Automatic Reference Selection for Parametric Color Correction Schemes for Panoramic Video Stitching

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Abstract. Panoramic views enhance the immersive visual experience by providing seamless high resolution image formed by stitching multiple low resolution images or videos. Color correction is a fundamental step in this process that operates to match the color of individual views with each other. Typically, one arbitrary view is taken as a reference and colors of the remaining views are matched to the reference view. This paper presents a scheme for automated selection of a reference image that results in a high contrast, visually appealing stitched panorama. The scheme is computationally efficient and applicable to a broad range of global parametric color correction schemes.

1 Introduction

Image stitching is the process of seamlessly aligning multiple images into a single image. Video stitching is a similar process where the images to be stitched are either acquired from the time elapsed sequences of the video frames or acquired from a synchronized set of multiple cameras. In the latter case, the goal is to generate a wide angle (high resolution) video using multiple low resolution cameras and we shall term it as Panoramic Video Stitching. With the advent in the display technologies and ever-growing demand for viewing high definition video contents; generation of high definition media content is a highly desirable necessity. By employing Panoramic Video Stitching, one can always go beyond what state-of-the-art video recorders can record. This can be typically achieved by placing multiple video cameras in a circular or planar fashion. Thus Panoramic Video Stitching can be an attractive technology for future real-time tele-broadcasting of, for example live sporting events [15]. There are three main steps in constructing a panorama i.e. geometric registration, photometric correction and finally blending [1]. A lot of work has been done in the domain of image and video stitching algorithms related to geometric correction [16, 17, 20]. Photometric color correction has also received attention recently [1]. When stitching images or video frames from multiple views into a single panorama, typically one of the views is arbitrarily selected as the reference or chosen by the user and the color of the remaining views is matched to the reference [2, 8, 9]. However, if the arbitrarily selected reference image has low contrast, the final output results into a visually unappealing panorama. Figure-1 compares the effect of selecting a low contrast image as a reference with that of selecting a higher contrast image.

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Fig. 1. (Top) Four images used to construct panoramas. (*Middle*) shows the output when the left-most image has been selected as reference. The second panorama (*Bottom*) is the output when third image is taken as reference.

As shown in the figure, the panorama with the higher contrast is more pleasing to look at. This effect is independent of the efficiency of the selected global color matching algorithms since the stitched output depends on the color constituency of the reference image, hence making automatic reference selection a useful task during the process of color correction. In this paper we present a simple and effective scheme that automatically selects an appropriate reference image that results in a visually pleasing panorama. Furthermore, it is shown that the scheme is applicable to a wide range of higher order global parametric color correction schemes. This paper is structured as follows. Section 2 provides a brief survey of color correction schemes. Section 3 describes the proposed scheme; Section 4 discusses the results followed by conclusions in Section 5.

2 Literature Survey

A lot of work has been done in the field of color correction for panorama stitching. As defined by Wei et al. in [1], color correction approaches can be divided into two broad categories: parametric and non-parametric. Parametric approaches assume a relation between the colors of the target image and those of the source image whereas non-parametric methods do not follow any particular model and most of them use some form of a look-up table to record the mapping for the full range of color intensity levels [9, 12]. As stated in [1], while non-parametric approaches provide better color matching results, parametric approaches are more effective in extending the color in non-overlapping regions of the source images without producing grain artifacts.

Parametric approaches are further classified as global schemes that assume a single relation between the reference and the target image, and local correction schemes. Local correction schemes are typically content based [2, 18] and are computationally expensive [19] thus making global color correction schemes a better candidate for the case of Panoramic Video Stitching. A few noteworthy global parametric approaches are reviewed next. Xiong et al. [5] employed diagonal model [3] for color and luminance compensation where the correction coefficients are the ratio of sum of pixel values in adjacent images in the overlap region. In another work [6] by the same authors, they perform gamma correction for luminance component and linear correction for chrominance component by minimizing error functions based on pixel values in the overlapping regions. In a later work [7], the authors use Poisson blending to reduce visibility of image seams produced due to difference in image colors. They compute the difference of the pixel values between the source image and the current panorama on the seam and then distribute and add this color difference to the rest of the image. In [8], the authors use a heuristic to select an image with the most similar means in R, G & B channels as the color reference. However, they do suggest a need for user input to select the best reference. Ha et al. [10] compensates color and luminance by using the linear model in the YCbCr color space, assuming that the objects in the scene have Lambertian reflectance. The gains are computed as the ratio of the average luminance value of adjacent overlapping regions, which are applied on the chrominance components too. In [11], Brown & Lowe use gain compensation for reducing color differences between source images forming a panorama. The gains are computed using an error function, which is the sum of gain normalized intensity errors for all overlapping pixels. However, Tian et al. [3] states that although gain compensation (diagonal model) is simple, it may not be sufficiently accurate. Doutre & Nasiopoulos [13] use a second-order polynomial to render a pixel in one image with the exposure and white balance of the reference image. The polynomial weights can be computed by comparing images in the overlap regions using standard linear least-squares regression. In [14], the blending width between two adjacent images is adjusted according to the color difference of corresponding pixels between seams of two adjacent images forming a panorama.

In almost all the methods mentioned above, the color reference for panorama construction is either selected by the user or chosen arbitrarily. To the best of our knowledge, there have only been two efforts [5,8] to automatically select the reference. Though Xiong et al. [5] suggests searching for an image with the overall best color and luminance distribution in the image sequence and using it as color reference, formal mathematical basis for the proposed scheme is not provided. Furthermore, an image with best global color and luminance distribution can have poor distribution at the image boundaries (due to phenomena such as vignetting). Since image boundaries are almost always part of the overlapping regions in panorama stitching and correction coefficients are computed by comparing the overlapping regions, this can result in the selection of an inappropriate reference. In this paper, a technique for selecting the most suitable color reference image is proposed that compares the global color correction parameters of all the input images evaluated only over the overlapping regions of adjacent images. In particular, we define an image with the most suitable color reference as the one that shall result in a high contrast panoramic image (or video frame for the case of video stitching). The technique requires no user input and is computationally simple.

3 Proposed Methodology

The proposed methodology comprises of three main steps. Firstly, color correction parameters are estimated using an arbitrarily selected image as reference using a global parametric color correction scheme. Next, the most suitable reference image is determined from the pre-calculated color correction parameters. Finally, the correction parameters are updated according to the selected reference image.

3.1 Color Correction Parameter Estimation

Consider a panoramic view being stitched from *n* different views. Let I_1, I_2 ...I_n represent the images acquired from *n* different views where I_1 is the left-most image in the panorama. Given an adjacent image pair forming a panorama, the colors of the right image can be matched to the colors of the left image by the following relationship:

$$I^{c}_{i,(R,G,B)} = T(M_i, \psi_i)\,. \tag{1}$$

$$\psi_i = \begin{bmatrix} R_i & G_i & B_i \end{bmatrix}^T . \tag{2}$$

where ψ_i consists of the R, G and B values of image I_i and M_i is a transformation matrix matching the colors of image I_i to a reference image. I_i^c refers to the corrected image i.e. after applying the transformation *T*. The diagonal plus affine model [3] is employed due to its low computational complexity and thus applicability to Video Stitching, although higher-order transfer functions can also be used. The transformation matrix *M* for the Diagonal plus Affine model [3] is:

$$M = \begin{bmatrix} \alpha & & & \alpha_1 \\ & \beta & & \beta_1 \\ & & \gamma & \gamma_1 \end{bmatrix}. \tag{3}$$

where α, β and γ are channel gains and α_1, β_1 and γ_1 are channel offsets for R, G and B channels respectively. For an image pair $\{I_{i-1}, I_i\}$ and their corresponding overlapping regions $\{I_{i-1,o}, I_{i,o}\}$, the left image i.e. I_{i-1} is used as the color reference. The histogram of $I_{i-1,o}$ is then specified onto $I_{i,o}$.

$$I^{h}_{i,o} = H(I_{i-1,o}, I_{i,o})\,. \tag{4}$$

where *H(a,b)* represented histogram specification of image *a* onto image *b* in RGB domain. The transformation matrix can then be calculated by comparing corresponding pixel values of $I_{i,o}^h$ and $I_{i,o}$ [3]. After applying the correction parameters to I_i, the corrected output, i.e. I_i^c is used as a reference for the next pair in the image sequence. In this way, the correction coefficients of all the images in the panorama with respect to the left-most image are determined.

3.2 Automatic Reference Selection

The next step is to automatically determine the reference image. Let $T(M_i, j)_{(k)}$ be the output value of applying the parametric transformation matrix to input gray value j in the kth channel of the ith image. We define the best reference as the one that has the minimum value of Ω, which is the sum of normalized transformed grayscale values over all channels. Thus, for an image I_i:

$$\Omega(i) = \frac{1}{3} \sum_{k \in R,G,B} \frac{1}{255} \sum_{j=1}^{255} \frac{T(M_i, j)_{(k)}}{j} . \tag{5}$$

$$ref = \arg\min\left(\{x : x = \Omega(i), 1 \le i \le n\} \right). \tag{6}$$

The reference image is therefore represented by I_{ref}. The image that requires the least gains and offset as a result of parametric correction is thus selected as the reference image since it will maximize the parameters for all other images, resulting in a high contrast panorama.

3.3 Color Correction Parameter Adjustment

The final step is to modify the correction parameters. This is done by transforming all the color transfer functions such that the transfer function of I_{ref} becomes identity i.e. I_{ref} remains unchanged and the colors of all other images will be matched to I_{ref}. To set the correction coefficients relative to I_{ref}, we use the following equation:

$$T^{new}(M_i, j)_{(k)} := \frac{T(M_i, j)_{(k)}}{T(M_{ref}, j)_{(k)}} \quad \{1 \le i \le n, 0 \le j \le 255, k \in R, G, B\} . \tag{7}$$

where T^{new} represents the updated transfer function. The updated transformation matrix can be extracted by interpolating a function of the desired order through T^{new}.

The same steps can be applied to higher-order parametric transfer functions since equation (**1**) represented a generic global parametric color transfer function. As an example, a quadratic transfer function [13] can be expressed in terms of M and ψ_i as:

$$M = [m_{R1}\ m_{R2}\ m_{R3} \quad m_{G1}\ m_{G2}\ m_{G3} \quad m_{B1}\ m_{B2}\ m_{B3}]^T . \tag{8}$$

$$\psi_i = \begin{bmatrix} R_i^2 & R_i & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & G_i^2 & G_i & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & B_i^2 & B_i & 1 \end{bmatrix}. \quad (9)$$

Equations (**5**)-(**7**) require no manual input and thus completely automate the reference selection procedure.

4 Results and Discussion

The performance of the proposed scheme is reported for four test cases. Fig-2 compares the output panoramas generated using the default reference (I_1) to using the automatically selected reference for both diagonal plus affine models and quadratic models. The pitch, scoreboard and the crowd all have a higher contrast, giving the panorama a pleasing look (Fig-2b & d). Table-1 compares the Ω values for the images of Fig-2. In both cases the Ω value for I_5 is the least and hence selected as reference.

(a) Diagonal + affine model: (*Top*) Default, (*Bottom*) Auto-Reference

(b) Quadratic model: (*Top*) Default, (*Bottom*) Auto-Reference

Fig. 2. Baseball Stadium Panorama stitched from five images

Table 1. Color Correction Coefficients for Panorama images in Figure 2. I_5 is selected as the reference for both cases.

Image	Diagonal + Affine Ω_i	Quadratic Ω_i
I_1	1	1
I_2	1.104	0.764
I_3	1.018	0.757
I_4	0.939	0.753
$\mathbf{I_5}$	**0.845**	**0.629**

(a) Fountain Panorama : (*Top*) Default, (*Bottom*) Auto-Reference

(b) Athletics Stadium Panorama : (*Top*) Default, (*Bottom*) Auto-Reference

Fig. 3. Panoramas stitched using four camera views with automatic color reference selection

In the fountain panoramas (Fig-3a), the top panorama appears dark, especially on the right side, where the details of the hills are difficult to discern. The bottom panorama of Figure-3a is the output when the third image is automatically set as reference resulting in enhanced contrast, making the hills on the right clearer. In the athletics stadium panoramas (Fig-3b), the color of the sky and grass has better color distribution in the automatically selected reference panorama compared to the default reference panorama.

In some cases (Fig-4), the color distribution of the selected reference image is such that the output panorama becomes saturated. This may become undesirable. When I_5 was selected as reference automatically, the overall panorama (Fig-4 *Middle*) became saturated. In particular, the details of the building in the middle are reduced due to clipping of intensity values as a result of saturation. The number of pixels whose intensity is clipped due to saturation depends on the nature of content in a particular view and its transformation *T*. To prevent this from happening, the increase in the amount of pixels being saturated for each image before and after modifying the correction parameters is determined using the following equation:

$$S = \frac{1}{n \times \sum_{k \in R,G,B} \sum_{j=1}^{255} p(I_{1,k}, j)} \times \left(\sum_{k \in R,G,B} \sum_{i=1}^{n} p(I_{i,k}^{c}, 255) - p(I_{i,k}, 255) \right). \qquad (10)$$

where $p(I_{i,k}, j)$ returns the number of pixels of gray value j in the kth channel of image I_i. If this increase is beyond a certain threshold (5% in our experiments), the next image with the least Ω value is considered a candidate for the auto-referencing scheme. Table-2 shows the percentage increase in saturation when the respective image is set as reference. Initially I_5 was automatically chosen as reference, but it resulted in the middle panorama of Fig-4. The percentage increase in saturation was greater than 5% and hence, it was removed from the reference selection process. Consequently, image I_4 was selected reference. However, it should be noted that the output panorama's color distribution depends entirely on the color distributions of the source images. In the case where all source images have low contrast, the output panorama will also have low contrast.

Fig. 4. Panorama stitched using five camera views with automatic color reference selection. *(Top)*: Default reference I_1, *(Middle)*: Setting I_5 as reference, *(Bottom)*: Setting I_4 as reference.

The proposed technique works successfully for a number of image sets. It is computationally efficient and equations (**5**)-(**7**) took 35.5 msec to execute in MATLAB when run on Intel Core I5 3.3 GHz with 4 GB RAM.

Table 2. Ω and %S values for Panorama image in Figure 4. Negative %S values represent a decrease in the number of saturated pixels.

Image	Ω_i	%S
I_1	1	-0.356
I_2	1.137	-0.3649
I_3	1.100	-0.345
I_4	**0.967**	**3.952**
$\mathbf{I_5}$	**0.814**	**10.799**

5 Conclusion

In this paper an automatic scheme for reference image selection for global parametric color correction techniques was presented. The scheme results in an output panorama with richer colors due to better color distributions of the output color channels. The effectiveness of the scheme is shown using real test images. Furthermore, a method was discussed to avoid making images as reference which result in the panorama becoming oversaturated. The scheme is scalable for higher order parametric color correction and supporting results were also provided. In the future, we would like to extend this technique to non-parametric color correction methods.

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