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BT Series: Broadcasting service (television)

A method of skin tone analysis for programme production

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***Note**: This ITU-R Report was approved in English by the Study Group under the procedure detailed in Resolution ITU-R 1.*

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REPORT ITU-R BT.2525-0

A method of skin tone analysis for programme production

(2023)

TABLE OF CONTENTS

Page

Introduction

This Report introduces a skin tone evaluation method based on the $J_za_zb_z$ colour space. It shows how this is used to verify the skin tone luminance, hue and saturation ranges for Fitzpatrick Scale skin type 1-4.

Background

Skin tone is a “memory colour”, and the human visual system has absolute judgment on skin tones without reference, while changes in the television signal differ from the actual impression of human eyes. In traditional objective test tools, the waveform and vector of the skin tone are distributed over a small area, and it is hard to judge skin tone. But the human eye can perceive a small change of skin tone.

To control the skin tone more precisely during production, it is helpful to use a perceptual colour space for analysing hue, saturation and lightness. These three indicators are closely related to the response of human eyes, which can measure skin tone more directly.

Report ITU-R BT.2408 describes ranges of luminance levels for different types of skin tones in HDR production, which is important. The method based on skin type 1-4 was verified, confirming the ranges of hue and saturation of skin type 1-4 and that these ranges could be used as a reference in Hybrid Log-Gamma (HLG) high dynamic range (HDR) and standard dynamic range (SDR) production.

1 Introduction to Test

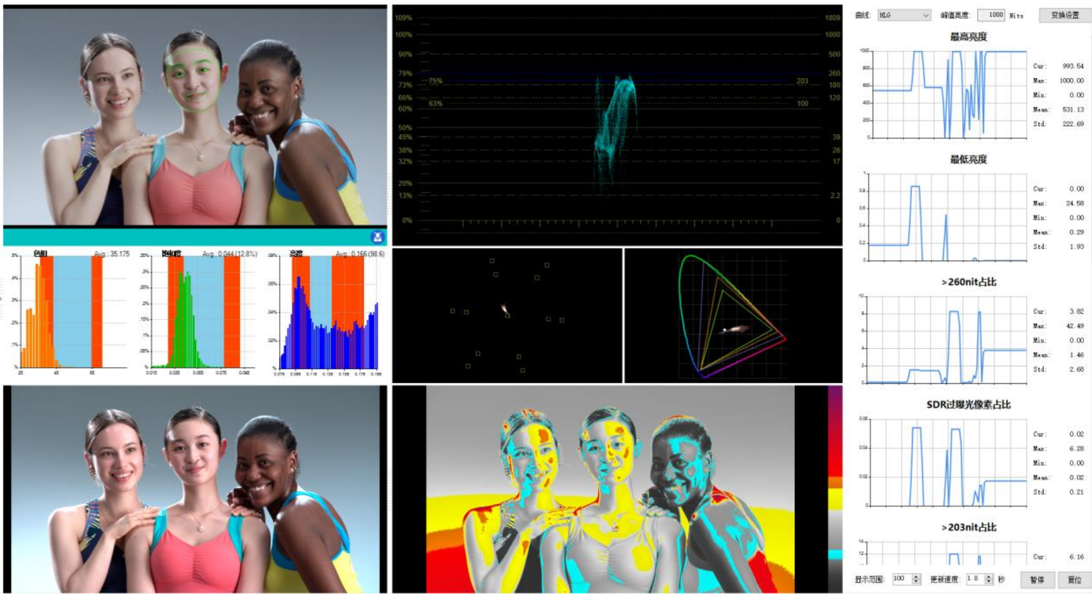
1.1 Analysis tool

1.1.1 Skin tone assessment software

Based on $J_za_zb_z$ colour space (see Annex 1), China Media Group (CMG) developed image assessment software, which can be used as an auxiliary image subjective assessment, focusing on skin tone study. The image waveform, vector, CIE and other aspects can be presented by analysing real-time image SDI signals (see Fig. 1). Attributes of image hue, saturation and lightness can also be presented in the form of a histogram, and the average value calculated. In Fig. 1, the abscissa of the hue is the angle, the abscissa of the saturation is percentage, and the abscissa unit of the lightness is cd/m^2. The calculation of hue, saturation and lightness values is described in Annex 2. Support is for HLG and SDR (gamma 2.4).

FIGURE 1

Image Assessment Software

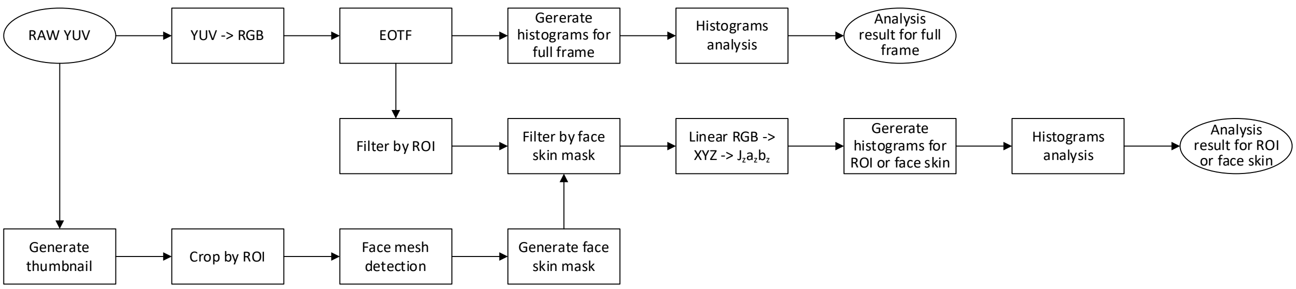


In skin tone studies, artificial intelligence technology is used to automatically identify and capture the face to analysis skin tone accurately. The software has a ruler function, which can use the presentation of a specific skin tone in a specific scene as a baseline, or use other methods to set up ranges for comparison.

The flow chart of the analysis tool processing is shown in Fig. 2. To concentrate the analysis results on face skin and reduce distractions, Face Mesh Detection will mark the point of faces whilst detecting them, and then based on these marked points, the eyebrows, eyes, lips and mouths will be cut out to form a face skin mask. The tool also supports refined analysis of specified regions by setting regions of interest (ROI).

FIGURE 2

Flow chart of the analysis tool processing

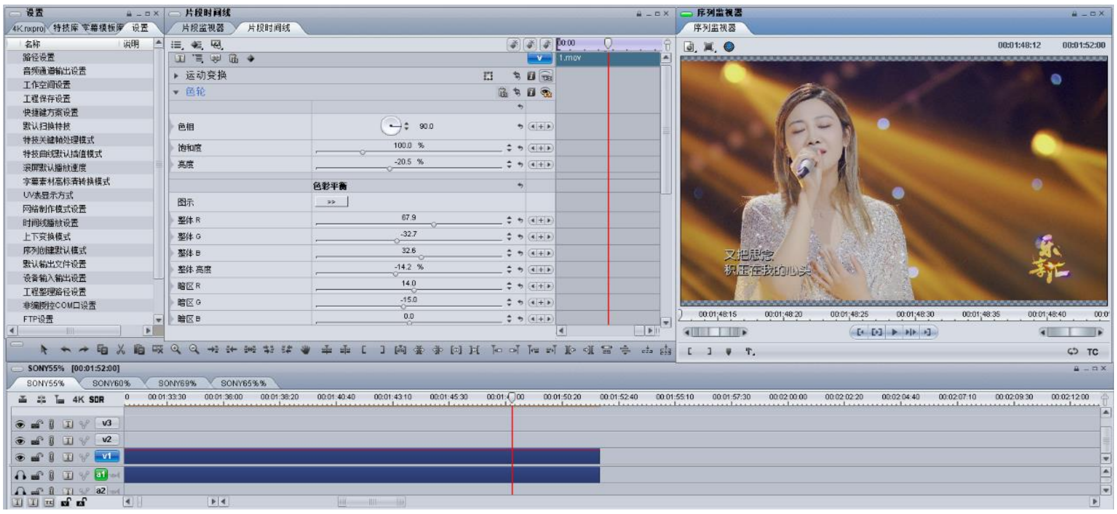


1.1.2 Custom colour grading software

Changing the colour saturation with traditional grading tools will also change the hue, and vice versa. In order to analyse the influence of lightness, hue and saturation on the change of skin tone, it is necessary to reduce or eliminate its influence on the hue when changing the saturation, and not change the saturation when changing the hue. For this purpose, a custom grading tool has been developed, based on the $J_z a_z b_z$ space. Adjusting any one of lightness, saturation or hue will not affect the other two factors.

FIGURE 3

Custom colour grading software



1.2 Range determination

1.2.1 Sample selection and shooting

Thirty people were selected for camera shooting and used as the basic material for the research on range determination. All are Chinese, including 13 males and 17 females. The age range is from 22 to 55 years. The latitude of their native places cover from 22° N to 50° N. None of them wears makeup. During camera shooting, the illumination is 1 000 lux, and the colour temperature is 5 600 K. The lightness level of skin tone is exposed at four HLG values, 55%, 60%, 65% and 69% (respectively indicated as V1, V2, V3, V4), and two cameras[1] (CAM1, CAM2) are used for shooting at the same time, recording eight clips for each person.

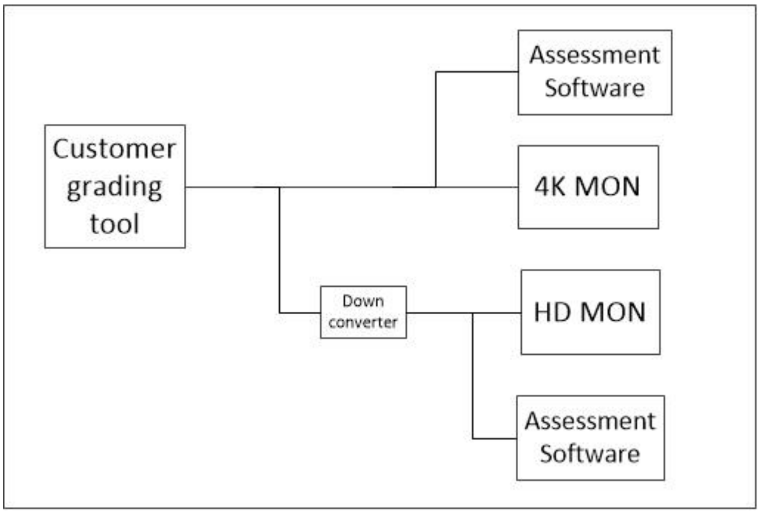
1.2.2 Range parameter determination method

The Single-stimulus (SS) subjective assessment methods of Recommendation ITU-R BT.500 were used to determine the range. The observers consist of ten experts. All 4K HDR materials shot by CAM1 with a skin tone of 65% HLG (V3) were selected as a group and adjusted with the custom colour grading software. The graded signals were put into the skin tone assessment software and presented on a 4K HDR monitor. At the same time, HD signals down-converted from the 4K graded signals were put into the skin tone assessment software and presented on an HD monitor.

1 Cameras are SONY HDC-4300 and GV LDX-100X.

FIGURE 4

Flow chart of range determination method



– Select one material, keep its saturation unchanged, and adjust the hue to the degree decreasing direction. At the same time, experts observe the HDR image until it is unacceptable, noting the hue value as HDR-H-1-1. Reset the image to normal, adjust the hue to the degree increasing direction. Experts observe the HDR image until it is unacceptable, noting the hue value as HDR-H-1-2. Then observe the SDR image and repeat the above method to obtain the two hue values in SDR as SDR-H-1-1 and SDR-H-1-2.

– Use the same material, keep its hue unchanged, and adjust the saturation as above to obtain the two saturation values in SDR as SDR-S-1-1 and SDR-S-1-2.

– Use the second material, repeat the above operation to obtain the second hue values and saturation values in HDR and SDR as H-2-1, H-2-2, S-2-1, S-2-2 and so on. Obtain all H-n-1, H-n-2, S-n-1, S-n-2 in HDR and SDR, *n* is the material ID.

TABLE 1

Range value of hue and saturation

Material ID	**Attribute**	**HDR**				**SDR**			
		H-n-1	**H-n-2**	**S-n-1**	**S-n-2**	**H-n-1**	**H-n-2**	**S-n-1**	**S-n-2**
1	H	66.082	41.667	0.06	0.06	65.8	42.0	0.046	0.049
	S	53.414	53.218	0.044	0.091	54.155	52.74	0.036	0.072
2	H	70.6	40.177	0.045	0.047	70.7	41.074	0.036	0.038
	S	54.221	54.94	0.035	0.077	56.489	55.13	0.028	0.061
3	H	66.36	35.702	0.049	0.049	66.55	36.42	0.039	0.040
	S	51.482	51.298	0.032	0.076	52.90	51.00	0.026	0.061
…	H								
	S								

According to the measured values, three zones are set as “safe zone”, “warning zone” and “unqualified zone”. The safe zone is considered to be a good zone, the warning zone means that in actual use manual re-inspection may be required, and the unqualified zone means that in actual use manual re-inspection and adjustment are required. In this software, the safe zone and the warning zone are represented as to the blue colour and the red colour respectively, and the zones outside these two ranges are considered to be unqualified.

The upper boundary of the red zone is the maximum value of H-n-2 (n = 1,2...30), denoted as V1-HBW-MAX = Max{H-n-2} (n = 1,2...30). The lower boundary of the red zone is the minimum value of H-n-1(n = 1,2...30), denoted as V1-HBW-MIN = Min{H-n-1}(n = 1,2...30). The upper boundary of the blue zone is the arithmetic mean of H-n-2 (n = 1,2...30), denoted as V1-HBN-MAX = Ave{H-n-2} (n = 1,2 ...30). The lower boundary of the blue zone is the arithmetic mean of H-n-1 (n = 1,2...30), denoted as V1-HBN-MIN = Ave{H-n-1} (n = 1,2...30). For HDR and SDR, the boundaries of the red and blue zones are set separately.

The saturation range setting is the same as the hue, also setting the red zone and the blue zone. The upper boundary of the red zone is the maximum value of S-n-2, denoted as V3-SBW-MAX = Max{S-n-2} (n = 1,2...30), and the lower boundary is the minimum value of S-n-1, denoted as V3-SBW-MIN = Min{S-n-1} (n = 1,2...30). The upper boundary of the blue zone is the arithmetic mean of S-n-2, denoted as V3-SBN-MAX = Ave{S-n-2} (n = 1,2...30), and the lower boundary is the arithmetic mean of S-n-1, denoted as V3-SBN-MIN = Ave{S-n-1} (n = 1,2...30). For HDR and SDR, the boundaries of the red and blue zones are set separately.

After the hue and saturation at the lightness value V3 have been set up, select all the materials shot by CAM1 with the lightness level V1, V2, V4 and repeat the above steps to obtain the boundary values of the skin tone lightness levels V1, V2, and V4 respectively, which are denoted as Vn-SBW-MAX, Vn-SBW-MIN, Vn-SBN-MAX, Vn-SBN-MIN, where *n* represents different skin tone lightness levels.

TABLE 2

Skin tone lightness level 55% HLG: H and S boundary values

V1 55%	**HBW-MAX**	**HBW-MIN**	**HBN-MAX**	**HBN-MIN**	**SBW-MAX**	**SBW-MIN**	**SBN-MAX**	**SBN-MIN**
HDR	66.088	35.444	54.94	30.823	27.5%	8.5%	16.5%	10.9%
SDR	70.809	36.693	59.96	32.825	33%	10.3%	26.9%	18.5%

TABLE 3

Skin tone lightness level 60% HLG: H and S boundary values

V2 60%	**HBW-MAX**	**HBW-MIN**	**HBN-MAX**	**HBN-MIN**	**SBW-MAX**	**SBW-MIN**	**SBN-MAX**	**SBN-MIN**
HDR	69.935	35.858	63.82	29.64	28.1%	8.9%	14.8%	11.8%
SDR	71.331	36.077	65.82	32.64	34.3%	10.8%	22.8%	14.8%

TABLE 4

Skin tone lightness level 65% HLG: H and S boundary values

V3 65%	HBW-MAX	HBW-MIN	HBN-MAX	HBN-MIN	SBW-MAX	SBW-MIN	SBN-MAX	SBN-MIN
HDR	70.6	35.702	64.393	43.449	26.7%	9.3%	15.2%	112.6%
SDR	70.7	36.42	64.357	43.984	33.9%	12.3%	24.6%	20.8%

TABLE 5

Skin tone lightness level 69% HLG: H and S boundary values

V4 69%	HBW-MAX	HBW-MIN	HBN-MAX	HBN-MIN	SBW-MAX	SBW-MIN	SBN-MAX	SBN-MIN
HDR	73.574	35.817	67.47	32.84	26.7%	9.3%	15.2%	12.6%
SDR	73.205	36.639	62.47	34.84	33.9%	12.3%	24.6%	20.8%

Comparing the boundary values of the four lightness levels V1, V2, V3, and V4 respectively, in different skin tone lightness levels the boundary value differences are very small, and it can be concluded that the skin tone lightness level has a little effect on the hue and saturation.

Referring to the boundary values of the four lightness levels, the range of hue, saturation and lightness is finally determined (see Table 6).

TABLE 6

Hue and saturation of skin tones for both HLG and SDR

Reflectance object		**Nominal Lightness, cd/m^2 (for a 1 000 cd/m^2 HLG display)**	**Attribute**	
Skin tones (Fitzpatrick scale)	Lightness		Hue	Saturation
Type 1-4 skin tone	HLG at 55% – 69%	65-141	35.4-70.6	8.5% – 28.1%
	SDR at 56% – 77%	25-54	36.1-71.3	10.3% – 34.3%

1.3 Range verification

All verification was carried out by subjective assessment, with a 15-person expert group (no overlap with the previous 10-person expert group). The verification mainly includes the following aspects:

1) Verify with CAM2 captured materials

Two cameras with different imaging styles (CAM1 and CAM2) in the same shooting environment adjust white balance and expose correctly, using the materials shot by CAM2 to verify the skin ranges that CAM1 obtained. Use the skin tone assessment software to observe whether the hue, saturation and lightness of a video match the ranges. The result shows that the hue, saturation and lightness of videos shot by CAM2 are all falling within the blue range determined by CAM1.

2) Colour grading

Original materials are used to compare with finished programmes and observe whether the H (hue) and S (saturation) values match the preset range. The left image is an original material, and the right image is the adjusted one. The material was adjusted according to the programme requirements and the colourist’s own habits. The adjusted image fits the ranges better than the original one, and the verification was conducted 50 times. It should be emphasized that the colour-grading software colourists used is popular, not the custom colour grading tools in this Report.

FIGURE 5

Before colour grading

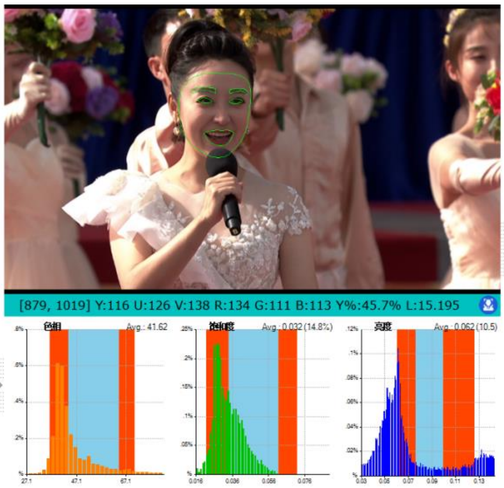
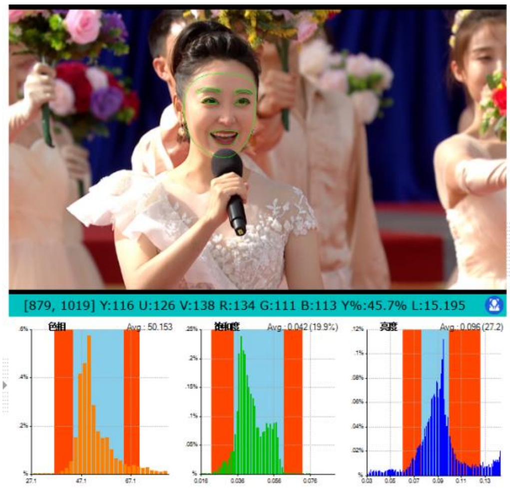


FIGURE 6

After colour grading



3) Using daily assessed programmes

In order to verify the ranges, a total of 1 500 programmes (or scenes) were randomly selected from the MAMS in CMG, including 300 4K HDR and 1 200 HD SDR. These programmes have been assessed by experts. Experts gave subjective assessment scores based on the single-stimulus (SS) method of Recommendation ITU-R BT.500. The programmes with score “excellent” were selected, and the skin tone assessment software was used to observe how much the hue, saturation and lightness of the programmes falls within the ranges. The results show that the percentage of programmes falling into the ranges exceeds 95%. At the same time, the programmes with scores “poor” were selected, and the skin colour software was used to observe how much the hue, saturation and lightness of the programmes falls within the ranges. The results show that the percentage of programmes falling outside the ranges exceeds 95%.

TABLE 7

Programme subjective assessment form

Excellent programme			**Unqualified programme**		
Programme ID	**Score**	**Within the ranges**	**Programme ID**	**Score**	**Within the ranges**
2022A0618001	98	√	2022A0617793	77	×
2022Z0712036	97	√	2022Z0303614	76	×
2022T0516156	95	√	2022T0516396	73	×
2021A0422001	97	√	2021A1203001	73	×

TABLE 7 (*end*)

Excellent programme			**Unqualified programme**		
Programme ID	**Score**	**Within the ranges**	**Programme ID**	**Score**	**Within the ranges**
2021F0301001	94	√	2021F0612001	73	√
2021Z1201009	93	√	2021Z1208389	70	×
2020A1012460	96	√	2020A1112459	77	×
2020T0522001	95	√	2020T0612081	75	×
2020B0118032	91	×	2020B0920312	77	×
2019A0517698	93	√	20191A122125	73	×

4) Using media assets and colour grading software

In order to verify the ranges, more than 150 items were randomly selected from the MAMS in CMG, including 50 items 4K HDR and more than 100 items HD SDR. The specific method is to watch the original materials first, then observe the hue and saturation of the videos using evaluation software. If the histogram deviates from the preset ranges, use general colour grading software to adjust the video so that the hue and saturation of the image can be within the ranges. Compare the videos before and after adjustment and check whether the video is optimized, then obtain the corresponding situation between the ranges and the subjective assessment.

FIGURE 7

Entertainment programme (studio)

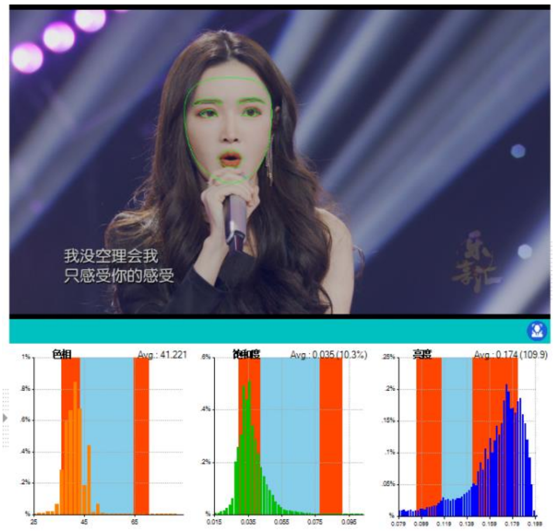


FIGURE 8

Entertainment programme (outside)

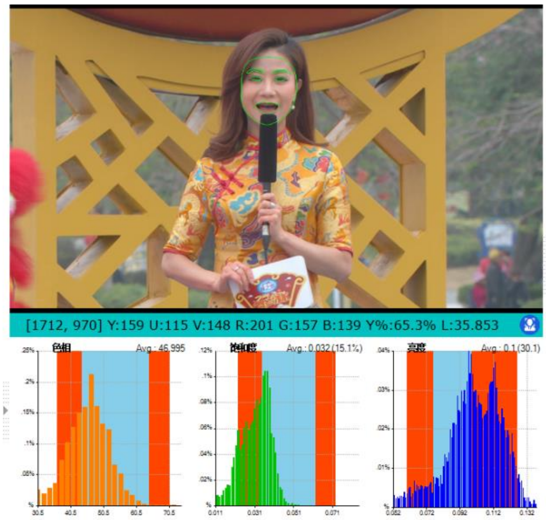


FIGURE 9

Documentary (indoor)

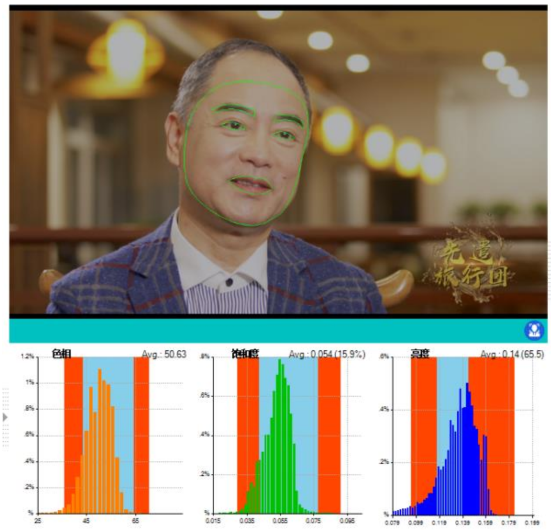


FIGURE 10

Documentary (outdoor)

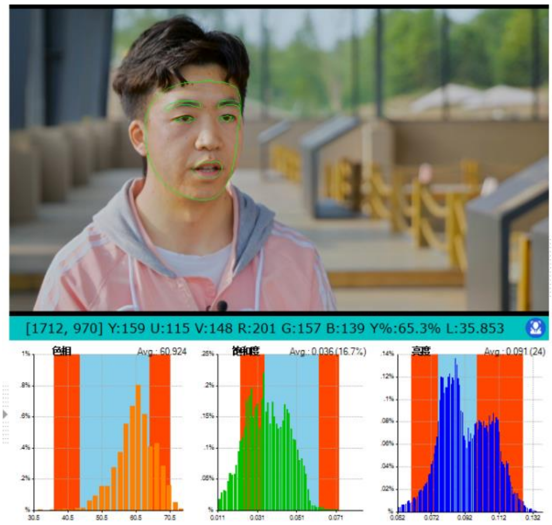


FIGURE 11

News (studio)

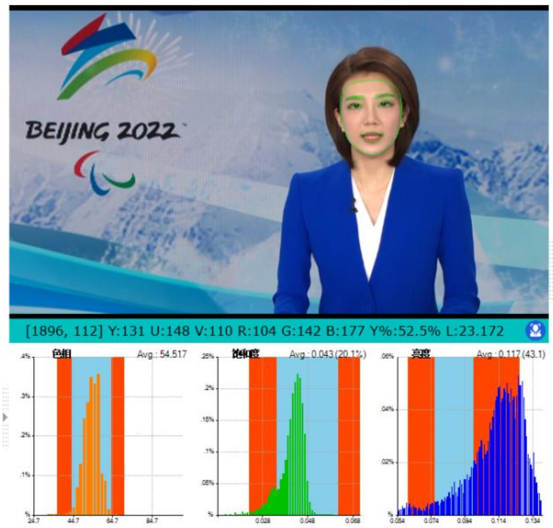


FIGURE 12

News (outside)

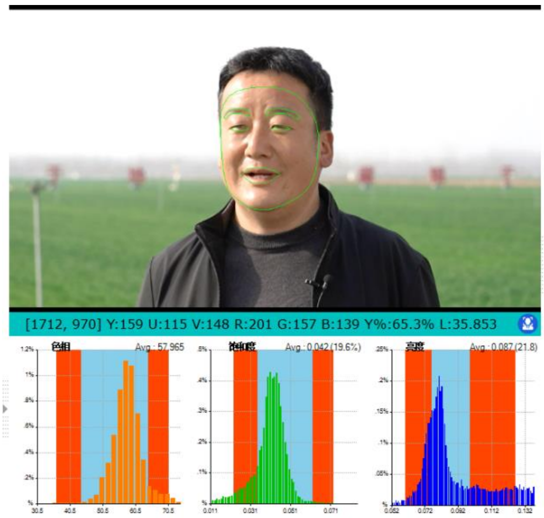


FIGURE 13

Sports (indoor)

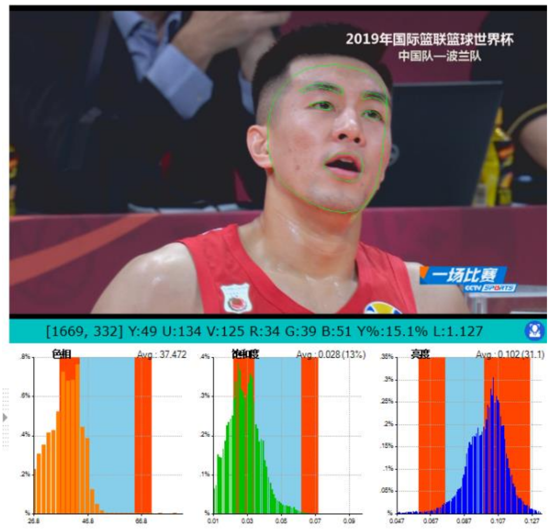
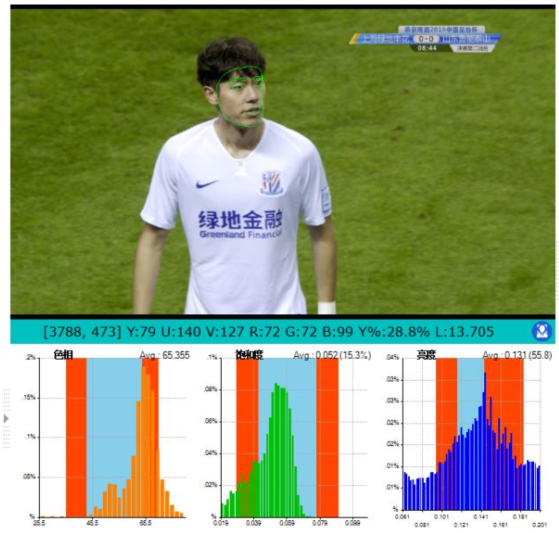


FIGURE 14

Sports (outside)



5) Summary

The programmes and materials used in the above verification cover studio news, outside news, studio entertainment, outside entertainment, documentaries, sports, etc. It can be found through the test that the skin tone baseline would not change due to changes of scenes, sunlight, or lighting. The skin ranges proposed in this Report are basically applicable to all scenarios.

2 Application

2.1 Programme quality assessment

Programme assessment currently mainly adopts the combination of objective evaluation and subjective assessment. The objective evaluation uses oscilloscopes to monitor technical indicators such as lightness, RGB, black level, and vector, and the subjective assessment follows the requirements of Recommendation ITU-R BT.500. In actual evaluations, there are large deviations in subjective and objective results constantly. Using the methods mentioned in this Report, based on the original objective indicators, adding the analysis of hue and saturation of the characters' skin tone, and through the setting ranges, problems in which the oscilloscope vector diagram cannot be displayed could be found.

The above methods could be used to filter "unqualified" programmes, to reduce the workload of subjective assessment.

If intelligent AI technology is used, it could be used as a key index item, by using the method of automatic evaluation and classification to replace subjective assessment.

2.2 Pre-shooting

Used in studio shooting, outdoor shooting and live broadcasts:

1) It is used for real-time calibration of normal restoration of ENG camera skin tone. It is used for real-time calibration of skin tone consistency in main characters in multi-camera shooting images.

2) It is used for real-time and continuous monitoring in live broadcasts, and assists the VE to adjust the camera.

3) Colours with obvious characteristics usually appear in the shot images, such as national flags and products with typical colours. The method of skin tone assessment proposed in this report can be applied to a wider range of colours in order to ensure the colour consistency of each shot of the programme.

2.3 Post-production

Used in post editing, colour grading, HDR-SDR conversion, technical review, and DIT material management:

1) Ensure the consistency of skin tone adjustment performed by the same colourist at different times and multiple colourists on multiple occasions. It could be used to check the colour consistency of skin tones in different production environments (environmental illumination, etc.) and different production stages (such as editing, colour grading, CG, etc.).

2) It could be used for the technical review of the finished programme, sorted by skin tone: “safety”, “warning”, and “unqualified”.

3) It could provide convenient auxiliary tools for DIT management of materials during outdoor shooting.

4) Ensure the accuracy of virtual characters’ skin tone design and the colour consistency of output signals when produce CG, AR, VR, etc.

3 Conclusion

Using a separable colour space of hue, saturation, and lightness, it is possible to conduct a non-reference, single stimulus, three-dimensional, quantifiable objective evaluation for the skin tone of the characters in programmes. The test results show that this method draws a similar conclusion to that of subjective assessment. CMG developed relevant testing and colour grading tools (hue, saturation, lightness), using subjective assessment method sampling through a large number of programmes including indoor and outdoor shooting of news, sports, and entertainment content, to verify the evaluation methods and define the skin tone ranges (“safety”, “warning”, “unqualified”). The above method is fully tested in pre-production, post-production and quality control processes in CMG. It should be noted that the sample data of the application is limited and mainly from the analysis of skin tone characters of mainland China, therefore for wider application it is necessary to expand the data source to test skin tones and verify ranges of skin type 4, and type 5-6.

In the next step, on the basis of the skin colour research, the aim is to use AI algorithms to expand the study to other dimensions such as colour fidelity, sharpness, and contrast. A more comprehensive and in-depth analysis will be conducted of the factors affecting the VQC to then define the evaluation method and establish an evaluation model.

Our final goal of the research is to obtain an automatic and intelligent classification and quality rating system of video contents.

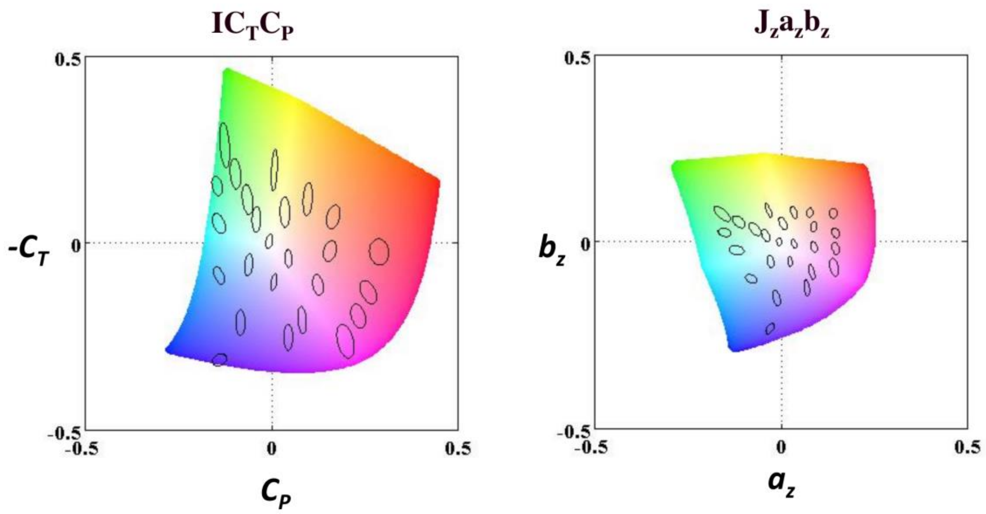
Annex 1

Colour gamut selection

Traditional SDR systems often use colour gamuts such as HSL, Lab, etc. to process or detect colour differences, but these colour gamuts themselves are not good enough in terms of perceptual uniformity, especially for colours that are brighter than diffuse white. With the deepening and popularization of high dynamic range and wide colour gamut production, there is a need for a more accurate representation of the three independent attributes (lightness, hue, and saturation) of images under high dynamic range and wide colour gamut conditions. Colour space is perceptually uniform in a wide colour gamut, linear in the isochromatic direction, and can more accurately identify large colour differences, small colour differences, and lightness differences in a high dynamic range environment. Considering encoding and decoding costs, it is best to have minimal real-time or near-real-time processing computational overhead.

Some candidate colour spaces that meet the above conditions include: ITP (Recommendation ITU-R BT.2124), IC_TC_P, $J_za_zb_z$, HDR-Lab, etc. Among them, HDR-Lab uses relative lightness and its value is related to the diffuse reflection white lightness. This cannot achieve uniform coverage of HDR and SDR, so it is not used. For IC_TC_P and $J_za_zb_z$, Fig. 15 shows the uniformity of the two colour gamuts in the wide colour gamut. It can be seen that the uniformity of the $J_za_zb_z$ colour gamut is better. This is expected since the C_T axis of IC_TC_P is scaled by two for compression efficiency. Hence, the $J_za_zb_z$ colour gamut is chosen to achieve the separation of lightness, hue and saturation, meanwhile corresponding values of ITP colour gamut can be obtained by conversion.

FIGURE 15



$J_za_zb_z$ is a colour model proposed for high dynamic range and wide colour gamut images in recent years. This model is based on the basic structure of the IC_TC_P model and is obtained by combining two additional equations to improve the hue linearity of the model (without affecting its uniformity performance) and its wide-range lightness prediction ability (without affecting the prediction performance on colour-difference datasets). The experimental results show that, compared with traditional colour spaces such as CIE LAB and CAM16-UCS, the $J_za_zb_z$ colour gamut is the best in terms of large colour difference recognition, wide colour gamut uniformity, hue linearity and wide-range luminance prediction. It also has excellent performance in the recognition of small colour differences, and the performance in grayscale convergence is also remarkable [1].

$J_z a_z b_z$ [1] is a uniform colour space based on vision perception. It is calculated in five steps from XYZ values (using a standard D65 illuminant):

1) Adjust XYZ values to remove blue tint bias

$$\begin{bmatrix} X' \\ Y' \end{bmatrix} = \begin{bmatrix} bX \\ gY \end{bmatrix} - \begin{bmatrix} (b-1)Z \\ (g-1)X \end{bmatrix}$$

with:

$$b = 1.15$$
$$g = 0.66$$

2) Transfer $X'Y'Z$ to LMS

$$\begin{bmatrix} L \\ M \\ S \end{bmatrix} = \begin{bmatrix} 0.41478972 & 0.579999 & 0.0146480 \\ -0.2015100 & 1.120649 & 0.0531008 \\ -0.0166008 & 0.264800 & 0.6684799 \end{bmatrix} \begin{bmatrix} X' \\ Y' \\ Z \end{bmatrix}$$

3) Apply non-linear operation to each LMS component

$$\{L' \;\; M' \;\; S'\} = \left(\frac{c_1 + c_2 \left(\frac{\{L \;\; M \;\; S\}}{10\,000} \right)^n}{1 + c_3 \left(\frac{\{L \;\; M \;\; S\}}{10\,000} \right)^n} \right)^p$$

with:

$c_1 = 3\,424/4\,096$

$c_2 = 2\,413/4\,096 \times 32$

$c_3 = 2\,392/4\,096 \times 32$

$n = 2\,610/16\,384$

$p = 1.7 \times 2\,523/4\,096 \times 128$

4) Calculate lightness $\boldsymbol{I_z}$ and chrominance $\boldsymbol{a_z}$, $\boldsymbol{b_z}$

$$\begin{bmatrix} I_z \\ a_z \\ b_z \end{bmatrix} = \begin{bmatrix} 0.5 & 0.5 & 0 \\ 3.524000 & -4.066708 & 0.542708 \\ 0.199076 & 1.096799 & -1.295875 \end{bmatrix} \begin{bmatrix} L' \\ M' \\ S' \end{bmatrix}$$

5) Adjust luminance to handle highlights

$$J_z = \frac{(1+d) \times I_z}{1 + (d \times I_z)} - d_0$$

with:

$d =$ –0.56

$d_0 =$ $1.6295499532821566 \times 10^{-11}$

Annex 2

Calculation of hue, saturation and lightness values

The calculation process of YUV to $J_z a_z b_z$ is defined as:

YUV → RGB → EOTF(RGB) → Linear RGB → XYZ → $J_z a_z b_z$

with XYZ → $J_z a_z b_z$ shown in Annex 1;

then,

$$\mathrm{Hue}_{rad} = \begin{cases} \tan^{-1}\left(\frac{b_z}{a_z}\right) & a_z > 0 \\ \tan^{-1}\left(\frac{b_z}{a_z}\right) + \pi & b_z \geq 0, a_z < 0 \\ \tan^{-1}\left(\frac{b_z}{a_z}\right) - \pi & b_z < 0, a_z < 0 \\ +\frac{\pi}{2} & b_z > 0, a_z = 0 \\ -\frac{\pi}{2} & b_z < 0, a_z = 0 \\ \text{undefined} & b_z = 0, a_z = 0 \end{cases}$$

$$\mathrm{Hue} = \mathrm{Hue}_{rad} \times 180° \div \pi$$

$$\mathrm{Saturation} = \sqrt{{a_z}^2 + {b_z}^2}$$

$$\mathrm{Lightness} = J_z$$

Higher saturation values indicate higher saturation and vice versa, but it is difficult for the values to be consistent with human perception. For example, when saturation value is 0.5, what is the perceived saturation? To increase the readability and sensibility of this value, a percentile process is performed. Divide the max saturation value of pure red, pure green and pure blue at nominal peak of the video source's transfer function into the saturation calculated; the answer is the saturation percentage.

$$\mathrm{Saturation\%} = \frac{\mathrm{Saturation}}{\mathrm{Max}(\mathrm{Saturation}(1,0,0),\ \mathrm{Saturation}(0,1,0),\ \mathrm{Saturation}(0,0,1))} * 100\%$$

References

[1] Muhammad Safdar, Guihua Cui, Youn Jin Kim, Ming Ronnier, Luo, "*Perceptually uniform color space for image signals including high dynamic range and wide gamut*", Vol. 25, No. 13 | 26 Jun 2017 | OPTICS EXPRESS 15131, https://www.osapublishing.org/oe/abstract.cfm?uri=oe-25-13-15131.

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