International Color Consortium®

Medical Photography task force
Teleconference
20 March 2014 • 10:00 (EDT)

The meeting was called to order at 10:00 am (EDT) by Craig Revie, chair of MIWG, with the following attendees:

James Chang	Sharp Laboratories
Wei-Chung Cheng	FDA
David Clunie	Bioclinica & PixelMed
John Dalrymple	Independent Consultant
Michael Flynn	Henry Ford Health System
Phil Green	ICC
William Li	Kodak
Andy Masia	X-rite
Masahiro Nishibori	International University of Health and Welfare
John Penczek	NIST
Craig Revie	Fujifilm
Thomas Schopf	University Hospital of North Norway
Stein Olav Skrøvseth	University Hospital of North Norway
John Sweeney	matchmycolor LLC
Yves Vander Haeghen	University of Ghent
Stephen Vastagh	DICOM
Hong Wei	Datacolor
Masahiro Yamaguchi	Tokyo Institute of Technology

After a check of the sound quality Mr. Revie outlined future meeting plans. In addition to the face-to-face meetings planned for Maryland in June and Boston in November, conference call dates have been set for 17 April (Mobile Displays), 15 May (Opthalmology), 17 July (TBD), 18 September (WSI), 18 October (TBD) and 11 December (WSI). He invited any of the activity leaders to use the TBD dates for their activity.

Andy Masia, activity leader for the Mobile Displays meeting, welcomed input on topics for the 17 April meeting.

Mr Revie provided an update on the Consensus paper from the May 2013 summit. BMC Medicine had declined the paper as they considered it more suitable to BMC Medical Imaging. He and Mr Aldo Badano were considering other alternatives including Telemedicine and e-Health. Mr Michael Flynn suggested the Journal of Digital Imaging and undertook to provide details to Mr Revie.

Mr Revie handed the meeting over to 5r John Penczek, who presented an update on ‘Best Practices for Digital Photography in Medicine’ [see attached]. He reviewed the mission and scope of the activity, and listed contributors and showed a draft outline of the document.

Dr Penczek reviewed the colour errors he had found in the work presented at the Summit, and noted factors contributing to these errors. They were large and dependent on both the specific colour in the test target and the illumination used. He stated that he had used auto white balance and a uniform background when capturing the test targets. He concluded that a smooth, daylight spectrum was better but this would depend on the camera white balance presets available.

Dr Phil Green noted that the errors were relatively large, and suggested the chromatic adaptation steps in the workflow might contribute to these. He also noted that rendered RGB JPEG images inevitably included adjustments to colour.

Dr Yves Vander Haeghen reported that he had data sets for different cameras, using different illumination sources, and can use this to analyze the effect of illumination. He agreed to consider sharing this data and providing an analysis.

Dr Penczek showed suggested recommendations on camera setup. The meeting discussed the appropriate white balance to use, and the use of rendered vs. RAW images. Dr Penczek reported that Nikon had proposed using manual white balance, using the setting for the appropriate illumination, at the Tokyo meeting. Dr Vander Haeghen stated that he had found the use of white balance variable, and had not found improvements by using manual white balance.

The meeting agreed that rendered images included colour enhancements, and that camera RAW might be better than rendered JPEGs where accuracy is needed. Dr Penczek noted that the Nikon ‘neutral’ setting minimises enhancements. Mr Andy Masia indicated that camera RGB was usually very scene content dependent, and rendering adjustments such as grey balance correction and contrast correction made it impossible to calibrate such cameras.

Dr Green noted that a single study might not be enough to base recommendations on, particularly as the errors reported were larger than other studies and his own experience. He suggested a camera characterization procedure to convert from camera RGB to XYZ, rather than using the rendered sRGB camera output, would give better results. Dr Penczek showed how errors could be reduced by using profiling software applied to the rendered RGB images, and reported that University of Ghent had also described a colour correction procedure.

Dr Penczek discussed the target design. Although larger targets gave smaller errors, the small ‘Passport’ chart was considered more useful for first responders who could not expect to carry large calibration targets to medical emergencies. He felt more flesh tone colours were desirable. Dr Vander Haeghen noted that durability of targets should be considered in medical use. His group had made new charts using different colours intended for interpolation, and these gave better characterization results with fewer patches. Mr Masia stated that his company, X-Rite, manufacture the ColorChecker targets, and could consider developing an alternative design if a different set of colours and target layout would meet the needs of the industry.

Dr David Clunie raised the issue of how important was accuracy, and noted that it was important to know how much improvement to colour errors was actually necessary. He felt that adopting a ‘best practices’ document would invariably lead to expectations that the recommendations should be followed, even if there was no medical justification. ‘Optimising consistency in digital photography’ might be a better title for the proposed document. Others agreed that it was important to have evidence on the accuracy recommendations. Dr Clunie emphasised that simply asking the opinions of clinicians was not sufficient, and it would be possible to design a trial that followed a diagnostic task and provided statistics. Dr Penczek considered this was out of scope for the activity, and the goal was not to set requirements but to identify best practices.

Dr Penczek invited any further comments and suggestions on the recommendations. Mr Revie proposed holding an ad-hoc call to focus on measurement in more detail (on April 9). Dr Penczek agreed to coordinate this meeting.

A full recording of the meeting is available at http://www.npes.org/Portals/0/standards/2014-03-20%2010.08%20MIWG_%20Digital%20Color%20Photography%20in%20Medicine.wmv

Action items from the meeting:

MIWG-14-19	Provide details Journal of Digital Imaging to Mr Revie (Flynn)
MIWG-14-20	Consider sharing scene analysis data with group (Vander Haeghen)
MIWG-14-21	Coordinate ad-hoc meeting on Measurement for Medical Photography (Penczek)

Best Practices for Digital Color Photography in Medicine

John Penczek
NIST & Univ. Colorado, Boulder

ICC Medical Imaging Task Force

Medical Photography Teleconference

March 20, 2014

Mission & Scope

- **Mission:**

  Collect industry best practices in the field of digital photography and write a guidance document which can be used by the medical industry to minimize the color errors created during the digital color camera image capture process.

- **Scope:**

  This guidance document will apply for a range of digital cameras (from cellphone cameras to scientific grade cameras) and lighting conditions. Recommendations will also be made for camera setup and color correction in post processing.

Contributors

John Penczek, NIST/Univ. of Colorado (project coordinator)

Ives Vander Haeghen, University of Ghent Hospital

Stein Olav Skrovseth, Norwegian Centre for Telemedicine

Elizabeth Krupinski, Arizona State University

Aldo Badano, FDA

Phil Green, ICC

Draft Outline

Introduction and background
Penczek, Krupinski, Skrovseth

Factors that can contribute to color errors
Penczek, Krupinski

Recommended light conditions
Penczek, Krupinski

Recommended camera setup
Penczek, Krupinski, Skrovseth, Vander Haeghen

Use of reference color charts
Penczek, Vander Haeghen

Color correction in post-processing
Skrovseth, Vander Haeghen

Recommendations on color management
Green, Vander Haeghen

Note: Content should expand on or introduce new information to what is already available (e.g. ATA Practice Guidelines for Teledermatology 2007)

Color Errors in Image Workflow

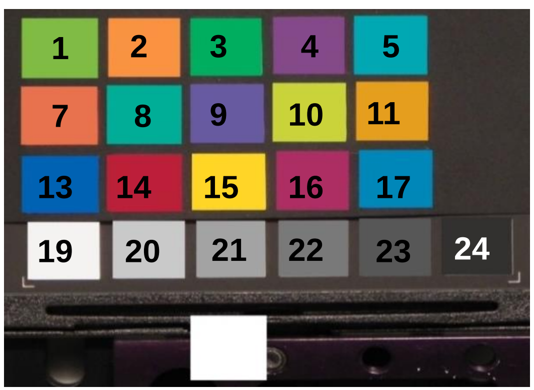
Color error can come from several sources in the color image workflow.

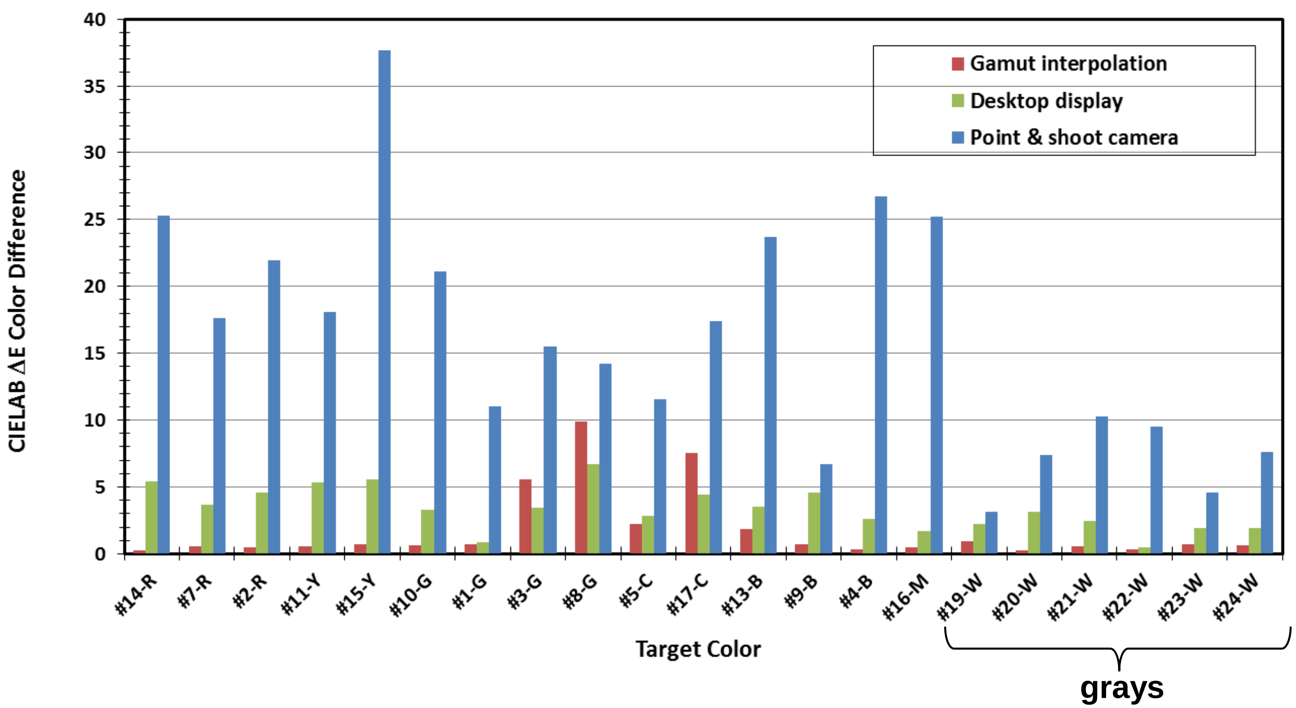
Object

Camera

Viewing Software

Display





Camera color error was determined to be dominant.

Data to be published at the Society of Information Display Symposium, June 2104

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Skrovseth, Vander Haeghen

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Green, Vander Haeghen

Camera Color Error Study

A large parametric study was conducted to identify the critical parameters that contribute to camera color error.

Camera

Camera image data

RGB → CIE XYZ @ sRGB → External correction → **Perceived color** CIE LAB

Dependencies

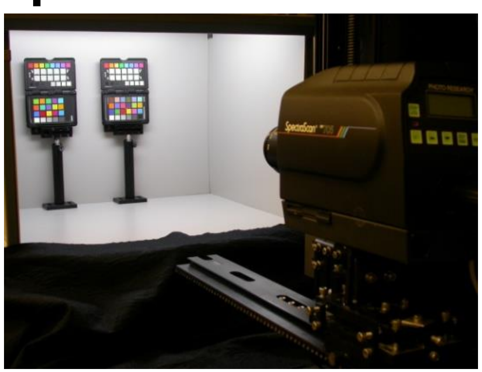
Lighting color
Lighting uniformity
Camera quality

Camera cal
Auto white balance

Correction software
Reference sample
Reference geometry
Reference cal data

ΔE Color Difference

Spectroradiometer



Lighting color
Instrument cal
Stray light

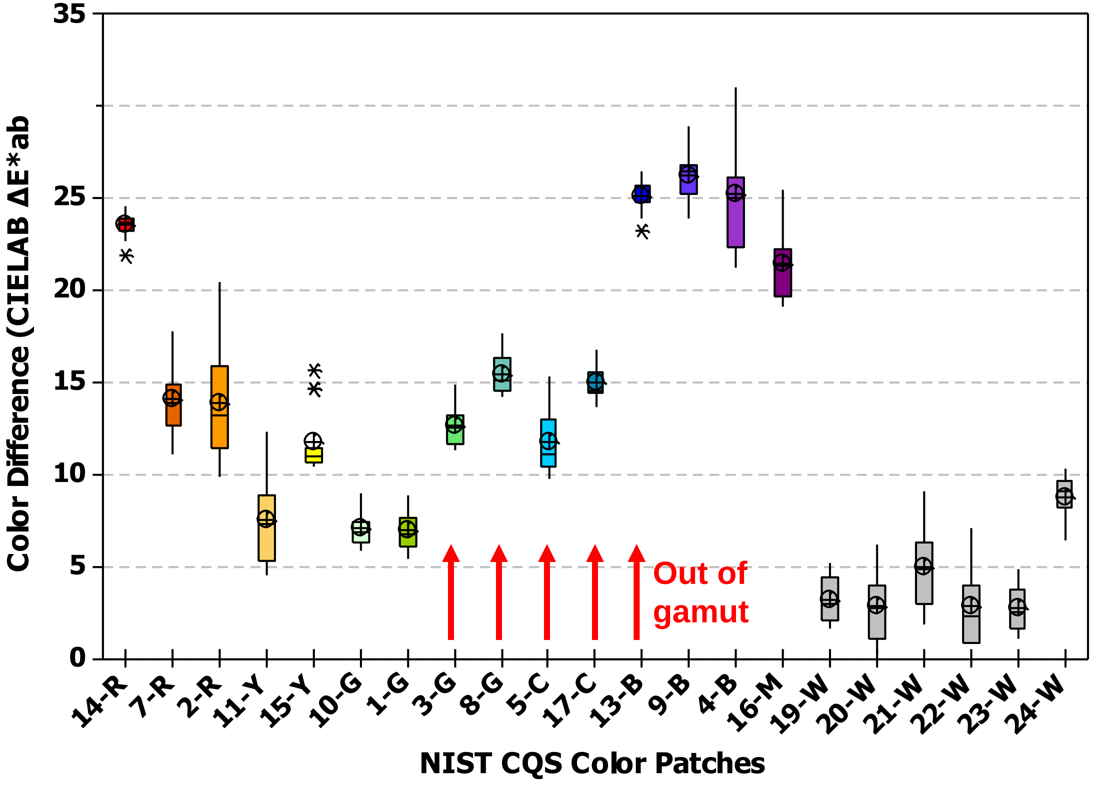
Spectra → CIE XYZ @ sRGB → CIE LAB

Spectroradiometer data

Camera Color Error Dependence on Color

Image color error of the NIST CQS color target using a mid-priced point & shoot camera under daylight fluorescent lighting conditions.

NIST CQS Color Chart



A color difference of CIELAB $\Delta E^*_{ab} = 1$ is considered a just noticeable difference (JND). Color difference is calculated relative to spectroradiometer data.

Color code: R=red, Y=yellow, G=green, C=cyan, B=blue, M=magenta, W=white and gray

NIST

J. Penczek, P.A. Boynton, J.D. Splett, "Color error in the digital camera image capture process," J. Digital Imaging, 27, 182-191 (2013).

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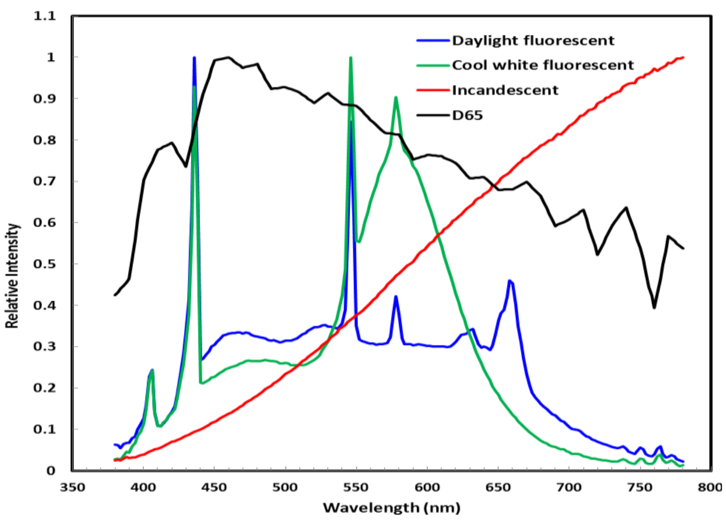
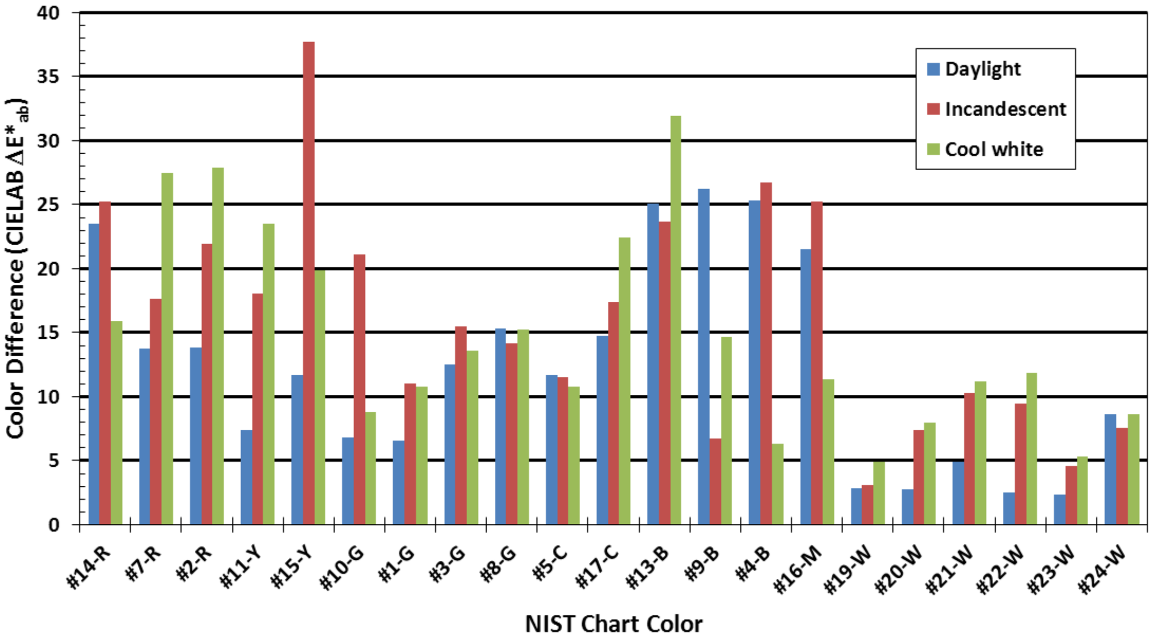
Color Error Dependence on Lighting

Image color error of the NIST CQS color target using a mid-priced point & shoot camera under different lighting conditions.





A color difference of CIELAB $\Delta E^*_{ab} = 1$ is considered a just noticeable difference (JND). Color difference is calculated relative to spectroradiometer data.

Color code: R=red, Y=yellow, G=green, C=cyan, B=blue, M=magenta, W=white and gray

J. Penczek, P.A. Boynton, J.D. Splett, "Color error in the digital camera image capture process," J. Digital Imaging, 27, 182-191 (2013).

Color Error Dependence on Lighting

Summary of image color error for the NIST CQS color target using a mid-priced camera under different lighting conditions.

Illumination source	Mean ΔE^*_{ab}	Max ΔE^*_{ab}	Mean ΔL^*_{ab}	Mean ΔC^*_{ab}	Mean ΔE_{00}
Daylight fluorescent	12	26	5.1	4.3	7.0
Incandescent	16	38	6.4	-3.2	9.1
Cool white fluorescent	15	32	4.6	4.7	8.8

where ΔE_{00} is the CIEDE2000 total color difference.

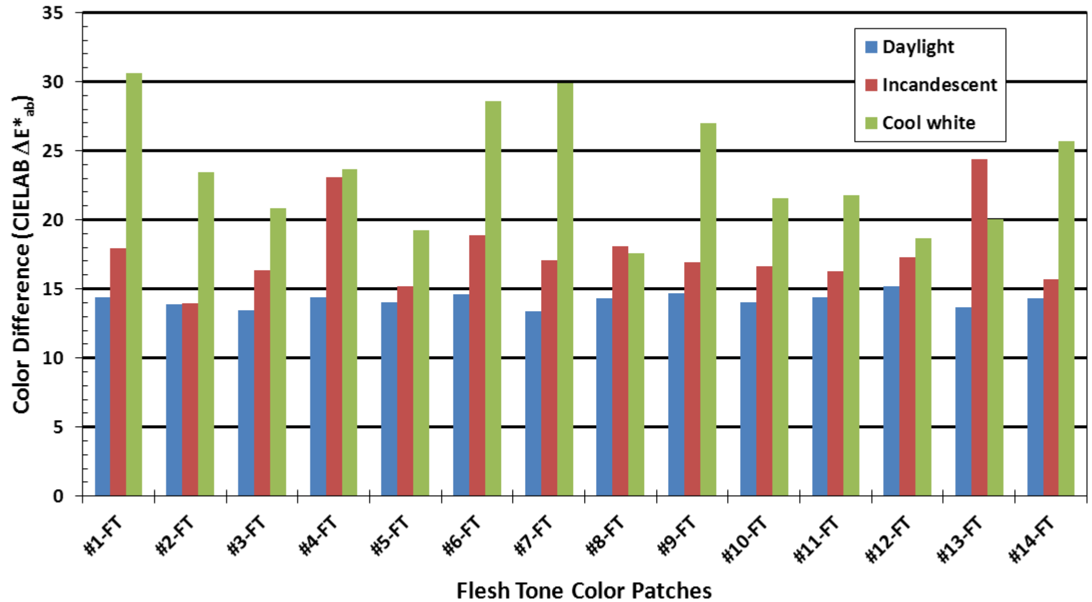
- A color difference of CIELAB ΔE^*_{ab}= 1 is considered a just noticeable difference (JND). Most consider ΔE^*_{ab}= 3 as a significant difference.
- The camera produces large color errors, even for the reference daylight fluorescent lamp.
- For this camera, more of the color error is a shift in lightness rather than chroma.

J. Penczek, P.A. Boynton, J.D. Splett, "Color error in the digital camera image capture process," J. Digital Imaging, 27, 182-191 (2013).

Color Error of Flesh Tones

Image color error of the flesh tones on the Digital ColorChecker SG color target using a mid-priced point & shoot camera under different lighting conditions.

Flesh tone color target



Illumination source	Mean ΔE^*_{ab}	Max ΔE^*_{ab}	Mean ΔL^*_{ab}	Mean ΔC^*_{ab}	Mean ΔE_{00}
Daylight fluorescent	15	16	13	-1.4	11
Incandescent	18	24	14	5.9	13
Cool white fluorescent	23	31	14	6.5	19

Color code: FT= flesh tone

J. Penczek, P.A. Boynton, J.D. Splett, "Color error in the digital camera image capture process," J. Digital Imaging, 27, 182-191 (2013).

Recommended Lighting Conditions

- **Illumination should be close to daylight**
- **Smooth broadband spectral distribution**
- **Uniform lighting** (valuable for image capture and calibration)
- **No glare or specular highlights**
- **Use gray or darker background to minimize stray light**
-
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Comparison of Camera Technology

Image color error of the NIST CQS color target was also evaluated using a range of camera technologies. Images were acquired using the auto setting on the camera.

Smart phone camera

Mid-priced point & shoot

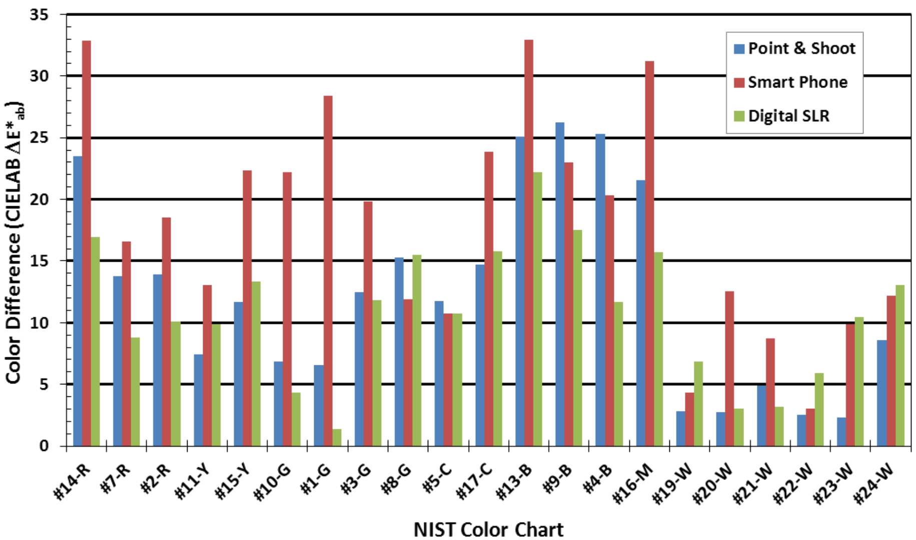
Digital SLR camera

Images were taken with a centered color target illuminated by daylight fluorescent, incandescent, and cool white fluorescent lamps.

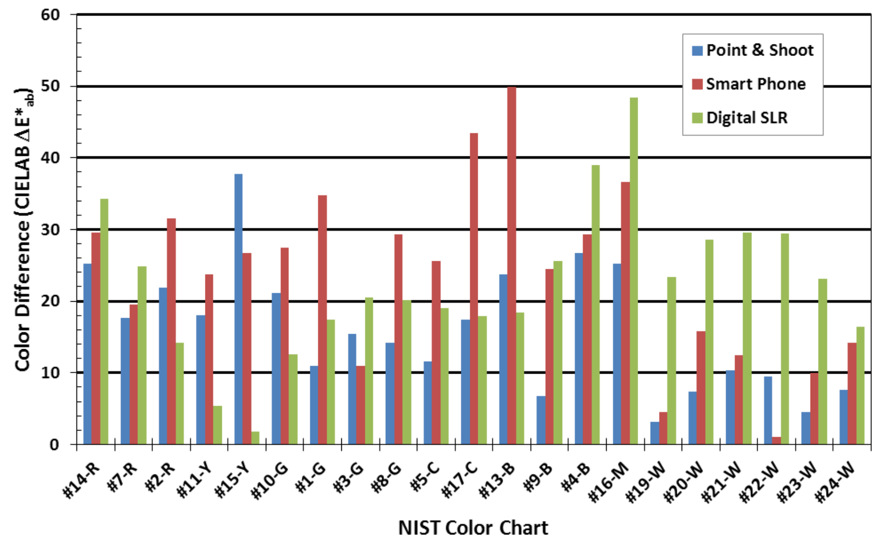
Color Error Dependence on Camera Technology

Image color error of the NIST CQS color target using a range of camera technologies under daylight and incandescent lighting conditions.

Daylight Fluorescent Illumination



Incandescent Lamp Illumination



Camera Type	Mean ΔE^*_{ab}	Max ΔE^*_{ab}
Point & Shoot	12	26
Smart Phone (HDR off)	18	33
Digital SLR	11	22

Camera Type	Mean ΔE^*_{ab}	Max ΔE^*_{ab}
Point & Shoot	16	38
Smart Phone (HDR off)	24	50
Digital SLR	22	48

Color error does not always improve with cost of the camera.

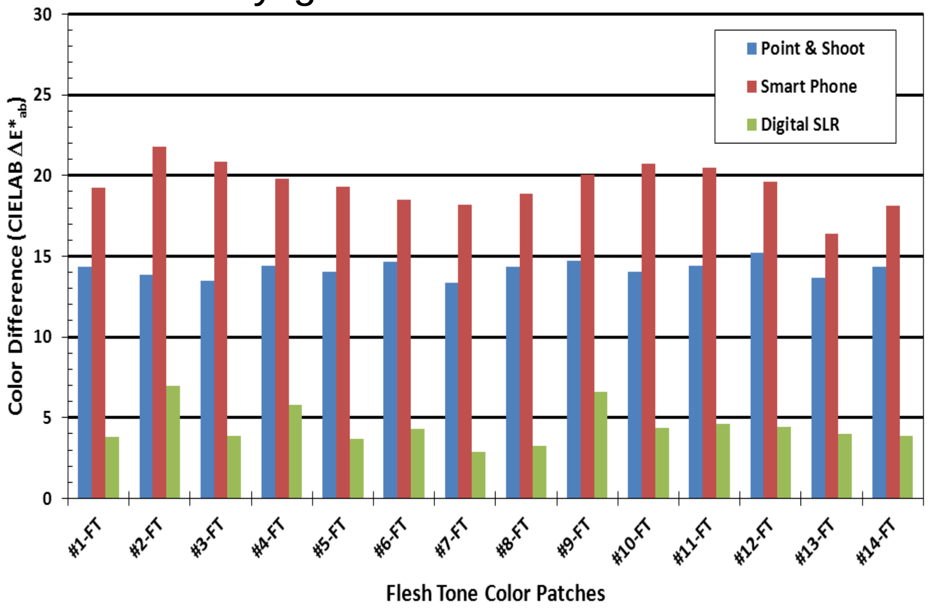
Color code: R=red, Y=yellow, G=green, C=cyan, B=blue, M=magenta, W=white and gray

J. Penczek, P.A. Boynton, J.D. Splett, "Color error in the digital camera image capture process," J. Digital Imaging, 27, 182-191 (2013).

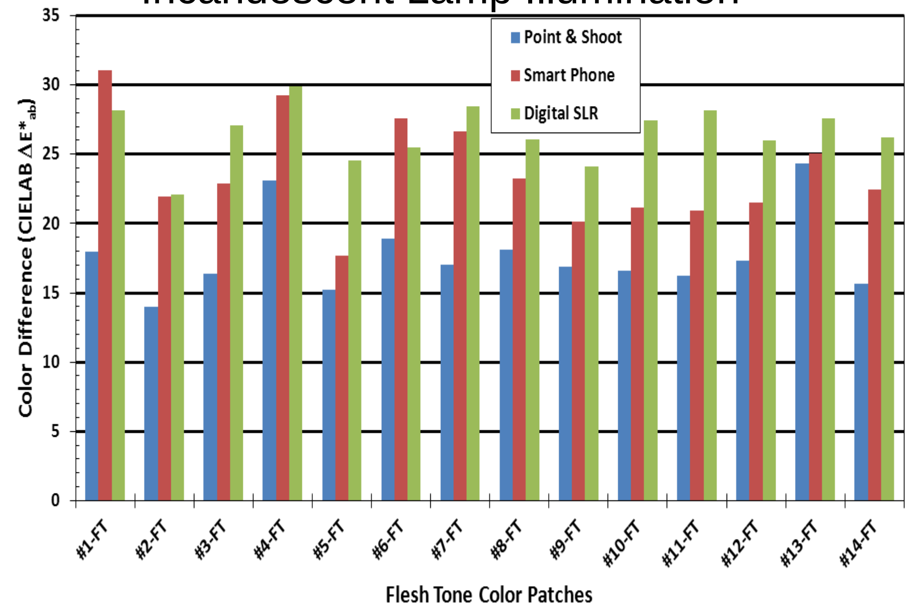
Flesh Tones with Different Cameras

Image color error of flesh tones in the Digital ColorChecker SG color target using a range of camera technologies under daylight and incandescent lighting conditions.

Daylight Fluorescent Illumination



Incandescent Lamp Illumination



Camera Type	Mean ΔE^*_{ab}	Max ΔE^*_{ab}
Point & Shoot	14	15
Smart Phone (HDR off)	19	22
Digital SLR	4.5	7.0

Camera Type	Mean ΔE^*_{ab}	Max ΔE^*_{ab}
Point & Shoot	18	24
Smart Phone (HDR off)	24	31
Digital SLR	27	30

Recommended Camera Setup

- Auto mode does not give the best results
- Suggest a manual or preset mode with defined illumination (Nikon)
- Better to use Raw image formats (Nikon)
- Use “Neutral” mode to minimize perceptual enhancements (Nikon)
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Image Color-Correction

Investigated image color–correction methods using reference color chart beside test chart.

NIST CQS
(Test chart)

Passport ColorChecker
(Reference chart)

NIST CQS

Digital ColorChecker SG

One color–correction method used a commercial ICC profiler that could be applied by image rendering software. The other (Univ. Ghent) method directly converted the raw image.

Color-Correction Results

The reduction in the amount of image color error is compared for the two reference charts using two color-correction methods.

Color-correction method	Percent Reduction in Color Error using Passport ColorChecker		
	NIST colors mean ΔE^*_{ab}	NIST colors max ΔE^*_{ab}	NIST colors mean ΔE_{00}
Commercial ICC Profiler	14%	16%	13%
Univ. Ghent	44%	22%	53%

Color-correction method	Percent Reduction in Color Error using Digital ColorChecker SG					
	NIST colors mean ΔE^*_{ab}	NIST colors max ΔE^*_{ab}	NIST colors mean ΔE_{00}	Flesh tones mean ΔE^*_{ab}	Flesh tones max ΔE^*_{ab}	Flesh tones mean ΔE_{00}
Commercial ICC Profiler	26%	40%	34%	26%	12%	35%
Univ. Ghent	53%	35%	61%	72%	40%	69%

J. Penczek, P.A. Boynton, J.D. Splett, "Color error in the digital camera image capture process," J. Digital Imaging, 27, 182-191 (2013).

Image Color-Correction

- Reference color charts need to include range of flesh tones
- Lighting needs to be uniform of reference and target objects
- Side-by-side reference configuration vs sequential capture
- Consider improved color-correction algorithms
- Smooth integration of color-correction into color management
- Mobile device color-correction
-

Publication

How will this document be published?

- ICC publication
- Journal article
- Collaboration with other organizations (e.g. American Telemedicine Association)