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iPhone12 Imagery in Scene-Referred Computer Graphics Pipelines

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Abstract

With the release of the Apple iPhone 12 Pro Max in 2020, various features were integrated that make it attractive as a recording device for scene-related computer graphics pipelines. The captured Apple RAW images have a much higher dynamic range than the standard 8-bit images. Since a scene-based workflow naturally has an extended dynamic range (HDR), the Apple RAW recordings can be well integrated.

To correctly integrate the iPhone12pro Apple RAW data into a scene-related workflow, two command-line software solutions, among others, are dcraw and rawtoaces. In this paper, we concentrate on dcraw. dcraw offers the possibility to export RAW images directly to ACES2065-1. Different images recorded under different lighting conditions are examined to determine which options for the dcraw development produce the best results.

Images from five different lighting situations like D65, D60, D55, D50, and 2980K, are examined. The DNG files are developed using different methods within dcraw. The values of the recorded ColorChecker24 patches are compared to reference values derived from BabelColor[1] and ACES[2].

***Keywords**: iPhone, computer graphics pipeline, DNG, dcraw, ACES, Nuke, Apple ProRAW*

1. Test goal and settings for developing DNG images

1.1. Test Goal

The quality of cameras in smartphones has improved significantly in recent years. In addition, with the iPhone 12 Max Pro, Apple has also opened up the possibility of capturing RAW images. Although, due to the miniaturization of lenses, the quality does not approach traditional workflows, images from the iPhone can be fed directly into a film pipeline as a supplement, input into visual effects and Matte Painting, as well as all kinds of textures.

Because the images are in DNG format, many programs (such as Nuke) cannot import them. Several programs are available for developing these images into a pipeline-safe format, such as OpenEXR or TIFF. However, they often have an unnecessary superstructure and many parameters that must be set. If the program allows it, then batch processing can be used to develop more extensive sequences of images.

This paper aims to find a simple and robust general-purpose solution for importing images directly into an ACES pipeline. Here, two objectives are given. The images should be developed in sufficient quality with and without subsequent white balance. For a white balance, either inserted references (ColorChecker24) or corresponding gray-level objects must be present in the image. This is not always given. On the other hand, it should also be possible to adjust the images with subsequent white balance.

1.2. Test Hardware

The test took place indoors at the University of Applied Sciences in Brandenburg in early December 2022.

An XRite ColorChecker24 [3] and a Perfect Reflecting Diffuser [4] were used as a reference, see Fig. 4. The scene was lit with an Aputure Amaran AL-F7 LED light [5]. It consists of two alternating LED rows, one yellowish and one white. To diffuse the outcoming light, the supplied filter for the device was used. The spectral data were recorded by a spectrometer *Qmini by rgbphotonics* [6], and the imagery was recorded by an iPhone 12 Max Pro [7].

The lighting condition was created by adjusting the light according to the measurement of the spectral data. We recorded three images from 3000K to 6500K, every step 100K apart.

1.3 Apple ProRAW

Apple ProRAW stores RAW data as regular DNG files. These colors contain all the original dynamic range and represent a linear relation to the light of the scene. The files are stored after the demosaic step.

> *"Apple's greatest strength is its unity of hardware and software, so they know exactly the sensor you are using and how it behaves with different ISO settings. In theory, they could even apply image recognition as part of the process; if iOS detects a night sky, it could automatically pick a star-friendly demosaic algorithm" [8]*

1.4 Scene-referred ACES color space

> *"The Academy Color Encoding System (ACES) is the industry standard for managing color throughout the life cycle of a motion picture or television production. From image capture through editing, VFX, mastering, public presentation, archiving and future remastering, ACES ensures a consistent color experience that preserves the filmmaker's creative vision" [9]*

This color system was developed over the last 15 years to unify and simplify interchanging and archiving motion picture images. Besides this general goal, it encompasses two recent technical developments in the media industry: the usage of wider color spaces and high dynamic range content. The workflow is based on OpenEXR files with 16-bit half-precision floating point accuracy (32 floating-point for utility data). It also encompasses a gamut where all colors detected by the human visual system can be encoded [10]. Currently, ACES 1.2 is in use.

The term *scene-referred* means that the linear relationship between the pixel color values and the light of the scene is maintained throughout the working process. Internal camera curves are removed, and the necessary Transfer Functions for the different displays and projectors are added in the production's final steps (mostly Digital Intermediate).

1.5. dcraw

We use dcraw as the developing software for the RAW image sequences [11]. dcraw is widely used in the industry and offers a wide range of control over the development process. It is command-line based and works on the most used computer operating systems. Concerning color space conversion, it offers a built-in primaries transformation and easy transfer function (gamma) adjustment. Only the RAW development towards the white point has to be found out experimentally.

1.6 Important dcraw options

```
Raw photo decoder "dcraw" v9.28
by Dave Coffin, dcoffin a cybercom o net

Usage:  dcraw [OPTION]... [FILE]...

-v        Print verbose messages
-c        Write image data to standard output
-e        Extract embedded thumbnail image
-i        Identify files without decoding them
-i -v     Identify files and show metadata
-z        Change file dates to camera timestamp
-w        Use camera white balance, if possible
-a        Average the whole image for white balance
-A <x y w h> Average a grey box for white balance
-r <r g b g> Set custom white balance
+M/-M     Use/don't use an embedded color matrix
-C <r b>  Correct chromatic aberration
-P <file> Fix the dead pixels listed in this file
-K <file> Subtract dark frame (16-bit raw PGM)
-k <num>  Set the darkness level
-S <num>  Set the saturation level
-n <num>  Set threshold for wavelet denoising
-H [0-9]  Highlight mode (0=clip, 1=unclip, 2=blend, 3+=rebuild)
-t [0-7]  Flip image (0=none, 3=180, 5=90CCW, 6=90CW)
-o [0-6]  Output colorspace (raw,sRGB,Adobe,Wide,ProPhoto,XYZ,ACES)
-o <file> Apply output ICC profile from file
-p <file> Apply camera ICC profile from file or "embed"
-d        Document mode (no color, no interpolation)
-D        Document mode without scaling (totally raw)
-j        Don't stretch or rotate raw pixels
-W        Don't automatically brighten the image
-b <num>  Adjust brightness (default = 1.0)
-g <p ts> Set custom gamma curve (default = 2.222 4.5)
-q [0-3]  Set the interpolation quality
-h        Half-size color image (twice as fast as "-q 0")
-f        Interpolate RGGB as four colors
-m <num>  Apply a 3x3 median filter to R-G and B-G
-s [0..N-1] Select one raw image or "all" from each file
-6        Write 16-bit instead of 8-bit
-4        Linear 16-bit, same as "-6 -W -g 1 1"
-T        Write TIFF instead of PPM
```

Figure 1. *dcraw manual*

Figure 1 lists all the options that come with dcraw. For the sake of this paper only the ones that deal with white balancing and clipping were of interest. So, the following information for the options are derived from [12]).

-v *prints the verbose message for the scaling of the four RAW channels und the saturation level. The latter scales basically the relationship between the highlights and reference white. It is not discussed in this paper because it aims at color deviation and does leaves out luminance issues.*

-o [0-5] *sets the output colour profile being possible the values: 0=none (no colour management), 1=sRGB, 2=AdobeRGB, 3=WideGamut, 4=ProPhoto, 5=XYZ. To convert to a colour space means a matrix transformation of the levels of the image and in some cases this could not be desirably. Not to perform any transformation we will use the option -o 0.*

-g gamma slope *Applies a gamma correction to the output defined by the gamma value and the toe slope of the curve. For a pure gamma curve set slope to 0. Some typical values are:*
-g 1 1 linear 1.0 gamma (default if -4 is used)
-g 2.2 0 pure 2.2 gamma (Adobe RGB)
-g 1.8 0 pure 1.8 gamma (ProPhoto RGB)
-g 2.4 12.9 sRGB gamma
-g 2.222 4.5 BT.709 specification gamma (default if -4 is not used)

-H [0-9] *With this option we will set the highlight behaviour being allowed the following values: 0=clip, 1=no clip, 2=neutral grey blown areas, 3-9=highlight recovery. This feature will be also studied deeply in the white balance and highlights section. I mainly use the -H 0 option for its linearity and -H 2 when there is risk of blowing important parts of the image with the previous value. The -H 1 option guarantees that we will not blow any previously non blown channel but can lead to strange tones in the blown areas. The highlight recovery options are more sophisticated and slow down noticeably the execution speed.*

-w *if dcraw manages to find it, it will use the white balance that was adjusted in the camera at shooting.*

-4 *It generates a linear 16-bit file instead of an 8-bit gamma corrected file which is the default. I always use this option.*

-T *It outputs a TIFF image file instead of PPM.*

2. Test procedure

From the set of photographs, five images with the following color temperatures were selected:

a) 6510K (approx. D65)
b) 5986K (approx. D60)
c) 5380K (approx. D55)
d) 5020K (approx. D50)
e) 2890K (approx. F12)

While the first four images cover typical sun position scenarios, the last image covers the area of fluorescent lamps.

In the first step, the respective image is developed with dcraw according to formulas 1 - 5. The two document developments (formulas 4 and 5) were exported by dcraw as ppm-files as the only option. To be able to import them into Nuke [13], they were converted into Apple's Preview and exported as Open EXR files.

The following command-line commands were used for the five methods:

Method *Basic*:
dcraw -v -o 6 -g 1 1 -4 -T *.DNG (1)

Method *Basic-H1:*
dcraw -v -H 1 -o 6 -g 1 1 -4 -T *.DNG (2)

Method *Basic-w-H1:*
dcraw -v -w -H 1 -o 6 -g 1 1 -4 -T *.DNG (3)

Method *Document mode*
dcraw -D *.DNG (4)

Method *Document mode raw*
dcraw -d *.DNG (5)

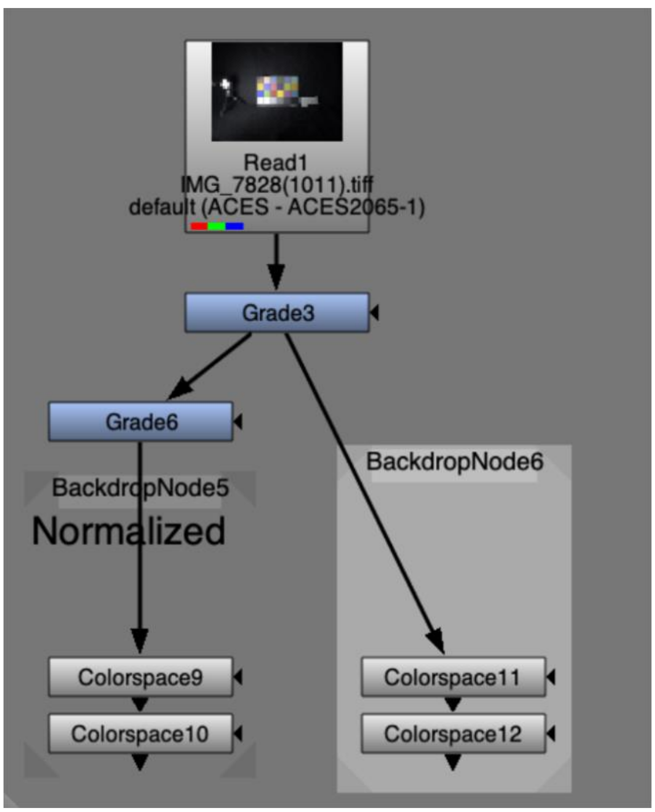

Figure 2. *Node Settings in Nuke*

The next step was to import the five developed images into Nuke. The working color space in Nuke was ACES3065-1. The import transform color space for the first three development methods was accordingly ACES2065-1. For both the (-d) method and the (-D) method, the import color space was *data (Utility Raw)*. This so-called data-specified import does not apply color conversion and leaves the data as is.

In the third step, the luminance adjustment was performed. For each of the five imported images, the value of the green color channel of the Perfect Reflecting Diffuser was set to the corresponding value (0.97784) in the ACES document [S-2008-0001 [2].

Next, white balances were performed for the three methods *Basic*, *Basic-H1*, and *Basic-w-H1*. The reference values for this were again those for the Perfect Reflecting Diffuser patch in the ACES document [S-2008-0001].

As a final step, color conversions from ACES2065-1 (ACES/White point) to CIE XYZ (D50 White point) were performed for all eight methods (1-8) using the Bradford Matrix. Finally, in order to read the pure color values, a color conversion from CIEXYZ to CIE Yxy was performed. The Node settings in Nuke are depicted in Figure 2.

3. Test Results – Image 6510K

In the following five sections, one image, each with a different lighting situation, is analyzed according to the same aspects. The first image was taken under approximate CIE D65 (6510K) color temperature. We start with this color temperature because it is used for videos and computer monitors and is much in use. A total of eight lighting scenarios are examined.

f) *Basic* (formula 1) post-white balanced.
g) *Basic* (formula 1) non-white balanced
h) *Basic -H1* (formula 2) post white balanced
i) *Basic -H1* (formula 2) non-white balanced
j) *Basic -w -H1* (formula 3) post white balanced
k) *Basic -w -H1* (formula 3) non-white balanced
l) Document mode without scaling (-D)
m) Document mode (no color, no interpolation (-d)

The scaling applied by the algorithm can be made visible with the ***-v*** (verbose) option during development *(Figure 3).*

```
Loading Apple iPhone 12 Pro Max image from IMG_7828.DNG ...
Scaling with darkness 0, saturation 65535, and
multipliers 1.000000 1.015902 1.079605 1.015902
Converting to ACES colorspace...
Writing data to IMG_7828.tiff ...
```

Figure 3. *Verbose description during the development of an AppleProRAW image in dcraw*

3.1. Development

In the raw state of the image data, four channels are present, arranged in a 2x2 pattern across the sensor: Red, Green, Blue, and Green. These describe the relationship to the incident light photons of the scene. Each pixel can thus have only one of the channels in RAW. Demosaicing is used to add the missing channels for each pixel by averaging the adjacent color values.

In order to reproduce the white point of the corresponding illuminant and, thus, the scene's color temperature, the raw color

channels must be scaled. The scaling factors for the D65 image are given in *Table 1*.
+

dcraw	Raw channel scaling Image D65		
Method	**Red**	**Green1,2**	**Blue**
Basic	1.000000	1.037978	1.083747
Basic -H1	0.922725	0.957768	1.000000
Basic -w -H1	1.000000	1.000000	1.000000

Table 1. *dcraw raw channel scaling*

For the *Basic* development, dcraw used the Red channel as the target channel (1.00000). It contributes the least to reaching the white point D65. This is verified by the fact that for *Basic-H1*-method, the blue channel achieves the peak value of 1.000000 and the other two channels have correspondingly less contribution. For the *Basic-w-H1* method, the camera's white balance is used. Therefore the scaling factor is equal to 1.000000 for all.

Two normalizations were applied to ensure a comparison of the test images taken in different lighting situations: a luminance peak adjustment and a white balance. The perfect reflecting diffuser was used as a reference (*Fig. 4*).

a) dcraw sets the peak value to 1.000000 during development. The reference value for all three channels ACES is 0.97784 in the corresponding table [2]. All channels were adjusted uniformly in the different development methods to achieve this value.
b) After the luminance adaptation, a white balance was applied, with the green channel keeping constant to match the three ACES values of ACESRGB[0.97784, 0.97784, 0.97784]

Figure 4. *Evaluation are of the perfect reflecting diffuser in Nuke*

To match the luminance ACES values of 0.97784 for the ACES *Perfect Reflection Diffuser* are the same for all methods, except *Basic-H1*

When comparing the values for the additional white balancing, the *Basic* method needed the lowest corrections. *Basic-H1* requires the highest corrections, and *Basic-w-H1* is in the middle (*Table 4)*. It is interesting to note that the *Basic-H1* method significantly reduces the blue channel, while the other methods scale the three channels in a relatively balanced way. Since the *Document* methods scale all three channels equally, no white balance is necessary after adjusting the luminance.

ACES2065-1		White Balancing Image D65		
Method		**Red**	**Green**	**Blue**
Basic	a)		0.97784	
	b)	1.00642	1.00000	1.00000
Basic -H1	a)		1.01760	
	b)	1.02400	1.00000	0.96093
Basic -w -H1	a)		0.97784	
	b)	1.00996	1.00000	1.00083
-D	a)		0.97784	
-d	b)		0.97784	

Table 2. *White Balance: Normalizing factors for a) luminance b) ACES RGB after luminance correction*

3.2. Results

In the following, the ACES RGB values for each patch of the ColorChecker24 were determined for each development scenario with and without additional white balance. These were then converted to the CIE Yxy chromaticity diagram. Since a white point conversion from ACES white point to D50 was necessary, the Bradford matrix implemented in Nuke was applied.

The differences between the values given in the BabelColor list and the values of the recorded image are displayed in *Table 4.*

CIE x,y (D50)	Differences Image D65 Rec. patches vs. BabelColor patches		
Method	**x**	**y**	**∑x,y**
Basic wb	0.5898	0.3841	0.9739
Basic	0.6059	0.3826	0.9885
Basic -H1 wb	0.5091	0.3517	0.8608
Basic -H1	0.6210	0.3934	1.0144
Basic -w -H1 wb	0.4692	0.3223	0.7915
Basic -w -H1	0.4882	0.3342	0.8224
Document mode	0.6868	0.4562	1.1430
Document raw	0.4028	0.5245	0.9273

Table 3. *Differences of the ColorChecker24 patches: BabelColor vs recorded Image*

CIE x,y (D50)	Differences Image D65 Rec. patches vs ACES patches		
Method	**x**	**y**	**∑x,y**
Basic wb	0.5654	0.3527	0.9180
Basic	0.5887	0.3504	0.9390
Basic -H1 wb	0.4647	0.3041	0.7687
Basic -H1	0.6128	0.3698	0.9825
Basic -w -H1 wb	0.4365	0.2723	0.7088
Basic -w -H1	0.4678	0.2632	0.7309
Document mode	0.7652	0.3296	1.0948
Document raw	0.4250	0.3983	0.8233

Table 4. *Differences of the ColorChecker24 patches: ACES vs recorded Image*

For a second reference, the values of the ColorChecker24 patches given in the ACES document [2] were also converted to CIE Yxy. Furthermore, the white point was converted from ACES to D50 using the Bradford matrix.

The differences between the values rendered in the ACES list and the values of the recorded image are given in *Table 5*.

3.3. Discussing the results

For a comparison of the results of the eight development methods, the sum of the differences in the CIE xy color chromaticity diagram is shown in *Table 5*. The x and y differences of the 24 patches are added for the BabelColor reference and the ACES reference.

CIE x,y (D50)	Differences Image D65 BabelColor patches vs. ACES patches		
Method	**Babel Color**	**ACES Patches**	**∑**
Basic wb	0.9739	0.9180	1.8919
Basic	0.9885	0.9390	1.9275
Basic -H1 wb	0.8608	0.7687	1.6295
Basic -H	1.0144	0.9825	1.9969
Basic -w -H1 wb	0.7915	0.7088	1.5003
Basic -w -H1	0.8224	0.7309	1.5533
Document mode	1.1430	1.0948	2.2260
Document raw	0.9273	0.8233	1.7506

Table 5. *Differences of the ColorChecker24 patches: BabelColor vs. ACES*

The developments with the white balance for the *Basic-w-H1* methods obtained the best values. The *Basic-H1-wb* method follows with an increased error of 9%. All other methods show an increased error larger than 26%. Interestingly, this method without the white balance also delivers better values than *Basic-H1* with a white balance performed.

Both development methods with (wb) and without white balance for the *Basic* method and the *Basic -H1* method without white balance have the highest differences. It is also interesting that the raw document method (-d) has relatively tiny differences and fits in the range of the *Basic-wb* and *Basic-H1-wb* methods.

Compared to the BabelColor patches and the ACES patches, the differences between the recorded ColorChecker 24 patches and the ACES patches are consistently much lower.

4. Test Results – Image 5986K

4.1. Development

This image was recorded under the illumination of D60 (5986K). This color temperature corresponds approximately to the white point of the illuminant used for ACES.

dcraw	Raw channel scaling Image D60		
Method	**Red**	**Green1,2**	**Blue**
Basic	1.000000	1.015902	1.079605
Basic -H1	0.926265	0.940994	1.000000
Basic -w -H1	1.000000	1.000000	1.000000

Table 6. *dcraw raw channel scaling*

For the *Basic* development, dcraw used the Red channel as the target channel (1.00000). This is verified by the fact that for *the Basic-H1* method, the blue channel achieves the peak value of 1.000000, and the other two channels have correspondingly less contribution. For the *Basic-w-H1* method, the white balance of the camera is used. Therefore the scaling factor is equal to 1.000000 for all RAW channels.

ACES2065-1	White Balancing Image D60		
Method	**Red**	**Green**	**Blue**
Basic a)		0.97784	
b)	1.00567	1.00000	1.00000
Basic -H1 a)		1.03440	
b)	1.00917	1.00000	0.94532
Basic -w -H1 a)		0.97784	
b)	1.00820	1.00000	1.00000
-D a)		0.97784	
-d b)		0.97784	

Table 7. *White Balance: Normalizing factors for a) luminance b) ACES RGB after luminance correction*

To match the luminance ACES values of 0.97784 for the ACES *Perfect Reflection Diffuser,* the correction values are the same for all methods except *Basic-H1*

When comparing the values for the additional white balancing, the *Basic* method needed the lowest corrections. On the other hand, the *Basic-H1* method requires the highest corrections, and the *Basic-w-H1* method is in the middle (*Table 7*). Here, the *Basic-H1* method significantly reduces the blue channel as well. In contrast, the other methods scale the three channels relatively balanced. Since the *Document* methods scale all three channels equally, no white balance is necessary after adjusting the luminance.

4.2. Results

The differences between the values given in the BabelColor list and the values of the recorded image are displayed in *Table* 8.

CIE x,y (D50)	Differences Image D60 Rec. patches vs. BabelColor patches		
Method	**x**	**y**	**∑x,y**
Basic wb	0.4751	0.3705	0.8456
Basic	0.5163	0.5056	1.0219
Basic -H1 wb	0.4213	0.3520	0.7733
Basic -H1.	0.4836	0.3726	0.8562
Basic -w -H1 wb	0.3888	0.3703	0.7591
Basic -w -H1	0.3978	0.3683	0.7661
Document mode	0.6465	0.5372	1.1837
Document raw	0.2719	0.5705	0.8424

Table 8. *Differences of ColorChecker24 patches: BabelColor vs. recorded image*

The differences between the values rendered in the ACES list and the values of the recorded image are given in *Table 9*.

CIE x,y (D50)	Differences Image D60 Rec. patches vs ACES patches		
Method	**x**	**y**	**∑x,y**
Basic wb	0.4183	0.2873	0.7055
Basic	0.4298	0.2865	1.2308
Basic -H1 wb	0.3560	0.2414	0.5974
Basic -H1	0.4490	0.3098	0.7587
Basic -w -H1 wb	0.3376	0.2521	0.5897
Basic -w -H1	0.3466	0.2411	0.5877
Document mode	0.6984	0.3916	1.0900
Document raw	0.2793	0.4389	0.7182

Table 9. *Differences of ColorChecker24 patches: ACES vs. rec. image*

4.3. Discussing the results

For a comparison of the results of the eight development methods, the sum of the differences in the CIE xy color chromaticity diagram is shown in *Table 10*. The x and y differences of the 24 patches are added for the BabelColor reference and the ACES reference.

CIE x,y (D50)	Differences Image D60 BabelColor patches vs. ACES patches		
Method	**Babel Color**	**ACES Patches**	**∑**
Basic wb	0.8456	0.7055	1.5511
Basic	1.0219	0.7162	1.7381
Basic -H1 wb	0.7733	0.5974	1.5533
Basic -H1.	0.8562	0.7587	1.6149
Basic -w -H1 wb	0.7591	0.5897	1.3488
Basic -w -H1	0.7661	0.5877	1.3538
Document mode	1.1837	1.0900	2.2737
Document raw	0.8424	0.7182	1.5606

Table 10. *Differences of ColorChecker24 patches: BabelColor vs. ACES*

The best values were obtained by the *Basic-w-H1* method, both white-balanced and non-white-balanced. The *Basic-wb* and *Basic-H1-wb* methods are followed with a 15% larger error. All other methods yield results with an even enlarged error. Compared to the BabelColor patches and the ACES patches, the differences between the recorded ColorChecker 24 patches and the ACES patches are consistently much lower.

5. Test Results – Image 5380K

5.1. Development

This image was recorded under the illumination of D55 (5380K). This color temperature corresponds to the international standard for medium sunlight (5380K). It was not possible with the test setup to come closer to 5500K.

dcraw	RAW channel scaling Image D655		
Method	**Red**	**Green1,2**	**Blue**
Basic	1.008978	1.000000	1.052248
Basic -H1	0.958878	0.950346	1.000000
Basic -w -H1	1.000000	1.000000	1.000000

Table 11*. dcraw raw channel scaling*

For the *Basic* method, dcraw used the Green channel as the target channel (1.00000). This is verified by the fact that for *the Basic-H1*-method, the blue channel achieves the peak value of 1.00000, and the other two channels have correspondingly less contribution. For the *Basic-w-H1* method, the white balance of the camera is used. Therefore the scaling factor is equal to 1.00000 for all.

ACES2065-1		White Balancing Image D55		
Method		**Red**	**Green1,2**	**Blue**
Basic	a)		0.97784	
	b)	1.00559	1.00000	1.00000
Basic -H1	a)		1.03606	
	b)	1.00337	1.00000	0.94381
Basic -w -H1	a)		0.97724	
	b)	1.00805	1.00000	1.00000
-D	a)		0.97784	
-d	a)		0.97784	

Table 12. *White Balance: Normalizing factors for a) luminance b) ACES RGB after luminance correction*

When comparing the results, the *Basic* method needed the lowest corrections. *Basic-H1* requires the highest corrections, and *Basic-w-H1* is in the middle (*Table 12*). The *Basic-H1* method significantly reduces here the blue channel. In contrast, the other methods scale the three channels relatively balanced. Since the *Document* methods scale all three channels equally, no white balance is necessary after adjusting the luminance.

5.2. Results

The differences between the values given in the BabelColor list and the values of the recorded image are displayed in *Table* 14.

CIE x,y (D50)	Differences Image D55 Rec. patches vs. BabelColor patches		
Method	**x**	**y**	**∑x,y**
Basic wb	0.4051	0.4733	0.8784
Basic	0.4860	0.3630	0.8490
Basic -H1 wb	0.4224	0.4137	0.8361
Basic -H1	0.4045	0.8633	1.2678
Basic -w -H1 wb	0.4189	0.4465	0.8654
Basic -w -H1	0.4085	0.4512	0.8597
Document mode	0.7557	0.6020	1.3577
Document raw	0.3287	0.6391	0.9678

Table 13. *Differences of ColorChecker24 patches: BabelColor vs. recorded image*

The differences between the values rendered in the ACES list and the values of the recorded image are given in *Table 14.*

5.3. Discussing the results

For a comparison of the results of the eight development methods, the sum of the differences in the CIE xy color chromaticity diagram is shown in *Table 15*. The x and y differences of the 24 patches are added for the BabelColor reference and the ACES reference.

CIE x,y (D50)	Differences Image D55 Rec. patches vs ACES patches		
Method	x	y	∑x,y
Basic wb	0.3484	0.3583	0.7068
Basic	0.4502	0.2488	0.6989
Basic -H1 wb	0.3575	0.2761	0.6337
Basic -H1	0.3513	0.7517	1.1029
Basic -w -H1 wb	0.3642	0.3027	0.6670
Basic -w -H1	0.3504	0.3058	0.6563
Document mode	0.7679	0.4470	1.2149
Document raw	0.2994	0.4913	0.7908

Table 14. *Differences of ColorChecker24 patches: ACES vs. recorded image*

CIE x,y (D50)	Differences Image D55 BabelColor patches vs. ACES patches		
Method	Babel Color	ACES Patches	∑
Basic wb	0.8784	0.7068	1.5852
Basic	0.8490	0.6989	1.5479
Basic -H1 wb	0.8361	0.6337	1.4697
Basic -H1	1.2678	1.1029	2.3707
Basic -w -H1 wb	0.8654	0.6670	1.5324
Basic -w -H1	0.8597	0.6563	1.5160
Document mode	1.3577	1.2149	2.5726
Document raw	0.9678	0.7908	1.7586

Table 15. *Differences of ColorChecker24 patches: BabelColor vs. ACES*

The best values were obtained by the developments with the white balanced for *Basic-H1* method. The *Basic-w-H1* methods, both non-white-balanced and white-balanced, follow with relatively small increased errors of 3% and 4%, respectively. However, the two *Basic* methods show a further increased error, and the two *Document* methods are way off.

In comparison between the BabelColor patches and the ACES patches, the differences between the recorded ColorChecker 24 patches and the Aces patches are consistently much lower.

6. Test Results – Image 5020K

6.1. Development

This image was recorded under the illumination of D50 (5020K). This color temperature is often used in graphic arts media.

dcraw	Raw channel scaling Image D50		
Method	Red	Green1,2	Blue
Basic	1.044756	1.000000	1.013311
Basic -H 1	1.000000	0.957161	0.969902
Basic -w -H 1	1.000000	1.000000	1.000000

Table 16. *dcraw raw channel scaling*

For the *Basic* method, dcraw used the Green channel as the target channel (1.00000). This development resulted in the peak value for *Basic-H1* being moved to the Red Channel. The other two channels have correspondingly less contribution. For the *Basic-w-H1* method, the white balance of the camera is used. Therefore, the scaling factor is equal to 1.00000 for all.

ACES2065-1	White Balancing Image D50		
Method	Red	Green	Blue
Basic a)		0.97784	
b)	1.00394	1.00000	1.00000
Basic -H 1 a)		1.02454	
b)	0.98665	1.00000	0.95938
Basic -w -H 1. a)		0.97784	
b)	1.00913	1.00000	1.00000
-D a)		0.97784	
-d a)		0.97784	

Table 17. *White Balance: Normalizing factors for a) luminance b) ACES RGB after luminance correction*

To match the luminance ACES values of 0.97784 for the ACES *Perfect Reflection Diffuser* are the same for all methods, except *Basic-H1*

When comparing the values for the additional white balancing, the *Basic* method needed the lowest corrections. *On the other hand, basic -H1* requires the highest corrections, and *Basic-w-H1* is in the middle (*Table 17*). For this image, the *Basic-H1* method significantly reduces the blue channel and, to a lesser extent, also the red channel. In contrast, the other methods scale the three channels relatively balanced. Since the *Document* methods scale all three channels equally, no white balance is necessary after adjusting the luminance.

6.2. Results

The differences between the values from the BabelColor list and the values of the recorded image are shown in *Table 18.*

CIE x,y (D50)	Differences Image D50 Rec. patches vs. BabelColor patches		
Method	x	y	∑x,y
Basic wb	0.4553	0.4278	0.8831
Basic	0.4520	0.8293	1.2813
Basic -H1 wb	0.4485	0.4680	0.9165
Basic -H1	0.4311	0.4214	0.8525
Basic -w -H1 wb	0.4399	0.4559	0.8958
Basic -w -H1	0.4291	0.4609	0.8900
Document mode	0.6853	0.6041	1.2894
Document raw	0.4118	0.6752	1.0870

Table 18. *Differences of ColorChecker24 patches: BabelColor vs recorded Image*

The differences between the values from the ACES list and the values of the recorded image are shown in *Table 19.*

6.3. Discussing the results

For a comparison of the results of the eight development methods, the sum of the differences in the CIE xy color chromaticity diagram is shown in *Table 20*. The x and y differences of the 24 patches are added for the BabelColor reference and the ACES reference.

CIE x,y (D50)	Differences Image D50 Rec. patches vs ACES patches		
Method	**x**	**y**	**∑x,y**
Basic wb	0.3926	0.2958	0.6885
	0.3909	0.6905	1.0814
Basic -H1 wb	0.3858	0.3234	0.7093
Basic -H1	0.3744	0.2860	0.6605
Basic -w -H1 wb	0.3772	0.3157	0.6930
Basic -w -H1	0.3638	0.3199	0.6838
Document mode	0.7288	0.4489	1.1777
Document raw	0.3743	0.5158	0.8902

Table 19. *Differences of ColorChecker24 patches: ACES vs. recorded Image*

CIE x,y (D50)	Differences Image D50 BabelColor patches vs. ACES patches		
Method	**Babel Color**	**ACES Patches**	**∑**
Basic wb	0.8831	0.6885	1.5716
Basic	1.2813	1.0814	2.3627
Basic -H1 wb	0.9165	0.7093	1.6258
Basic -H1	0.8525	0.6605	1.5130
Basic -w -H1 wb	0.8958	0.6930	1.5888
Basic -w -H1	0.8900	0.6838	1.5738
Document mode	1.2894	1.1777	2.4671
Document raw	1.0870	0.8902	1.9772

Table 20. *Differences of ColorChecker24 patches: BabelColor vs. ACES*

The developments with the non-balanced Basic-H1 method obtained the best values. Three other methods are following (*Basic-wb*, *Basic-w-H1-nwb*, *Basic-w-H1-wb*) relatively close to each other but with an increased error of 5%. The *Basic-H1-wb* method, which yields the best results with the 5380K image, has an increased error of 7.5%. All other development methods show even more significant errors.

In comparison between the BabelColor patches and the ACES patches, the differences between the recorded ColorChecker 24 patches and the ACES patches are consistently much lower.

7. Test Results – Image 2890K

7.1. Development

This image was recorded under the illumination of 2890K, roughly CIE F12. This color temperature is produced by a fluorescent lamp (Philips TL83, Ultralume 30).

dcraw	RAW channel scaling Image F12		
Method	**Red**	**Green1,2**	**Blue**
Basic	2.216165	1.557190	1.000000
Basic -H 1	1.000000	0.702651	0.451230
Basic -w -H 1	1.000000	1.000000	1.000000

Table 21. *dcraw raw channel scaling*

The images developed for all five methods show intense color casts in the neutral patches. The development with the *Basic-w-H1* method delivered the best results of the three *Basic* methods (*Fig. 5*).

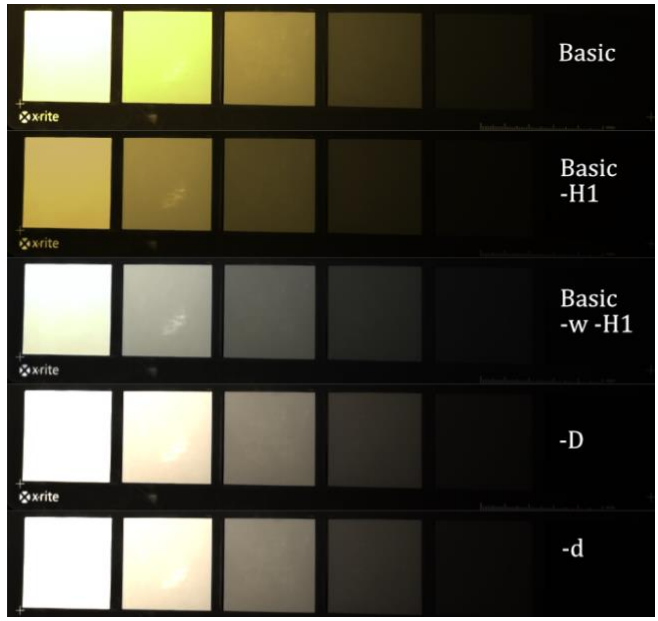

Figure 5. *Color cast of the neutral ColorChecker24 patches for the CIE F12 image*

These color casts can also be seen in the Perfect Reflecting Diffuser. For this reason, the Neutral 5 patch of ColorChecker24 was selected as the reference value for the luminance and white balance.

So, a new luminance and white point balance system was applied.

a) dcraw sets the peak value to 1.00000 during development. The reference value for the green channel of patch Neutral 5 is 0.20243 according to the ACES document S-2008-001. To achieve this value, all channels were adjusted uniformly in the different development methods to match the green channel.
b) After the luminance adaptation, a white balance was applied, with the green channel keeping constant to match the three ACES values of ACESRGB[0.20253, 0.20243, 0.20287]

ACES RGB values of common stimuli as produced by the ACES Reference Input Capture Device			
	Red	Green	Blue
Color Checker Neutral 5	0.20253	0.20243	0.20287

Table 22. *dcraw raw channel scaling*

For the *Basic* method, dcraw used the Blue channel as the target channel (1.00000). The other two channels have relatively high scaling factors to compensate for the lack of red and green colors under these lighting conditions. For the *Basic-H1* method, the peak is in the red channel. The other two channels have correspondingly less contribution. For the *Basic-w-H1* method, the white balance of the camera is used. Therefore, the scaling factor is equal to 1.00000 for all.

ACES2065-1	White Balancing Image F12		
Method	Red	Green	Blue
Basic a)		0.91939	
b)	0.84501	1.00000	2.20238
Basic -H1 a)		2.03769	
b)	0.84495	1.00000	2.20286
Basic -w -H1. a)		1.41912	
b)	0.99828	1.00000	1.13140
-D a)		1.19553	
-d a)		1.16886	

Table 23. *White Balance: Normalizing factors for a) luminance b) ACES RGB after luminance correction for 2890K image*

7.2. Results

The differences between the values from the BabelColor list and the values of the recorded image are shown in *Table 24.*

CIE x,y (D50)	Differences Image F12 Rec. patches vs. BabelColor patches		
Method	x	y	∑x,y
Basic wb	0.5787	0.5809	1.1596
Basic	1.7554	1.3381	3.0935
Basic -H1 wb	0.3027	0.3557	0.6584
Basic -H1	1.9417	1.4180	3.3597
Basic -w -H1 wb	0.3600	0.4353	0.7953
Basic -w -H1	0.4766	0.5622	1.0388
Document mode	0.8302	0.7596	1.5898
Document raw	2.1715	1.3298	3.5013

Table 24. *Differences of ColorChecker24 patches: BabelColor vs. recorded image*

The differences between the values from the ACES list and the values of the recorded image are shown in *Table 25*.

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CIE x,y (D50)	Differences Image F12 Rec. patches vs ACES patches		
Method	x	y	∑x,y
Basic wb	0.5955	0.5143	1.1097
Basic	1.7257	1.1803	2.9060
Basic -H1 wb	0.3317	0.2945	0.6261
Basic -H1	1.9220	1.2606	3.1826
Basic -w -H1 wb	0.2865	0.3169	0.6035
Basic -w -H1	0.4077	0.4078	0.8156
Document mode	0.8733	0.6008	1.4741
Document raw	2.1418	1.1662	3.3080

Table 25. *Differences of ColorChecker24 patches: ACES vs. recorded image*

7.3. Discussing the results

For a comparison of the results of the eight development methods, the sum of the differences in the CIE xy color chromaticity diagram is shown in *Table 27*. The x and y differences of the 24 patches are added for the BabelColor reference and the ACES reference.

CIE x,y (D50)	Differences Image F12 BabelColor patches vs. ACES patches		
Method	Babel Color	ACES Patches	∑
Basic wb	1.1596	1.1097	2.2693
Basic	3.0935	2.9060	5.9995
Basic -H1 wb	0.6584	0.6261	1.2845
Basic -H1	3.3597	3.1826	6.5423
Basic -w -H1 wb	0.7953	0.6035	1.3988
Basic -w -H1	1.0388	0.8156	1.8544
Document mode	1.5898	1.4741	3.0639
Document raw	3.5013	3.3080	6.8093

Table 26. *Differences of ColorChecker24 patches: BabelColor vs. ACES*

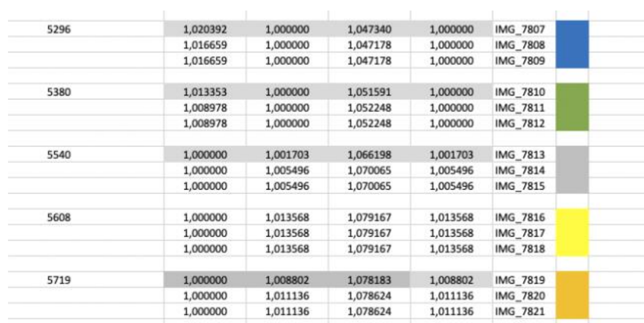
The developments with the white balance for the *Basic-H1* method obtained the best values. The *Basic-w-H1-(wb*)-method follows with an increased error of 9%. All other methods have larger errors. It is visible that all the non-white-balanced methods show huge differences, around 370%. Only the *Basic-w-H1-(nwb)* method is only 44% off due to the white balance performed in-camera.

In comparison between the BabelColor patches and the ACES patches, the differences between the recorded ColorChecker 24 patches and the ACES patches are consistently much lower.

8. Discussing the results by comparing the different images

For the data collection, three images each were taken for lighting situations from 3000K to 3300K and from 5000K to 6600K in steps of about 100K each. However, dcraw did not always develop these three images with the same coefficients for scaling the four RAW color channels. (*Fig. 6*).

In the ACES document S-2008-001, the RGB values (ACES2065-1) for the Perfect Reflecting Diffuser are given as 0.97784, 0.97784, 0.97784. The ColorChecker24 patch White is given as 0.86653, 0.86792, 0.85818. For the developed images, this difference in dynamics is no longer present. Both patches have the same value.



5296	1,020392	1,000000	1,047340	1,000000	IMG_7807
	1,016659	1,000000	1,047178	1,000000	IMG_7808
	1,016659	1,000000	1,047178	1,000000	IMG_7809
5380	1,013353	1,000000	1,051591	1,000000	IMG_7810
	1,008978	1,000000	1,052248	1,000000	IMG_7811
	1,008978	1,000000	1,052248	1,000000	IMG_7812
5540	1,000000	1,001703	1,066198	1,001703	IMG_7813
	1,000000	1,005496	1,070065	1,005496	IMG_7814
	1,000000	1,005496	1,070065	1,005496	IMG_7815
5608	1,000000	1,013568	1,079167	1,013568	IMG_7816
	1,000000	1,013568	1,079167	1,013568	IMG_7817
	1,000000	1,013568	1,079167	1,013568	IMG_7818
5719	1,000000	1,008802	1,078183	1,008802	IMG_7819
	1,000000	1,011136	1,078624	1,011136	IMG_7820
	1,000000	1,011136	1,078624	1,011136	IMG_7821

Figure 6. *Non-uniform development of images in the same lighting situation*

8.1. RAW Channel scaling

Basic	Channel scaling		
Color temperature	Red	Green	Blue
6510	1.000000	1.037978	1.083747
5986	1.000000	1.015902	1.079605
5380	1.008978	1.000000	1.070065
5020	1.044756	1.000000	1.013311
2890	2.216165	1.557190	1.000000

Table 27. *dcraw raw channel scaling for Basic method for all images*

In *Table 27*, the channel scalings for the *Basic* method are shown. For 6510K and 5908K, the red channel is the least significant because the illumination is slightly blueish. The green channel has minor significance for 5380K and 5020K. The blue and red channel scalings create the correct color.
For the 2890K image, the blue channel contributes the least because of the orange-reddish illuminant.

Basic	Normalized to red channel		
Color temperature	Red	Green	Blue
6510	1.000000	1.037978	1.083747
5986	1.000000	1.015902	1.079605
5380	1.000000	0.991022	0.008978
5020	1.000000	0.955244	0.968555
2890	1.000000	0.341025	-0.21616

Table 28. *dcraw raw channel scaling normalized to red channel for Basic method for all images*

In *Table 28*, all scalings are normalized to the red channel for comparing reasons. The normalization achieves acceptable values in the range from 5000K to 6500K. For the 2890K image. However, negative values are obtained, which has a corresponding effect on the color errors.

Basic -H1	Channel scaling		
Color temperature	Red	Green	Blue
6510	0.922725	0.957768	1.000000
5986	0.926265	0.940994	1.000000
5380	0.958878	0.950346	1.000000
5020	1.000000	0.957161	0.969902
2890	1.000000	0.702651	0.451230

Table 29. *dcraw raw channel scaling for Basic -H1 method for all images*

Basic -H1	Normalized to red channel		
Color temperature	Red	Green	Blue
6510	1.000000	1.035043	1.077275
5986	1.000000	1.014729	1.073735
5380	1.000000	0.991468	1.041122
5020	1.000000	0.957161	0.969902
2890	1.000000	0.702651	0.451230

Table 30. *dcraw raw channel scaling normalized to red channel for Basic -H1 method for all images*

For the *Basic-H1* method, slightly lesser corrections appear. Above all, the 2890K image scalings lead to reasonable values.

8.2. Comparing Development with and without additional white balancing

Tables 31- 33 show the white balance correction values for the three methods *Basic*, *Basic-H1*, and *Basic-w-H1*. The Perfect Reflecting Diffuser was the reference for the images with color temperatures from 5000K to 6500K. For the image taken at color temperature 2890K, the *Neutral 5* patch of the ColorChecker24 was the reference.

Basic	White Balance scaling		
Color temperature	Red	Green	Blue
6510	1.00642	1.00000	1.00000
5986	1.00567	1.00000	1.00000
5380	1.00357	1.00000	1.00000
5020	1.00394	1.00000	1.00000
2890	0.84501	1.00000	2.20238

Table 31. *White balance scaling for the Basic method for all images*

The *Basic* method requires only low scaling values in the red channel but very high ones for the 2890K image.

Basic -H1	Channel scaling		
Color temperature	Red	Green	Blue
6510	1.02400	1.00000	0.96093
5986	1.00917	1.00000	0.94532
5380	0.99805	1.00000	0.95433
5020	0.98665	1.00000	0.95938
2890	0.84495	1.00000	2.20286

Table 32. *White balance scaling for Basic-H1 method for all images*

The *Basic-H1* method requires much stronger scaling values in the red and green channels and also very high ones for the 2890K image.

Basic -w -H1	Channel scaling		
Color temperature	Red	Green	Blue
6510	1.00996	1.00000	1.00000
5986	1.00820	1.00000	1.00000
5380	1.00803	1.00000	1.00000
5020	1.00913	1.00000	1.00000
2890	0.99828	1.00000	1.13140

Table 33. *White balance scaling for Basic-w-H1 method for all images*

The *Basic-w-H1* method requires slightly stronger scaling values than the *Basic* method. The significant advantage lies in the development of the 2890K image. In contrast to the other two modes, only minor corrections are necessary here. These small errors make the *Basic-w-H1* method much more suitable for a general solution.

8.3. Comparing the results for the development with BabelColor D50 patches as target

Table 34 shows the results of the differences between the reference and the image. The reference is the ColorChecker24 values for CIE Yxy under the CIE illuminant D50. The differences in the individual values of the patches of the recorded

ColorChecker24, also converted to D50, were added for CIEx and CIEy and then summed.

CIE xy	All images:	Normalized BabelColor D50		
Image (K)	Method	x	y	∑x,y
6510	Basic wb	0.5898	0.3841	0.9739
	Basic -H1 wb	0.5091	0.3517	0.8608
	Basic -w -H1 wb	0.4692	0.3223	0.7915
	Basic-w-H1nwb	0.4882	0.3342	0.8224
5986	Basic wb	0.4751	0.3705	0.8456
	Basic -H 1 wb	0.4213	0.3520	0.7733
	Basic -w -H1 wb	0.3888	0.3703	0.7591
	Basic-w-H1nwb	0.3978	0.3683	0.7661
5380	Basic wb	0.4051	0.4733	0.8784
	Basic -H1 wb	0.4224	0.4137	0.8361
	Basic -w -H1 wb	0.4189	0.4465	0.8654
	Basic-w-H1nwb	0.4085	0.4512	0.8597
5020	Basic wb	0.4553	0.4278	0.8831
	Basic -H1 wb	0.4485	0.4680	0.9165
	Basic -H1 nwb	0.4311	0.4214	0.8525
	Basic -w -H1 wb	0.4399	0.4559	0.8958
	Basic-w-H1nwb	0.4291	0.4609	0.8900
2890	Basic wb	0.5787	0.5809	1.1596
	Basic -H 1 wb	0.3027	0.3557	0.6584
	Basic -w -H1 wb	0.3600	0.4353	0.7953
	Basic-w-H1nwb	0.4766	0.5622	1.0388

Table 34. *Differences between recorded ColorChecker24 patches and BabelColor patches under D50 illuminant*

Interestingly, the methods with the best results in each case correspond to the RAW channels listed in 8.1 with the lowest contribution to illumination. The corresponding channel is red for 6510K/5986K (range1), green for 5380K/5020K (range2), and blue for 2890K (range3).

Thus, the method *Basic-w-H1* has the slightest error for the range1. The following is the *Basic-H1* method with a more significant error of approx. 9% and 2%, respectively. It should be noted that even the non-white-balanced method *Basic-w-H1-nwb* still shows better results than the white-balanced method *Basic-H1* (only 4 and 1% error).

Except for the 2890K image, the error distribution is reasonably small. These results speak for a suitable measuring method.

8.4. Comparing the results for the development with BabelColor D50 patches vs. ACES patches as target

Here we look at the differences between the measured values for the ColorChecker24 patches and the comparison values listed in ACES document TB-2014-004. It is noticeable that these errors are smaller than those compared with the BabelColor-D50 values. This is mainly due to the fact that the ACES values are native, and no additional white point conversions are necessary for the measured values.

The error distribution is more or less similar to the BableColorD50 results with the corresponding lower errors. Notably, the *Basic-w-H1-wb* method performs significantly better on the 2890K image.

Adding both errors (BabelColorD50 method and ACES method) leads to the following comparisons regarding the best methods with the lowest errors for each image:

1. The combined results for the 6510K image are the same as for the BabelColorD50 comparison, with the *Basic-w - H1-wb* method as the best.
2. For the 5986K image, the results are also the same, with the *Basic-w-H1-wb* method as the best. A slight change appears for the *Basic* methods where the non-white-balanced method shows a slightly smaller error than the balanced method.
3. The results for the 5380K image are identical to those for the *BabelColorD50* method, with the *Basic-H1-wb* method as the best.
4. The results for the 5020K image are identical to those for the *BabelColorD50* method, with the *Basic-H1-nwb* method as the best.
5. The results for the 2890K image are identical to those for the *BabelColorD50* method, with the *Basic-H1-wb* method as the best.

CIE xy	All images:	Normalized BabelColor D50		
Image (K)	Method	Babel Color	ACES	∑
6510	Basic wb	0.9739	0.9180	1.8919
	Basic -H1 wb	0.8608	0.7687	1.6295
	Basic -w -H1 wb	0.7915	0.7088	1.5003
	Basic-w-H1nwb	0.8224	0.7309	1.5533
5986	Basic wb	0.8456	0.7055	1.5511
	Basic -H1 wb	0.7733	0.5974	1.5533
	Basic-w -H 1 wb	0.7591	0.5897	1.3488
	Basic-w-H1nwb	0.7661	0.5877	1.3538
5380	Basic wb	0.8784	0.7068	1.5852
	Basic -H1 wb	0.8361	0.6337	1.4697
	Basic -w -H1 wb	0.8654	0.6670	1.5324
	Basic-w-H1nwb	0.8597	0.6563	1.5160
5020	Basic wb	0.8831	0.6885	1.5716
	Basic -H1 wb	0.9165	0.7093	1.6258
	Basic -H1 nwb	0.8525	0.6605	1.5130
	Basic -w -H1 wb	0.8958	0.6930	1.5888
	Basic-w-H1nwb	0.8900	0.6838	1.5738
2890	Basic wb	1.1596	11.097	2.2693
	Basic -H1 wb	0.6584	0.6261	1.2845
	Basic -w -H1 wb	0.7953	0.6035	1.3988
	Basic-w-H1nwb	10.388	0.8156	1.8544

Table 35. *Differences between recorded ColorChecker24 patches, BabelColor patches, and ACES patches under D50 illuminant*

8.5. Discussing the results for the white balanced vs. non-white balanced methods

In *Table 36*, the differences between the white-balanced and non-white balanced for the three main methods are displayed. The *Basic-w-H1* method delivers the best results across all color temperatures. These minor errors are because white balancing already takes place in the camera. The *Basic* method has twice the error value, while the *Basic-H1* method has 100 times higher errors, which makes subsequent white balancing necessary. Thus, only the *Basic-w-H1* method is suitable for an all-in-one solution.

CIE xy	All images:	Normalized BabelColor D50		
Image (K)	**Target**	**Basic**	**Basic -H1**	**Basic -w -H1**
6510	Babel Color	0.0146	0.1536	0.0309
	ACES	0.0210	0.2138	0.0221
	∑	**0.0356**	**0.3674**	**0.0530**
5908	Babel Color	0.1763	0.0829	0.0070
	ACES	0.0107	0.1613	0.0020
	∑	**0.1870**	**0.2442**	**0.0090**
5380	Babel Color	0.0294	0.4317	0.0057
	ACES	0.0079	0.4692	0.0107
	∑	**0.0373**	**0.9009**	**0.0164**
5020	Babel Color	0.3982	0.0640	0.0058
	ACES	0.3929	0.0488	0.0092
	∑	**1.0510**	**1.6253**	**0.0934**
2890	Babel Color	1.9339	2.7013	0.2435
	ACES	1.7963	2.5565	0.2121
	∑	**4.7812**	**6.8831**	**0.5490**

Table 36. *Differences between white balanced vs. non-white balanced methods*

8.6. Discussing the document development

CIE xy	All images:	Normalized BabelColor D50	
Image (K)	**Target**	**Document mode -D**	**Document mode -d**
	BabelColor		
6510		1.1430	0.9273
5908		1.1837	0.8424
5380		1.3577	0.9678
5020		1.2894	1.0870
	∑	**6.1168**	**4.7518**
2890		1.5898	3.5013
	∑	**7.7066**	**8.2531**
	ACES		
6510		1.0948	0.8233
5908		1.0900	0.7182
5380		1.2149	0.7908
5020		1.1777	0.8902
	∑	**4.5774**	**3.2225**
2890		1.4741	3.3080
	∑	**7.7066**	**8.2531**

Table 37. *Differences between document modes*

According to the dcraw manual, the -D option means *Document mode without scaling (totally raw)* (see. Fig. 1). Luijk Guillermo [12], describes this option in his dcraw tutorial the following:

Extracts an image with the pure RAW data without any demosaicing or scaling applied. It is very useful to analyse the real captured levels in the sensor's native range of 12, 14 or 16 bits.

Because Apple does a demosaicing in advance, this advantage is not entirely available.

According to the dcraw manual, the -d option means *Document mode (no color, no interpolation)* (*see. Fig. 1*). Luijk Guillermo [12], describes this option in his dcraw tutorial the following:

As the previous command, it does not perform any demosaicing but goes one step ahead in the development process since it adjusts black and saturation points, white balance and rescales to the output 16-bit range. It is very interesting to get linearized (for substracting the black point) undemosaiced data in a 16-bit scale with **dcraw -d -r 1 1 1 1** *that allows to obtain histograms in stops of exposure with Histogrammar. It can also be used to study the Bayer pattern of the RAW file, permitting for instance to detect malfunction in the camera sensor or individual anomalous pixels.*

Table 37 shows the errors for the BableColorD50 reference. Because of the additional adjustments in the developing process, option -d has roughly 25% fewer errors than option -D. However, the errors are generally too large to use these options as a general solution.

8.7. Comparing special color areas for the D65 image

Table 38 displays the errors for different color areas from the developing results for the BableColor reference and the D65 image, and the *Basic-w-H1* method.

Table 39 shows the errors for the *Basic-H1* method. Because of the additional white-balancing, the neutral areas show the least amount of errors. The reddish and yellowish areas show the most significant errors for both methods (see *Fig. 7).*

Basic -w -H1	Differences BabelColor D50		
Color Area	**CIE x**	**CIE y**	**∑**
Primary	0.0303	0.0147	**0.0450**
Sekundary	0.0288	0.0063	**0.0351**
Neutral	0.0074	0.0042	**0.0116**
Skin	0.0390	0.0108	**0.0498**
Greenish	0.0090	0.0133	**0.0222**
Bluish	0.0060	0.0253	**0.0313**
Reddish	0.0638	0.0070	**0.0708**
Yellowish	0.0231	0.0484	**0.0715**
Purple	0.0120	0.0063	**0.0182**
∑			**0.2140**

Table 38. *Differences for selected color areas for method Basic-w-H1 and D65 image*

Basic -H1	Differences BabelColor D50		
Color Area	**CIE x**	**CIE y**	**∑**
Primary	0.0319	0.0159	**0.0479**
Secundary	0.0313	0.0063	**0.0375**
Neutral	0.0081	0.0057	**0.0138**
Skin	0.0412	0.0147	**0.0559**
Greenish	0.0100	0.0176	**0.0276**
Bluish	0.0071	0.0242	**0.0313**
Reddish	0.0668	0.0077	**0.0745**
Yellowish	0.0268	0.0492	**0.0760**
Purple	0.0134	0.0056	**0.0190**
∑			**0.2284**

Table 39. *Differences for selected color areas for method Basic-H1 and D65 image*

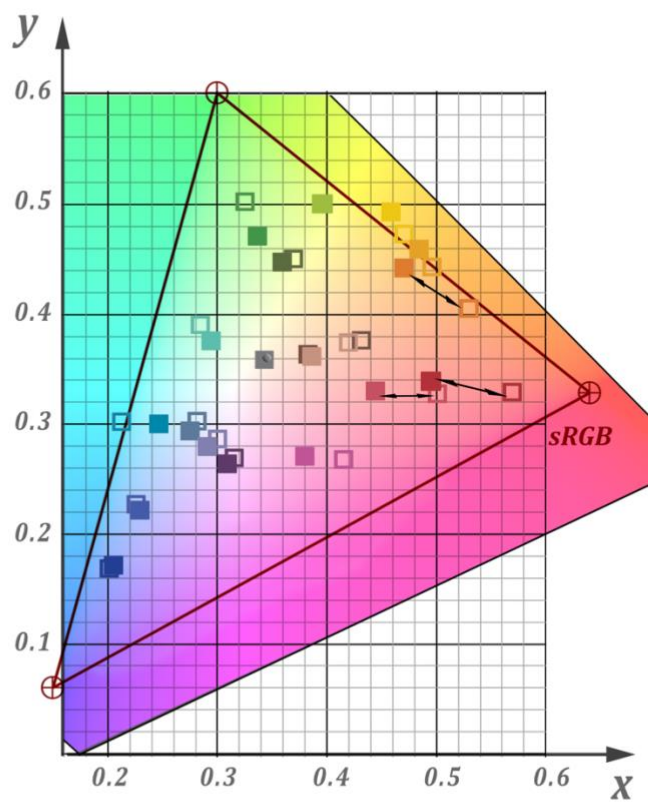


Figure 7. *Position of ColorChecker24 patches in CIE xy chromaticity diagram – Recorded D65 image solid, BabelColor D50 outlined*

9. Conclusions

Due to the fast access and sufficient quality, images captured with iPhone can be an added value for film productions. Especially for the documentation of setups and camera positions, but also in acquiring textures, panoramas, and input into other imaging processes, these iPhone recordings can be used.

Since the ACES system increasingly dominates film pipelines, it is of great importance to add still photographs to this system in addition to the well-documented input from film cameras [14][15][16]. AppleProRAW image files are well suited for this purpose due to their extended luminance range.

This work aimed to find a robust all-in-one solution for developing AppleProRAW DNG files across all significant color temperatures, using the widely used and batch-processing enabled dcraw command-line solution as a foundation.

As a robust solution without further white balancing after developing the method *Basic -w -H1-nwb* is recommended with the following command line:

dcraw -v -w -H 1 -o 6 -g 1 1 -4 -T *.DNG

Because of the white balancing already done in the camera, it yields good results throughout the color temperatures.

He *Basic -w -H1 (wb)* may be used in the range from D55-D65 with additional white balancing to achieve slightly better results than the general resolution. In addition, the *Basic -H1 (wb)* method may be used in the range from D50 and beneath with additional white balancing and the following command line:

dcraw -v -H 1 -o 6 -g 1 1 -4 -T *.DNG

References

[1] D. Pascale. „RGB Coordinates of the Macbeth ColorChecker“. The Babel Color Company. http://www.babelcolor.com/index_htm_files/RGB%20Coordinates%20of%20the%20Macbeth%20ColorChecker.pdf. Retrieved 2019-01-07.

[2] Technical Bulletin TB-2014-004, Informative Notes on SMPTE ST 2065-1 – Academy Color Encoding Specification (ACES) https://acescentral.com/aces-documentation-copy/. Retrieved 2023-03-18

[3] ColorChecker24 website: https://www.xrite.com/de/categories/calibration-profiling/colorchecker-classic. Retrieved 2023-03-18

[4] SphereOptics diffuse 99% reflectance filter SG3051: https://sphereoptics.de/product/zenith-polymer-reflexionsstandards/?c=79. Retrieved 2023-03-18

[5] Aputure AL-F: https://www.aputure.com/products/al-f7. Retrieved 2023-03-18

[6] Qmini_Spectrometer: https://www.rgb-photonics.com/fileadmin/user_upload/downloads/datasheets/Qmini_Spectrometer.pdf. Retrieved 2019-01-07

[7] https://support.apple.com/kb/SP832?locale=de_DE&viewlocale=en_US Retrieved 2023-03-18

[8] https://lux.camera/understanding-proraw/ Retrieved-2023-01-10

[9] ACES: https://www.oscars.org/science-technology/sci-tech-projects/aces

[10] Eberhard Hasche, Oliver Karaschewski, Reiner Creutzburg, "Comparing ACES Input Device Transforms for the Canon EOS 5D Mark III DSLR camera" in Proc. IS&T Int'l. Symp. on Electronic

Imaging: Mobile Devices and Multimedia: Enabling Technologies, Algorithms, and Applications, 2018, pp 138-1 - 138-13, https://doi.org/10.2352/ISSN.2470-1173.2018.06.MOBMU-138

[11] dcraw website: https://www.dechifro.org/dcraw/, Retrieved 2022-02-08

[12] Guillermo, Luijk: dcraw Tutorial http://www.guillermoluijk.com/tutorial/dcraw/index_en.htm, Retrieved 2023-02-06

[13] The Foundry website: https://www.foundry.com, Retrieved 2023-02-04

[14] Eberhard Hasche, Dominik Benning, Oliver Karaschewski, Florian Carstens, Reiner Creutzburg, "Creating high-resolution 360-degree single-line 25K video content for modern conference rooms using film compositing techniques" in Proc. IS&T Int'l. Symp. on Electronic Imaging: Mobile Devices and Multimedia: Technologies, Algorithms & Applications, 2020, pp 206-1 - 206-14, https://doi.org/10.2352/ISSN.2470-1173.2020.3.MOBMU-206

[15] Eberhard Hasche, Dominik Benning, Reiner Creutzburg, "Using ACES Look Modification Transforms (LMTs) in a Visual Effects Production Environment — Part 1: Rec.709 Inputs and Outputs" in Proc. IS&T Int'l. Symp. on Electronic Imaging: Mobile Devices and Multimedia: Technologies, Algorithms, and Applications, 2020, pp 205-1 - 205-14, https://doi.org/10.2352/ISSN.2470-1173.2020.3.MOBMU-205

[16] Eberhard Hasche, Oliver Karaschewski, Reiner Creutzburg, "RAW images and videos for 30K panoramic projection using the ACES workflow" in Electronic Imaging, 2022, pp 400-1 - 400-13, https://doi.org/10.2352/EI.2022.34.3.MOBMU-400

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