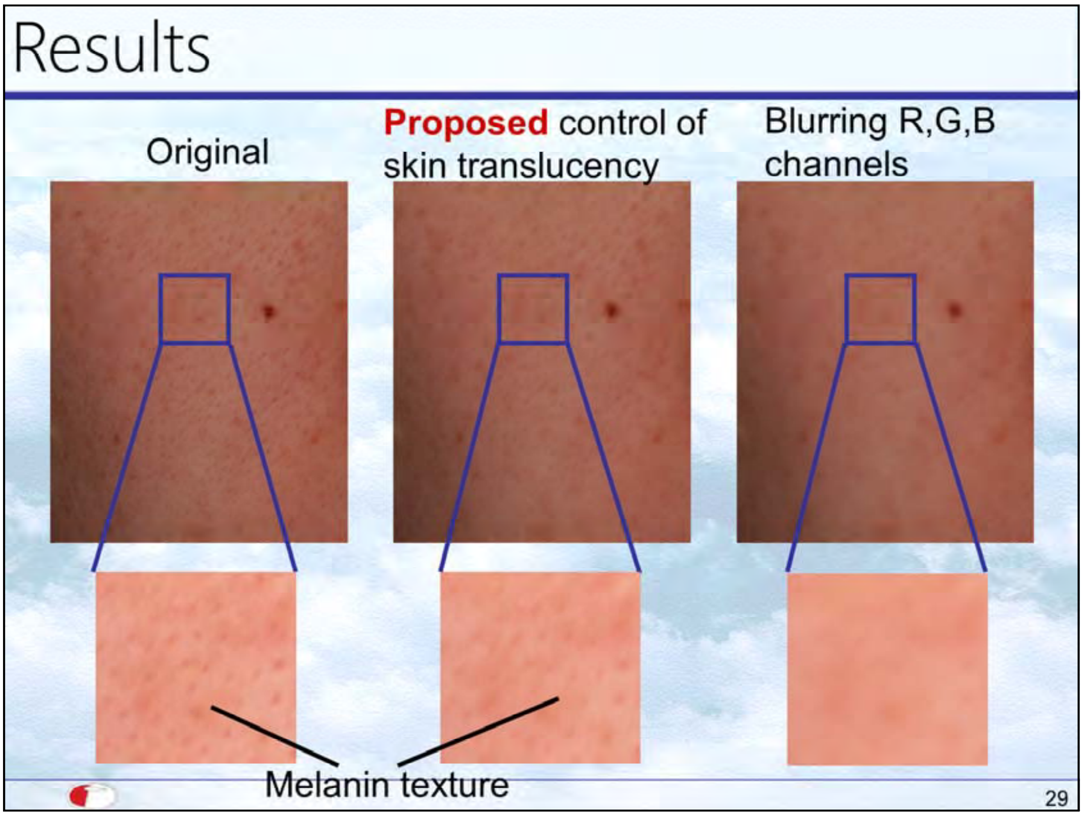
Theses are real images for the phantoms with various densities of scatters.

And, these are synthesized images from this single real-image by using the each PSF.

If you compare each pairs, you can see that the proposed method can simulate the change of translucency realistically.



Next is application to real skin image.



This is the original image, and this is the image controlled by our proposed technique by applying the PSF for the components of shading and hemoglobin. Not melanin.

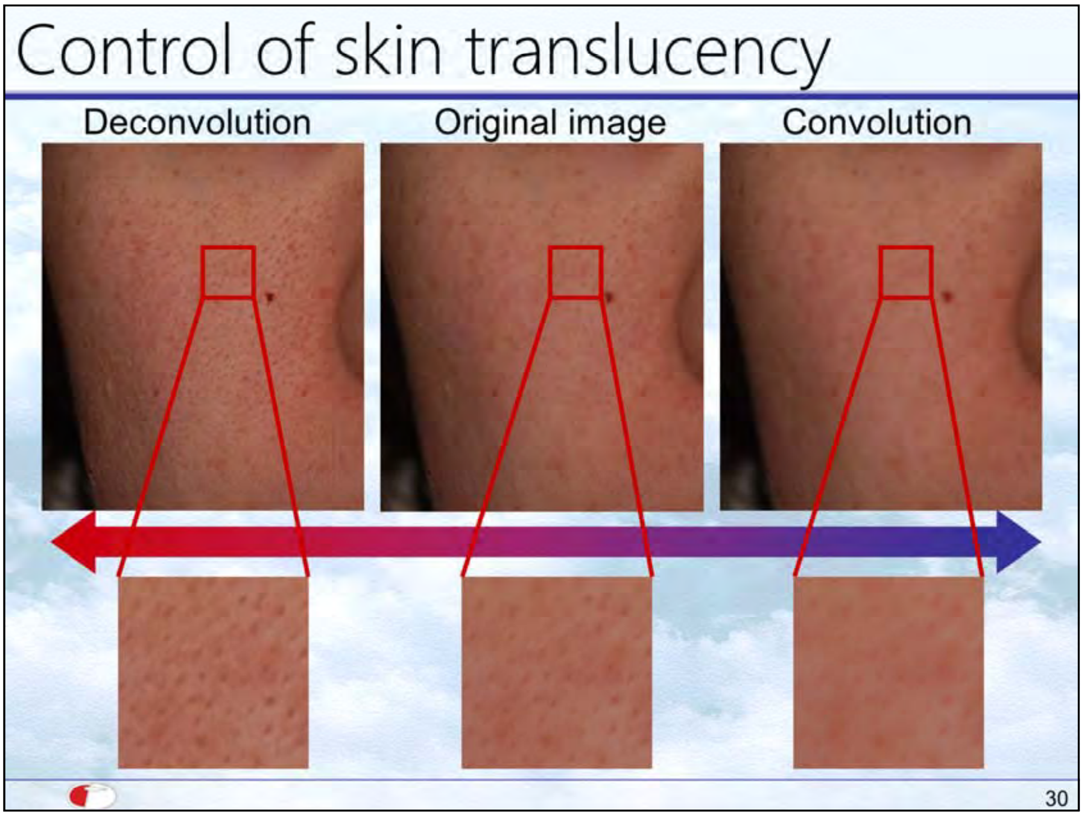
You can see the change of translucency.

This is the image by applying the PSF for R, G, B channels without separating the components.

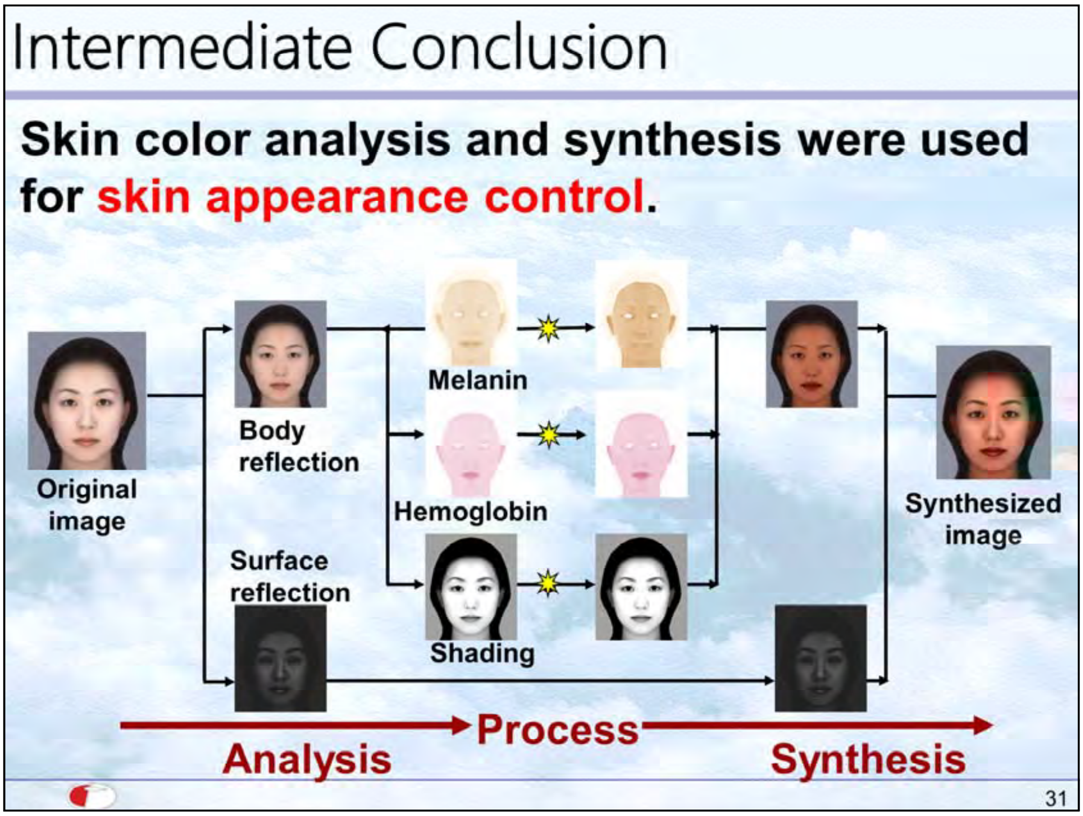
Here is the enlarged image.

You can see that this image looks just blurred or out of focus. Melanin pattern is also blurred.

It is found that the proposed method can perform realistic change.



This is another example of results. You can see the realistic change of translucnecy.



That is our talk.

Thank you very much for your attention.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