



Achieving a realistic colour appearance for 3-D printed skin

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EPSRC

Engineering and Physical Sciences
Research Council



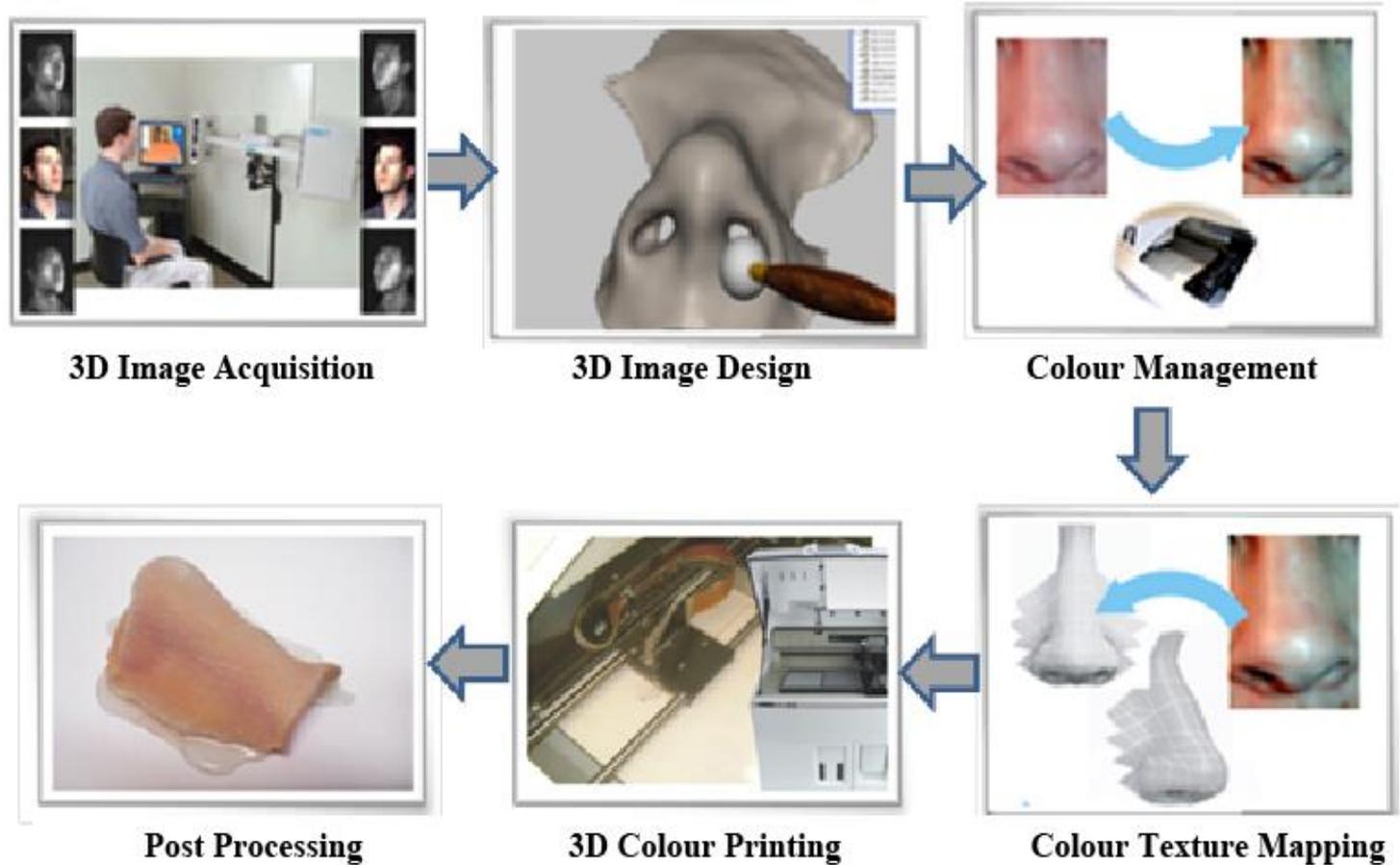
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ACADEMY OF
ENGINEERING

MANCHESTER
1824

The University of Manchester



PURPOSE OF PROJECT



Advanced Method of Facial Prostheses

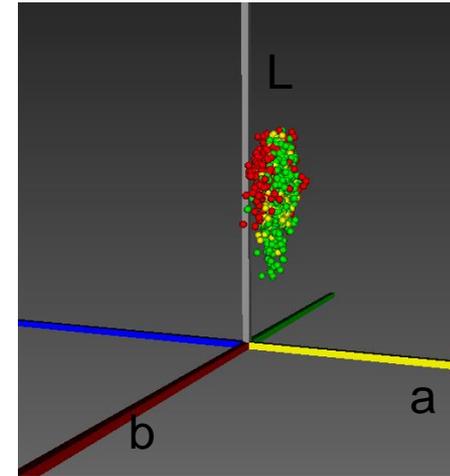


IMAGE ACQUISITION



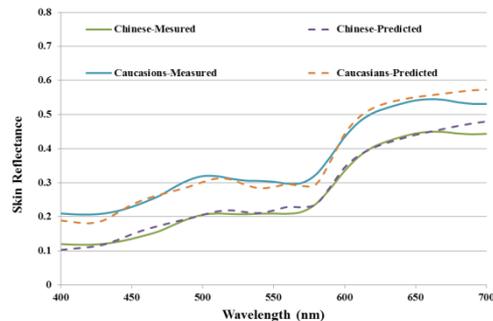
Reliability and repeatability

SKIN COLOUR DATABASE



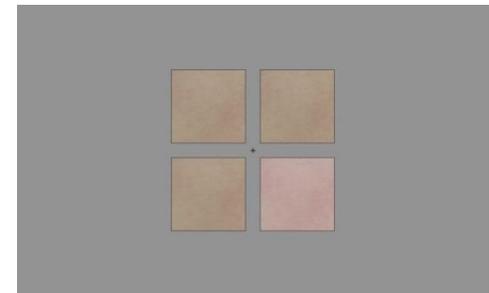
For different ethnicities

SPECTRAL RECONSTRUCTION



RGB -> XYZ-> SPECTRA

TOLERANCE LIMITS

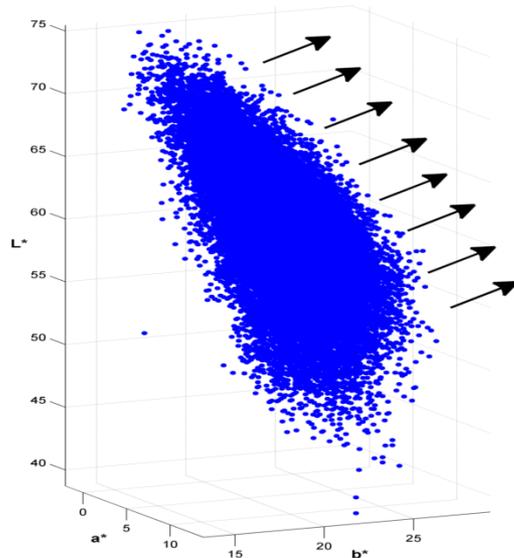


Perceptual experiments



Problems to consider with skin appearance

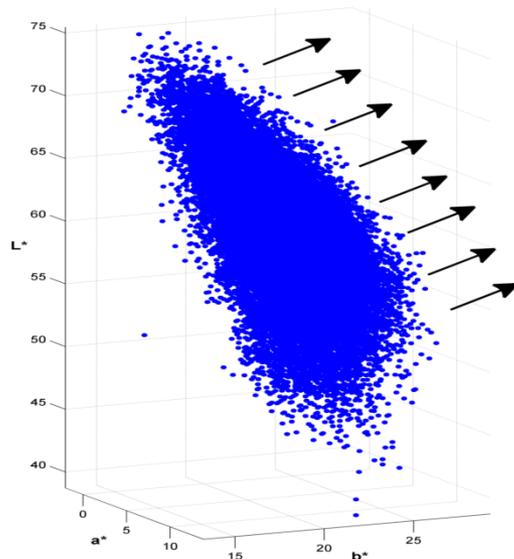
- textured = polychromatic
- non-flat material
- 3D facial structure



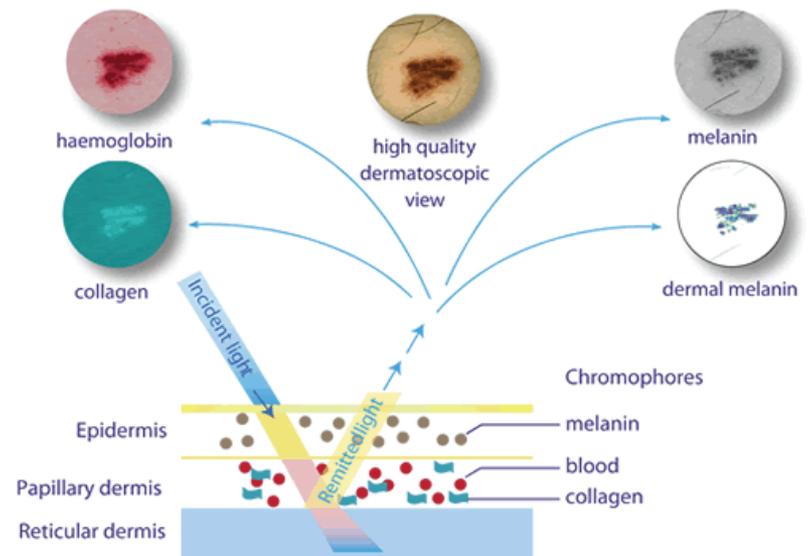


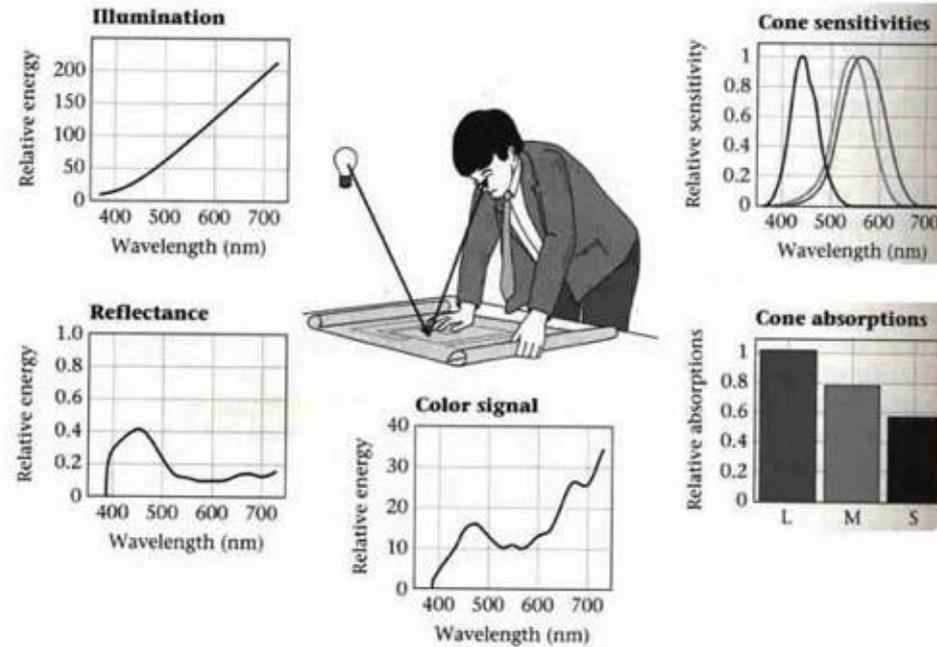
Problems to consider with skin appearance

- textured = polychromatic
- non-flat material
- 3D facial structure



Complicated structure





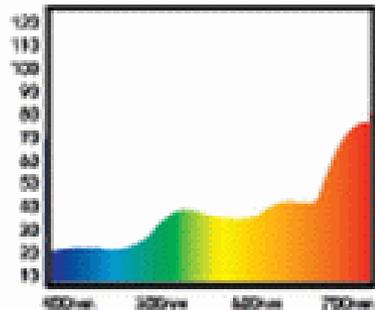
COLOR SIGNAL = ILLUMINANT * REFLECTANCE

(Source: Wandell; Foundation of Vision)

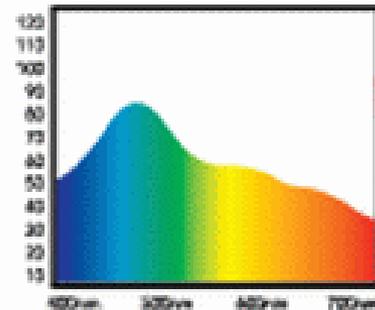


Problems to consider with skin appearance

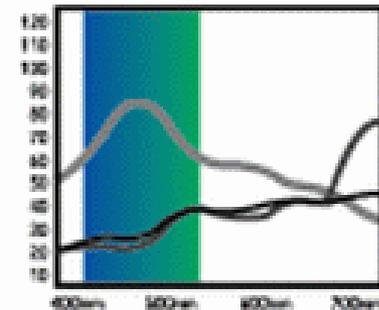
- Metamerism



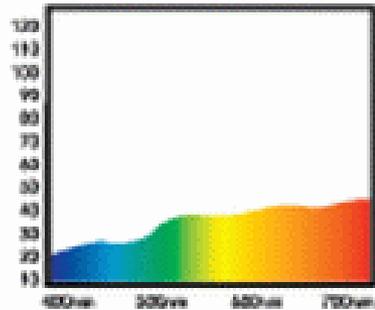
Sample 1 reflectance



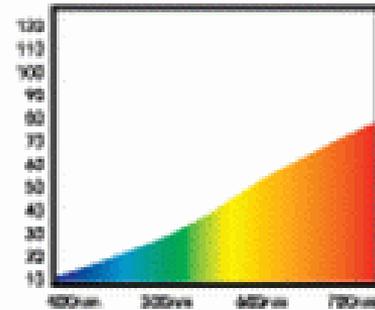
Daylight reflectance



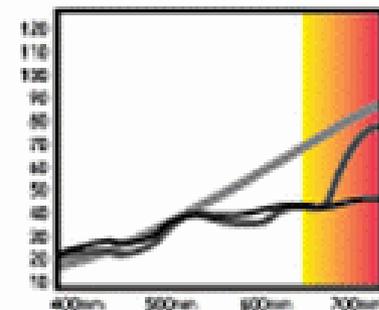
Samples under daylight



Sample 2 reflectance



Incandescent
reflectance



Samples under
incandescent

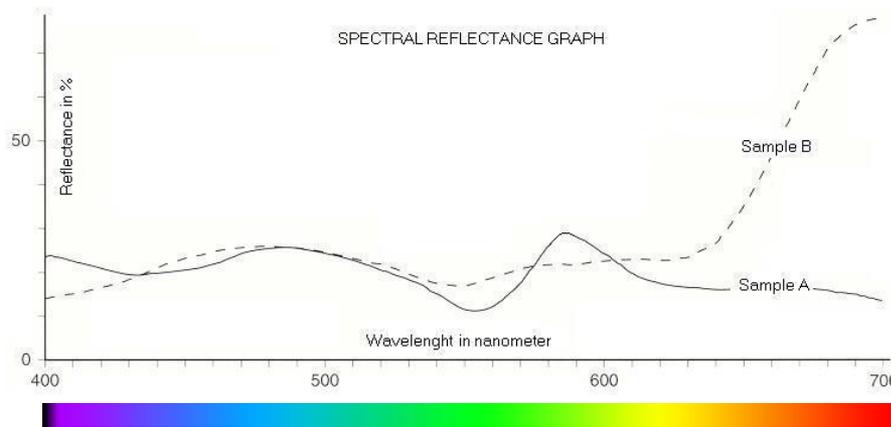
Skin changes under changes in illumination is a serious problem for skin prostheses.

Solution: use spectral-based evaluation, instead of colorimetric

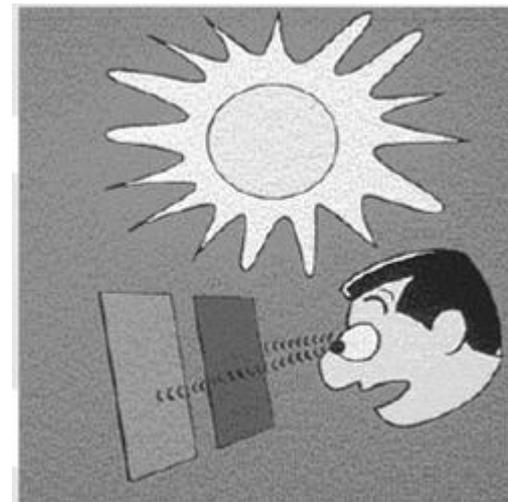
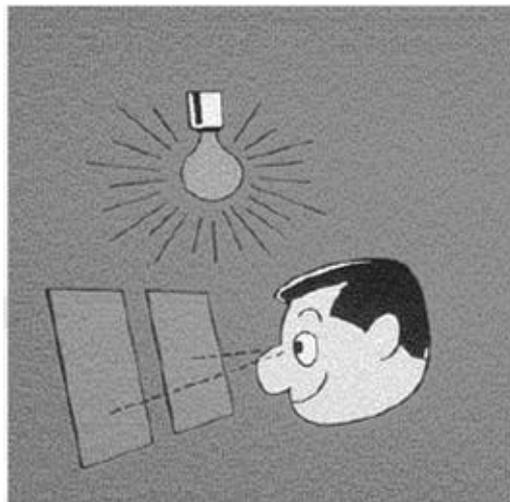


Illumination Metamerism

Metamerism: two physically different spectra appear the same to the observer



	Sample A	Sample B
L*	50.93	50.93
a*	4.54	4.54
b*	-5.12	-5.12
ΔE^*_{ab}	0	



	Sample A	Sample B
L*	50.94	53.95
a*	3.42	10.80
b*	-5.60	-2.00
ΔE^*_{ab}	8.71	

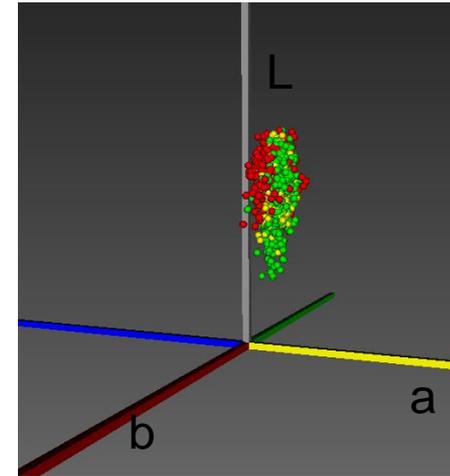


IMAGE ACQUISITION



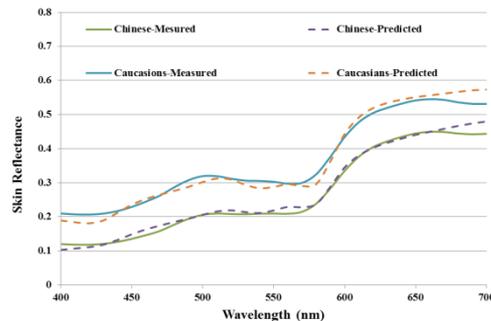
Reliability and repeatability

SKIN COLOUR DATABASE



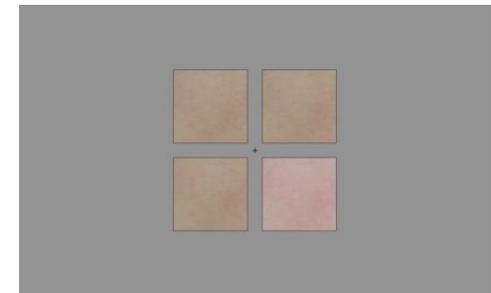
For different ethnicities

SPECTRAL RECONSTRUCTION



RGB -> XYZ-> SPECTRA

TOLERANCE LIMITS



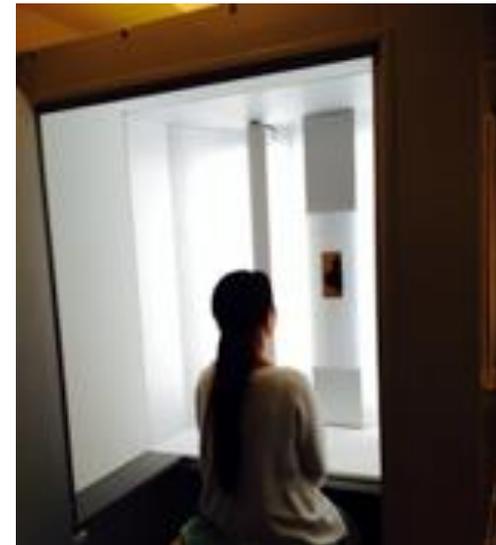
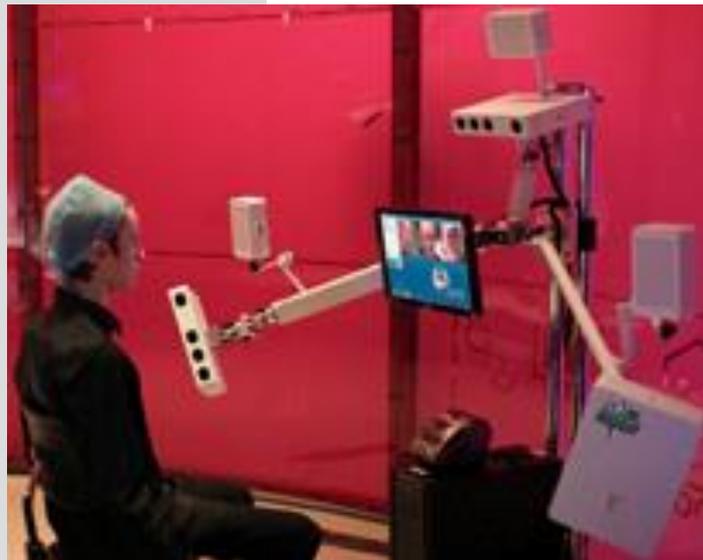
Perceptual experiments



IMAGE ACQUISITION

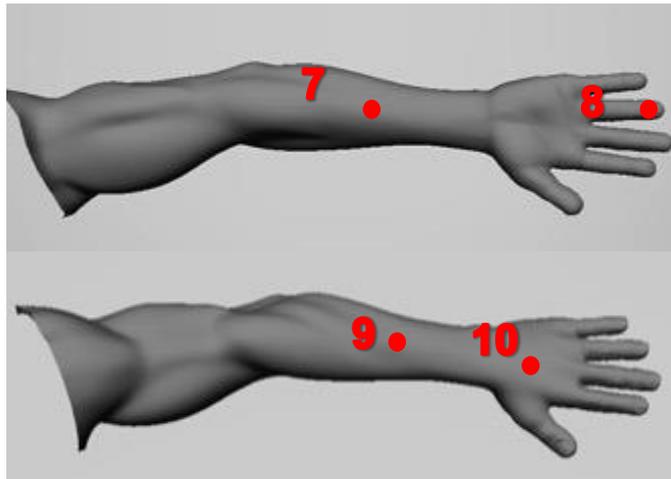
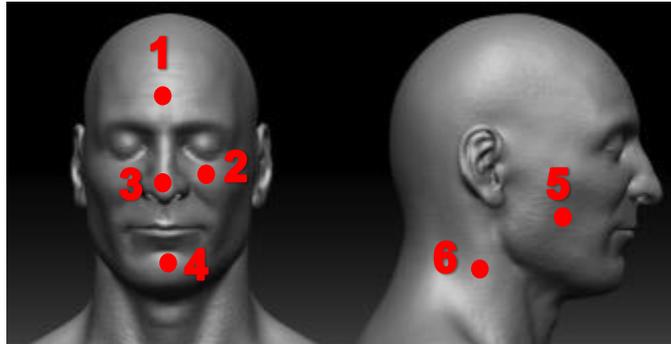


- ❑ Nikon D7000 camera with DigiEye imaging system
- ❑ Tele-spectroradiometer: PhotoResearch SpectraScan PR650
- ❑ 3D camera: 3dMD Triosystem
- ❑ Spectrophotometer: Konica Minolta CM-700d with CM-SA skin analysis software
- ❑ Verivide facial imaging lighting booth





10 locations were measured



1. Forehead
2. Zygomatic (cheekbone)
3. Nose tip
4. Chin
5. Cheek
6. Neck
7. Inner forearm
8. Ringfinger pulp
9. Outer forearm
10. Back of hand



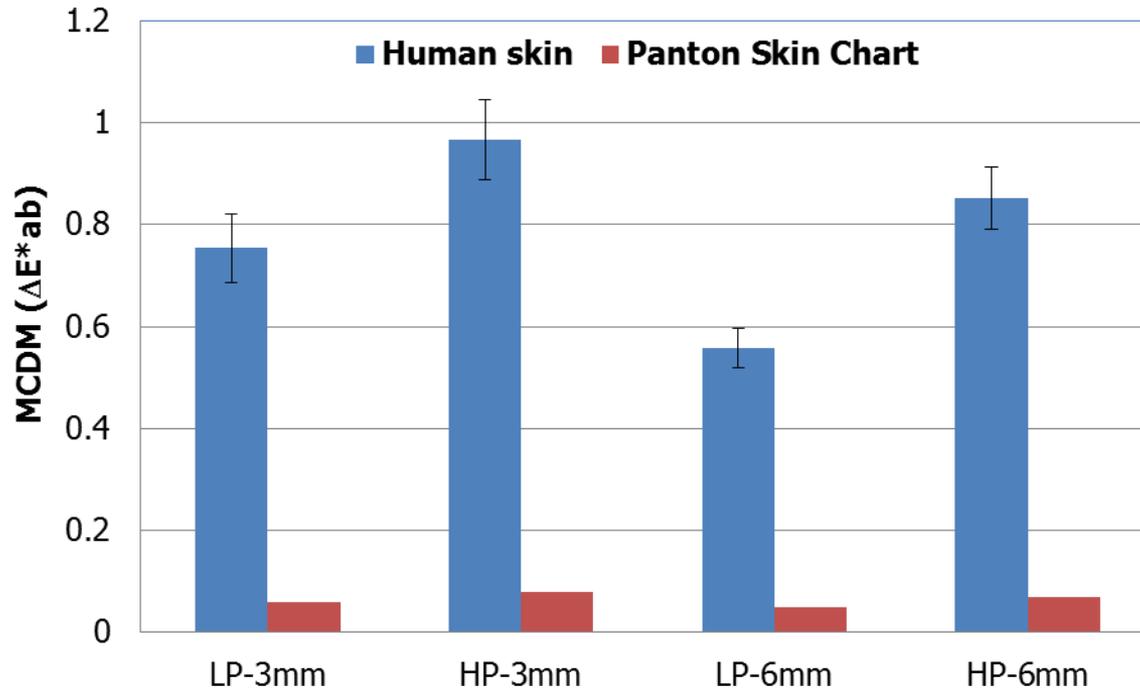
IMAGE ACQUISITION

- 4 ethnic groups:
 - Chinese 86
 - Caucasian 79
 - African 10
 - Sub-Asian 13
- Totally measured 188 People
- Collected over 10000 spectra and 900 2D images



IMAGE ACQUISITION

Repeatability



MCDM	LP-3mm	HP-3mm	LP-6mm	HP-6mm	Mean
Subjects	0.75	0.98	0.56	0.85	0.79
Panton	0.06	0.08	0.05	0.07	0.07

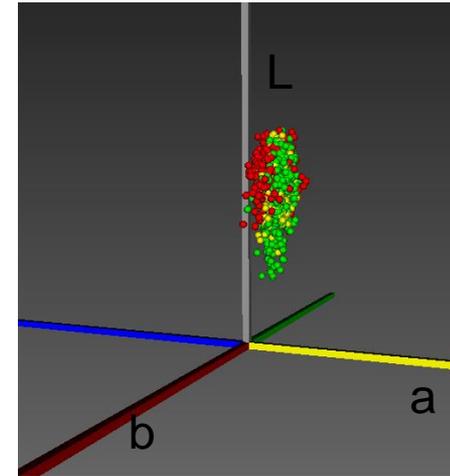


IMAGE ACQUISITION



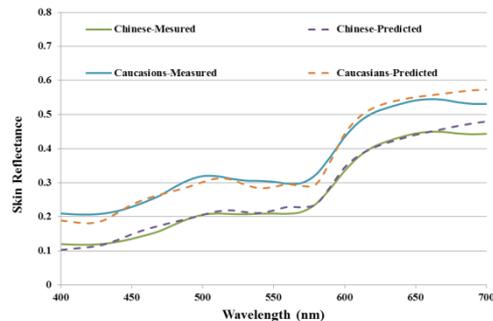
Reliability and repeatability

SKIN COLOUR DATABASE



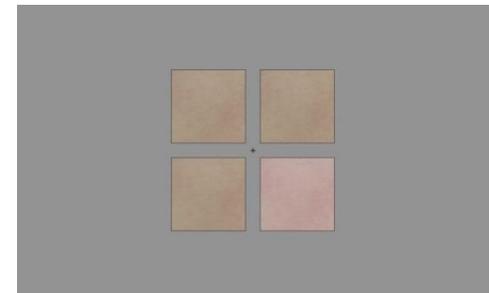
For different ethnicities

SPECTRAL RECONSTRUCTION



RGB -> XYZ-> SPECTRA

TOLERANCE LIMITS



Perceptual experiments

Caucasians	Chinese	Kurdish	Thai
217	288	146	426

Spectrophotometer measurement (same protocol)

Location: UK, China, Iraq, Thailand

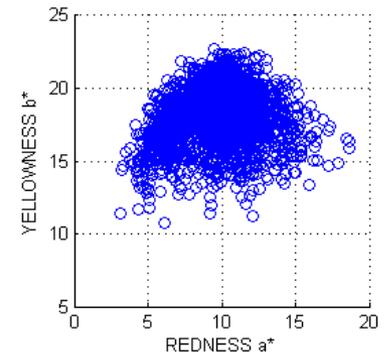
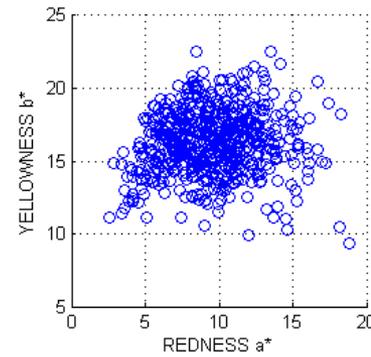
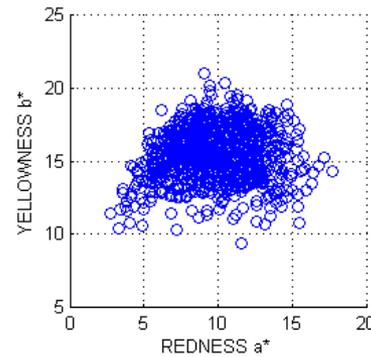
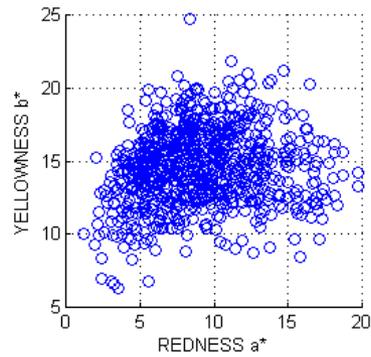
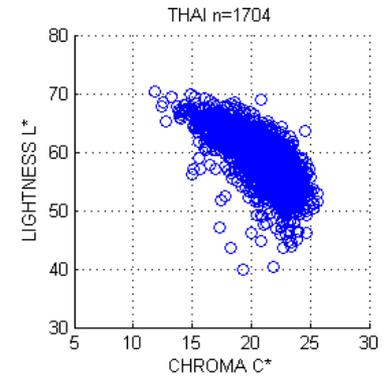
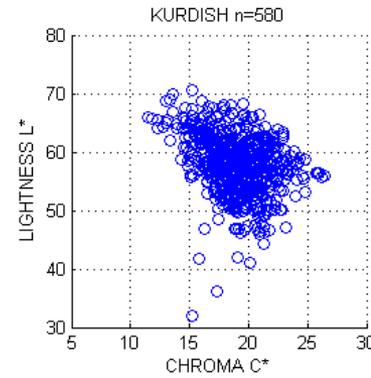
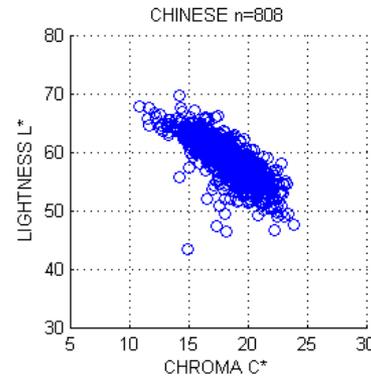
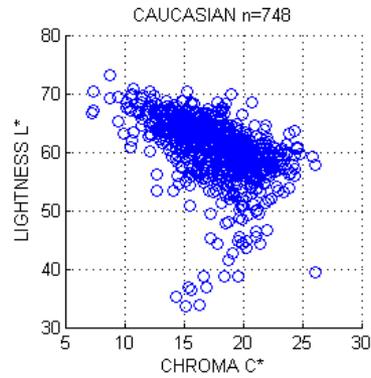
Body area: facial and arm colours



SKIN COLOUR DATABASE



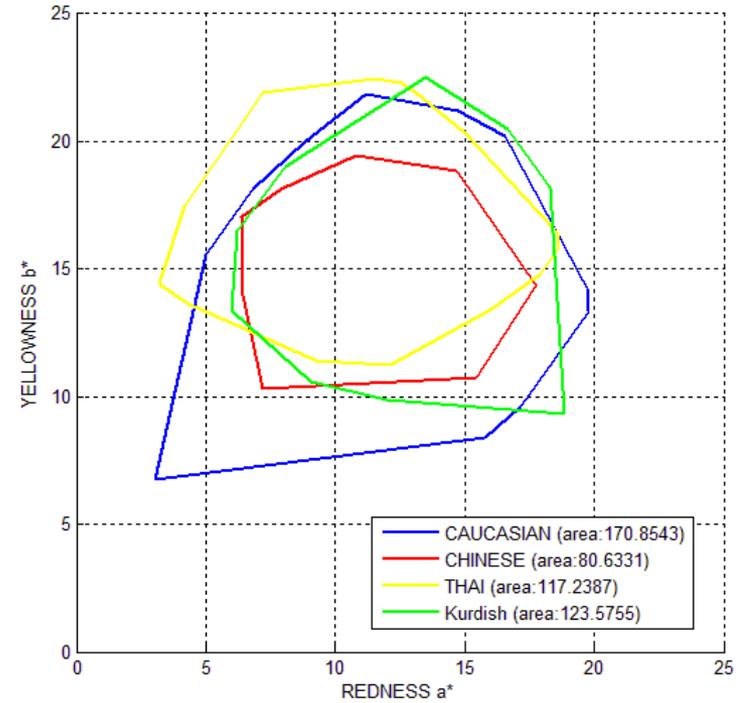
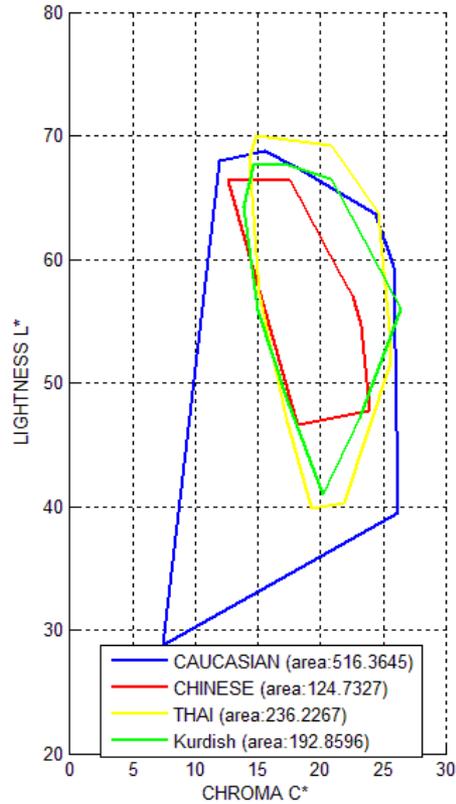
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SKIN COLOUR DATABASE

Face



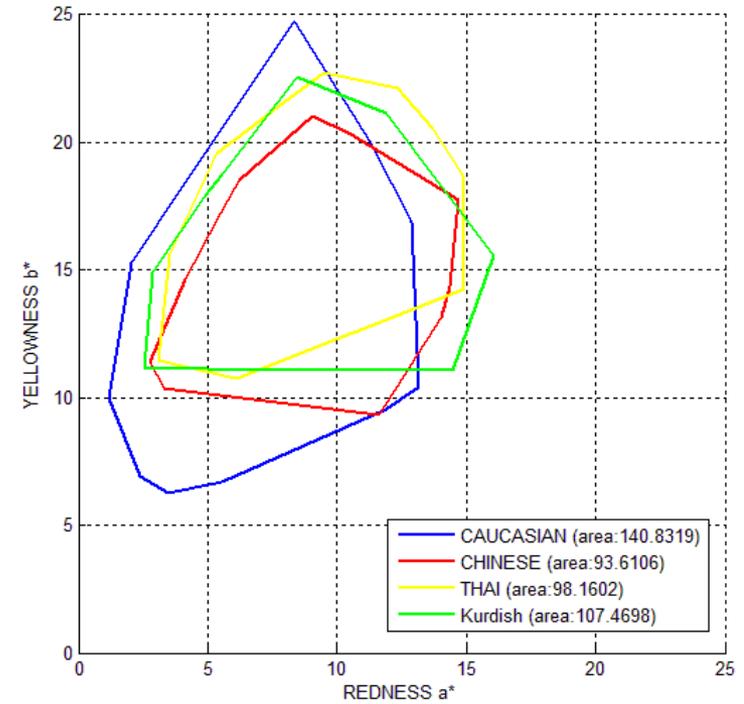
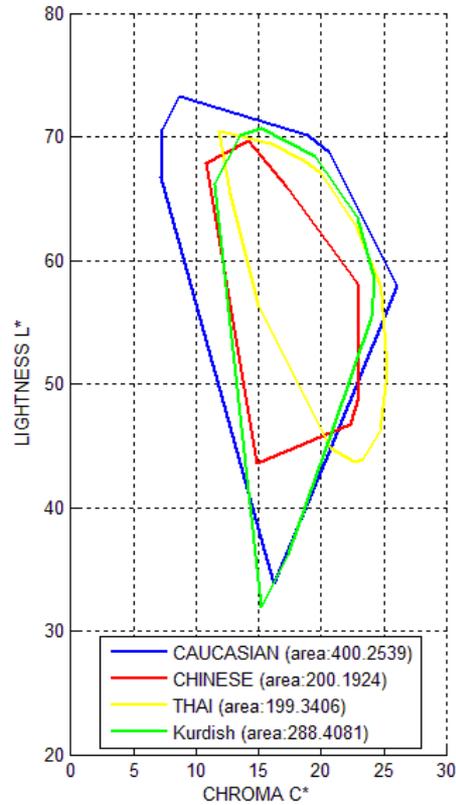


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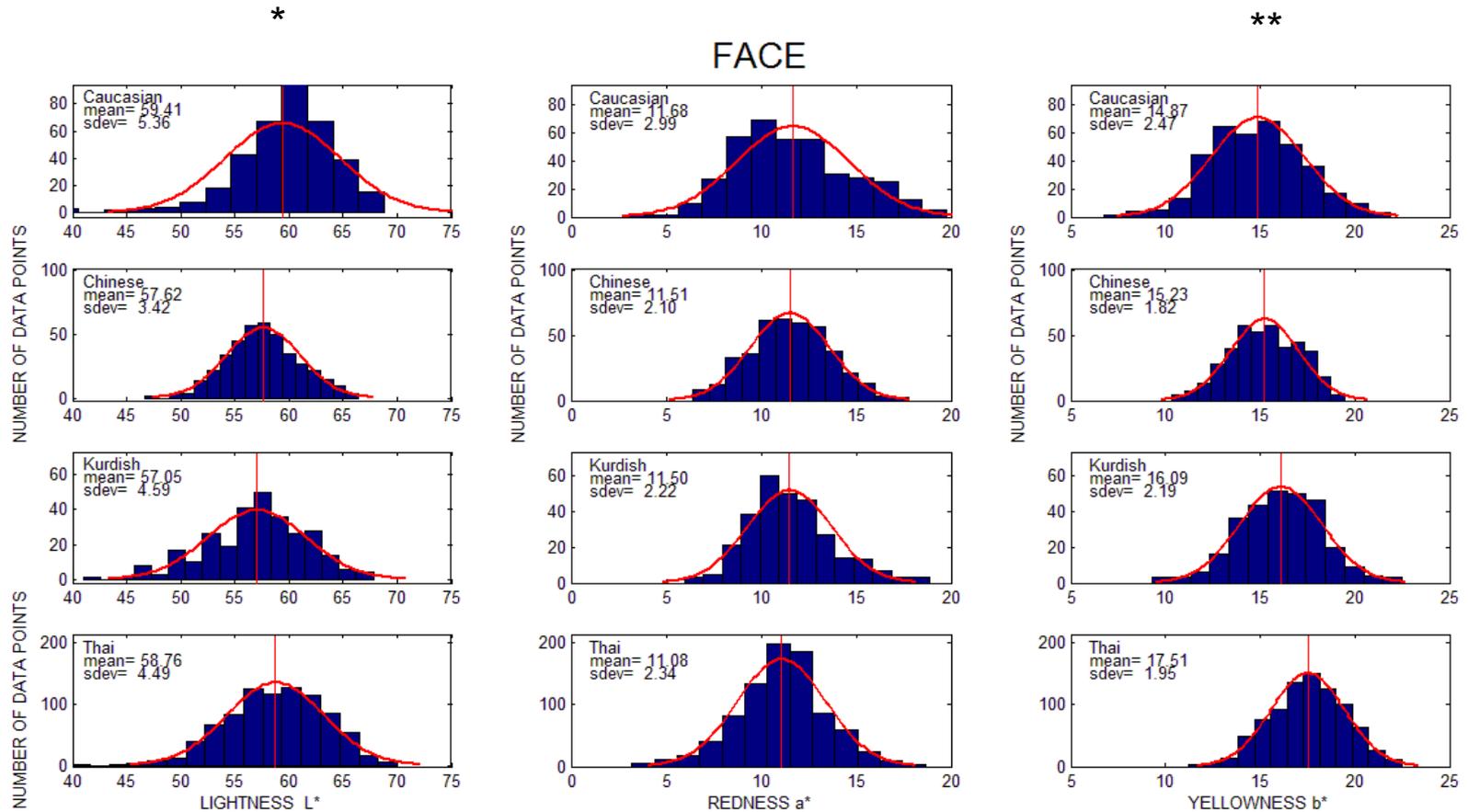
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Arm





SKIN COLOUR DATABASE



Most significant ethnic differences in yellowness; followed by lightness; less so in redness



SKIN COLOUR DATABASE



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ARM

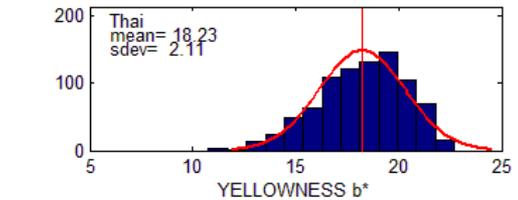
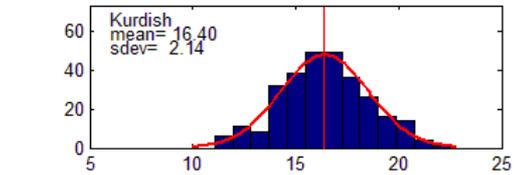
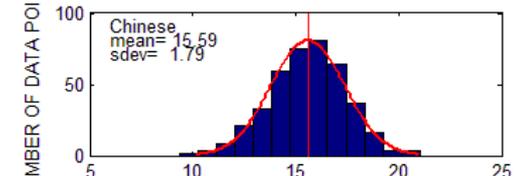
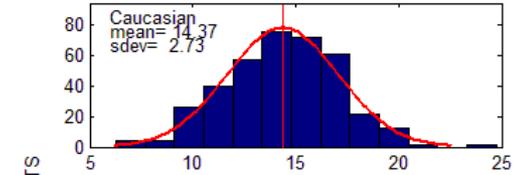
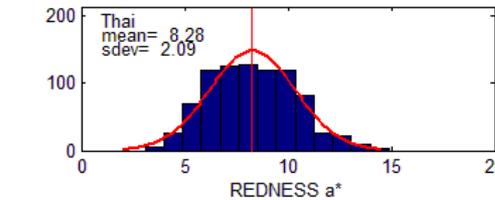
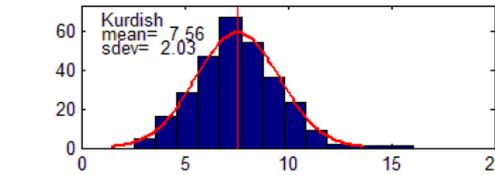
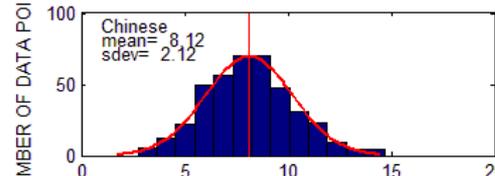
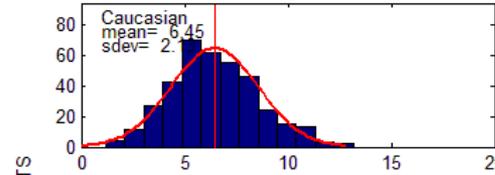
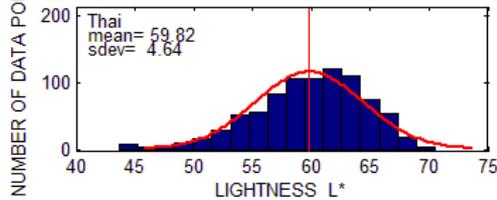
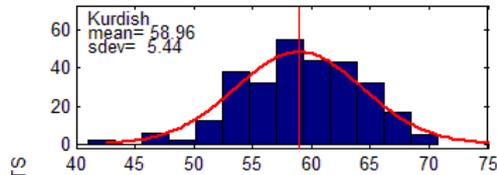
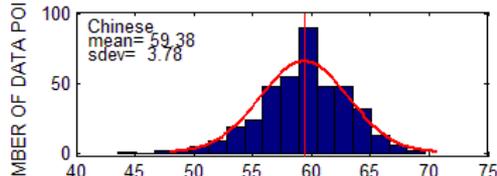
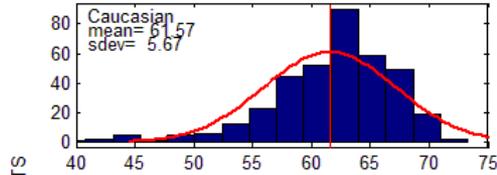


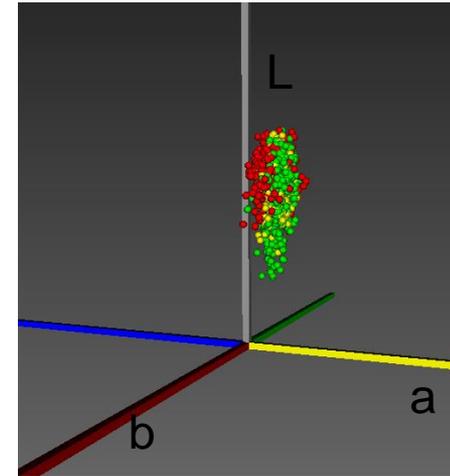


IMAGE ACQUISITION



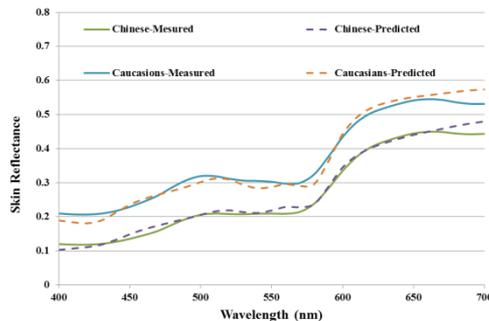
Reliability and repeatability

SKIN COLOUR DATABASE



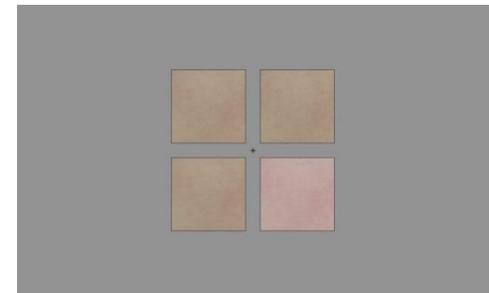
For different ethnicities

SPECTRAL RECONSTRUCTION



RGB -> XYZ-> SPECTRA

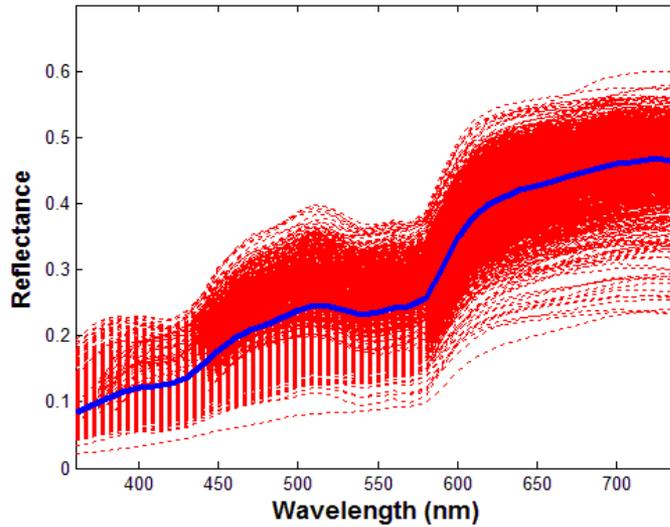
TOLERANCE LIMITS



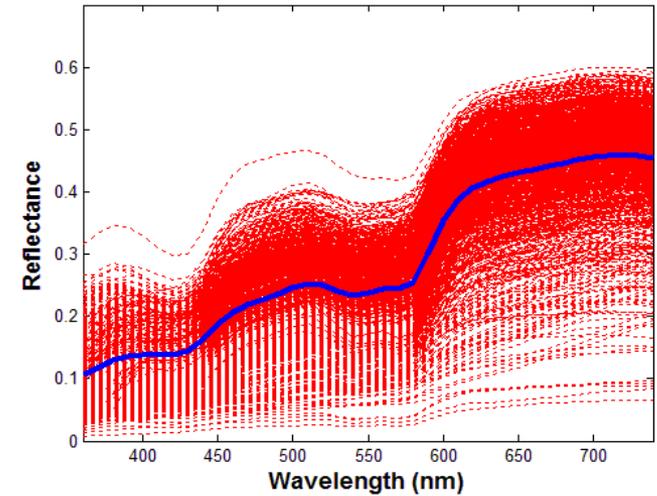
Perceptual experiments

SPECTRAL RECONSTRUCTION

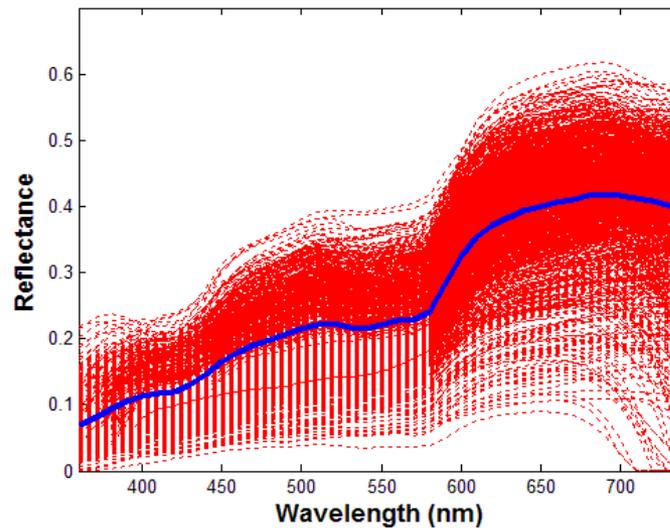
Reflectance of Chinese skin



Reflectance of Caucassian skin



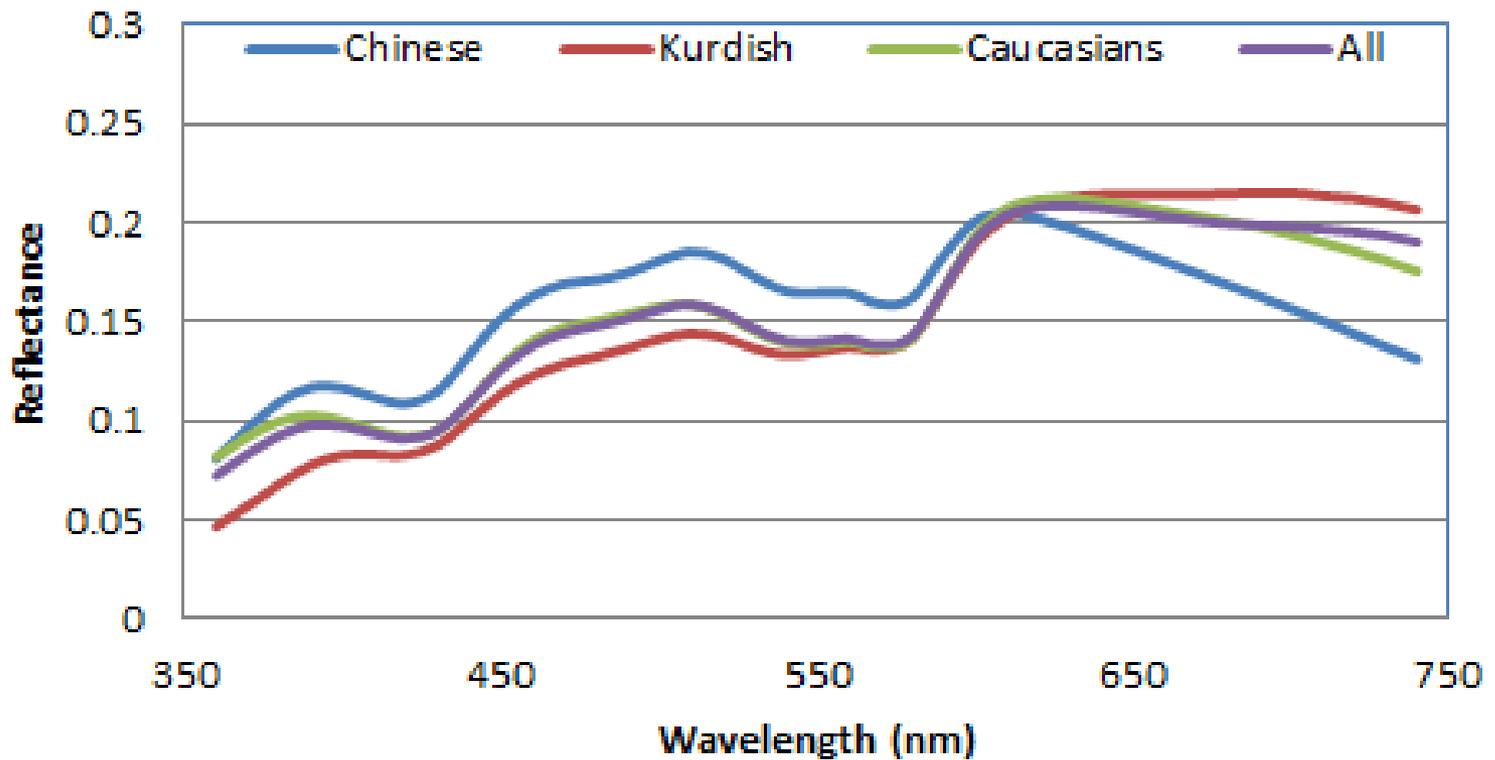
Reflectance of Kurdish skin



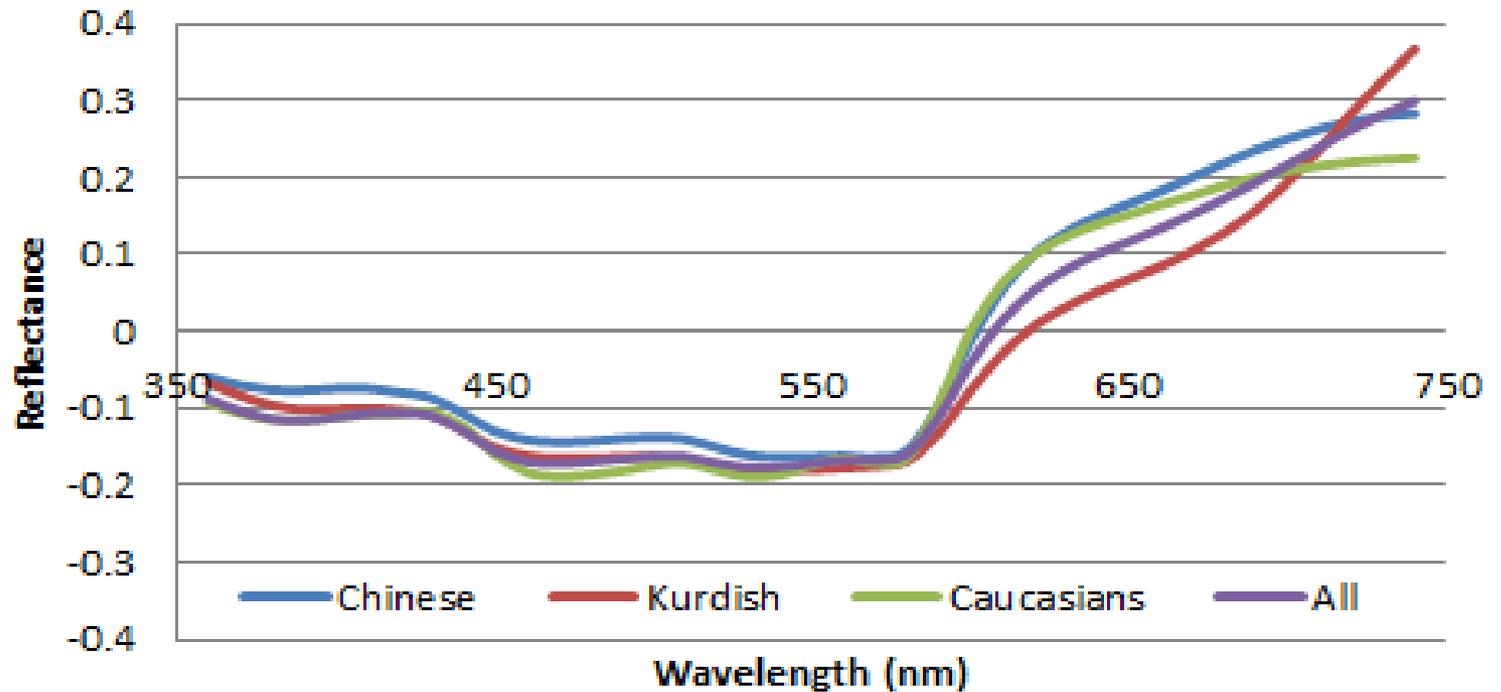
Skin Spectra

PCA

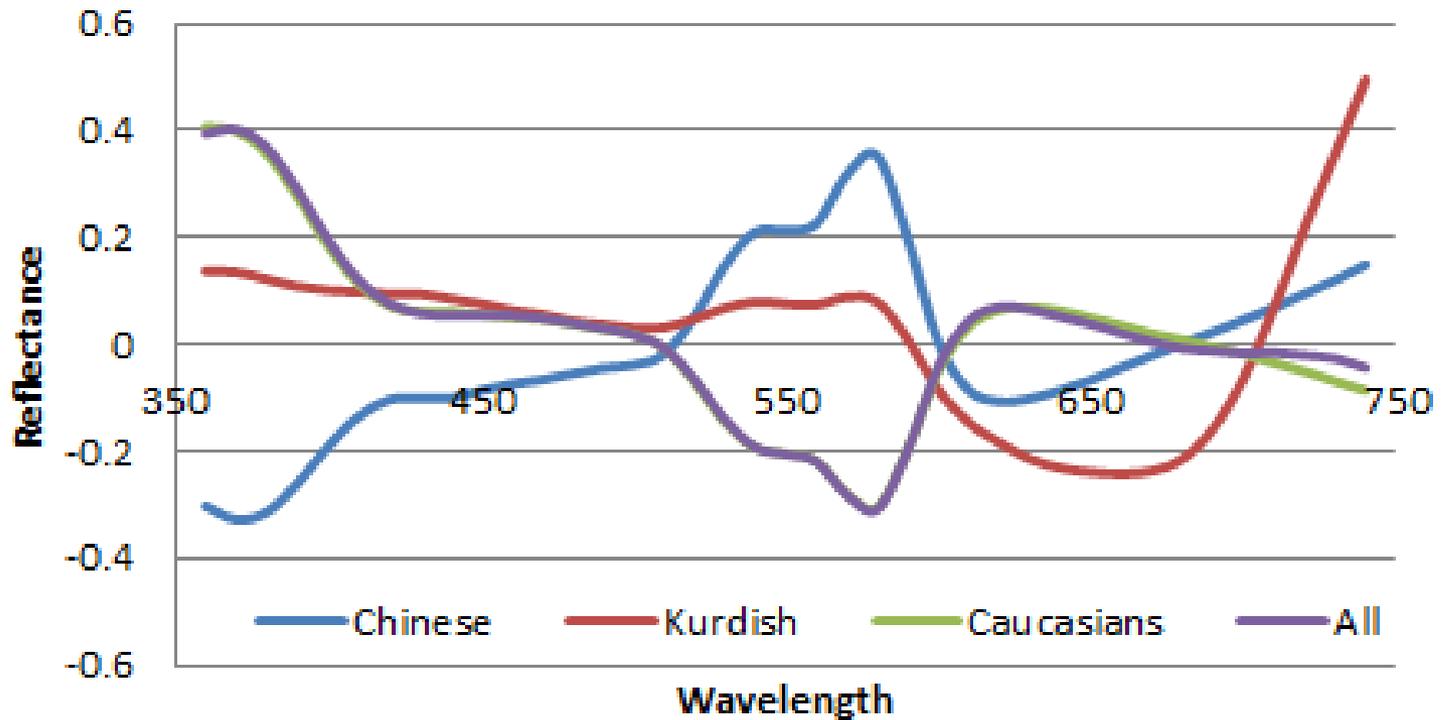
First Component



Second Component



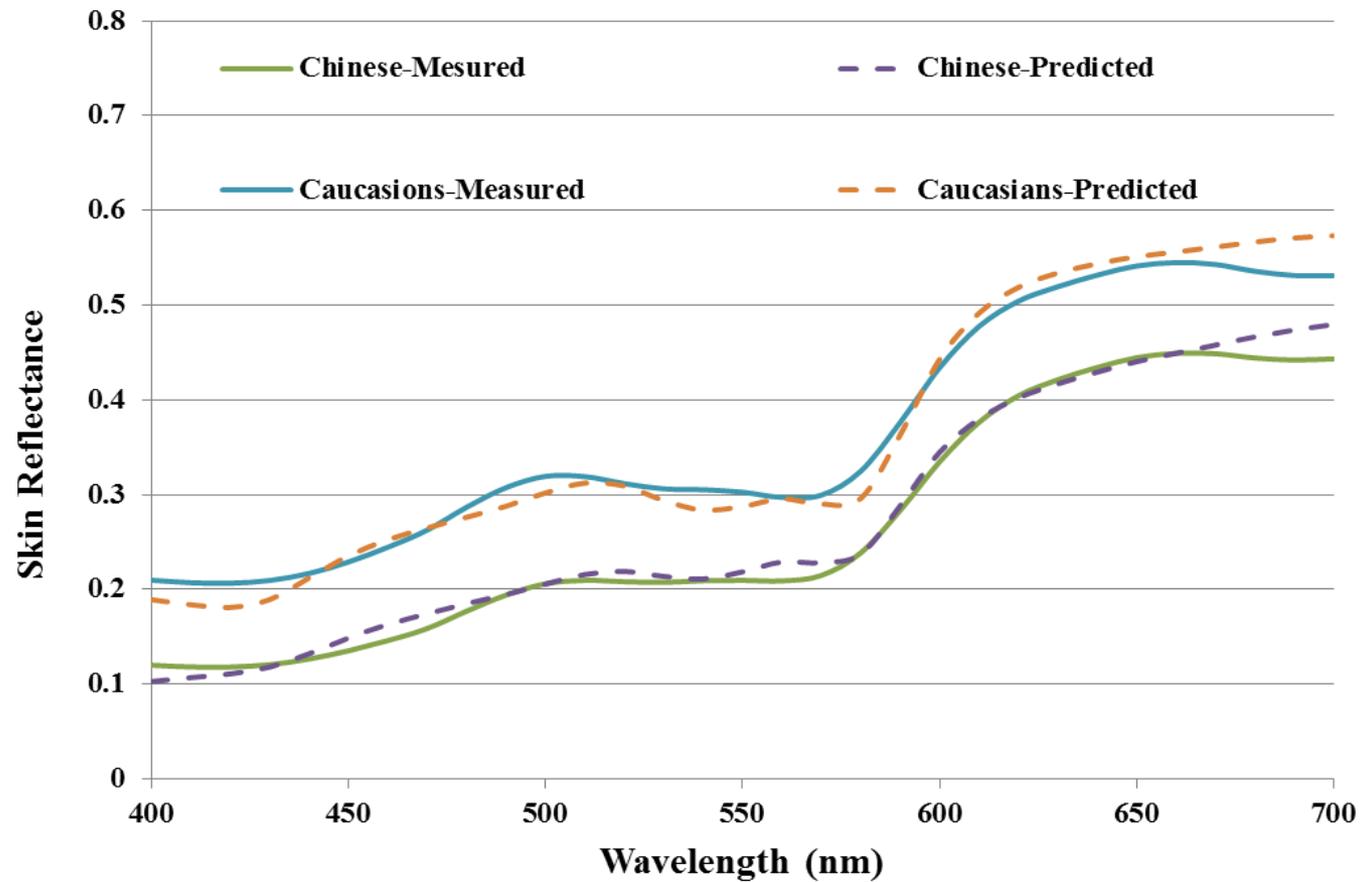
Third Component



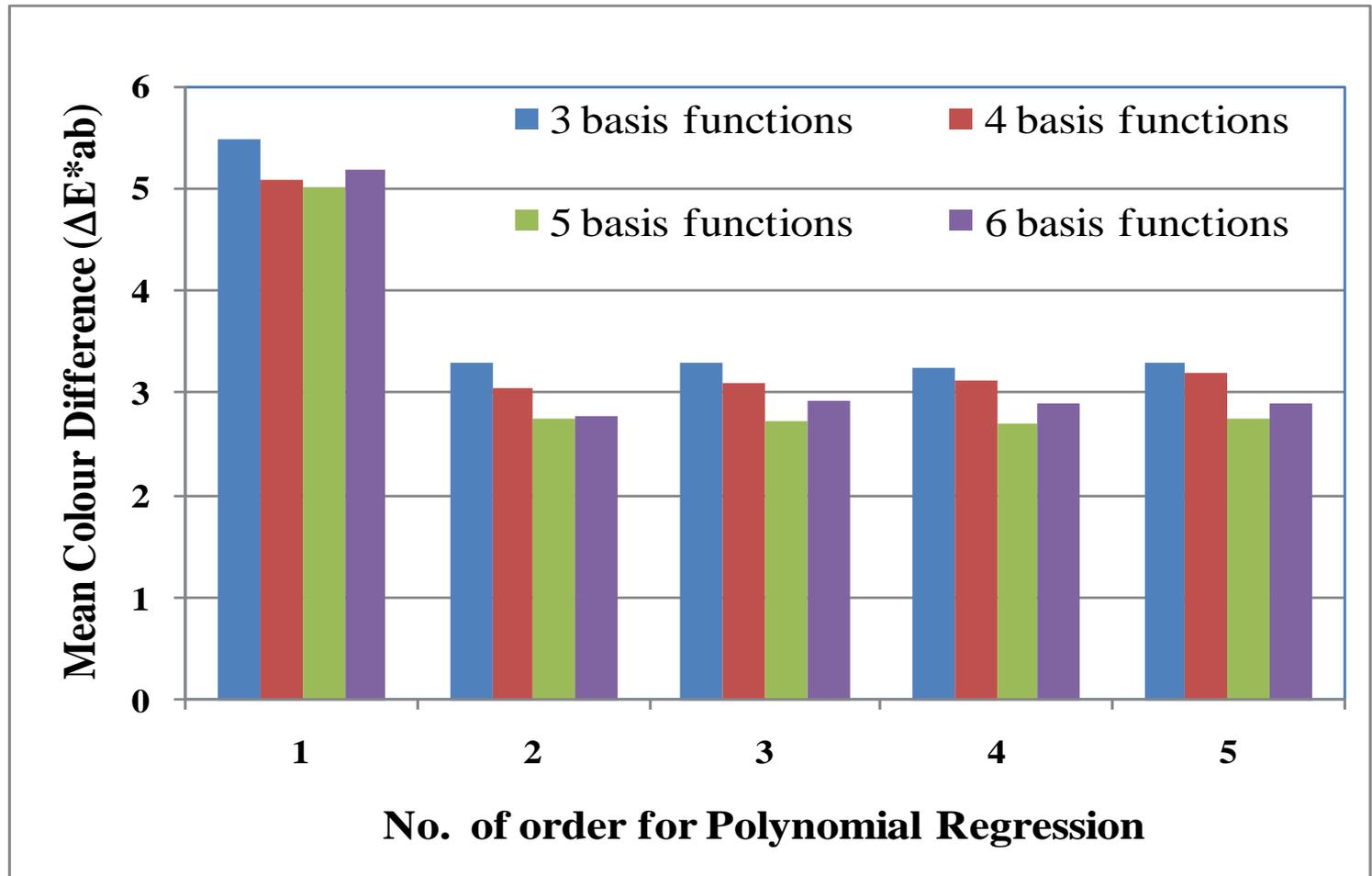
PCA

CCP (%)	First Component	Second Component	Third Component	Sum
Chinese	84.1	12.3	2.2	98.5
Kurdish	86.6	7.9	3.1	97.6
Caucasians	87.4	8.4	2.6	98.5
All	85.4	9.4	2.3	97.1

SPECTRAL RECONSTRUCTION



RGB->spectra





Skin spectral prediction



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- **Colour chart for training colours**
 - Conventional colour chart, skin colour chart
- **Mathematic Model**
 - Camera rgb to Reflectance
 - Camera rgb to CIE XYZ and to spectral reflectance
 - PCA, ICA, Wiener
- **Skin spectral database**
 - Local
 - Globe

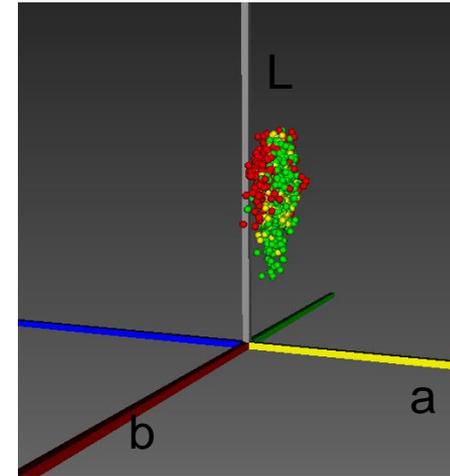


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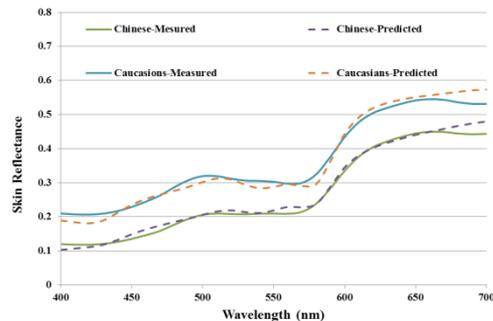
Reliability and repeatability

SKIN COLOUR DATABASE



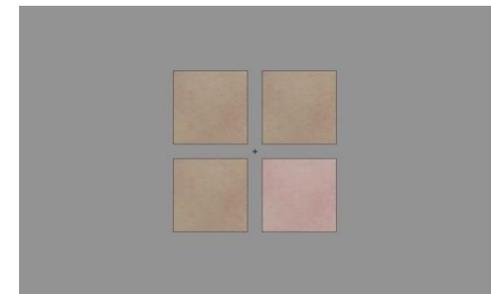
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TOLERANCE LIMITS



Perceptual experiments

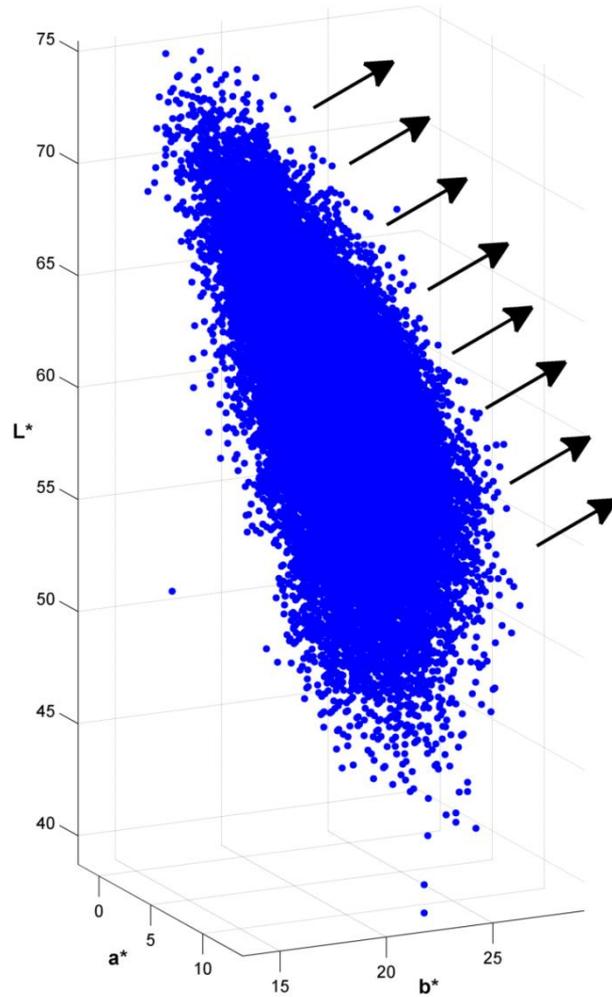
SKIN TOLERANCE LIMITS

Develop a metric optimised for skin colours:
Psychophysical experiment to determine thresholds for
skin patches - 4AFC – adaptive procedure

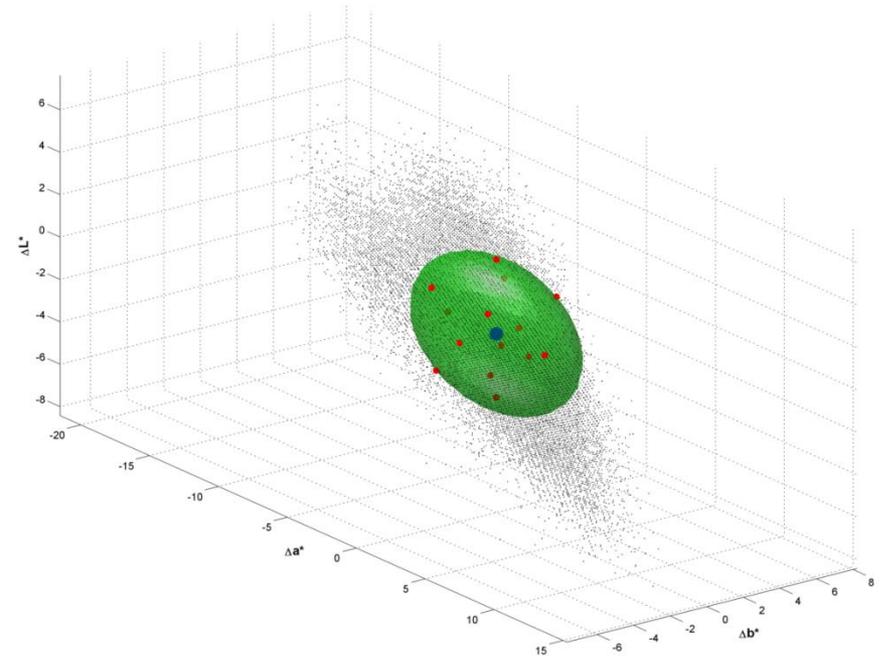




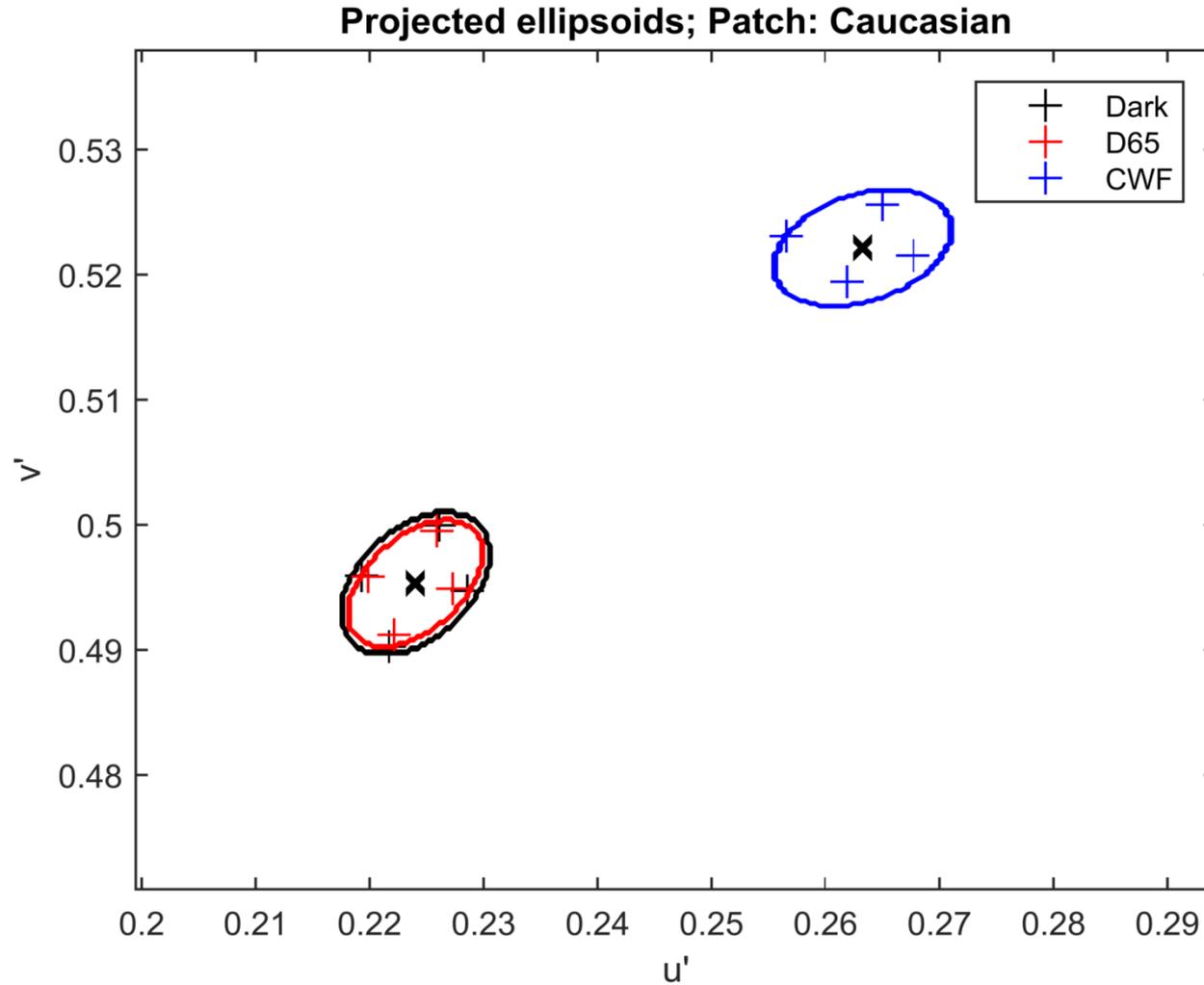
SKIN TOLERANCE LIMITS



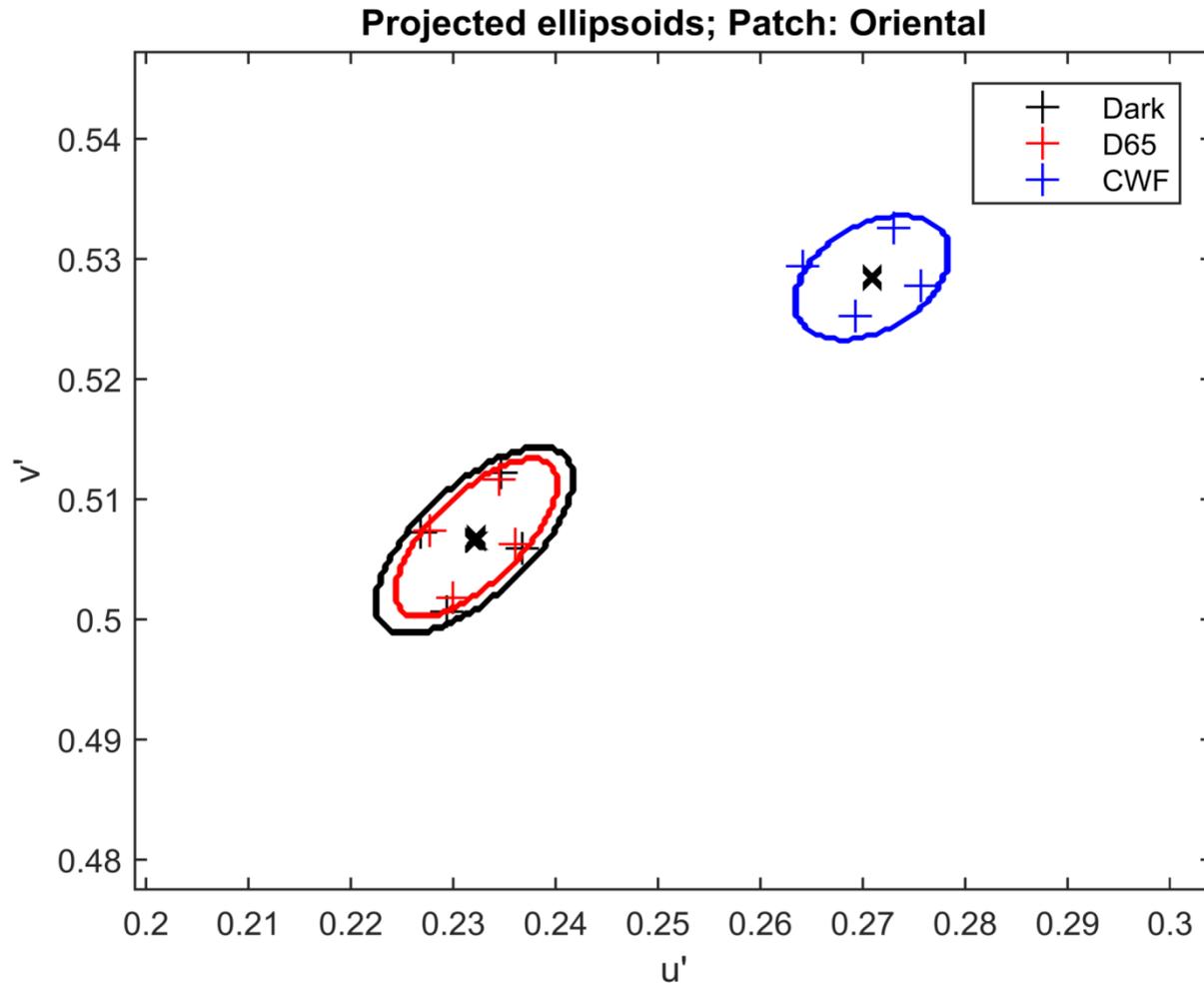
ELLIPSOID - threshold contours



SKIN TOLERANCE LIMITS

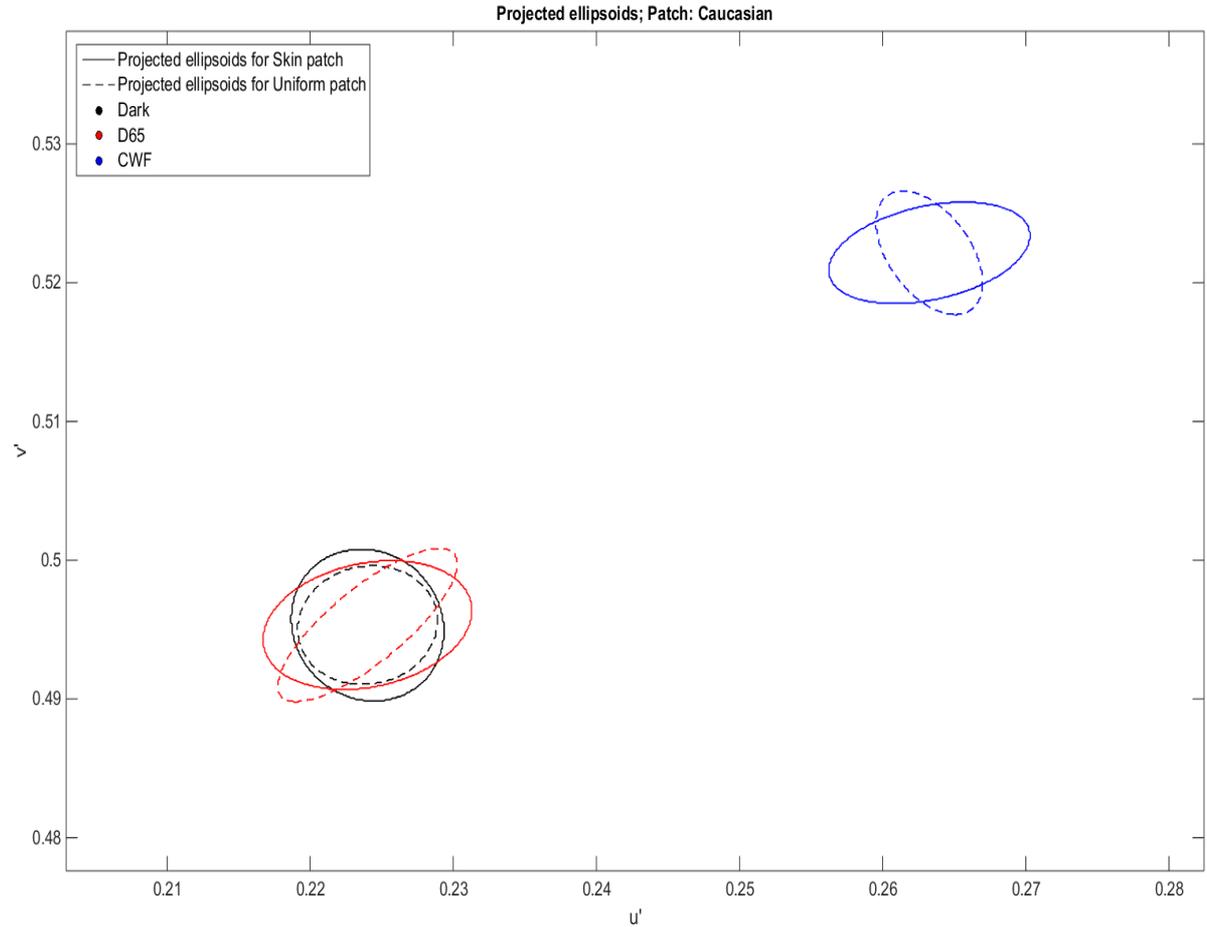


SKIN TOLERANCE LIMITS



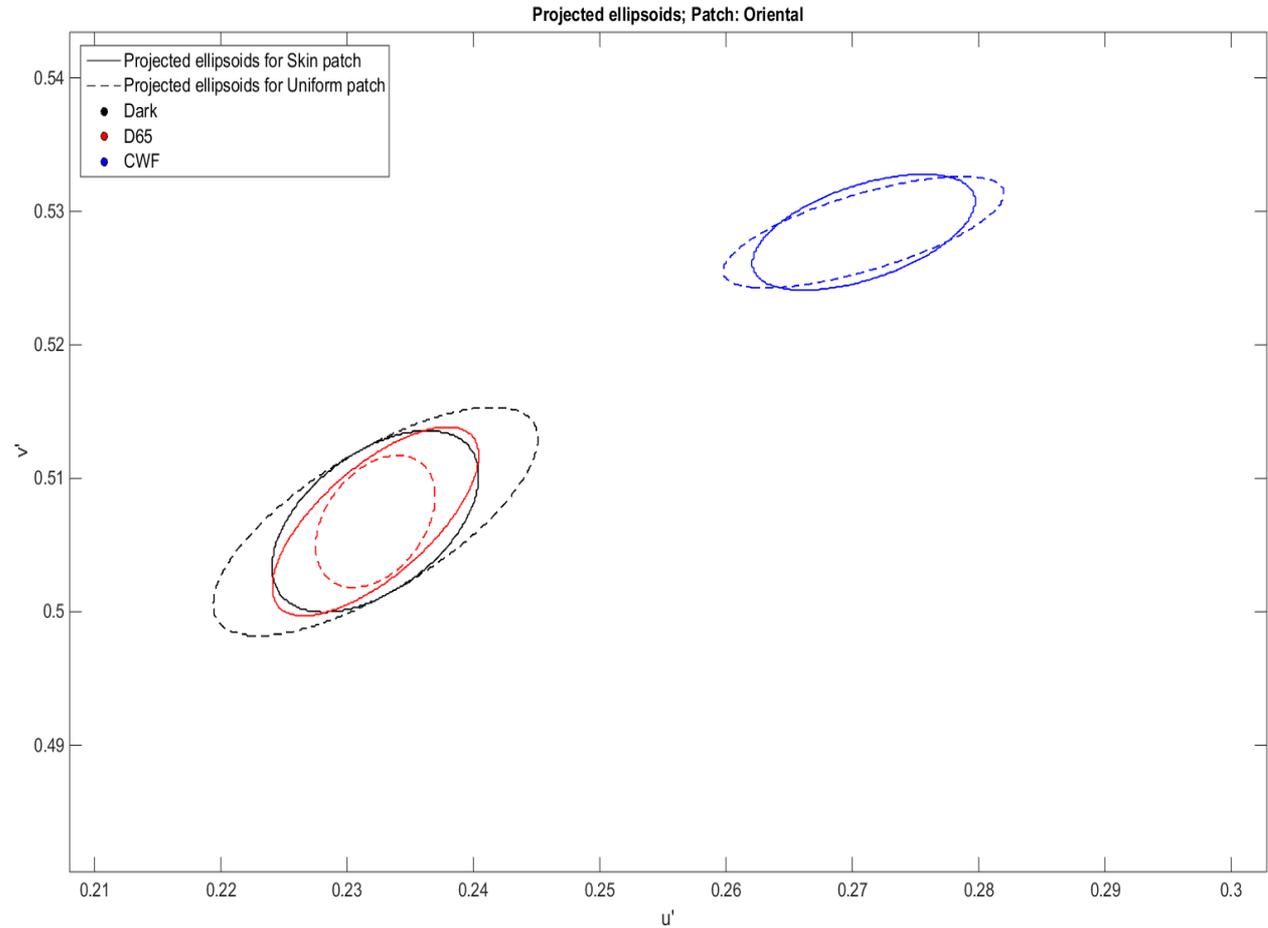


SKIN TOLERANCE LIMITS





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SKIN TOLERANCE LIMITS



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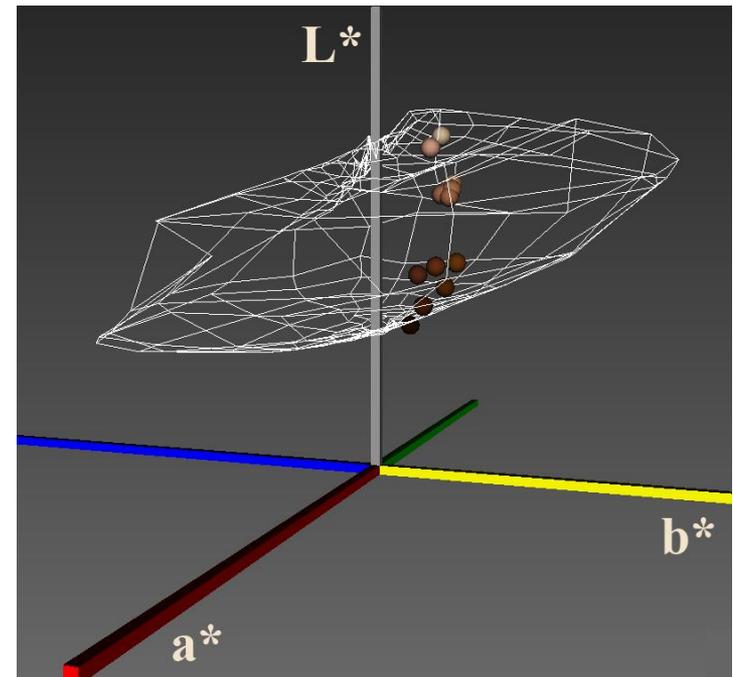
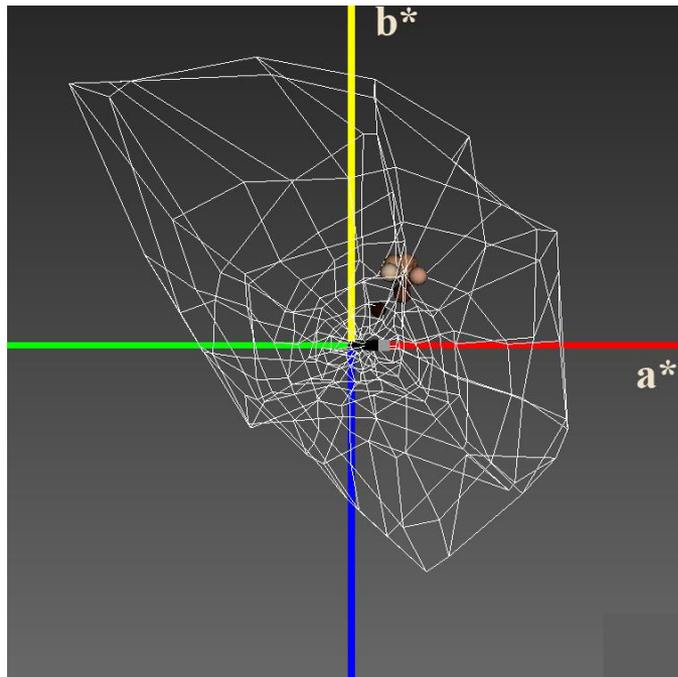


Further improvements of 3D printing of skin?

- Development of pigments with material & spectral properties closer to skin
- Pigments optimised for small skin gamut
- New materials responsive to temperature?



Colour Gamut of Z-corp 3D printer





Spectral Reflectance

