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How Accurate can be the Smartphone camera for Cultural Heritage Color Reproduction with Auto Settings?

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Abstract

Accurate Color Reproduction is very important for Cultural Heritage purposes, mainly for documentation. Normally the digital images are more saturated and contrasted than the human eye can see it and became necessary to recover the right color information. This research will present the color difference, in terms of CIELAB ΔE_{ab}^*, by four different smartphones with Auto Settings, with and without neutral color on the image provided by color targets (Colorchecker passport and Kodak Q-13 grayscale). To verify the color accuracy, some color samples were produced by a professional print and fineart paper. The colors printed were: Red, Green, Blue, Cyan, Magenta and Yellow. To perform the color analysis and color correction were used four methods: image without color target, with color target, linearization by Colorchecker (greyscale patches) and Color Profile. The result shows the accuracy in terms of color reproduction, the best, the worst and the average for each smartphone for all six printed color, as well as the best methodology for each smartphone.

INTRODUCTION

Motivation

Many professionals, who need to use digital images on their activities, as historians, conservators, restorers, museologists, color scientists, conservation scientists and others, need to understand the quality of each device in terms of color reproduction, which is good or not good enough for specific purpose. The common use for all professionals is the generation of images as document. It means, generate image able to represent the object as it is, or as close as possible, because all pictures are just a representation form, and aren't as real as the human eyes are able to see/feel it.

Since the beginning of the 20th Century many different devices and techniques have been used to match the original color and the color created by many different image systems and technologies. In the 21st Century several digital technologies have being developed, and the color reproduction/color accuracy [1,2,5] is one of the imaging company purposes.

Digital color reproduction has been developed for many scientists, in different areas, which the main purpose is to get the better color as possible from the most efficient system/algorithm [7, 8]. For example, the smartphone was used for colorimetric pH detection [7] by a color target printed, a light box and the color calibration by a white paper.

The smartphones or tablets have been used for many professionals and institutions to generate and to view the digital images. This paper will adopt smartphone camera to include all portable camera's device, as tablet for example. The main question is: How accurate can be the smartphone camera for color reproduction? The evaluation of image resolution and optical distortion for smartphone in cultural heritage collections have already been analyzed [6].

Some researchers have been developing standard procedures, which the IEEE[1] P1858 - CPIQ[2] have a clear purpose: standard for camera phone image quality [3]. Some measurement techniques and quality level for: Spatial Frequency Response (SFR), Lateral Chromatic Displacement, Chroma Level, Color Uniformity, Local Geometric Distortion, Visual Noise and Texture Blur [9].

Color accuracy can be made by many ways. Taking pictures from standard setup, with gray background and a color target on the center. Can be made just using a Color Target on the picture. This research shows another possibility, another reality, connecting cultural heritage reproduction and smartphone camera.

Problem

Some Cultural Heritage objects are produced from specific color or many different ones. Accurate color reproduction by imaging devices, like smartphones, is a challenge. Is important to check how precise is the smartphone's camera for color reproduction using Auto Settings, standard color samples, with and without neutral color references on the image. To make it is necessary to verify the color accuracy (ΔE_{ab}^*) when there is / there isn't a neutral color on the image, because the digital camera system (software) take in account the neutral color on the scene to adjust all colors [4]. After that the images need to be processed and analyzed by different methodologies.

Some primaries colors, as RGB (Red, Green, Blue) and CMY (Cyan, Magenta, Yellow) are complementary and cover all visible spectrum, as presented on Fig 1.

These colors have been measured after printed: Innova FineArt Paper – Smooth Cotton High White 450 gsm by Canon iPF5100 printer with custom color profile.

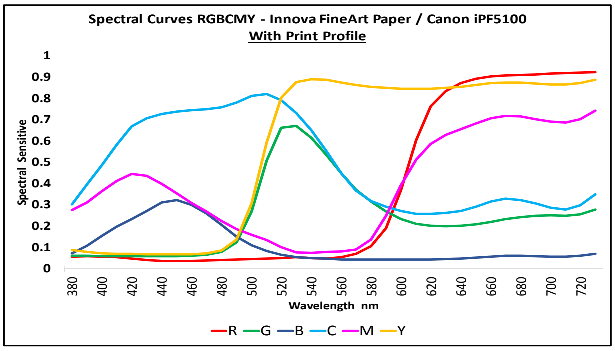

***Figure 1**. Spectral Curves – RGB and CMY*

[1] IEEE – Institute of Electrical and Electronics Engineers

[2] CPIQ – Color Phone Image Quality

Some questions to be answered: Can the smartphone camera generate high quality color images for these six colors individually? Which color can be generated better? Which methodology can generate better result for each smartphone?

To answer these questions some specific tests were developed in this research, because the most common test normally uses a standard setup with gray background and color target. Not is very useful verify how precise can the smartphone camera be for each color individually.

METHODOLOGY

Three main steps were used for this research: produce the reference colors (RGB and CMY) in an A-4 paper size individually; generate the images by smartphone camera with high-quality light source; digital imaging processing by four methodologies.

Reference Colors:

RGB and CMY reference colors – these colors have been printed in an A-4 paper size to turn possible take picture just for the specific color, avoiding any color around. The paper selected was matt to avoid specular reflection and its color needs to be white and neutral. For this reason, were tested four different professional printing art papers: Innova Art Soft Textured Natural White 315 gsm, Hahnemühle Photo Rag® Bright White 310 gsm, Harman Matt Cotton Smooth 310 gsm and Innova Art Smooth Cotton High White 450 gsm. All of them were measured by spectrophotometer i1Pro 2 - X-Rite to compare the color and choose the most neutral paper. The a* and b* data need to be close to “0” for the neutral paper color, as Table 1.

Table 1: CIELAB color data measured in four different professional print art paper.

Paper	L	a	b
Innova Art Soft Textured Natural White 315 gsm	96.69	-0.10	4.91
Hahnemühle Photo Rag® Bright White 310 gsm	97.39	1.57	-4.13
Harman Matt Cotton Smooth 310 gsm	98.09	2.20	-6.00
Innova Art Smooth Cotton High White 450 gsm	97.53	0.89	-0.20

After choosing the most neutral paper, the colors RGB and CMY were created in photoshop: sRGB color space, RGB mode, A-4 paper size. To print them was used a professional printer – Canon iPF5100, original inks and specific color profile for the print and paper, provided by the paper company: iPFx100_IFA14_High.icc[3]. The colors created in photoshop, by RGB colors numbers, were converted to Lab* by Gimp image software; and after that the printing was measured by the spectrophotometer i1Pro, as Table 2.

Smartphone Imaging:

Initially, four different smartphones were used to take pictures, as Table 3. The methodology and camera settings to capture the images is very important. Anyway, was used the standard procedure, as the people usually used to take their pictures: HDR = on; Flash = off; White Balance = Auto (AWB); ISO = auto; Exposure = 0; Resolution = higher; File Format = JPG; Image Quality = Fine or High; Metering Mode = Average. Some smartphones camera App don’t allow to settings all these options, so in this case Auto settings was the standard.

Table 2: RGB and CMY color samples - RGB reference data converted to Lab and printed paper with color profile

	Color Reference sRGB Created by Photoshop			Color Reference Lab* converted by Gimp			Color Paper – printed with profile – Lab*		
Color	R	G	B	L	a	b	L	a	b
R	255	0	0	54.3	80.8	69.9	50.32	66.45	46.62
G	0	255	0	87.8	-79.3	81	69.91	-47.91	58.65
B	0	0	255	29.6	68.3	-112.0	29.04	18.74	-50.3
C	0	255	255	90.7	-50.7	-15.0	76.14	-31.46	-21.78
M	255	0	255	60.2	93.5	-60.5	52.19	58.72	-19.06
Y	255	255	0	97.6	-15.7	93.4	91.45	-9.33	91.48

Table 3: Digital cameras specification

Camera / Smartphone	Resolution MegaPixels	Focal distance Equiv 35mm	Aperture
Asus Zenfone 3 Zoom	12	25mm - 59mm	f/1.7 – f/2.8
iPhone 7 Plus	12	28mm – 56mm	f/1.8 – f/2.8
Motorola Moto G5S Plus	13	28mm	f/2.0
Samsung J7 Metal	13	28mm	f/1.9

Two color targets were used on the images: Colorchecker Passport by X-Rite and Kodak Q-13 – grayscale, as Fig 2 (right side). The colorimetric data were generated for both by the spectrophotometer i1Pro by X-Rite, illuminant D-50, 2 degree.

***Figure 2**. Color sample without (left) and with (right) Color Target on the image*

The light source quality is extremely important for this research and for this reason was used a fluorescent standard D65: Verivide DigiEye – Micro Control Panel DCAC 60, D65, as Fig 3. There are some light controls, which has been chosen angled option (angled and diffuse) for the light direction inside the box and D-65 as light source.

***Figure 3**. DigiEye by Verivide (left); Smartphone on top and imaging surface (right)*

[3] https://www.innovaart.com/icc-profiles-1/

For each smartphone has been taken two images, one without color target on the paper color and another with color target on it, as Fig 3. To take these images was necessary to use the "zoom" to cover all color area. It was made to verify the color consistency with some neutral data on the image and to understand how it can interfere on the color quality/reproduction. The color target is very useful for linearization and color profiler.

Each color was captured separately: R, G, B, C, M and Y. For each device was generated 12 images, six with color target and six without color target.

Digital Imaging Processing:

To process and analyze the images: a computer (i7 processor 2.4 GHz; 16GB RAM, Windows 8, 64-bit), a Spectrophotometer i1Pro 2 and some software: Adobe Photoshop CS4, Adobe Bridge CS4, Adobe Camera Raw, Gimp 2.10.6, i1Profiler 1.7.1.2596, InCamera Profiler 4.0.1, Adobe Color Calculator, Microsoft Excel.

Four different methodologies were used to verify the color information from the images:

- NO CT: Image without Color Target
- CT: Image with Color Target
- CL: Color Linearization
- CP: Color Profile

NO CT: the picture has been taken directly by the image sample and after that processed to get the color's number in terms of Lab* data.

CT: two color targets have been used on the image, which the main purpose was verify how the neutral could interfere in each color sample.

CL: the grayscale on the color target was used to correct the image in terms of Linearization, including White Balance correction. All gray samples from Colorchecker were used for it. This methodology has used curves adjustment by Photoshop, as Fig 4.

CP: the Colorchecker has been used for Incamera profiler to create a color profile. The color data was generated specifically for this Colorchecker, where each color was measured by i1Pro2 – X-Rite to create the custom reference color file (.txt).

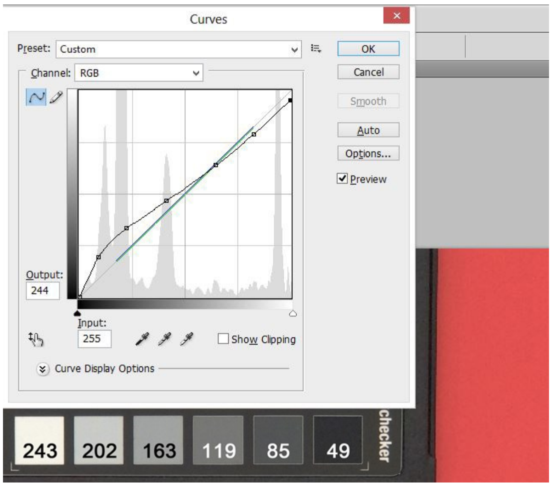

Figure 4*. Color Linearization. Adjustment by curves and reference grayscale RGB values*

The methodologies, step by step, are show on the Fig 5. For each image has been selected an area. On this area was applied the average filter and save as JPG file format, high quality, with a specific file name. These images have been opened on Gimp software to convert RGB to Lab* color numbers. These numbers were plotted/saved in a spreadsheet.

To calculate the color difference between the reference data and each methodology was adopted CIELAB ΔE_{ab}^*.

$$\Delta E_{ab}^* = [(L_1-L_2)^2 + (a_1-a_2)^2 + (b_1-b_2)^2]^{½}$$

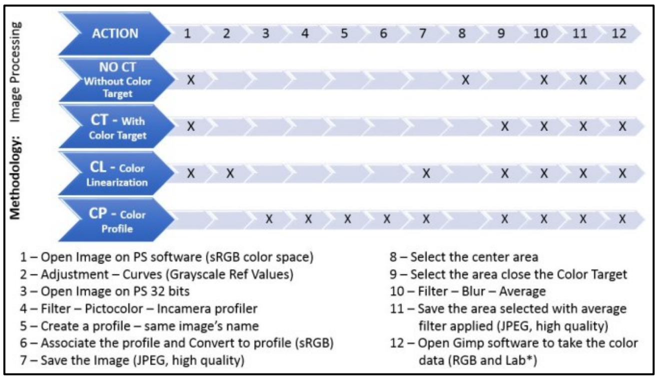

Figure 5*. Image Processing for each Methodology: NO CT, CT, CL and CP.*

RESULTS

The color samples printed on professional art paper were used as reference for all methodologies. The colors (RGB and CMY) created by Photoshop are different when compared with the color printed. The difference between them is presented on the Table 4. Anyway, the reference colors for this research were the colors printed.

Table 4: Delta E between RGB and CMY colors created by Photoshop (sRGB) and the colors printed by Canon iPF5100, Innova Fineart paper and color profile.

	Color Reference Lab* Created by Photoshop			Color Paper – printed with profile – Lab*			ΔE_{ab}^*
Color	L	a	b	L	a	b	
R	54.3	80.8	69.9	50.32	66.45	46.62	27.0
G	87.8	-79.3	81	69.91	-47.91	58.65	42.1
B	29.6	68.3	-112.0	29.04	18.74	-50.3	78.5
C	90.7	-50.7	-15.0	76.14	-31.46	-21.78	24.4
M	60.2	93.5	-60.5	52.19	58.72	-19.06	54.4
Y	97.6	-15.7	93.4	91.45	-9.33	91.48	8.9
AVERAGE							39.2

The worst result was the Blue, ΔE_{ab}^* = 78.5 and the better was the Yellow ΔE_{ab}^* = 8.9. The paper profile is smaller than sRGB, which can be viewed on the Fig 6. The white circle emphasizes the colors blue and yellow.

For each smartphone were analyzed each color sample separately using all different methodologies, as an example for the Asus Zenfone Zoom 3, Blue color, by four methodologies, showed on Table 5.

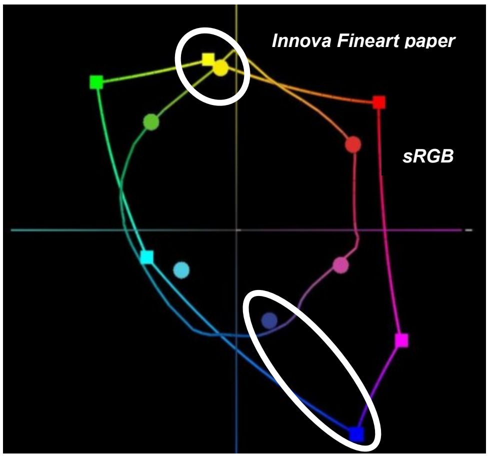

Figure 6. CIELAB color space. sRGB and Innova Fineart paper profile. RGB and CMY plotted on its respective color area.

Table 5: Blue color data by Asus Zenfone 3 Zoom. Four different methodologies.

ASUS ZENFONE ZOOM 3

Color	B - BLUE			
	L	a	b	Delta E
REF	29.04	18.74	-50.30	
NO CT	32.30	20.80	-59.50	10.0
CT	30.00	32.40	-74.50	27.8
CL	30.10	22.80	-56.00	7.1
CP	27.80	17.50	-49.90	1.8

	number of samples
DE < 5	1
5 < DE < 10	2
DE > 10	1
DE MEAN	11.7

After that was created a table to show the average produced by each methodology, the lower and the higher Delta E, it means, the better and the worst color for each individual methodology. In general terms, the most important information is which methodology generate the lower average. Is important to verify the cost and efficacy of each process. For each device, the best methodology can be different.

The Table 6 shows the results for Asus Zenfone 3 Zoom smartphone, on the left side. The number of colors for each Delta E range is shown on the left side. On the right there is the "Average" for each methodology and the lower and higher Delta E for each methodology, as well. For this device, for example, the best methodology is CP = 7.2 which number is lower than another, but it's the most expensive method. The second better is CL = 7.8, which is good enough, very close to CP result, but less expensive. The worst result was obtained with color target on the image, CT = 15.5.

Table 6: Asus Zenfone Zoom 3 analyses from all methodologies.

SMARTPHONE: ASUS ZENFONE ZOOM 3 - RGBCMY color samples

number of colors

REF	DE<5	5<DE<10	DE>10	Average	< DE	> DE
1 – NO CT	1	3	2	13.4	M = 2.8	Y = 33.6
2 – CT	1	1	4	15.5	Y = 5.0	B = 27.8
3 – CL	1	3	2	7.8	M = 3.6	Y = 12.7
4 - CP	3	2	1	7.2	B = 1.8	G = 18.2

On the Fig 7, looking to all six colors, RGBCMY and the average, is possible to understand which color each device can reproduce it better. Otherwise, is possible to know which colors represent a challenge for a specific smartphone. The higher bar represents the worst result in terms of color reproduction for the specific smartphone. For example: Samsung J7 generated a great result for Green and a bad result for Yellow.

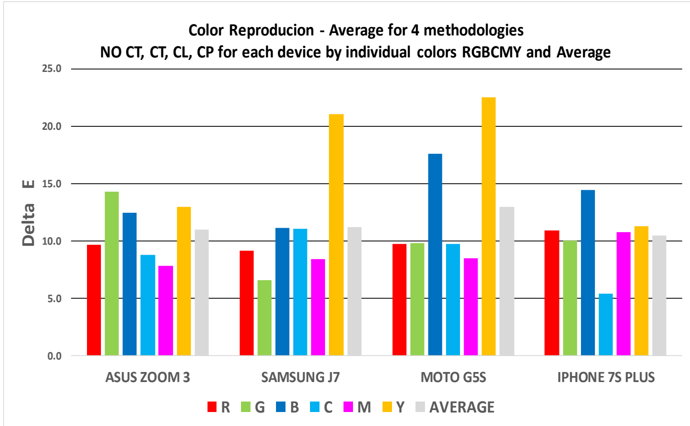

Figure 7. Smartphone versus color reproduction from all methodologies together, NO CT, CT, CL and CP for each color RGBCMY and Average.

Another important issue is the methodology applied for all devices. The Fig 8 shows the methodologies for each device and which one of them generated better results.

For all smartphones, the CP produced the best color quality. The second better methodology was CL, which procedure and cost are reasonable lower than CP, except for iPhone 7S Plus. The worst result was NO CT, without Color Target, when the picture is produced without any neutral on it, except for Asus Zenfone zoom 3, which the worst result was CT, with Color Target on the image.

This research can generate for each smartphone the visual color difference between the Reference Color (Printed) and all four methodologies, as Fig 9 – iPhone 7S Plus.

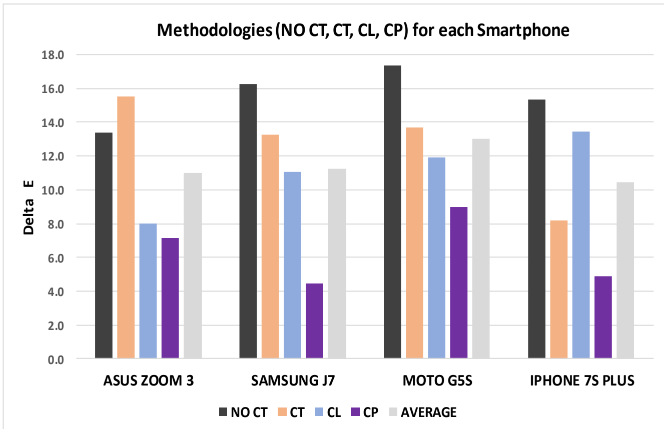

Figure 8. Comparative between methodologies: NO CT, CT, CL and CP for each smartphone.

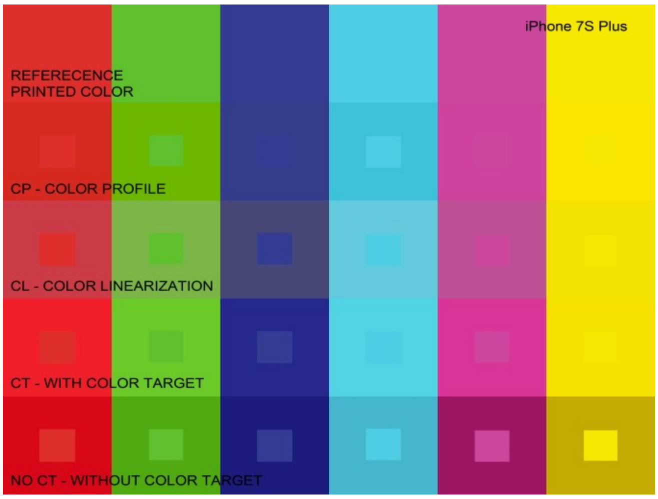

Figure 9*. Visual Color Difference from Reference Color versus all four methodologies. Reference color is in the middle of each color sample: iPhone 7S Plus*

CONCLUSION

Many works of art are made by specific color, can be mainly red, green, red and green, orange, yellow, can be mixed colors, and many different possibilities. For this reason, understand which color can be reproduced with better and worst accuracy, turns a very important information for documentation purpose.

The smartphone camera is a very new technology and the image quality has been improved constantly. Anyway, is not very common this kind of test by the smartphone companies, testing the efficacy of color individually.

All smartphone tested in this research, none could reproduce all six colors with high accuracy, it means, Delta E < 10.

This research and methodologies can be useful as part of a group of tests to verify the smartphone's abilities for color reproduction, or at least, to know the best and the worst color reproducible by the smartphone.

The neutral reference color on the image, while using Auto settings, modify the image color and the results, for most of the smartphones, was better if compared without color target on the image.

Anyway, for color reproduction purpose (documentation) the best results from four methodologies were: CL – Color Linearization and CP – Color Profile, both using the color reference target on the image. Those procedures need to be done by software after taking the pictures. The methodologies can be improved, different software can be used and probably would be possible to make the process more accurate and faster.

Future works

Make a device/system which should be possibly make all these procedures, applying all methodologies and generate all results in a short time, automatically.

Development of a new color target specific for smartphone and easier to use by no professional users. It means, the images need to be good, accurate, but not high precise, like can be made using professional camera, high quality color management and imaging professionals.

Achnowledgement

iLAB – Scientific Imaging Laboratory and Department of Photography at Fine Art School, UFMG – Federal University of Minas Gerais, Brazil; Colour Lab and Lighting Lab, University of Leeds, UK.

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