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Abstract

Recently, AI-based techniques have been used quite frequently in video coding experiments. Software modules often operate on RGB representations, while others, including input and output modules, operate on YC_BCR components. In this study, we examine the quality losses resulting from color-space transformations. It is clear that these losses must be considered when developing software for prospective new standards.

1 Introduction

Visual data is expressed in various color spaces. The plethora of color coordinate systems constitutes a field of study in itself. However, most electronic and computer engineering students never study this topic in depth, so they rarely pay close attention to it in their professional lives.

This observation is also related to research on image and video compression. The problem has become even more pronounced due to the use of various software programs that operate on video represented in different color spaces. These approaches result in the application of color transformations.

This paper aims to highlight that color transformations result in image/video quality loss.

2 Color spaces

In video technology, digital data is mostly represented in YC_BC_R color spaces due to the low correlation between color components. In video research and standardization, the YUV annotation is often used. Unfortunately, this annotation is incorrect because it refers to the color coordinates of the now-defunct European analog television system. For most works, it is merely a naming problem. Moreover, several variants of the YC_BC_R color space are used in digital television. For example, there are different YC_BC_R variants designed for standard definition television, high definition television, and ultra high definition television. In these color spaces, the coordinate values for a given color are different. Nevertheless, this issue is often not carefully considered, and it does not cause problems as long as the entire processing path is based on a single color space.

In machine vision, the RGB representations are often used, and people often do not take care about the version of the RGB color space. Again, it causes no problem as long a single color space is in use.

Recently, the standardization video experts tend to use mixtures of software modules that operate both on RGB and YC_BC_R representations. Such modus operandi needs:

1. Care on versions of RGB and YC_BC_R and the usage of proper transformations between selected versions of RGB and YC_BC_R color spaces;
2. The video quality losses due to color transformations need to taken into account.

This contrition focuses mostly on the latter problem.

3 Color transformations

In general, the color transformations between RGB and YC_BC_R may expressed as [2]

$$\begin{bmatrix} D \\ E \\ F \end{bmatrix} = \begin{bmatrix} c_1 \\ c_2 \\ c_3 \end{bmatrix} + \frac{1}{256} \begin{vmatrix} t_{11} & t_{12} & t_{13} \\ t_{21} & t_{22} & t_{23} \\ t_{31} & t_{32} & t_{33} \end{vmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix},$$

$$\begin{bmatrix} R \\ G \\ B \end{bmatrix} = \frac{1}{256} \begin{bmatrix} s_{11} & s_{12} & s_{13} \\ s_{21} & s_{22} & s_{23} \\ s_{31} & s_{32} & s_{33} \end{bmatrix} \begin{bmatrix} D - c_1 \\ E - c_2 \\ F - c_3 \end{bmatrix}, \qquad (1)$$

where RGB and YC_BC_R component values are integers and

$D = Y, \; E = C_B, \; F = C_R$.

Most of the MPEG/JVET work is done for

$$c_1 = c_2 = c_3 = 0 \;, \qquad (2)$$

whereas the values

$$c_1 = 16, \quad c_2 = c_3 = 128 \qquad (3)$$

are common in television technology. The latter version of equations prevents underflow and overflow in the YC_BC_R components.

4 Color transformations on integer samples

Color component samples are represented as integers, mostly as 8- or 10-bit numbers. The calculations are executed on higher-accuracy representations and the results are rounded to the assumed number of bits in the representation format chosen.

After the transformation cycle RGB → YC_BC_R → RGB, the RGB values are rounded to *N* bits (e.g. N=8 or N=10), i.e. there emerge rounding errors

$$\delta_R = R^{rd} - R$$
$$\delta_G = G^{rd} - G$$
$$\delta_B = B^{rd} - B \qquad (4)$$

where

$R,\ G$ and B

are the exact values and

$R^{rd},\ G^{rd},\ B^{rd}$

are the integer values rounded to *N* bits.

According to Preposition 1 from [1]

$$|\delta_R| \le L_R, |\delta_G| \le L_G, |\delta_B| \le L_B \;,$$
$$L_R = round[(|s_{11}| + |s_{12}| + |s_{13}|)/2]$$
$$L_G = round[(|s_{21}| + |s_{22}| + |s_{23}|)/2]$$
$$L_B = round[(|s_{31}| + |s_{32}| + |s_{33}|)/2] \qquad (5)$$

if

$$\begin{aligned}(|t_{11}|+|t_{12}|+|t_{13}|)&<1\\(|t_{21}|+|t_{22}|+|t_{23}|)&<1\\(|t_{31}|+|t_{32}|+|t_{33}|)&<1\end{aligned} \quad . \qquad (6)$$

For color transformations RGB → YC_BC_R , the conditions (6) usually hold if the version with (3) is used. For transformations with the property (2) the condition (6) does not hold as the sums of the rows of t_{ij} coefficients are exactly equal to 1. For example, see for the formulas defined in BT.709 [3] with the conditions (3) the property (6) holds

$$\mathbf{T}=\frac{1}{256}\begin{bmatrix}46.742 & 157.243 & 15.874\\ -25.765 & -86.674 & 112.439\\ 112{,}439 & -102.129 & -10.310\end{bmatrix} \qquad (7)$$

Remark: This Preposition 1 holds if condition (6) holds and no saturation or overflow occurs at the ends of the interval (0, 2^{N-1}) for RGB.

In practice, such phenomena occur, and the rounding errors exceed the limits (5) for a small number of RGB samples, often below 1% of samples.

Moreover, if the Remark is true, after the first cycle, all consecutive cycle of forward and backward do not influence the rounded values

$R^{rd}, G^{rd}, \bar{B}^{rd}$

obtained in the first cycle [1]. This property holds if condition (6) holds and no saturation or overflow occurs at the ends of the interval (0, 2^{N-1}) for RGB. In practice, such phenomena occur, and some further rounding occur on the RGB values even if condition (6) holds. Nevertheless the numbers of the rounded samples decay in the consecutive color transformation cycles and usually no further rounding occurs after second or third cycle of color transformation [3].

5 Experimental examples

The experiments are provided for the image database TID2013 [4] and for the BT.709 color transformation.

5.1 Consecutive cycles of color transformations

Table 1. PSNR after one, two and three cycles of BT.709 color transformation RGB → YC_BC_R → RGB with condition (3)

	First cycle			Second cycle			Third cycle		
Image	PSNR R	PSNR G	PSNR B	PSNR R	PSNR G	PSNR B	PSNR R	PSNR G	PSNR B
I01.BMP	52.67908	56.61716	51.20734	52.67908	56.61716	51.20725	52.67908	56.61716	51.20725
I02.BMP	52.10277	58.23516	51.40239	52.10271	58.23516	51.40108	52.10271	58.23516	51.40108
I03.BMP	51.99614	56.82355	51.09728	51.99566	56.82208	51.09356	51.99566	56.82208	51.09356
I04.BMP	52.32084	57.48157	51.64287	52.32066	57.48157	51.64277	52.32066	57.48157	51.64277
I05.BMP	52.28321	57.43408	51.98352	52.2824	57.4322	51.98041	52.2824	57.4322	51.98041
I06.BMP	52.54568	57.2812	51.49117	52.54562	57.28102	51.49074	52.54562	57.28102	51.49074
I07.BMP	52.15066	56.58176	51.81179	52.15044	56.58053	51.81034	52.15044	56.58053	51.81034
I08.BMP	52.42622	57.05729	51.68057	52.42586	57.05643	51.67897	52.42586	57.05643	51.67897
I09.BMP	51.53947	58.47231	51.28803	51.53947	58.47231	51.28761	51.53947	58.47231	51.28761
I10.BMP	52.33059	57.31164	51.75081	52.33053	57.31164	51.75081	52.33053	57.31164	51.75081
I11.BMP	51.55067	57.58961	51.09912	51.55058	57.58883	51.09864	51.55058	57.58883	51.09864
I12.BMP	51.84969	57.15358	51.63128	51.84969	57.15358	51.63128	51.84969	57.15358	51.63128
I13.BMP	52.40572	57.03956	51.67172	52.40572	57.03956	51.67052	52.40572	57.03956	51.67052
I14.BMP	52.42818	56.52538	52.09043	52.42788	56.52523	52.08741	52.42788	56.52523	52.08741
I15.BMP	52.52989	57.08429	50.94621	52.52989	57.08429	50.94325	52.52989	57.08429	50.94325
I16.BMP	51.86929	56.73776	50.65336	51.86929	56.73776	50.65328	51.86929	56.73776	50.65328
I17.BMP	53.15131	56.73392	52.26858	53.15103	56.7336	52.26806	53.15103	56.7336	52.26806
I18.BMP	52.36424	57.00465	51.82671	52.36336	57.0038	51.82511	52.36336	57.0038	51.82511
I19.BMP	52.38713	57.07718	51.34145	52.3866	57.07579	51.34067	52.3866	57.07579	51.34067
I20.BMP	54.22168	58.03118	51.63469	54.21209	58.02019	51.634	54.21209	58.02019	51.634
I21.BMP	52.44216	58.07763	51.30148	52.44109	58.07698	51.30148	52.44109	58.07698	51.30148
I22.BMP	52.4991	56.96985	51.86381	52.49506	56.95281	51.86381	52.49506	56.95281	51.86381
I23.BMP	52.49482	57.42412	51.34118	52.48909	57.41681	51.33083	52.48909	57.41681	51.33083
I24.BMP	52.43579	56.96799	51.72825	52.43519	56.96681	51.72825	52.43519	56.96681	51.72825
i25.bmp	52.68185	58.90357	52.16467	52.68185	58.90357	52.16467	52.68185	58.90357	52.16467
Average	**52.38745**	**57.30464**	**51.55675**	**52.38643**	**57.30279**	**51.55539**	**52.38643**	**57.30279**	**51.55539**

The condition (6) holds. For the first cycle of transformation 50-70% of RGB samples remain unchanged and this yields PSNR of order of 52-57 dB. The quality losses are negligible in the consecutive color transformation cycles.

Table 2. PSNR after one, two and three cycles of BT.709-like color transformation RGB → YC_BC_R → RGB with condition (2)

	First cycle			Second cycle			Third cycle		
image	PSNR R	PSNR G	PSNR B	PSNR R	PSNR G	PSNR B	PSNR R	PSNR G	PSNR B
I01.BMP	45.49162	53.91397	44.59724	40.05602	47.39801	38.79219	37.10725	43.49912	35.55439
I02.BMP	45.36974	55.03331	44.5536	40.00054	48.59197	38.71522	36.76381	44.47518	35.40036
I03.BMP	45.15977	56.50103	44.26564	39.42832	50.37576	38.02581	36.1187	46.12637	35.05045
I04.BMP	45.0343	56.06088	44.5039	39.37578	49.47984	38.83048	36.39127	44.96616	35.60505
I05.BMP	45.16405	54.83981	44.04154	39.71558	48.35381	38.49049	36.77342	44.03689	35.40772
I06.BMP	45.06526	55.05317	44.13555	39.81554	48.21487	38.57448	36.95966	43.95283	35.42404
I07.BMP	44.96443	55.97546	44.23344	39.67874	49.47196	38.63562	36.83516	45.10375	35.75593
I08.BMP	45.11341	55.29017	44.23242	39.70309	48.90587	38.63973	36.88688	44.54573	35.62661
I09.BMP	45.10541	55.83846	44.40609	39.98417	49.38049	38.54263	37.2592	45.24038	35.28223
I10.BMP	45.36392	55.02661	44.30534	40.27339	48.61875	38.6023	37.56556	44.4176	35.53238
I11.BMP	45.22485	55.86119	44.66924	39.40158	49.50011	39.03361	36.18862	45.26623	35.58012
I12.BMP	44.86796	55.55524	44.0599	39.41202	48.74275	38.68563	36.59135	44.42374	35.45013
I13.BMP	45.1532	54.95351	44.27374	39.83224	48.30682	38.56653	36.99155	44.16363	35.5757
I14.BMP	45.17911	54.90385	44.25666	39.81264	48.47941	38.70616	36.97233	44.1829	35.66978
I15.BMP	45.25787	55.74169	44.17313	39.82887	49.37248	38.83441	36.98676	45.12011	35.82899
I16.BMP	44.99486	55.34007	44.20636	39.46956	49.12386	38.19594	36.23138	45.54607	35.39381
I17.BMP	44.96678	54.54309	44.0855	39.48789	48.16997	38.6081	36.54747	43.77339	35.41229
I18.BMP	45.06274	55.25449	44.17177	39.51471	48.87377	38.67056	36.41646	44.63217	35.55102
I19.BMP	45.01506	55.78318	44.03392	39.56102	49.12745	38.25182	36.68185	44.92047	35.23868
I20.BMP	45.76388	54.76111	44.87835	40.39	48.12101	39.53015	37.27851	43.98306	36.47335
I21.BMP	44.98805	55.51551	44.03192	39.55697	49.45853	38.20693	36.49682	45.39465	34.99411
I22.BMP	45.21114	55.01236	43.98114	39.69744	48.6764	38.31781	36.75766	44.50844	35.35268
I23.BMP	45.23086	55.47745	44.2226	39.74501	48.86927	38.46936	36.88119	44.57551	35.38428
I24.BMP	45.03654	55.02628	44.31765	39.46476	48.61058	38.39022	36.3364	44.45635	35.07231
i25.bmp	46.42153	55.01118	45.87505	40.49559	48.48902	39.41835	37.38462	44.48426	36.40407
Average	**45.20825**	**55.29092**	**44.34047**	**39.74806**	**48.82851**	**38.62938**	**36.77616**	**44.6318**	**35.52082**

For the results from Table 2 condition (6) does not hold and the loss of quality due to color transformations is significantly higher than for the case when the condition (6) holds. As before the quality loses in the consecutive cycles are smaller.

5.2 Consecutive color transformations with YC_BC_R manipulations

Here, we demonstrate how luma and chroma manipulations influence image quality. The experiment flow is as follows:

Step 1: RGB → YC_RC_B .
Step 2: The values of YC_RC_B samples are multiplied by 0.9 (float).
Step 3: YC_RC_B → RGB . (end of the first cycle)
Step 4: RGB → YC_RC_B .
Step 5: The values of YC_RC_B samples are multiplied by 1/0.9 (float).
Step 6: YC_RC_B → RGB . (end of the second cycle)
Step 7: RGB → YC_RC_B .
Step 8: YC_RC_B → RGB . (end of the third cycle)

Table 3. The RGB PSNR after cycles of color transformations with luma and chroma manipulations for the case when conditions (3) holds

	First cycle			Second cycle			Third cycle		
image	PSNR R	PSNR G	PSNR B	PSNR R	PSNR G	PSNR B	PSNR R	PSNR G	PSNR B
I01.BMP	51.73078	55.8472	50.6549	51.73078	55.8472	50.65478	51.73078	55.8472	50.65478
I02.BMP	51.74858	55.66953	50.82726	51.74842	55.66903	50.82537	51.74842	55.66903	50.82537
I03.BMP	52.0696	55.70818	50.95301	52.06746	55.70477	50.9495	52.06746	55.70477	50.9495
I04.BMP	51.77723	55.40008	51.05311	51.77723	55.40008	51.05255	51.77723	55.40008	51.05255
I05.BMP	51.40714	55.53369	51.10043	51.40601	55.53199	51.09575	51.40601	55.53199	51.09575
I06.BMP	52.13147	55.89565	51.38227	52.13025	55.89552	51.38035	52.13025	55.89552	51.38035
I07.BMP	51.69369	55.98866	51.27498	51.69309	55.98812	51.27352	51.69309	55.98812	51.27352
I08.BMP	51.74304	55.73316	50.90104	51.74	55.72846	50.89694	51.74	55.72846	50.89694
I09.BMP	51.71043	55.79774	51.0649	51.70973	55.79774	51.0633	51.70973	55.79774	51.0633
I10.BMP	51.95055	56.1497	50.92724	51.9481	56.1497	50.92157	51.9481	56.1497	50.92157
I11.BMP	51.31461	55.77059	51.79799	51.31424	55.77033	51.7965	51.31424	55.77033	51.7965
I12.BMP	51.73437	55.71641	51.1396	51.7323	55.71641	51.13656	51.7323	55.71641	51.13656
I13.BMP	51.67182	55.69253	50.85894	51.66918	55.69253	50.85356	51.66918	55.69253	50.85356
I14.BMP	51.80931	55.77791	50.73733	51.80875	55.77624	50.73282	51.80875	55.77624	50.73282
I15.BMP	51.97955	56.25167	50.83125	51.97955	56.25167	50.82771	51.97955	56.25167	50.82771
I16.BMP	51.76655	55.71869	50.92321	51.7665	55.71869	50.92308	51.7665	55.71869	50.92308
I17.BMP	51.70138	55.45759	51.26578	51.70107	55.45747	51.26469	51.70107	55.45747	51.26469
I18.BMP	51.91525	55.66853	51.23466	51.91398	55.6664	51.23227	51.91398	55.6664	51.23227
I19.BMP	51.69159	55.57666	50.79438	51.68813	55.56894	50.79352	51.68813	55.56894	50.79352
I20.BMP	52.15696	56.49133	51.19377	52.01469	56.48845	50.88131	52.01469	56.48845	50.88131
I21.BMP	51.40793	55.60892	51.10845	51.40446	55.60867	51.09934	51.40446	55.60867	51.09934
I22.BMP	51.84356	55.7192	50.82118	51.83769	55.7102	50.82069	51.83769	55.7102	50.82069
I23.BMP	51.83173	55.71894	51.27484	51.82966	55.71273	51.25947	51.82966	55.71273	51.25947
I24.BMP	51.54422	55.70654	51.0196	51.54199	55.70565	51.01535	51.54199	55.70565	51.01535
i25.bmp	51.87227	57.59312	52.0988	50.64295	56.10971	50.81253	50.64295	56.10971	50.81253
Average	**51.76814**	**55.84769**	**51.08956**	**51.71185**	**55.78667**	**51.02252**	**51.71185**	**55.78667**	**51.02252**

Of course, the quality is worse, although theoretically the original image is recovered.

Table 4. The RGB PSNR after cycles of color transformations with luma and chroma manipulations for the case when conditions (2) holds

	First cycle			Second cycle			Third cycle		
Image	PSNR R	PSNR G	PSNR B	PSNR R	PSNR G	PSNR B	PSNR R	PSNR G	PSNR B
I01.BMP	44.25201	54.20385	43.3593	38.72538	47.9528	37.57554	36.07909	44.19977	34.29805
I02.BMP	43.93597	54.7385	43.03331	38.43253	48.42982	37.59896	35.55279	44.6646	34.47466
I03.BMP	44.48581	54.49913	42.79828	38.66914	48.36212	37.46624	36.03246	44.60199	34.34074
I04.BMP	44.15353	54.06601	43.12043	38.53484	47.81246	37.53835	35.73608	44.14177	34.32178
I05.BMP	44.12237	54.377	43.2849	38.59008	48.10387	37.67316	35.88202	44.33497	34.48196
I06.BMP	44.20501	54.2377	43.3049	38.74809	48.15009	37.66072	36.16378	44.47502	34.50017
I07.BMP	43.84415	54.37374	43.28908	38.4764	47.97582	37.54913	35.82073	44.24049	34.35885
I08.BMP	44.43561	54.00408	43.32685	38.7309	47.86566	37.59703	36.00885	44.17239	34.44656
I09.BMP	44.41417	53.98567	43.41269	39.04713	47.77715	37.64978	36.40557	44.10921	34.47117
I10.BMP	44.16152	54.19795	43.33394	38.74924	47.81977	37.55387	36.15898	44.09739	34.342
I11.BMP	44.14438	54.58702	43.42237	38.63189	48.1571	37.72099	35.83105	44.48521	34.55736
I12.BMP	44.30594	54.29759	43.14025	38.73339	48.14388	37.59067	36.15838	44.30145	34.44596
I13.BMP	44.10564	54.24853	43.35138	38.73244	47.95547	37.63605	35.99661	44.13847	34.4297
I14.BMP	44.26685	54.23788	43.16767	38.86864	47.981	37.39634	36.15509	44.19642	34.21416
I15.BMP	44.50547	53.85927	43.59124	38.92136	47.46075	37.79346	36.00326	43.83658	34.56845
I16.BMP	43.91183	54.67215	43.32144	38.49798	48.2256	37.67634	35.96924	44.26521	34.44328
I17.BMP	44.47002	53.90036	43.06458	38.76154	47.87919	37.51728	35.95339	44.11932	34.2015
I18.BMP	44.08908	54.11638	43.41324	38.7316	47.83749	37.69852	35.98532	44.11435	34.54225
I19.BMP	44.16753	54.37904	43.14184	38.76718	48.03412	37.45383	35.98025	44.20462	34.30836
I20.BMP	44.06866	53.90946	43.24253	38.33019	47.88543	37.41915	35.55693	43.8819	34.37471
I21.BMP	44.54784	54.35425	43.0625	38.979	48.02066	37.43045	36.26028	44.25122	34.31777
I22.BMP	44.27886	54.07061	43.36456	38.78702	47.82584	37.58812	36.05295	44.05155	34.39858
I23.BMP	44.05958	54.26237	43.41545	38.72296	47.9571	37.73115	36.00466	44.25239	34.57431
I24.BMP	44.20351	54.22061	43.35557	38.69597	47.9328	37.66895	36.00903	44.11989	34.43245
i25.bmp	45.12613	53.083	43.74277	39.41321	47.50837	38.70847	36.56065	44.10754	35.43343
Average	**44.25046**	**54.19529**	**43.28244**	**38.73112**	**47.96218**	**37.6357**	**36.0127**	**44.21455**	**34.45113**

5.3 Compression: PSNR of RGB versus PSNR for compression only

The processing path is following :

Step 1: RGB → YC_RC_B .
Step 2: The values of YC_RC_B are compressed and decompressed using the XXX video codec in the intra mode.
Step 3: YC_RC_B → RGB

Table 5 The results for the case when (3) holds

6 Conclusions

Color transformations may degrade image or video quality.

When developing software that uses modules operating in different color spaces, care should be taken with the results of PSNR or other quality measures.

Even marginally different color transformations may have substantially different effects on image/video quality. It seems that RGB to YC_BC_R transformations less deteriorate image/video quality when used in version defined by (3).

References

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