

RAW images and videos for 30k panoramic projection using the ACES workflow

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Abstract

According to our recent paper [1], the concept of creating a still image panorama with the additional inclusion of video footage up to 30k resolution has proven to be successful in various application examples. However, certain aspects of the production pipeline need some optimization, especially the color workflow and the spatial placement of the video content. This paper aims to compare two workflows to overcome these problems. In particular, the following two methods are described in detail:

1) Improving the current workflow with the Canon EOS D5 Mark IV camera as the central device

2) Establishing a new workflow using the Apple iPhone 12 Pro MAX possibilities

The fundamental idea is to use ACES as the central color management system. This paper investigates if the direct import from Canon RAW to ACES2065-1 (AP0) via dcrw shows advantages to our current workflow using the sRGB/Rec.709 color spaces. In addition, we compare the conversion from Apple DNG RAW files to ACES2065-1 to the Canon Workflow. Also included is an investigation into whether the stitching process in PTGUI changes the original colors of the ColorChecker24 patches.

Eventually, we investigate the SDR video import from the Canon EOS D5 Mark IV camera and compare the new workflow

using ACES2065-1 as the central color space to the existing workflow in sRGB/Rec.709.

1. The Project Room

1.1. The situation

The paper [1] described our workflow to generate 30k-Videos for a projection room at the Hotel Park Soltau in Soltau, Niedersachsen in Germany [2]. The basic idea is to shoot a still image panorama using a DSLR camera (Canon EOS D5 Mark IV) with a 28 mm focal length. Due to the 36x24 mm chip inside the camera, the stitched panorama has a resolution of around 30 000 pixels (30k). According to the recommendation ITU-R BT.2123-0 [3]. This resolution is sufficient for an immersive experience for VR.

Recording videos and still images with the same camera mounted on a tripod – albeit with different focal lengths – maintains the same position and shooting direction. We are recording videos wherever movement in the panorama field appears. The videos are then applied to the still panorama using The Foundry Nuke [4]. Because of the resolution of the projection system, the resulting panorama video is then scaled down to 12k (Fig. 1).



Figure 1. Panorama (latlong map) in the projection room

1.2. Possible improvements

Because of the complex nature of the task, we divide the research into several parts to carefully test out the scenarios. Because the different parts of the investigation should be seen as a unity, we describe the possible improvements we are looking for, even when researching them in the future.

In the first part of this paper, we concentrate on the SDR color workflow. We import a CR2 RAW images sequence from the Canon EOS D5 Mark IV camera and the MPEG coded video into ACES2065-1. This color management system has a high level of control. We investigate how close it is possible to match the still imagery to the video.

We apply the same procedure to the Apple RAW image sequence. Then we compare the result to the Canon panorama.

Only a part of the camera sensor is used when recording videos to get a better image quality. There is a 1 to 1 relationship between a pixel and a photo element using this technology. The technology to use only the number of pixels needed for the resolution – in contrast, to record the entire chip and scale down – is widely used with cinema cameras. It leads to some improvements in quality, f. i. Optical Low Pass Filters are working better with adjacent pixels. The problem is that a crop factor of 1.74 appears when recording still images and 4K videos with the Canon Mark IV camera. To match the shooting angle, we use a 16 mm focal length. Using this focal length leads to lens distortion and makes it challenging to integrate the videos in the still panorama, recorded with a 28 mm lens. Ways to remove the lens distortion will be part of a future investigation.

Another problem is the somewhat washed-out projection of videos in contrast to still images. The reduced number of colors in a Y'Cb'Cr' coded video may cause this problem. So, we will investigate if the Dolby analysis of the video content leads to a better saturation distribution (in contrast to increasing the saturation). We will investigate his topic also in future research.

2. Test procedure

First, we develop the still image sequence recorded with the Canon EOS D5 Mark IV camera. Applied to the scene was an artificial light around 4000K. We want to maintain the reddish color tint to avoid extended white point conversion and keep the warm light.

To develop the RAW footage, we are using ddraw [5]. It is possible to convert to ACES2065-1 directly. The linear export and the conversion to the ACES primaries are addressable inside the software. For the ACES white point (~D60), we apply the multipliers to the four RAW color channels by analyzing an image recorded with a 6000K white point.

In the next step, we are experimentally finding out the four multipliers for developing the iPhone 12 max pro to match the D60 development of the CR2 sequence.



Figure 2. Patch #22 Neutral 5 at the ColorChecker24

The central value for our research is the value of the *Neutral 5* color patch of the ColorChecker24 card (Fig. 2) [6]. We are using

this patch because it is closed to the central value of 18% linear gray in scene-referred workflows.

According to the ACES specification S-2008-0001 [7] the values for this patch are depicted in Tab. 1. Therefore, we only match the green channel to keep the color tint.

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

Table 1. ACES2065-1 values of the patch Neutral 5 of the ColorChecker24 [6]

After this, we convert the two still image sequences to ACES 1065-1 with the appropriate gamma and primary settings and the experimentally found multipliers of the four RAW channels.

The second part generates panoramas for the Canon CR2 images using PTGUI. We are starting with a basic image, which contains the ColorChecker24 chart. Then we add two more images to the primary image each time. After this, we evaluate a possible color correction that will cause a change in the color patterns of the ColorChecker24 chart due to the panorama stitching. Finally, we create the complete panorama and compare the chart color values of the ColorChecker24 chart to the basic chart in ACES2065-1. We also convert the color checker image and the panorama to the CIE xy chromaticity diagram and compare color differences.

In the third part, we apply the same steps of the previous section to the Apple DNG image sequence. We also compare the differences between the original image with the color checker and the panorama in ACES2065-1 and CIE xy.

In the fourth part, we are setting up the Canon EOS D5 Mark IV video to match the ColorChecker24 values of the basic CR2 image as close as possible. This time, the matching references are **all three** RGB color channels of the ColorChecker24 *Neutral 5* in ACES2065-1 to maintain the color shift caused by the artificial lighting during the recording.

In the next part, we compare the color differences in the ColorChecker24 chart between the Canon CR2 based panorama and the imported Mark IV video between the existing and the new workflow.

In the last part, we present the conclusions and discuss further research.

3. Developing the RAW image sequences

We use ddraw as the developing software for the RAW image sequences. Ddraw is widely used in the industry [7] and offers a wide range of control over the developing process. It is command-line based and is working on the main computer operating systems. Concerning color space conversion, it offers a build-in primaries transformation and easy adjustment of the transfer function (gamma). Only the RAW development towards the white point has to be found out experimentally.

3.1. Finding the multipliers for CR2 image sequence

When developing RAW images, a pixel in an image of digital photo- and film-cameras contains only the light information depending on the filter settings of the corresponding photo elements on the sensor. For example, a photo element with a green filter applied will only contain the green part of the spectrum due to the filter settings. Therefore, that specific pixel's red and blue color information must be retrieved from the surrounding pixels.

The four RAW channels must be scaled to convert correctly to the specific illuminant and its white point. Because the green channel encompasses the most significant part of a scene's luminance, we use an option in dcrw that keeps the RAW value of the green channels at 1.00 and change the values of the blue and red channels.

First, we set up a test scenario to get the corresponding multiplier values for the Mark IV camera. This camera offers a possibility to set up the color temperature in steps of 100K (Fig. 3). Based on a method described by Guillermo Luijk [8], we record images with a color temperature between 5000K and 6500K in 100K steps. With the derived data, we understand of how the red and blue channels are taking place in this range.



Figure 3. Color Temperature settings for Canon EOS D5 Mark IV camera [9]

We develop the images in dcrw using the command line (1) to get the multipliers. The verbose (-v) option displays the RAW development internal done by dcrw, most notably the values of the multipliers (Fig. 4). Note that for better handling, the images are developed to sRGB.

```
dcrw -v -w -g 2.4 12.9 -T *.CR2      (1)
```

```
Loading Canon EOS 5D Mark IV image from 62A9771.CR2 ...
Scaling with darkness 2047, saturation 16383, and
multipliers 2.178711 1.000000 1.307617 1.000000
AHD interpolation...
Converting to sRGB colorspace...
Writing data to 62A9771.tiff ...
```

Figure 4. Verbose description during the RAW development of an CR2 image in dcrw

The multipliers of the different color temperatures are depicted in Tab. 2.

Color Temp. (K)	Red	Green	Blue	Green
5000	1.931641	1.000 000	1.488281	1.000 000
5100	1.954102	1.000 000	1.471680	1.000 000
5200	1.972656	1.000 000	1.452148	1.000 000
5300	1.992188	1.000 000	1.438477	1.000 000
5400	2.007812	1.000 000	1.423828	1.000 000
5500	2.027344	1.000 000	1.410156	1.000 000
5600	2.043945	1.000 000	1.397461	1.000 000
5700	2.060547	1.000 000	1.385742	1.000 000
5800	2.077148	1.000 000	1.374023	1.000 000
5900	2.093750	1.000 000	1.363281	1.000 000
6000	2.107422	1.000 000	1.352539	1.000 000
6100	2.124023	1.000 000	1.343750	1.000 000
6200	2.137695	1.000 000	1.334961	1.000 000
6300	2.151367	1.000 000	1.326172	1.000 000
6400	2.165039	1.000 000	1.316406	1.000 000
6500	2.178711	1.000 000	1.307617	1.000 000

Table 2. Color temperatures and RAW multipliers for Canon EOS D5 Mark IV

A diagram of the relationship between the red and blue color channel and the color temperature for the Canon EOS 5D Mark IV camera is shown in Fig. 5.

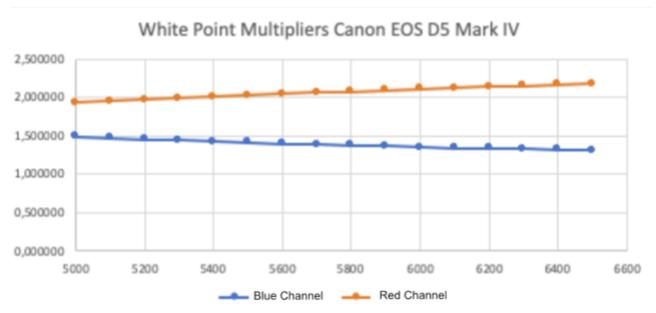


Figure 5. White point multipliers for Canon EOS D5 Mark IV

After evaluating the test images, the multipliers assigned to 6000K are used to develop the CR2 image containing the ColorChecker24 chart. Finally, the image is converted to ACES2065-1 linear as a 16bit Tiff file according to the command line (2).

```
dcrw -v -r 2.107422 1.000 000 1.352539
1.000 000 -o 6 -g 1 1 -4 -T *.CR2      (2)
```

We import the image into NukeX using OpenColorIO [10] as the color management system with the working color space set to ACES2065-1 to avoid a second conversion to ACEScg (Fig. 6).

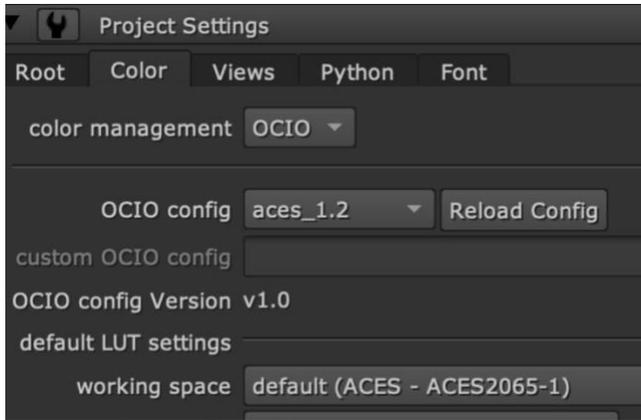


Figure 6. Working color space settings in NukeX

We scale the developed CR2-Chart image is to 0.20243 for the green channel of the Neutral 5 color patch of the ColorChecker24 chart. All three channels of patch Neutral 5 are then used as a reference for developing the corresponding Apple DNG image. It must be pointed out that the conversion to the ACES white point is not entirely accurate because the color temperature of the ACES white point – around 6003 [10] – cannot be targeted in the color temperature settings of the Mark IV camera with the internal 100K steps.

3.2. Finding the multipliers for DNG image sequence

The development of the corresponding Apple DNG ColorChecker24 chart image is done experimentally. First, we start with the white point multipliers for 6000K with the Canon CR2 image following command line (3). Then we iteratively change the value until the three channels for patch *Neutral 5* match the corresponding Canon CR2 image values.

```
dcrw -v -r 2.107422 1.000 000 1.352539
1.000 000 -o 6 -g 1 1 -4 -T *.DNG (3)
```

The results of this approach are displayed in Appendix A. The multipliers that were sufficiently close to the Canon CR2 Neutral 5 patch in ACES2065-1 are shown in Tab. 3. It must be pointed out that the found multipliers are not suitable to perform a general Apple DNG conversion to ACES via dcrw. Instead, they are matches that maintain the original scene's color shift (tint).

Color Temp.(K)	Red	Green	Blue	Green
6000	2.318	1.000	1.8184	1.000

Table 3. RAW multipliers for Apple iPhone 12 max to ACES2065-1 for the specific scene in this research

We convert the DNG image that contains the ColorChecker24 chart to ACES2065-1 using the multiplier values of Tab. 3. Then we import the developed image into Nuke and scale it, so the value of the green channel of the *Neutral 5* patch in the DNG image matches the ACES value in Specification S-2008-001 (0.20243).

ACES2065-1 patch	Differences CR2 - DNG		
	Red	Green	Blue
blue sky	0.00459	-0.00251	0.06589
foliage	0.01418	0.00470	-0.00363
blue flower	-0.00551	-0.00217	0.00459
bluish green	-0.00239	0.00456	0.00265
orange	-0.00031	-0.00675	0.00072
purplish blue	-0.00747	-0.01990	0.00175
moderate red	0.02807	0.00127	0.00815
purple	-0.00963	-0.01213	0.00474
yellow green	0.01799	-0.00607	-0.00460
orange yellow	-0.00038	-0.00845	-0.00751
blue	0.00817	0.02898	-0.00316
green	0.03430	0.01648	0.02605
red	-0.00907	-0.01221	0.01403
yellow	-0.00747	0.01405	-0.00426
magenta	0.01432	-0.00766	0.00649
cyan	0.03745	0.03073	-0.00726
white 9.5	0.01264	-0.01479	0.02557
neutral 8	-0.01515	-0.00098	-0.01068
neutral 6.5	0.01469	0.01699	0.00464
neutral 5	0.00775	0.01045	0.00836
neutral 3.5	0.00098	0.00229	0.00525
black 2	-0.00006	0.00000	0.00191
blue sky	-0.00268	-0.00229	-0.00004
foliage	-0.00391	-0.00449	-0.00227
Sum (ABS)	0.25916	0.23090	0.16118

Table 4. Differences of the ColorChecker24 patches between the reference CR2 image and the developed DNG image

It shows that the multipliers are not entirely correct because the differences in the red channel compared to the blue channel are much higher than the CR2 image.

Fig. 7 shows the location of the ColorChecker24 patches in the CIE xy chromaticity diagram. Based on the positions of the ColorChecker patches, the yellow color cast is clearly visible. Also visible is that the wide ACES2065-1 color space keeps the positions of the patches, whereas they would be clipped in sRGB/Rec.709 color space. However, the diagram also shows that the CR2 and Apple DNG image match is incomplete. Here, further research is needed.

4. Panorama creation and evaluation in PTGUI for the Canon CR2 image sequence

First, we are developing the CR2 image sequence using Formula 2. The image sequence consists of 16 images with steps of 22.5° apart in a circle recording pattern. We manually fix the exposure settings during recording to avoid automated exposure changes. With a focal length of 28 mm, the stitched still image panorama will have a width of ca. 30 000 pixels (30k). This resolution meets the pixel count of mapped images in Recommendation ITU-R BT.2123-0.

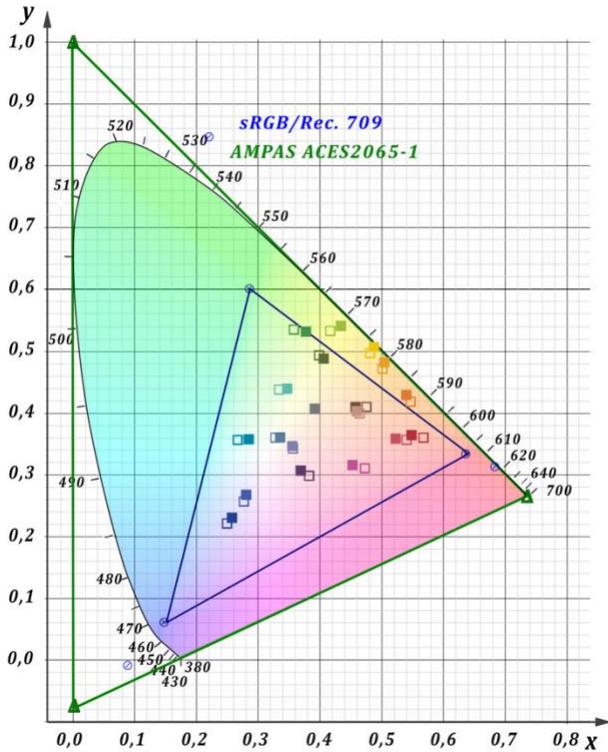


Figure 7. Position of ColorChecker24 patches in CIE xy chromaticity diagram – Canon CR2 image outlined, Apple DNG image solid

4.1. Stitching the images in PTGUI

We import the images that should be stitched together into PTGUI. PTGUI [12] is a panorama stitching program based on *Panorama Tools* [13] and is widely used in the industry. It maintains the imported image sequence's ACES2065-1 color space (Fig. 8).

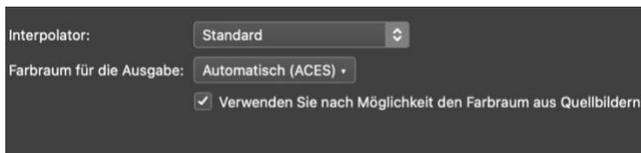


Figure 8. Color management in PTGUI

The algorithm may change the original colors because of the processing during the image blending in the stitching process.

Colors are adjusted between images to compensate for exposure differences [14]

In the next step, we investigate the possible color changes in the image that contains the original ColorChecker24 chart when the program adds additional images. We start with the color chart image and add two images next in the panorama. In Fig. 9, the natural light sources in the window are visible and may color correct the original color chart.

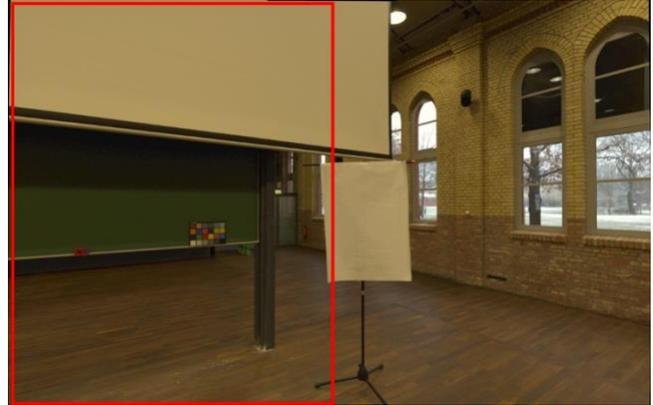


Figure 9. Chart image (red outline) and additional two images stitched together

In the next stitches, each time, we add two other images. They contain the artificial light sources in the room (Fig. 10). At least the complete panorama is created (Fig. 11).



Figure 10. Chart image with additional four images (red outline) and additional six images stitched together



Figure 11. The entire panorama stitched together

4.2. Evaluating the ColorChecker24 patches in the stitching process

We concentrate on selected patches of the ColorChecker24 chart (skin tones, primary and secondary colors, white and neutral 5). We are calculating the difference between the original image and the appearance of the color chart in the partially stitched panoramas. First, we scale the value of the green channel for the *Neutral 5* patch to match the value of the same patch in the original image. The results for the ACES-2065-1 color space are shown in Tab. 5. The results for the CIE xy chromaticity diagram are shown in Tab. 6.

There are only minor changes to the colors of the ColorChecker24 chart in the original image when additional images in the panorama stitching process are added. The deviation in Tab. 5 is more significant for the red and blue channels than for the green channel. The green channel holds the color better, maybe caused by the manual matching to the green channel for the *Neutral 5* patch.

ACES2065-1	Differences to original color chart		
PTGUI/CR2	Red	Green	Blue
Single - 0 2	0.07150	0.03720	0.06589
Single - 0 4	0.06147	0.03348	0.06253
Single - 0 6	0.05989	0.03507	0.06032
Single - Full Panorama	0.05300	0.03584	0.05675

Table 5. Differences of the ColorChecker24 patches between the single image and the stitched panoramas in ACES2065-1 color space in PTGUI

CIE xy	Differences to original color chart	
PTGUI/CR2	x	y
Single - 0 2	0.03997	0.05018
Single - 0 4	0.03249	0.04930
Single - 0 6	0.03521	0.04872
Single - Full Panorama	0.03409	0.04413

Table 6. Differences of the ColorChecker24 patches between the single image and the stitched panoramas in CIE xy in PTGUI

While the deviation in the ACES color space includes luminance differences, in the CIE xy chromaticity diagram, only changes in the color itself are examined. As a result, minor deviations are visible with a more considerable drift in the y-direction than in the x-direction.

To understand how these values are classified, we are performing the same tests in the stitching process in Affinity Photo [15]. Affinity Photo is a modern and reliable image editing program. However, it must be pointed out that it is not a panorama editor, even if it offers this possibility. Tab. 7 and 8 show the results for ACES2065-1 and CIE xy color spaces, respectively. Interestingly, the color deviation increases when more images are added to the original image containing the ColorChecker24 chart. Apparently, color information in the added images causes these color variations. This information is ignored by PTGUI and leads to a more consistent result.

ACES2065-1	Differences to original color chart		
Affinity Photo/CR2	Red	Green	Blue
Single - 0 2	0.15654	0.12815	0.06356
Single - 0 4	0.38712	0.34562	0.17378
Single - 0 6	0.34032	0.30411	0.14854
Single - Full Panorama	0.54099	0.49681	1.03780

Table 7. Differences of the ColorChecker24 patches between the single image and the stitched panoramas in ACES2065-1 color space in PTGUI

In the next step, we calculate the differences for the selected patches of the color checker between the original image and the panorama. The results are displayed in Tab. 9. Again, it has to be stated that the color cast caused by the scene's lighting is figured into the calculation.

CIE xy	Differences to original color chart	
Affinity Photo/CR2	x	y
Single - 0 2	0.09278	0.05569
Single - 0 4	0.16649	0.15431
Single - 0 6	0.15027	0.12473
Single - Full Panorama	0.23550	0.33790

Table 8. Differences of the ColorChecker24 patches between the single image and the stitched panoramas in CIE xy chromaticity diagram in Affinity Photo

In Tab. 9, the color deviation is more or less uniform. Only the red channel of the yellow patch has a substantial discrepancy.

For this scene, PTGUI is reliable for our purposes and holds the colors during the stitching process with only minor changes. However, it is essential to manually fix the exposure settings during recording to avoid exposure shifts between the panorama images.

ACES2065-1	Absolute Differences CR2		
patch	Red	Green	Blue
blue sky	0.00520	0.00200	0.00199
foliage	0.00368	0.00213	0.00762
blue flower	0.00346	0.00314	0.00173
bluish green	0.00372	0.00334	0.00765
orange	0.00010	0.00439	0.00273
purplish blue	0.00389	0.00184	0.00643
moderate red	0.01065	0.00173	0.00027
purple	0.00280	0.00130	0.00349
yellow green	0.00527	0.00355	0.00020
orange yellow	0.00487	0.00362	0.00092
blue	0.00879	0.00517	0.00103
green	0.00911	0.00434	0.00261
red	0.00353	0.00118	0.00523
yellow	0.07120	0.00194	0.00255
magenta	0.00399	0.00037	0.00525
cyan	0.00693	0.00890	0.00790
white 9.5	0.00736	0.00151	0.00182
neutral 8	0.00073	0.00182	0.00664
neutral 6.5	0.02017	0.01599	0.00953
neutral 5	0.01126	0.00937	0.00477
neutral 3.5	0.00962	0.00783	0.00287
black 2	0.00025	0.00000	0.00822
blue sky	0.00395	0.00191	0.00037
foliage	0.00067	0.00174	0.00832
Sum (ABS)	0.20120	0.08911	0.10014

Table 9. Differences of the ColorChecker24 patches between the single image and the stitched panorama for the CR2 sequence

5. Panorama creation and evaluation in PTGUI for the Apple DNG image sequence

First, we develop the DNG image sequence using Formula 3. The image sequence consists of 16 images with steps of 22.5° apart in a circle recording pattern. We used the 24 mm lens (35 mm equivalence) of the Apple iPhone 12 pro max device and zoomed in with a factor of 1.1 to achieve the same angle of view as with the lens for the Canon camera. For all other parameters, we used the default settings. With these settings, the panorama will have a width

of ca. 22 000 pixels, which is too small to meet the pixel count of mapped images in Recommendation ITU-R BT.2123-0.

5.1. Stitching the images in PTGUI

The stitching process in PTGUI is the same as described in section 4.1 with the CR2 images. It turned out that one image of the sequence could not be adequately developed and was left out of the stitching process. As a result, it left a small black space in the complete panorama.

5.2. Evaluating the ColorChecker24 patches in the stitching process

For evaluating, we are concentrating on selected patches of the ColorChecker24 chart (skin tones, primary and secondary colors, white and neutral 5). Again, we calculate the difference between the original image and the appearance of the color chart in the partially stitched panoramas, this time for the Apple DNG images. The color values for all patches in the stitched image are scaled. So, the value of the green channel for the Neutral 5 patch matches the value of the same patch in the original image. The results for the ACES-2065-1 color space are shown in Tab. 10. The results for the CIE xy chromaticity diagram are shown in Tab. 11.

ACES2065-1	Differences to original color chart		
PTGUI/DNG	Red	Green	Blue
Single - 0 2	0.07493	0.07702	0.09859
Single - 0 4	0.08857	0.08247	0.07408
Single - 0 6	0.11907	0.07981	0.07292
Single - Full Panorama	0.13067	0.07642	0.09894

Table 10. Differences of the ColorChecker24 patches between the single image and the stitched panoramas in ACES2065-1 color space for PTGUI

CIE xy	Differences to original color chart	
PTGUI/DNG	x	y
Single - 0 2	0.07781	0.10806
Single - 0 4	0.09848	0.08856
Single - 0 6	0.08722	0.08634
Single - Full Panorama	0.09551	0.09046

Table 11. Differences of the ColorChecker24 patches between the single image and the stitched panoramas in CIE xy for PTGUI

The image sequence displays only minor changes in the panorama stitching process for the green and blue ACES channels. The deviation of the red channel is increased, but not significantly.

5.3. Comparing the results between Canon CR2 and Apple DNG panoramas

This section compares the panorama stitching process results for the CR2 and DNG image sequences.

The different noise patterns between the CR2 and DNG panoramas are evident. However, they are still not very obvious in

the original images with the ColorChecker24 chart. The substantial noise reduction in the iPhone images creates visible chunks. They make one hand evaluation more complex and, on the other hand, lead to an unattractive image structure (Fig. 12). With the CR2 panorama, these chunks are also present but much less pronounced. Thus, there is not much difference between the original image with the ColorChecker24 chart and its appearance in the panorama. (Fig. 13).

ACES2065-1	Absolute Differences DNG		
patch	Red	Green	Blue
dark skin	0.0054	0.0071	0.0147
light skin	0.0281	0.0060	0.0020
blue sky	0.0053	0.0008	0.0224
foliage	0.0058	0.0129	0.0057
blue flower	0.0001	0.0055	0.0208
bluish green	0.0178	0.0068	0.0171
orange	0.0079	0.0031	0.0126
purplish blue	0.0080	0.0026	0.0310
moderate red	0.0236	0.0030	0.0184
purple	0.0060	0.0093	0.0021
yellow green	0.0036	0.0056	0.0039
orange yellow	0.0197	0.0142	0.0040
blue	0.0094	0.0049	0.0371
green	0.0109	0.0043	0.0068
red	0.0038	0.0165	0.0061
yellow	0.0268	0.0082	0.0064
magenta	0.0238	0.0092	0.0105
cyan	0.0159	0.0148	0.0077
white 9.5	0.0007	0.0056	0.0039
neutral 8	0.0165	0.0106	0.0148
neutral 6.5	0.0040	0.0181	0.0144
neutral 5	0.0060	0.0000	0.0037
neutral 3.5	0.0012	0.0010	0.0034
black 2	0.0036	0.0037	0.0194
Sum (ABS)	0.2537	0.1736	0.2889

Table 12. Differences of the ColorChecker24 patches between the single image and the stitched panorama for the DNG sequence

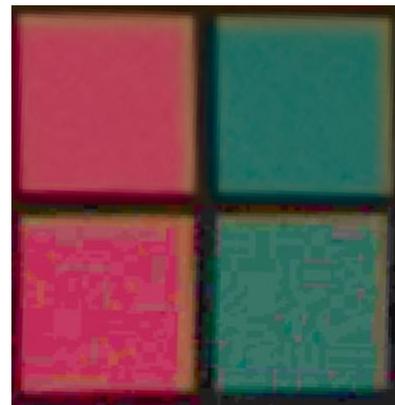


Figure 12. Noise in the DNG images (above appearance in original image, below in panorama)

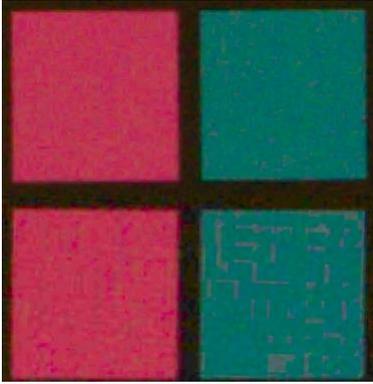


Figure 13. Noise in the CR2 images (above appearance in original image, below in panorama)

In the ACES color space, the total error sum for the green channel is two times higher for the DNG sequence than for the CR2 sequence; and three times higher for the blue channel. There is only one patch whose green channel has an error greater than 0.01. Furthermore, the blue channel has none. The red channel has one patch (neutral 6.5) with an error greater than 0.02 and two with an error greater than 0.01. This result would be excellent if patch yellow did not have a very high deviation of 0.07 in comparison. Why this error is so high is not immediately apparent. Possibly the stitching algorithm in PTGUI has increased the yellowish character of the panorama (Tab. 9).

For the iPhone-DNG image panorama, the differences in the color patches between the original image and the panorama are more evident. The red channel exhibits four patches with an error greater than 0.02 and for patches with an error greater than 0.01. The errors of the green channel are relatively moderate. There are five patches with an error greater than 0.01. The blue channel shows two patches with an error greater than 0.03, two with an error greater than 0.02, and 9 with an error greater than 0.01. Thus, more than half of the patches have an error greater than 0.01 (Tab. 12).

Any errors arising from the experimental finding of the multiplier values can be neglected. However, the iPhone's substantial noise reduction and chunk formation possibly play an important role and lead to more significant errors.

CIE xy	Differences panorama – original color chart	
	x	y
PTGUI		
CR2 with black patch	0.0834	0.1230
CR2 without black patch	0.0636	0.0915
DNG with black patch	0.2216	0.2932
DNG without black patch	0.1743	0.2360

Table 13. Differences of the ColorChecker24 patches between the single image and the stitched panorama for CR2 and DNG sequences

The total errors for the CIE xy color space are displayed in Table 13. This color space displays only the pure color values without the luminance and is another tool for evaluating the process. In the table, the results are depicted. They contain the color differences with all the 24 patches on the one hand, and on the other hand, they exclude

the errors of the black patch. They are significantly high due to the image noise in the patch. The values demonstrate that the colors of the CR2 Panorama are more reliable than the colors of the iPhone panorama.

6. Importing and adjusting the Canon Mark IV video

Mark IV video has a 4096 x 2160 pixels resolution and is encoded with the MotionJPEG codec. The first task is to find out the correct Rec.709 gamma settings. Due to our paper [16] and recent development, there are four OpenColorIO input possibilities with different gamma settings without render intent curves (f. i. ACES Output-Rec.709)

OCIO name.	Gamma
Rec.709 texture 1.8	1.8
Rec.709 camera	1.95
Rec.709 texture 2.28	2.2
Rec.709 display	2.4

Table 14. Rec.709 Inputs in OpenColorIO (v1.0)

To determine which gamma curve is applied in the recording, we import the Mark IV video using the four OCIO possibilities shown in Tab. 14. Then the patch Neutral 5 is color corrected in all three color channels to match the values of the CR2 Panorama. We do not match the video to the single image with the color checker because our goal is to match the stitched panorama and the video.

Green Color Ch.	Rec.709 Texture	Rec.709 Camera	Rec.709 Texture	Rec.709 Display
Gamma	1.8	1.95	2.2	2.4
white 9.5	1.0170	1.0530	1.4553	1.7407
neutral 8	0.7672	0.7762	1.0311	1.1953
neutral 6.5	0.4809	0.4750	0.5828	0.6415
neutral 5	0.2024	0.2024	0.2024	0.2024
neutral 3.5	0.0557	0.0680	0.0419	0.0363
black 2	0.0085	0.2144	0.0042	0.0030
Gain	1.66660	1.8204	2.66110	3.36220
Difference	0.81452	0.85060	1.25285	1.53830

Table 15. Video values for the green channel for grayscale ColorChecker24 patches, difference between patches white 9.5 and neutral 5

The *Rec.709 Texture 1.8* option is not technically correct because video content is rarely encoded with a transfer function of 1.8. However, we want a close match of the video color to the panorama, so we investigate both options. The luminance difference between patch *Neutral 5* and patch *White 9.5* is slightly more in the expected range for the *Rec.709 Texture 1.8* option than the *Rec.709 camera* option. Nevertheless, when calculating the differences between video and panorama for all patches, the differences for the green and blue channels are better for the *Rec.709 camera* option. When converting the images to the CIE xy chromaticity diagram, the differences for the *Rec.709 camera* options are significantly more minor, above all in the y-direction (Tab.16).

ACES2065-1	R	G	B
Rec.709 camera	1.1543	1.0970	0.8221
Rec.709 texture 1.8	1.1470	1.1475	0.8741
CIE xy	x	y	
Rec.709 camera	0.3006	0.2160	
Rec.709 texture 1.8	0.3000	0.3017	

Table 16. Differences for all ColorChecker24 patches between the panorama and Mark IV video for OCIO Inputs Rec.709 camera and Rec.709 texture 1.8

7. Comparing the ACES workflow with recent workflow

The existing workflow follows the one described in the paper [1]. The CR2 image sequence is stitched in PTGUI without further color conversion. The panorama is then imported into Nuke with the default color management (i. e., without OCIO and ACES). There are no primary or white point conversions, and only the sRGB transfer function is removed. Then, the video is imported with the default Rec.709 settings. We also scale the video to the panorama. The patch white 0.95 is scaled to 0.9131 for all three color channels to match the luminance settings according to the values in the paper [17]. The video is scaled the same way. The differences between the CR2 panorama and the Rec.709 video for the new workflow are depicted in Appendix B. The positions of the ColorChecker24 patches in the CIE xy chromaticity diagram are shown in Fig. 14.

We cannot compare the results in one common color space because conversion would require additional color space. We compare the differences between still image panorama and video in the respective systems to avoid this.

The first system is the new one and consists of the following steps:

1. Developing the CR2 images in ddraw to ACES2065-1
2. Generating the still image panorama in PTGUI
3. Importing the panorama into Nuke's ACES2065-1 color space without further conversion
4. Importing the video via OCIO, using the Rec.709 camera import settings
5. Scaling both elements to match the ColorChecker24 patch *Neutral 5*
6. Calculating the differences in ACES2065-1
7. Converting the color space to the CIE xy chromaticity diagram and calculating the differences

The second system is our existing one and consists of the following steps:

1. Importing the CR2 sequence into PTGUI
2. Generating the still image panorama in PTGUI
3. Importing the panorama into Nuke's ACES2065-1 color space with the default sRGB settings
4. Importing the video into Nuke using the Rec.709 settings
5. Scaling both elements to match the patch White 0.95 according to the values in paper [17]
6. Calculating the differences in linear sRGB/Rec709 color space

7. Converting the color space to the CIE xy chromaticity diagram and calculating the differences

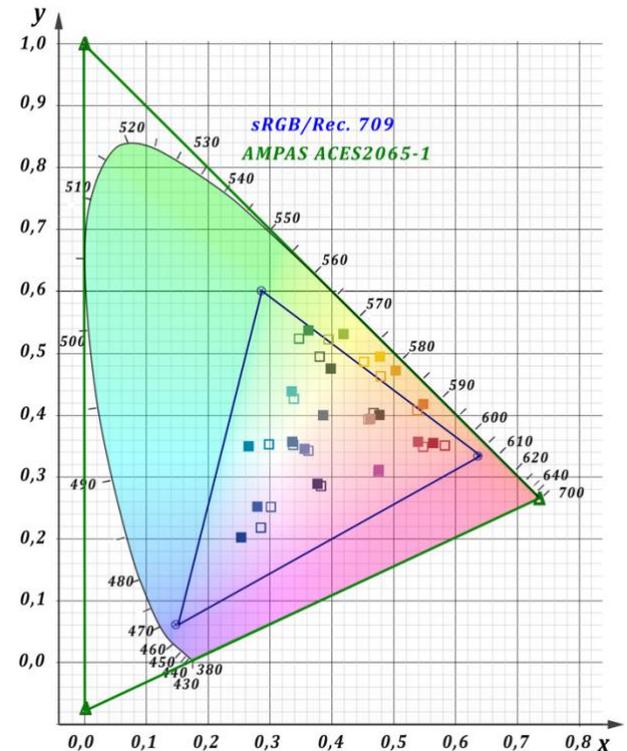


Figure 14. Position of ColorChecker24 patches in CIE xy chromaticity diagram – New Workflow: Panorama solid, Video outlined

Again, our goal for evaluating the existing workflow is to minor differences between the still image panorama and the video. The full results and differences between the CR2 panorama and the Rec.709 video for the existing workflow are depicted in Appendix C. In addition, the position of the ColorChecker24 patches in the CIE xy chromaticity diagram is shown in Fig. 15.

8. Conclusions and further research

The new ACES-based workflow for the Canon imagery improves the existing sRGB/Rec.709 workflow. It offers more flexibility with the ddraw development and the power of the ACES system in Nuke.

Workflow	ACES2065-1			CIE xy	
	Red	Green	Blue	x	y
New	1.1543	1.0970	0.8221	0.3006	0.2160
Existing	0.9421	1.1029	0.7913	0.4103	0.5407

Table 17. Differences between still image panorama and video for all ColorChecker24 patches between the new and existing workflow

Comparing the existing workflow with the new workflow (Tab. 17) shows slightly fewer differences between the video and

panorama. The CIE xy chromaticity diagram differences are more significant than in the ACES color space, above all in the y-direction. Because the ACES results contain luminance values, they may be easier to scale than the pure color in CIE xy. In this color space, the new workflow is significantly better. Interestingly, the darker patches show the most considerable differences (indicated with an arrow). It is also evident that this workflow shifts the panorama patches towards the boundary of the sRGB/Rec.709 gamut.

The Apple DNG based panorama encompasses only two-thirds of the Canon CR2 resolution (without further zooming). It delivers more color differences between the original image and the panorama, and a somewhat strange noise responsibility appears. So, some research dealing with these issues is needed.

The first part of our future testing consists of the following topics:

1. Generating a list of correct multipliers for Apple iPhone 12 DNG images using a controlled lighting environment
2. Testing import into Nuke via rawtoaces for DNG images
3. Testing import into Nuke via rawtoaces for CR2 images

Also, we will test the iPhone Dolby video possibilities in an HDR scenario. Also, we will test the iPhone Dolby video possibilities in an HDR scenario

Furthermore, we want to deal with the spatial resolution and test several lens distortion removals to undistort the Mark IV videos.

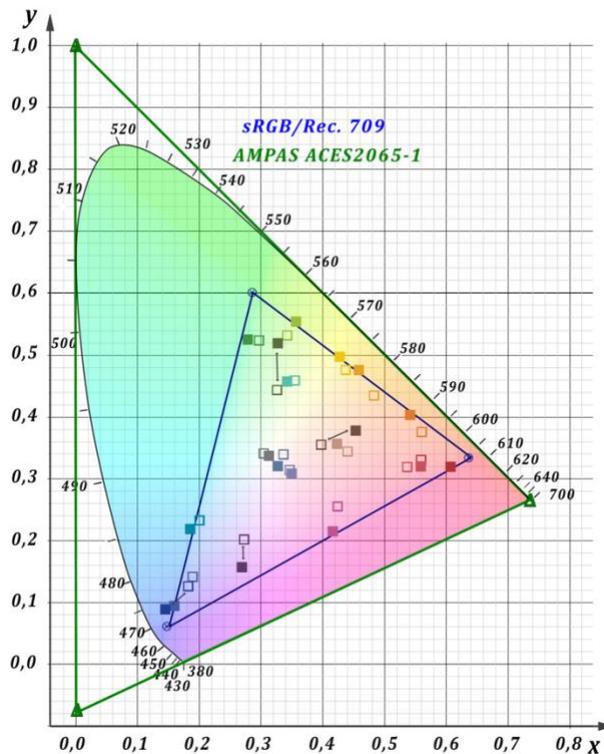


Figure 15. Position of ColorChecker24 patches in CIE xy chromaticity diagram – Existing Workflow: Panorama solid, Video outlined

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Appendix A

iPhone ACES2065-1	RAW Multipliers					ACES values for patch Neutral 5 after scaling to green: 0.20243		
	Red	Green1	Blue	Green2	Gain	Red	Green	Blue
Reference Neutral 5 CR2						0.21645	0.20243	0.10506
Iteration	2.107 422	1.000 000	1.352 539	1.000 000	6.7208	0.1977	0.20243	0.05792
1	2.200 000	1.000 000	1.500 000	1.000 000	6.7214	0.20517	0.20243	0.07301
2	2.300 000	1.000 000	2.000 000	1.000 000	6.7334	0.21776	0.20243	0.1231
3	2.350 000	1.000 000	1.700 000	1.000 000	6.7538	0.2108	0.20243	0.09301
4	2.280 000	1.000 000	1.800 000	1.000 000	6.7428	0.21391	0.20243	0.10307
5	2.290 000	1.000 000	1.900 000	1.000 000	6.7477	0.21582	0.20243	0.11304
6	2.290 000	1.000 000	1.850 000	1.000 000	6.7504	0.21517	0.20243	0.10808
7	2.293 000	1.000 000	1.830 000	1.000 000	6.7497	0.2151	0.20243	0.10611
8	2.296 000	1.000 000	1.820 000	1.000 000	6.7497	0.21513	0.20243	0.10512
9	2.310 000	1.000 000	1.818 000	1.000 000	6.7507	0.21595	0.20243	0.10502
10	2.318 000	1.000 000	1.818 400	1.000 000	6.7513	0.21642	0.20243	0.10507

Table 18. Iterative approach to find the matching 6000K multipliers in dcrw for the Apple iPhone 12 Max Pro

Appendix B

Canon EOS 5D Mark IV New Workflow		ACES2065-1			CIE xy chromaticity diagram	
Patch Nr.	Patch Name	Red	Green	Blue	x	y
1	dark skin	0.0478	0.0277	0.0102	0.0104	0.0033
2	light skin	0.0457	0.0327	0.0199	0.0029	0.0021
3	blue sky	0.0189	0.0120	0.0171	0.0029	0.0057
4	foliage	0.0290	0.0174	0.0090	0.0170	0.0199
5	blue flower	0.0530	0.0246	0.0450	0.0054	0.0134
6	bluish green	0.1321	0.1400	0.0920	0.0039	0.0122
7	orange	0.0162	0.0075	0.0202	0.0103	0.0101
8	purplish blue	0.0224	0.0027	0.0089	0.0227	0.0012
9	moderate red	0.0074	0.0160	0.0021	0.0082	0.0087
10	purple	0.0192	0.0141	0.0177	0.0063	0.0041
11	yellow green	0.0916	0.1525	0.0531	0.0239	0.0080
12	orange yellow	0.0542	0.0697	0.0469	0.0238	0.0092
13	blue	0.0158	0.0004	0.0106	0.0317	0.0157
14	green	0.0311	0.0549	0.0241	0.0134	0.0124
15	red	0.0229	0.0147	0.0104	0.0185	0.0049
16	yellow	0.0838	0.1160	0.0622	0.0237	0.0095
17	magenta	0.0223	0.0072	0.0122	0.0008	0.0026
18	cyan	0.0715	0.0533	0.0371	0.0331	0.0030
19	white 9.5	0.0966	0.0914	0.1214	0.0089	0.0130
20	neutral 8	0.1458	0.1280	0.1153	0.0069	0.0116
21	neutral 6.5	0.0797	0.0741	0.0601	0.0065	0.0084
22	neutral 5	0.0000	0.0000	0.0000	0.0001	0.0001
23	neutral 3.5	0.0337	0.0295	0.0121	0.0114	0.0075
24	black 2	0.0138	0.0108	0.0147	0.0081	0.0293
	Sum	1.1543	1.0970	0.8221	0.3006	0.2160

Table 19. Differences between Canon CR2 panorama and MARKIV video in ACES2065-1 and CIE xy color space (new workflow)

Appendix C

Canon EOS 5D Mark IV Existing Workflow		ACES2065-1			CIE xy chromaticity diagram	
Patch Nr.	Patch Name	Red	Green	Blue	x	y
1	dark skin	0.0339	0.0061	0.0024	0.0546	0.0227
2	light skin	0.1027	0.0771	0.0380	0.0176	0.0137
3	blue sky	0.0002	0.0212	0.0788	0.0195	0.0182
4	foliage	0.0004	0.0347	0.0066	0.0026	0.0759
5	blue flower	0.0441	0.0205	0.0881	0.0012	0.0048
6	bluish green	0.0360	0.0648	0.0579	0.0135	0.0007
7	orange	0.0297	0.0758	0.0176	0.0199	0.0407
8	purplish blue	0.0229	0.0119	0.0853	0.0392	0.0499
9	moderate red	0.1099	0.0108	0.0024	0.0229	0.0090
10	purple	0.0075	0.0051	0.0122	0.0032	0.0437
11	yellow green	0.0447	0.0736	0.0318	0.0152	0.0216
12	orange yellow	0.0390	0.1767	0.0197	0.0261	0.0402
13	blue	0.0135	0.0055	0.0110	0.0360	0.0374
14	green	0.0261	0.0813	0.0062	0.0193	0.0317
15	red	0.0809	0.0109	0.0034	0.0463	0.0119
16	yellow	0.0053	0.1482	0.0240	0.0108	0.0238
17	magenta	0.1027	0.0267	0.0697	0.0095	0.0400
18	cyan	0.0222	0.0319	0.0804	0.0162	0.0045
19	white 9.5	0.0000	0.0000	0.0000	0.0000	0.0000
20	neutral 8	0.0971	0.0864	0.0492	0.0064	0.0076
21	neutral 6.5	0.0768	0.0869	0.0723	0.0006	0.0056
22	neutral 5	0.0378	0.0382	0.0276	0.0081	0.0150
23	neutral 3.5	0.0069	0.0061	0.0039	0.0087	0.0126
24	black 2	0.0018	0.0025	0.0028	0.0131	0.0096
	Sum	0.9421	1.1029	0.7913	0.4103	0.5407

Table 20. Differences between Canon CR2 panorama and MARKIV video in ACES2065-1 and CIE xy color space (existing workflow)