Color Error in the Digital Camera Image Capture Process

John Penczek
NIST & Univ. Colorado, Boulder

Paul A. Boynton
NIST

Jolene Splett
NIST, Boulder, CO

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Study Description

- **Investigate the influence of ambient lighting conditions and camera technology on the color accuracy of a typical digital image workflow.**

- **Compare the relative improvements in color error produced by various color-correction methods.**

Digital Color Image Workflow

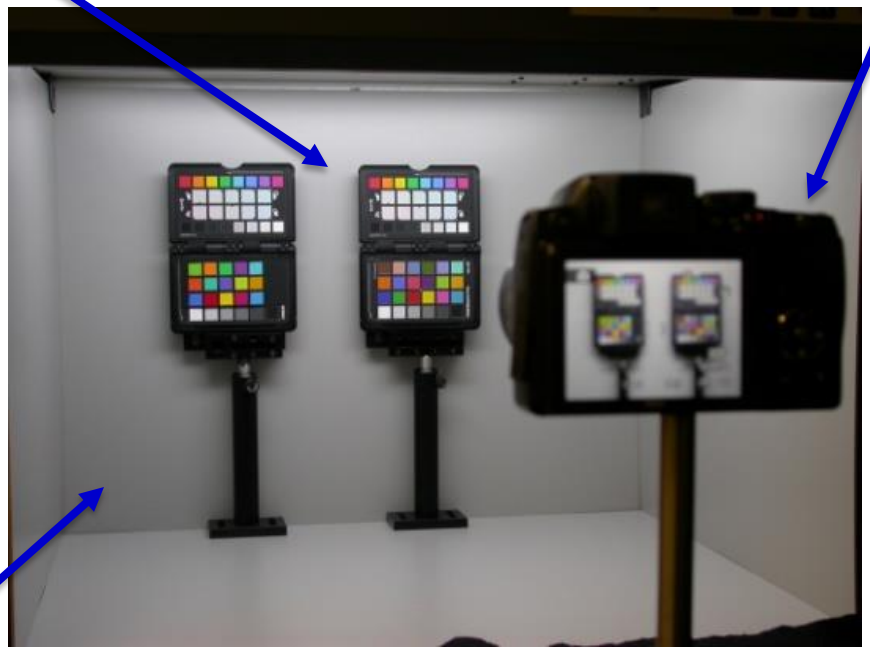
Major functions affecting the rendered color in workflow

	Image capture	Color management	Display image
Major factors:	• Camera quality • Lighting conditions • Camera calibration	• Chromatic adaptation • Gamut mapping	• Color gamut • Lighting conditions • Display calibration

Measurement Setup

Color targets:
Used to sample a range of colors.

Camera:
Compared various digital camera technologies.



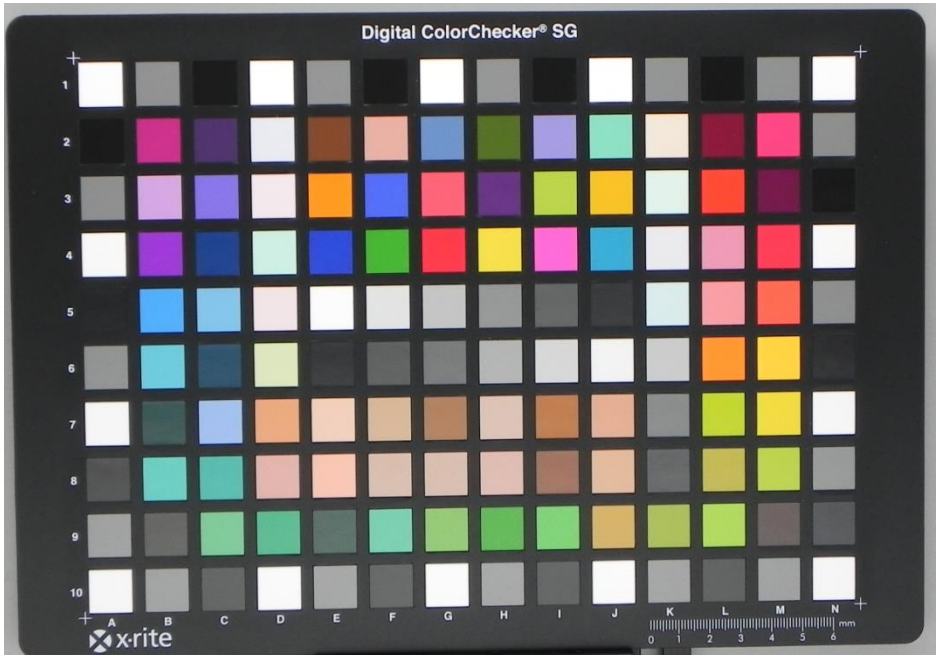
Light booth:
Used to simulate daylight, fluorescent lamp, or incandescent lamp lighting conditions.

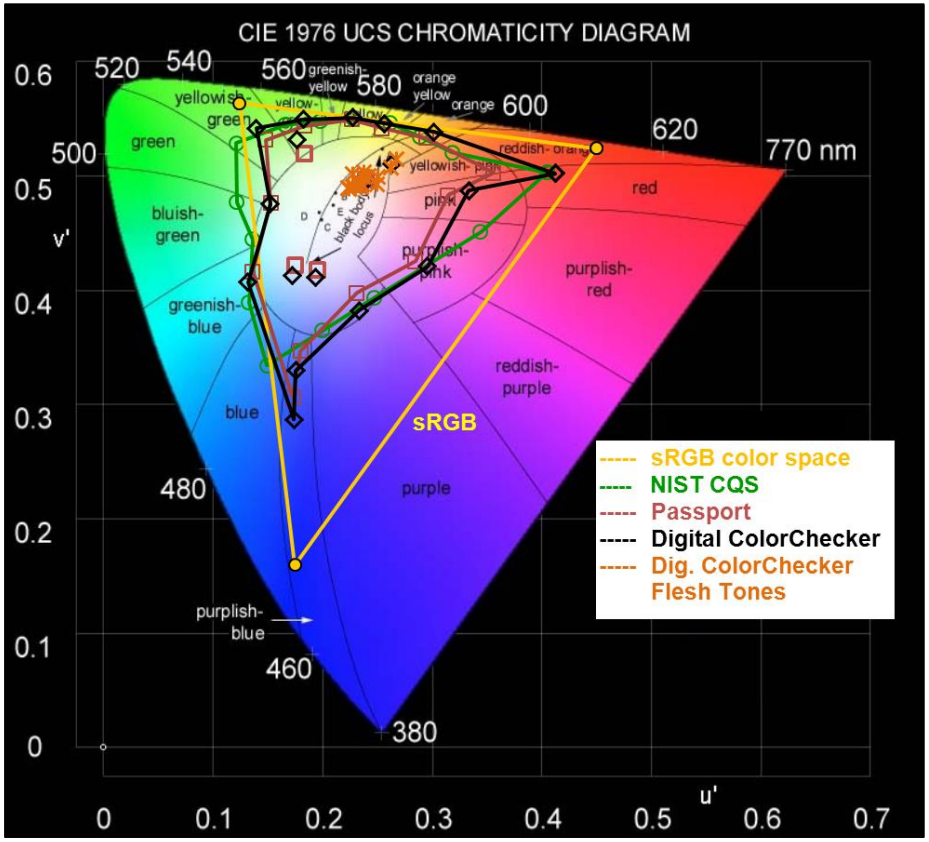
Reference data:
Reference measurements taken with spectroradiometer under same conditions.

Color Targets

Three color targets where used to evaluate the performance of the imaging system under different test conditions.

X-rite Digital ColorChecker SG



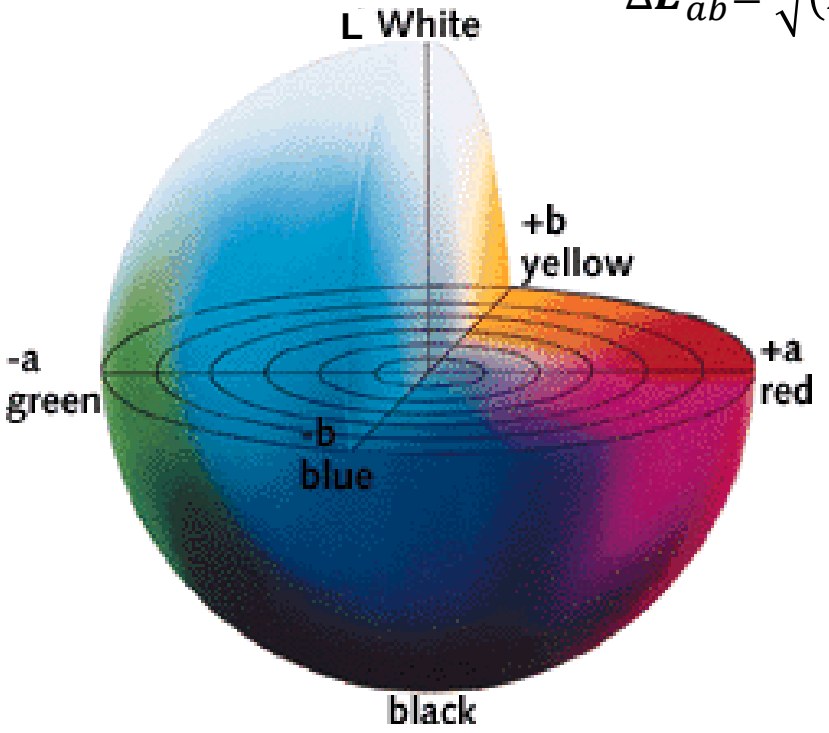


The range of colors in each color target is illustrated at right relative to all possible perceived colors and the sRGB color gamut for standard photography and displays.

CIELAB Color Space

The CIE has developed a uniform color space where the perceived color difference ΔE can be estimated between any two colors (L^*_1, a^*_1, b^*_1) and (L^*_2, a^*_2, b^*_2).

$$\Delta E^*_{ab} = \sqrt{\left(L_2^* - L_1^*\right)^2 + \left(a_2^* - a_1^*\right)^2 + \left(b_2^* - b_1^*\right)^2}$$



Lightness difference

$$\Delta L^*_{ab} = L^*_{ab,2} - L^*_{ab,1}$$

Chroma difference

$$\Delta C^*_{ab} = C^*_{ab,2} - C^*_{ab,1}$$

where

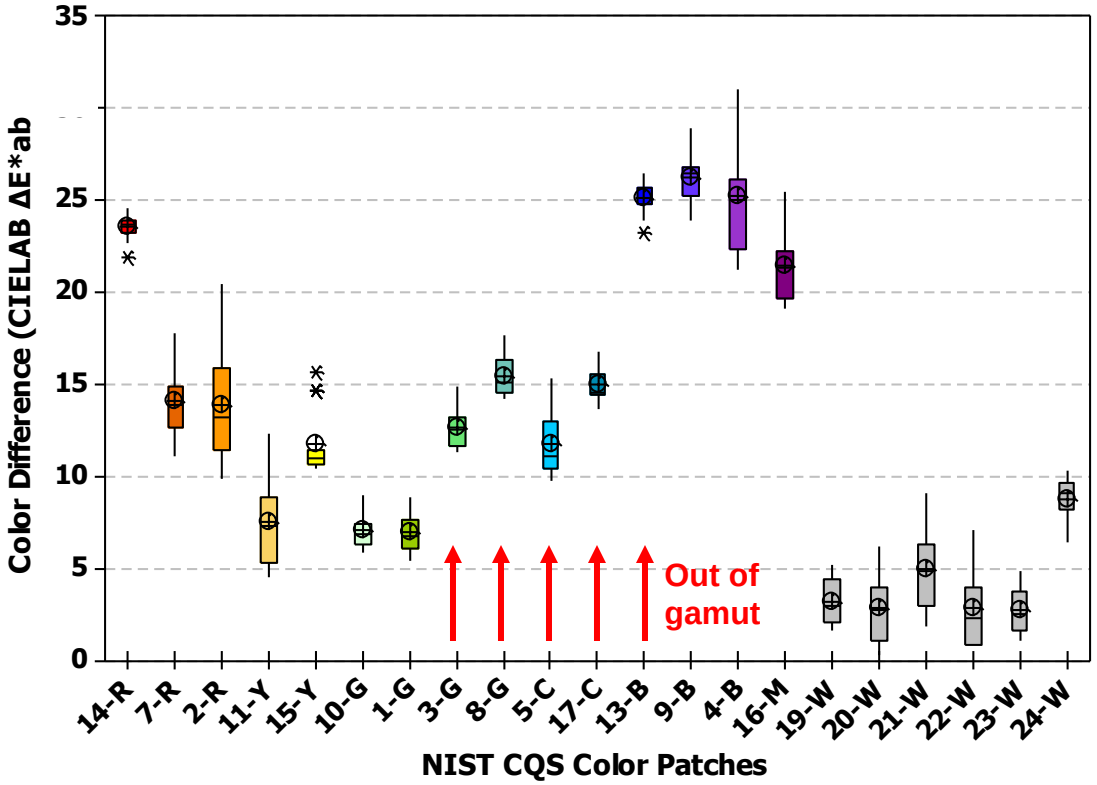
$$C^*_{ab} = \sqrt{(a^*)^2 + (b^*)^2}$$

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 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

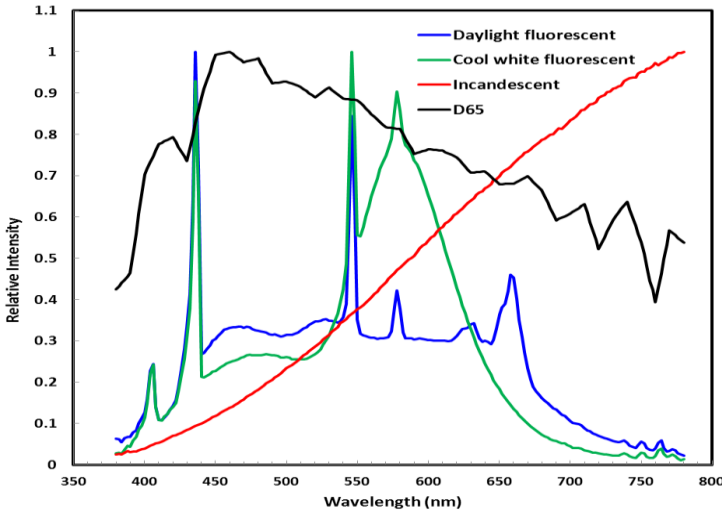


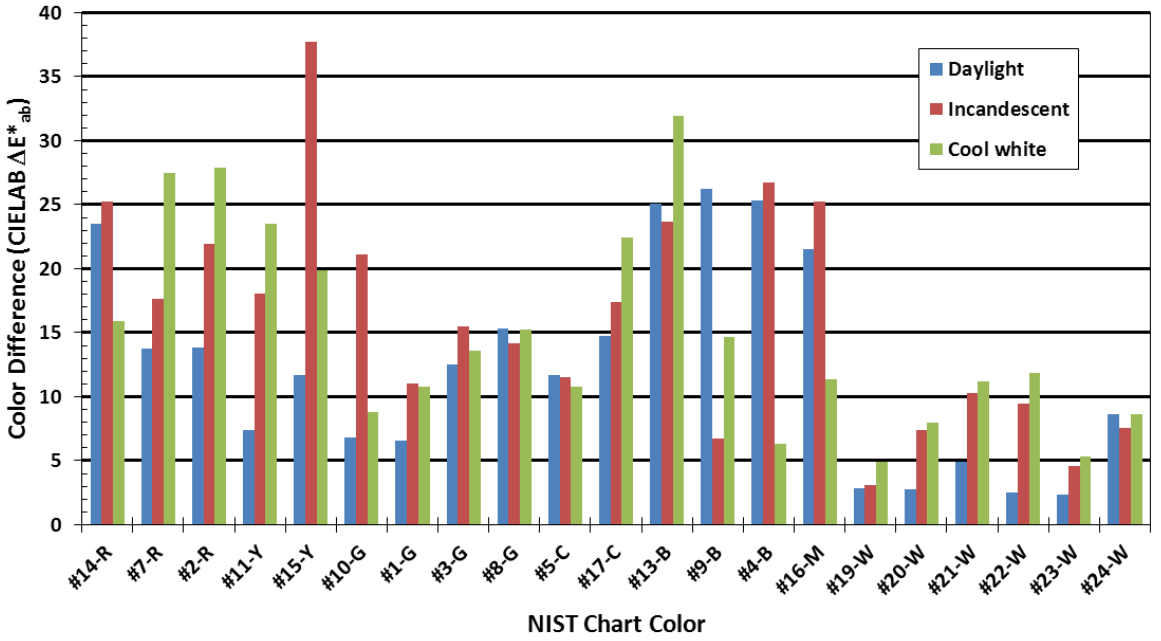
A color difference of CIELAB $\Delta E^*_{ab} = 1$ is considered a just noticeable difference (JND). Color difference is calculated relative to spectroradiometer data.

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

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 ΔE^*_{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

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

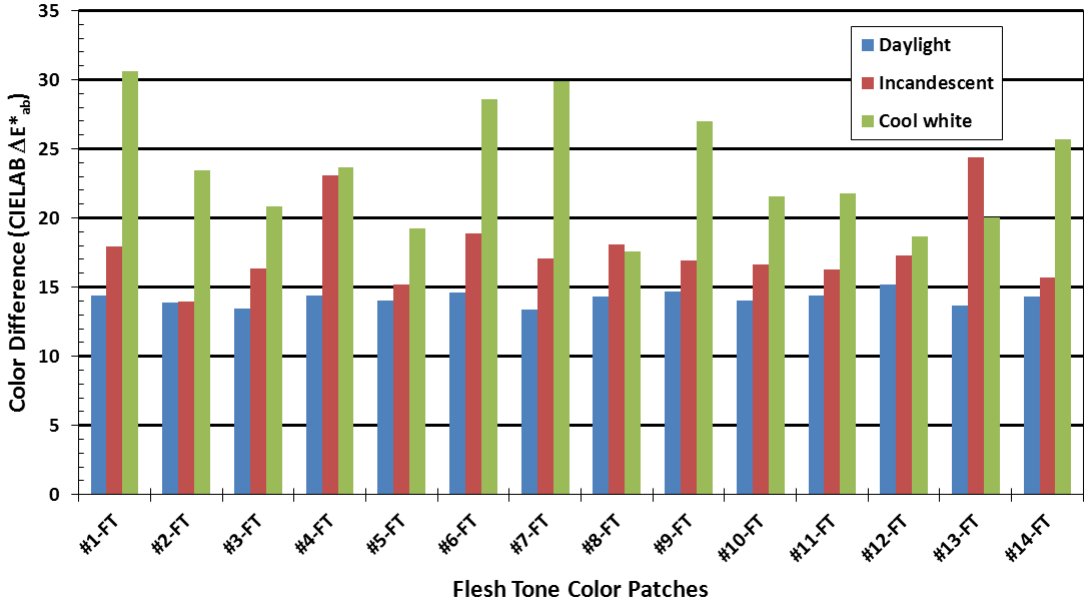
where ΔE_{00} is the CIEDE2000 total color difference.

- 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.

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

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

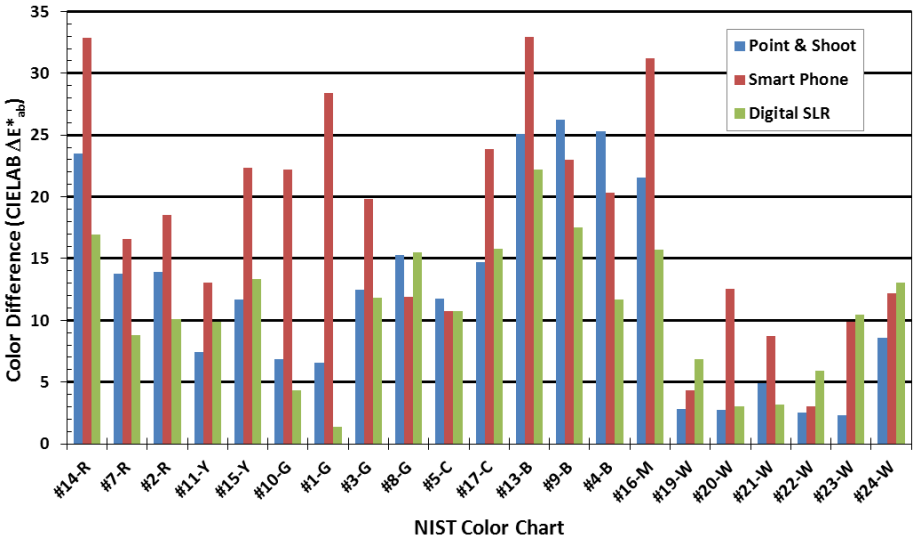
Digital SLR camera

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

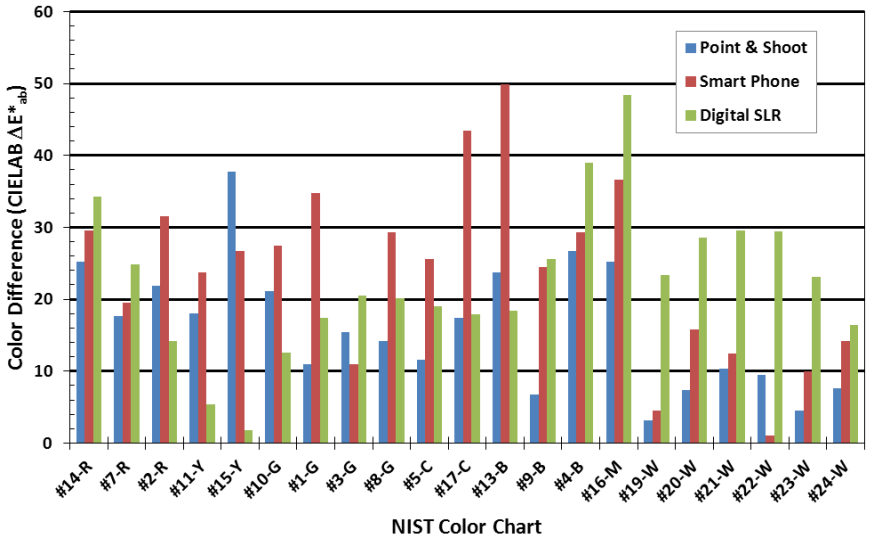
Color Error Dependence on Camera Technology

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

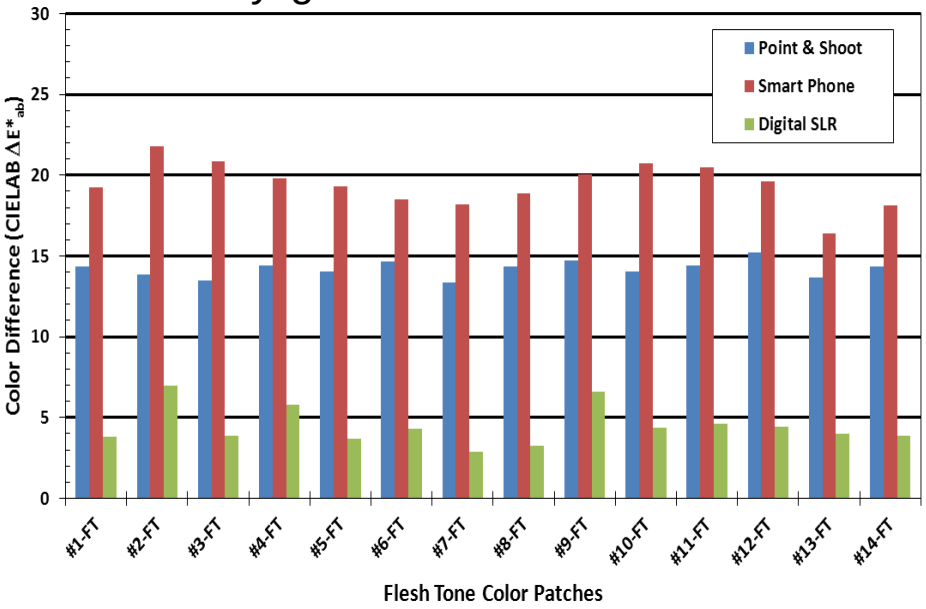
Color error does not always improve with cost of the camera.

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

Flesh Tones with Different Cameras

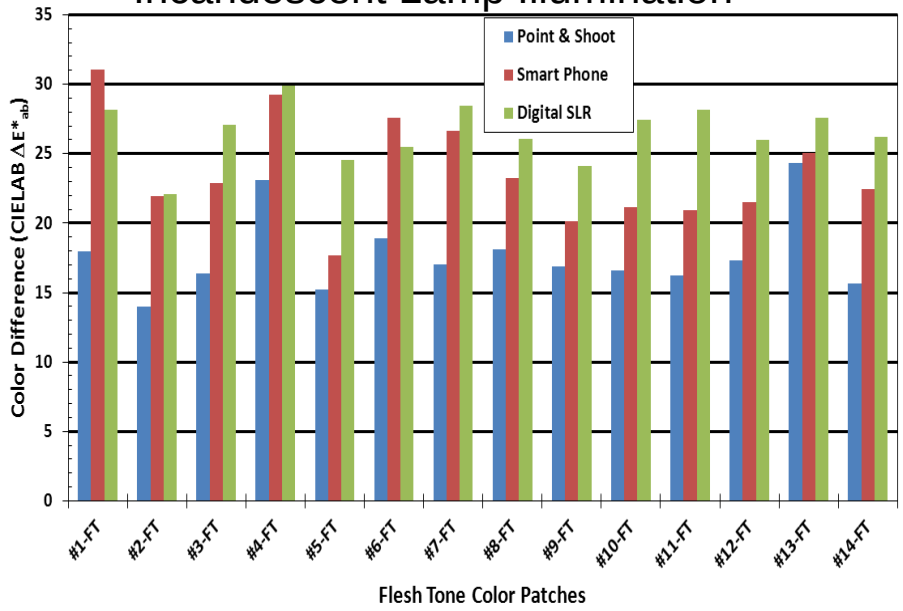
Image color error of flesh tones in the Digital ColorChecker SG color target using a range of camera technologies under daylight and incandescent lighting conditions.

Daylight Fluorescent Illumination



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

Incandescent Lamp Illumination



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

Image Color-Correction

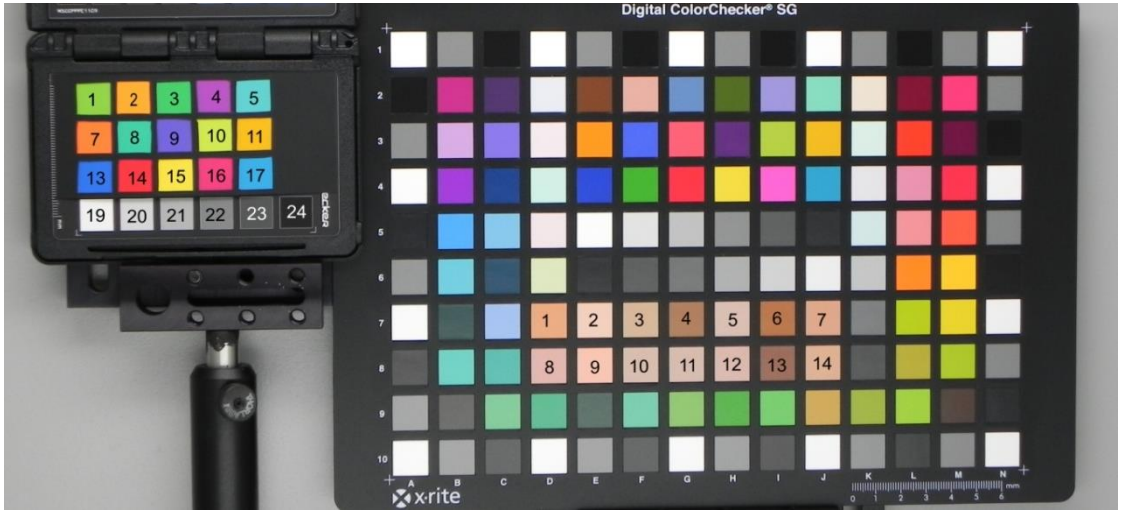
Investigated image color–correction methods using reference color chart beside test chart.

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%

Summary

- The amount of color error in the digital image depends on the color, with gray shades generally giving the least amount of error.
- The type of ambient lighting used can be an important contributor to color error, with daylight illumination tending to give better results.
- Color errors can be somewhat reduced by using higher quality camera technology, but may still produce large errors in auto mode with difficult lighting environments.
- Color-correction methods can significantly reduce color errors, but further improvements are needed.
- Note: any references to commercial products are for illustrative purposes only and do not constitute an endorsement by NIST