

Single-Shot High Dynamic Range Imaging with Spatially Varying Exposures Considering Hue Distortion

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Abstract—We propose a novel single-shot high dynamic range imaging scheme with spatially varying exposures (SVE) considering hue distortion. Single-shot imaging with SVE enables us to capture multi-exposure images from a single-shot image, so high dynamic range images can be produced without ghost artifacts. However, SVE images have some pixels at which a range supported by camera sensors is exceeded. Therefore, generated images have some color distortion, so that conventional imaging with SVE has never considered the influence of this range limitation. To overcome this issue, we consider estimating the correct hue of a scene from raw images, and propose a method with the estimated hue information for correcting the hue of SVE images on the constant hue plain in the RGB color space.

Index Terms—high dynamic range imaging, spatially varying exposures, maximally saturated color

I. INTRODUCTION

The low dynamic range (LDR) imaging sensors used in modern digital cameras cannot express the dynamic range of a real scene, due to a limited dynamic range which imaging sensors have [1]–[3]. The limitation results in the low contrast of images taken by digital cameras. The most common approach for HDR imaging is to fuse multi-exposure images which are to merge a set of LDR images taken with different exposure times. This approach requires to capture multi-exposure images by taking at the different time, so there are ghost artifact issues, due to the movement of the camera and the subject. One of ghost-free techniques for HDR imaging is to employ spatially varying exposures (SVE) [4]–[7]. In the SVE-based imaging, a scene is captured with varying exposures for each pixel in a single image, and multiple sub-images with each exposure are obtained. However, conventional SVE-based methods focus on the luminance of a scene, so they cause color distortion, due to the influence of the limited dynamic range.

To overcome this issue, a novel single-shot imaging scheme with SVE is proposed in this paper. The correct hue of a scene is estimated from raw images, and then the estimated hue information is employed on the constant hue plain in the RGB color space [8] for correcting the hue of SVE images.

II. RELATED WORKS

A. SVE image

A raw Bayer image \mathbf{X} sensed with SVE sensor is illustrated in Fig.1, where the exposure value alternates every two lines in the Bayer image. The raw image \mathbf{X} is separated into

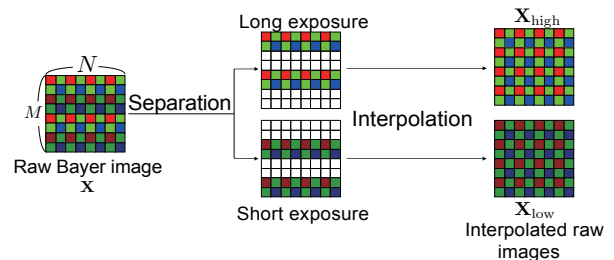


Fig. 1. SVE image

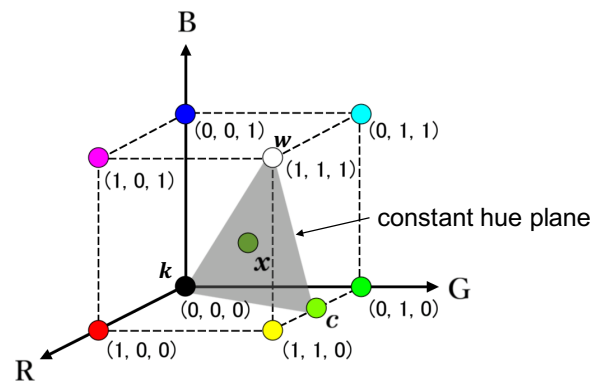


Fig. 2. Constant hue plane with RGB color space

two images according to exposure values. An interpolation operation is applied to each raw image for producing two raw images with the same size as \mathbf{X} : \mathbf{X}_{low} and \mathbf{X}_{high} . However, \mathbf{X} has some pixels at which a range supported by the camera sensor is exceeded.

B. Constant hue plane in the RGB color space

An input image is a 24-bit full color image and each pixel of the image is represented as $\mathbf{x} \in [0, 1]^3$. x_r , x_g and x_b are the R, G, and B components of the pixel \mathbf{x} , respectively, as shown in Fig.2. In the RGB color space, a set of pixels which has the same hue forms a plane, called constant hue plane [8]. The shape of the constant hue plane is the triangle whose vertices correspond to white, black and the maximally saturated color, where $w = (1, 1, 1)$, $k = (0, 0, 0)$ and c are white, black

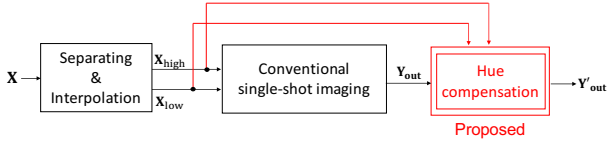


Fig. 3. Outline of proposed method

and the maximally saturated color with the same hue as \mathbf{x} , respectively. The maximally saturated color $\mathbf{c} = (c_r, c_g, c_b)$ is calculated by, under $l = \{r, g, b\}$

$$c_l = \frac{x_l - \min(\mathbf{x})}{\max(\mathbf{x}) - \min(\mathbf{x})} \quad (1)$$

where $\max(\cdot)$ and $\min(\cdot)$ are functions that return the maximum and minimum elements of the pixel \mathbf{x} , respectively.

A pixel \mathbf{x} can also be represented as a linear combination as

$$\mathbf{x} = a_w \mathbf{w} + a_k \mathbf{k} + a_c \mathbf{c} \quad (2)$$

where the coefficient meet the equations,

$$a_w + a_k + a_c = 1, \quad (3)$$

$$0 \leq a_w, a_k, a_c \leq 1. \quad (4)$$

This method is applied to various methods [9], [10].

III. PROPOSED METHOD

The outline of the proposed method is shown in Fig.3.

A. Procedure

1) *Separation and interpolation*: A raw image \mathbf{X} is first divided into two raw images, according to the exposure value. Next, interpolation processing is applied to each raw image for producing two raw images: \mathbf{X}_{low} and \mathbf{X}_{high}

2) *Exposure compensation*: Perform scene-segmentation based exposure compensation [3].

3) *Demosaicing*: A demosaicing algorithm is applied to the compensated images to obtain RGB images.

4) *Image fusion*: The RGB images are fused by using a fuse function.

5) *Hue compensation*: The hue of the fused image \mathbf{Y}_{out} is compensated by using the proposed method as shown below.

B. Hue estimation and hue correction

From Eq.(2), a pixel value \mathbf{y}_{out} in \mathbf{Y}_{out} is given by,

$$\mathbf{y}_{\text{out}} = a_w \mathbf{w} + a_k \mathbf{k} + a_c \mathbf{c}_{\text{out}}, \quad (5)$$

where \mathbf{c}_{out} is the maximally saturated color of \mathbf{y}_{out} , and a_w , a_k , a_c and \mathbf{c}_{out} are calculated from \mathbf{y}_{out} . Note that \mathbf{c}_{out} may be distorted due to the influence of some pixels at which a range supported by the camera sensor is exceeded. Each pixel value \mathbf{y} of the conventional method is recalculated using the maximally saturated color values \mathbf{c}_{low} , \mathbf{c}_{high} calculated from each pixel value x_{low} , x_{high} to suppress the hue distortion. Therefore, we propose replacing \mathbf{c}_{out} with \mathbf{c}'_{out} to reduce the hue distortion, as,

$$\mathbf{y}'_{\text{out}} = a_w \mathbf{w} + a_k \mathbf{k} + a_c \mathbf{c}'_{\text{out}}, \quad (6)$$

where

$$\mathbf{c}'_{\text{out}} = \begin{cases} \mathbf{c}_{\text{low}} & \text{if } x_{\text{low}} \neq 0 \text{ and } x_{\text{low}} \neq 1 \\ \mathbf{c}_{\text{high}} & \text{if } x_{\text{high}} \neq 0, x_{\text{high}} \neq 1, x_{\text{low}} = 0, \text{ and } x_{\text{low}} = 1 \\ \mathbf{c}_{\text{out}} & \text{if } x_{\text{low}} = 0, x_{\text{low}} = 1, x_{\text{high}} = 0, \text{ and } x_{\text{high}} = 1 \end{cases} \quad (7)$$

where x_{low} and $x_{\text{high}} \in [0, 1]$ are pixel values in the raw images, \mathbf{X}_{low} and \mathbf{X}_{high} , and the maximum saturated colors \mathbf{c}_{low} and $\mathbf{c}_{\text{high}} \in [0, 1]^3$ are calculated from x_{low} , x_{high} . RGB images, \mathbf{Y}_{low} and \mathbf{Y}_{high} are first calculated by applying a demosaicing algorithm to \mathbf{X}_{low} and \mathbf{X}_{high} , and then \mathbf{c}_{low} and \mathbf{c}_{high} are calculated from pixel values \mathbf{y}_{low} and \mathbf{y}_{high} of \mathbf{Y}_{low} and \mathbf{Y}_{high} , respectively. Eq.(7) allows us to avoid using the pixels at which over-exposure and under-exposure occurs.

IV. EXPERIMENT

In an experiment, the performance of the proposed scheme was compared with the conventional single-shot imaging with SVE .

A. Dataset

564 input SVE images \mathbf{X} were prepared by using 141 HDR images selected from a database [11]. Four SVE image sets with two exposure values $\pm 1\text{EV}$, $\pm 2\text{EV}$, $\pm 3\text{EV}$, or $\pm 4\text{EV}$ were generated as \mathbf{X} from each HDR image.

B. Objective metrics

The hue distortion of images produced by each method was evaluated in two objective metrics; the cosine similarity of maximally saturated color values, and the difference of hue values in CIEDE2000 [12]. The difference of hue values between a reference image (HDR) and the generated one was calculated for each pixel, and then the average value of all pixels was computed. For cosine similarity, a larger value means higher quality, and for the difference of hue values, a smaller value means higher quality.

The quality of images produced by each method was evaluated in the objective metrics; the tone mapped image quality index (TMQI) [13]. TMQI measure the quality of a tone mapped image from an HDR image and it consists of structural fidelity and statistical naturalness. For TMQI, a larger value means higher quality.

C. Experiment results

From Table I and Table II, it is confirmed that the proposed method had higher scores than conventional method. Therefore, the proposed method is effective for improving hue distortion.

From Table III, it is confirmed that the proposed method had lower scores than conventional method. Although the image quality decreases slightly, the performance of the conventional method can be maintained in terms of TMQI.

TABLE I
AVERAGE SCORES OF THE MAXIMALLY SATURATED COLOR SIMILARITY

	$\pm 1EV$	$\pm 2EV$	$\pm 3EV$	$\pm 4EV$
Conventional method	0.9250	0.9290	0.9308	0.9304
Proposed method	0.9302	0.9382	0.9432	0.9441

TABLE II
AVERAGE SCORES OF THE DIFFERENCE HUE VALUES IN CIEDE2000

	$\pm 1EV$	$\pm 2EV$	$\pm 3EV$	$\pm 4EV$
Conventional method	15.15	14.73	15.07	15.28
Proposed method	15.00	14.53	14.87	15.23

TABLE III
AVERAGE SCORES OF TMQI

	$\pm 1EV$	$\pm 2EV$	$\pm 3EV$	$\pm 4EV$
Conventional method	0.2126	0.2120	0.2106	0.2091
Proposed method	0.2121	0.2115	0.2101	0.2084

V. CONCLUSION

In this paper, we proposed a novel single-shot high dynamic range imaging scheme with SVE considering hue distortion. We considered estimating the correct hue of a scene from raw images, and proposed a method with the estimated hue information for correcting the hue of SVE images on the constant hue plain in the RGB color space.

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