Template matching with white balance adjustment under multiple illuminants

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Abstract—In this paper, we propose a novel template matching method with a white balancing adjustment, called N-white balancing, which was proposed for multi-illuminant scenes. To reduce the influence of lighting effects, N-white balancing is applied to images for multi-illumination color constancy, and then a template matching method is carried out by using adjusted images. In experiments, the effectiveness of the proposed method is demonstrated to be effective in object detection tasks under various illumination conditions.

Index Terms—Color Image Processing, Color Constancy, White Balance Adjustment, Object Detection, Template Matching

I. INTRODUCTION

White balancing (WB) is a technique that reduces color distortion caused by the difference between light sources (i.e., lighting effects). WB is also related to color constancy, so algorithms used to attain color constancy are frequently used for WB [1]–[16]. Typical algorithms are carried out by mapping a source white point (i.e., a set of tristimulus values calculated from pixels in a white region remaining lighting effects) into a ground truth white point, which is a set of tristimulus values that serves to define the color “white” in image capture [17]. However, most conventional white balance algorithms do not consider adjusting multi-illuminant scenes. Therefore, when applying color template matching [18] to a query image captured under multiple illuminants, the image cannot be correctly adjusted, so the accuracy of template matching may significantly decrease. Accordingly, in this paper, we propose a template matching scheme that uses N-white balancing, which was proposed for correcting images captured under various illumination conditions [19]. In experiments, the proposed method was demonstrated to be effective in color template matching under various illumination conditions.

II. PROPOSED METHOD

We propose a template matching scheme that uses N-white balancing.

A. Overview

Figure 1 shows an overview of the proposed method, where $I$ with a size of $W \times H$ and $T$ with a size of $w \times h$ denote a query image and a template image, respectively. In the proposed method, color template matching [18] is carried out to distinguish the color difference of templates. We assume that $I$ is captured under various illumination conditions including multiple illuminants. Hence, to efficiently reduce the influence of multiple illuminants, N-white balancing [19] is applied to $I$. Existing methods proposed for multi-illumination color constancy [20]–[23] are required to estimate the exact number of light sources. In contrast, N-white balancing can maintain a high accuracy even when we cannot estimate the exact number of light sources. Accordingly, we apply N-white balancing to $I$ to reduce the influence of lighting effects for color template matching.

B. N-white balancing

The procedure of N-white balancing [19] is given as follows.

1) Determine a ground truth white point $G = (X_G, Y_G, Z_G)^T$ by calculating from pixels in a white region under an ideal light source as in [24].

2) Determine the number of source white points $N$.

3) Divide $I$ into $N$ blocks.

4) Apply a source white point estimation algorithm [1]–[9] to each block to determine $N$ source white points $S_m = (X_{Sm}, Y_{Sm}, Z_{Sm})^T$ ($m \in \{1, 2, \ldots, N\}$).

5) Calculate the cosine similarity between $S_m$ and every pixel in each block, and then decide the coordinates of the closest pixel to $S_m$ as $(x_{Sm}, y_{Sm})$.

6) Adjust pixels in $I$ by using $G$, $S_m$, $(x_{Sm}, y_{Sm})$ in accordance with the method in [19].

Also, N-white balancing has the following properties.

(a) N-white balancing enables us to adjust multi-illuminant scenes in addition to single ones.

Fig. 1: Overview of proposed method.
(b) N-white balancing can give a high accuracy even when the parameter N is larger than the exact number of light sources in a scene. Because of property (b), we recommend setting N to between 4 and 10 in 2), which is sufficiently larger than the number of light sources in general scenes. Also, if N = 1 is chosen, N-white balancing is reduced to white balance adjustments for single illuminants.

C. Template matching with N-white balancing

The proposed method is carried out as follows.

(i) Prepare \( T \) captured under a single light source.

(ii) Apply a conventional white balance adjustment to \( T \) to map a source white point into a ground truth one.

(iii) Prepare \( I \) as a query image.

(iv) Apply N-white balancing to \( I \) following 1)–6) in Section II-B.

(v) Calculate normalized cross-correlation \([25]\), given as

\[
R(x, y) = \frac{\sum_{i=1}^{W} \sum_{j=1}^{H} T(i, j, c) \cdot I(x + i, y + j, c)}{\sqrt{\sum_{i=1}^{W} \sum_{j=1}^{H} (T(i, j, c))^2 \sum_{i=1}^{W} \sum_{j=1}^{H} (I(x + i, y + j, c))^2}}, \tag{1}
\]

where \((x, y)\) is the pixel coordinates of \( I \), \( c \in \{R, G, B\} \) is the channels of \( I \) and \( T \), \( T(i, j, c) \) is the pixel value in \( T \) with coordinates \((i, j)\) and a channel \( c \), and \( I(x + i, y + j, c) \) likewise.

(vi) Calculate

\[
(x', y') = \arg \max_{(x', y')} R(x', y'), \tag{2}
\]

where \((x', y') \in \{(0, 0), (0, 1), \cdots, (W, H)\}\). \((x', y')\) is the location of template \( T \).

III. EXPERIMENTS

We conducted experiments to confirm the effectiveness of the proposed method.

A. Experimental conditions

In the first experiment, we used two sets of images with a size of 627 × 418 as query images for template matching, and the two sets were named “four stars” and “seven stars,” respectively. In each set, the same scene was captured under two different illumination conditions: single and multiple illuminants (see Fig. 2). A template image with a size of 81 × 81 was captured under a single light source (see Fig. 3). In the second experiment, we used the Robust pattern matching performance evaluation dataset (available online in [26]). This dataset includes three subsets named “Guitar dataset,” “Mere Poulard A dataset,” and “Mere Poulard B dataset.” In this experiment, we used the Guitar dataset and the Mere Poulard A dataset. The Guitar dataset contains 7 templates with a size of 63 × 63 and 10 query images with a size of 640 × 480. Also, the Mere Poulard B dataset includes a template with a size of 85 × 53 and 12 query images with a size of 640 × 480.

The proposed method was performed in accordance with Section II-C, where the D65 standard illuminant [24] was used for a ground truth white point. To compare N-white balancing with the conventional white balancing, a white balance adjustment [17] was also applied to \( I \) in (iv) in Section II-C. In this experiment, we set \( N \) to 9 for N-white balancing. The White-Patch algorithm [1] was applied to estimate a source white point for an image or a sub-image. We subjectively evaluated the accuracy of template matching with each adjustment. Additionally, the intersection over union (IoU) was used as a metric for evaluating the performance [27], [28]. The metric is given as

\[
IoU = \frac{TP}{TP + FP + FN}, \tag{3}
\]

where \( TP \), \( FP \), and \( FN \) are true positive, false positive, and false negative values calculated from a detected matching region and a ground truth one, respectively. The metric ranges from 0 to 1, where a value of one indicates that a detected matching region is the same as a ground truth one, and a value of zero indicates that there is no overlap.

B. Experimental results

Figures 4–7 show experimental results of template matching in the first experiment. As shown in Figs. 4 and 6, the location of the template was correctly detected since both
the conventional white balancing and N-white balancing sufficiently reduced lighting effects for the single-illuminant scene.

In contrast, as shown in Figs. 5 and 7, the location of the template was correctly detected by the proposed method while it was not correctly detected by template matching with the conventional white balancing. This is because N-white balancing enables us to reduce lighting effects over the image captured under multiple illuminants, unlike the conventional white balancing. Tables I and II show the IoU value of template matching with each adjustment. From the tables, the proposed method outperformed the conventional white balancing under multi-illuminant scenes.

Figures 8 and 9 show two examples of experimental results on the Guitar dataset and the Mere Poulard A dataset [26]. As shown in Figs. 8 and 9, the proposed method maintained the accuracy of template matching especially under non-uniform illumination (e.g., the matching results in the second row of

| Adjustment     | Fig. 4 (single-illuminant) | Fig. 5 (multi-illuminant) |
|----------------|---------------------------|---------------------------|
| No adjustment  | 0.000                     | 0.000                     |
| White balancing| 0.975                     | 0.000                     |
| N-white balancing | 0.975               | 0.975                     |
IV. CONCLUSION

In this paper, we proposed a template matching scheme that uses N-white balancing proposed for adjusting images captured under various illumination conditions. In the scheme, N-white balancing is applied to query images, and then template matching is performed by using adjusted images. Because N-white balancing considers adjusting single- and multi-illuminant scenes, the accuracy of template matching with N-white balancing can be maintained even when query images are captured under multiple illuminants. In experiments, the effectiveness of the proposed method was shown.

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