A New Uniform Colour Space for Comprehensive Image Applications

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ABSTRACT

In this study, a new uniform colour space was developed for perceptions-based image processing desired in comprehensive image applications. Many colorimetry-based colour spaces have been developed before to uniformly encode colour difference signals. In the modern imagery, high dynamic range and wide gamut colour difference should also be encoded ensuring perceptual uniformity. Researchers have reported that there is always a trade-off between uniformity and hue linearity. A perceptual colour space was developed by minimizing this trade-off and was named as $J_za_zb_z$. Different stages of the development of the new colour space and different versions of testing together with state-of-the-art colorimetry-based uniform colour spaces are presented in this paper.

KEYWORDS: Uniform Colour Space, Perceptual Image Processing, Colour Modeling

INTRODUCTION

A perceptually uniform colour space is desired in many image applications such as gamut mapping, image enhancement, lossy image compression, device characterization, etc. [1]. A colour space that is perceptually uniform, constant in iso-hue directions, can encode high dynamic range (HDR) colour difference signals with wide colour gamut (WCG) has long been desired. None of the state-of-the-art colour spaces including, CIELAB, CIELUV, IPT [2], CAM16-UCS [3], and IC_TC_P [4], could achieve these aims satisfactorily and comprehensively. Also, researchers have reported that there is always a trade-off between uniformity and hue linearity when developing a uniform colour space. Dealing with this challenge was one of the aims in the current study.

Dolby has recently proposed a uniform colour space, IC_TC_P, for HDR and WCG imaging applications [4]. We firstly defined a number of criteria to develop a perceptually uniform colour space [5]. In our preliminary study [6], Dolby model was re-optimized using a large set of colour difference data (i.e. combined colour difference data (COMBVD)) that was previously used to develop CIEDE2000 colour difference formula [7]. The model was later extended to minimize the trade-off between perceptual uniformity and hue linearity. In a perceptually uniform colour space (see Figure 1(a) as where COMBVD data [7] is plotted in CIELAB a^*b^* plane) all the chromatic ellipses should be circles and equal in size. Further, iso-hue colours (see Figure 1(b) where Hung & Berns data set [8] is plotted in CIELAB a^*b^* plane) should lie on a linear line. From Figure 1, it can be seen that CIELAB does not perform well in a^*b^* plane. Next section will introduce the development of the new colour space followed by results and discussions. Conclusions will be drawn in the end.

DEVELOPMENT OF UNIFORM COLOUR SPACE

Six different criteria including uniformity, hue linearity, colour different prediction, lightness prediction in high dynamic range, grey-scale convergence, and minimum computational cost, were defined to develop a new uniform colour space [5, 9]. A wide range of experimental data were collected for training and/or testing of the colour space. A most reliable colour difference data set COMBVD [7], that has been previously used to develop CIEDE2000 colour difference formula, was selected to train the colour space and optimize it for perceptual uniformity. Another widely used data set, Hung & Berns iso-hue data, was used as reference for hue linearity. To test the colour space for prediction of colour difference or lightness difference data and that of constant hue data, the results were computed in terms of STRESS and standard deviation (SD) of hue angles, respectively. STRESS was used as a measure of optimization for the development of the colour space. Two new equations were introduced to extend the preliminary model in order to minimize the trade-off between uniformity and hue linearity and to accurately predict wide-range lightness data, respectively.

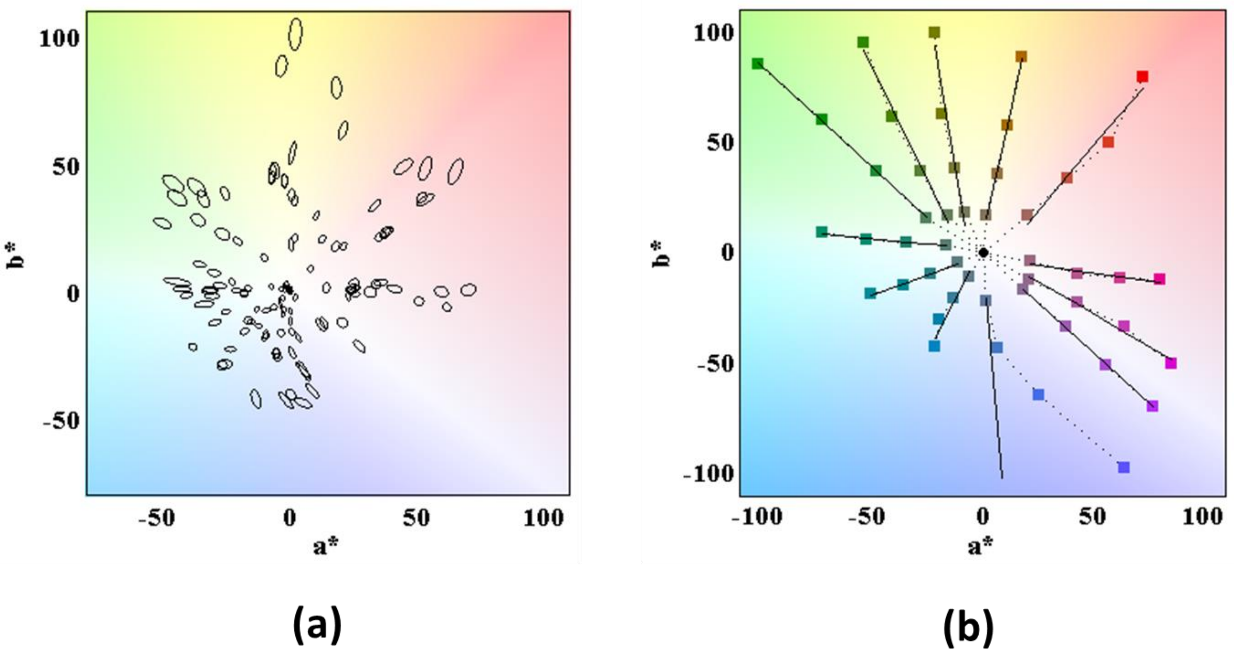

Figure 1: (a) COMBVD colour discrimination ellipses, and (b) Hung & Berns iso-hue data plotted in CIELAB a^*b^* plane.

The full model of the developed uniform colour space, $J_za_zb_z$, is given in [8] and its MATLAB code is given at https://figshare.com/articles/JzAzBz_m/5016299.

RESULTS

The proposed uniform colour space was tested to predict a wide range of experimental data. The prediction results of the new colour space were compared with state of the art uniform colour spaces including CIELAB, CAM16-UCS, and IC_TC_P. Figure 2 shows the quantitative results in STRESS unit to predict COMBVD colour difference data, Optical Society of America (OSA) colour order system [10], COMBVD ellipses data, MacAdam ellipses data, and HDR-range lightness data. It can be seen in the figure that $J_za_zb_z$ either performed best or similar to the best colour space for the available visual data sets. Dolby model performed the worst to predict small and large colour difference data sets except MacAdam data because IC_TC_P was trained for MacAdam data. Dolby model also performed worst to predict wide-range lightness data i.e., lightness above and below diffuse white. When predicting Hung & Berns iso-hue data, SD value for CIELAB, CAM16-UCS, IC_TC_P, and $J_za_zb_z$ are 3.8, 4.1, 3.0, and 2.7, respectively, and further, SD value of the blue tuple are 13.2, 9.9, 3.1, and 3.1, respectively. As SD values for blue tuples in CIELAB and CAM16-UCS are too high so they may not be suitable for many colour imaging applications. This shows that $J_za_zb_z$ best predicted iso-hue data not only on average but also in blue region (similar to IC_TC_P).

Figure 3(a) and (b) show the COMBVD and Hung & Berns data sets potted in $J_za_zb_z$ colour space. Analysis of Figure 3 shows that $J_za_zb_z$ obtained optimal trade-off between perceptual uniformity and hue linearity. Although CAM16-UCS performed best to predict COMBVD data but could not perform well to predict MacAdam data i.e., self-luminous colours. On the other hand, IC_TC_P gave reasonable performance to predict iso-hue data but did not perform well to predict lightness differences or colour difference data in three dimensions. Gray-scale convergence of the new colour space was also tested using chroma-ratio metric i.e., ratio of the chroma of white to the mean chroma of red, green, and blue vertices of sRGB gamut. The chroma-ratio of $J_za_zb_z$ is 0.1% which cannot be discriminated visually.

By comparing Figures 1 and 3, it can be clearly seen that $J_za_zb_z$ is more uniform (all ellipses are close to circles and have similar sizes in all regions) and more linear hue (especially for the blue hue) comparing with CIELAB.

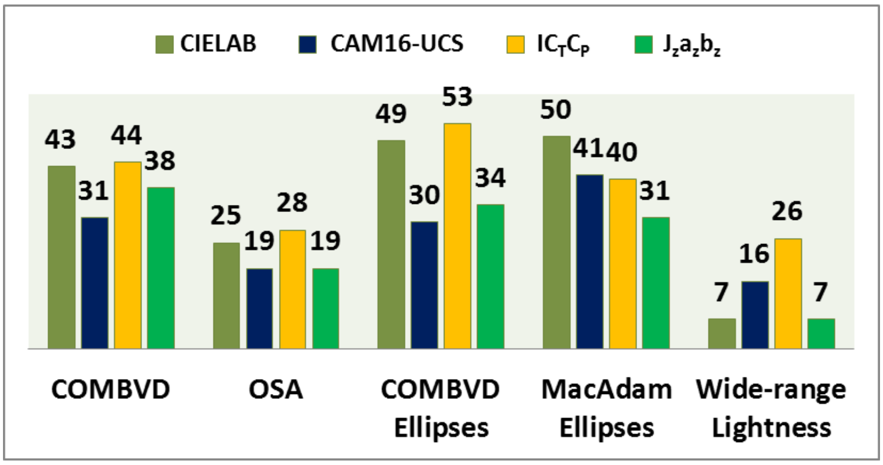

Figure 2: Results for prediction of COMBVD colour difference, OSA Colour difference, COMBVD ellipses, MacAdam ellipses, and wide-range lightness data in terms of STRESS.

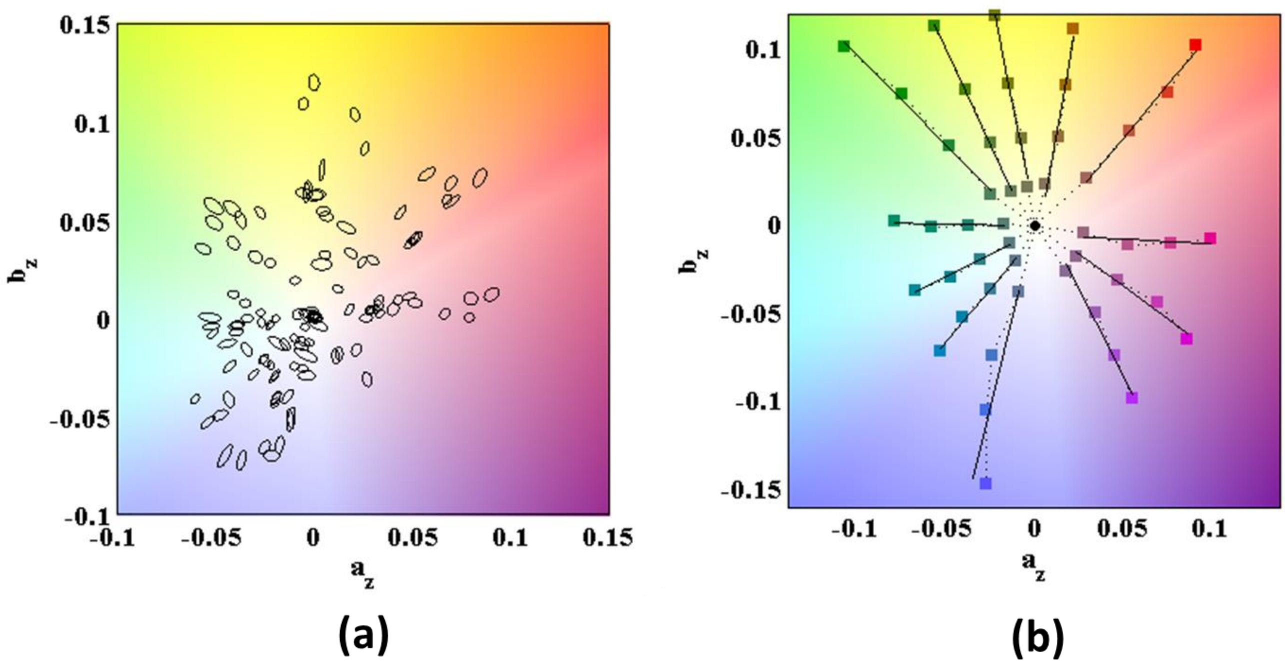

Figure 3: (a) COMBVD ellipses and (b) Hung & Berns data plotted in new $J_za_zb_z$ uniform colour space.

CONCLUSION

Performance of a new colour space that is perceptually uniform and linear in iso-hue directions is presented. The results showed that the proposed colour space can uniformly encode high dynamic range signals as well as standard dynamic range and also offers minimum trade-off between perceptual uniformity and hue linearity. In addition, $J_za_zb_z$ causes much less computational cost compared with the most uniform colour space CAM16-UCS that also has hue shift problem in the blue region.

ACKNOWLEDGEMENTS

This work was supported by Huawei Technologies Co., Ltd., Shanghai, China (No. KH20161715) and International Color Consortium (ICC) colour management research fund 2016 awarded to the first author (No. 2016080100017653).

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