Color Correction for Panorama Video Surveillance

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***Abstract*—**In panorama surveillance video, color inconsistency among different cameras always exists because of imperfect camera calibration, different reflection functions, CCD noise, etc. Since color inconsistency greatly reduces rendering quality of panorama surveillance video, a hybrid color correction method by combining the region matching with the gamma correction and the linear correction is proposed in this paper. Firstly, two frames from two adjacent cam-eras are matched using point feature correspondences and the overlapping areas are located by the homography. Secondly, the images in the overlapping areas are segmented into regions by marker-controlled watershed transformation and regions are matched using point feature correspondences. Finally, the color-corrected frame is generated from the combination of gamma correction for the luminance component and linear correction for the chrominance components of corresponding regions in the YUV color space. Experimental results show that the performance of color correction for panorama video is visually acceptable. This method can be improved the market competitiveness of panoramic video surveillance products.

***Keywords*—**color correction, region segmentation, gamma correction.

I. INTRODUCTION

Color correction is an active research problem due to its wide spectrum of applications in areas such as panorama video surveillance, the repurposing of sports videos and home videos. In the scenario of the panorama video surveillance, multiple individual surveillance videos are merged into a panorama video; the merged panorama video will appear photometric inconsistency problem.

The color of an object is affected by the radiance of an illuminant and the reflectance of the object surface. When capturing the object via a camera, we should consider an additional factor, a camera property. The camera responds to incident light based on its own properties including a shutter speed, sensor, sensitivity, and aperture. Therefore, even though we capture the same object under the same illuminant, the colors of the captured image can be varied according to the camera properties. Since it is hard to perfectly adjust all the properties of multiple cameras as we wish, the color inconsistency among multiple cameras is induced even though we use the cameras of the same kind; it is an inevitable problem.

The inconsistent colors among multiple cameras degrade not only the visual quality of panorama video but also the performance of image processing. Most of the image processing algorithms have been designed under the color conservation assumption that correspond in g pixels among views have similar colors. If this assumption is invalid, their performance becomes considerably degraded.

Therefore, color correction plays an important role in panorama video surveillance system which consists of the multiple cameras. Color correction is often used before the stitching process to balance colors and luminance in the whole image sequence. A common approach is to transform the color of all the images in the sequence to match the basis image. The transform matrix across images can be represented as a linear model [1][2] or a diagonal model [3], in which the mapping parameters are computed from the averages of each channel over the overlapping areas or from the mapping of histograms [1][4]. These approaches are not sensitive to the quality of geometric alignment, but the accuracy of color correction needs to be improved. Recently, Xiong et al. [5] proposed a much accurate color correction algorithm that minimizes a global error function, to get the correction coefficients simultaneously for the whole image sequence. To establish the global error function, it is necessary to extract all the mean values of overlapping areas between every pair of adjacent images. However, the overlapping areas are limited for regular rectangle regions, and they are just the translation relationship. While stitching panorama video, the all overlapping areas from adjacent cameras are impossible on the same horizontal line and may be the irregular regions. Hence, the problem is how to exactly match overlapping areas.

Some region-based approaches [6, 7, 8] were proposed in the past few years. The region-based approach in [8] produced the best results among several compared approaches. Inspired by the methods in [5] and [8], this paper proposes a hybrid color correction method by combining the region matching with the gamma correction and the linear correction. This method consists of four steps. The first step is to decom-pose the overlapping areas between every pair of adjacent frames into regions using watershed transformation. The second one is a region matching process based on point feature

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correspondences. The third one is to finely compute the gamma and linear correction coefficients by the matching regions and finally obtain the color corrected frame. The fourth one is to generate the lookup table for reducing the computational complexity. The proposed approach aims at panorama surveillance video and it improves the color correction process proposed in [5]. The proposed method is able to handle frames under different acquisition conditions. The results of color correction for panorama video have shown that color transition is natural and smooth.

The rest of this paper is organized as follows. Section 2 describes our proposed approach. The evaluation results are given in section 3. Section 4 concludes the paper.

II. A Hybrid Color Correction Method

A hybrid color correction method by combining the region matching with the gamma correction and the linear correction is presented in this section. The pseudocode of the proposed method is shown in Figure 1.

Algorithm I: Hybrid Color Correction

Input: two frames I_r (reference frame from camera1) and I_s (source frame from camera2) .

Output: I_{sc} (output frame) from I_s with color correction.

Step1: Find point correspondences between I_r *and* I_s .

Step2: Find the overlapping areas between I_r *and* I_s .

Step3: Segment the two frames in the overlapping areas.

Step4: Match two regions if they are straddled by matched points.

Step5: Gamma and linear correction coefficients.

Step6: Weighted color and luminance correction.

Step7: Lookup table and conversion.

Fig.1. The pseudocode of the hybird color correction algorithm.

2.1Feature Correspondence Acquisition

SIFT [9] is adopted to acquire feature correspondences of two frames because it is invariant to image translation, rotation, scaling and illumination changes. Next, feature correspondences are acquired by using the Brute-Force matcher and refined by RANSAC [10]. The acquired feature correspondences are the best matches fitted to the best estimated homography, but it is not guaranteed that they are spatially distributed all over the frame. An incremental tiling method is implemented to better the correspondence distribution. After one set of point correspondences is found, we mask the frame part straddled by these points in both frames and search for point correspondences within the unmasked frame part. This mask can be computed by a rotated rectangle or a convex hull bounding a set of point. The point matching with mask is repeated until the final mask covers most of the frame, 80% in our case. A homography is computed according to the acquired correspondences. Then, the computed homography tells overlapping areas between two frames. The overlapping areas in frame I_r *and* I_s is denoted as $I_{r,s}$ and $I_{s,r}$, respectively.

2.2 Region Segmentation and Matching

The overlapping areas $I_{r,s}$ and $I_{s,r}$ are segmented into regions using watershed transformation [11]. The idea is to consider a gray-scale frame as a topographic relief and to flood this relief from different sources until they start to merge. This results in watershed lines separating different catchment basins. In addition, predefined markers can be used as flooding sources to control segmentation procedure, e.g. to avoid over segmentation. The marker-controlled watershed segmentation is described as follows.

1) Computation of Segmentation Criterion and Markers

In order to partition the frame into homogeneous regions, the frame gradient is used as the segmentation criterion (or the topographic relief mentioned above) since the gradient value is low within a homogeneous region and high at its boundary. The markers should locate inside the regions, hence can be computed from the local minima of the gradient frame or by applying a threshold to the gradient frame. Note that the maximum gradient of all color channels, instead of the gradient of gray frame, is used in order to preserve better region boundaries.

2) Marker-controlled Watershed Segmentation

The frame gradient and markers are provided to watershed segmentation. If the resulting regions are more numerous than expected, we can run an additional region fusion: if the color difference between two adjacent regions is inferior to a given threshold, we eliminate their inner boundary and keep their outer boundaries with other regions in order to avoid incorrect boundary elimination and region fusion. Each pair of regions between the overlapping areas $I_{r,s}$ and $I_{s,r}$ is matched if they are straddled by matched points. In addition, merge regions in case of one-to-multiple matching, which may happen when a region in one frame corresponds to several adjacent regions in the other frame. At last, K pairwise matching regions $S^i_{r,s}$ and $S^i_{s,r}$ $(i=1,2,\cdots,K)$ are obtained from the overlapping areas $I_{r,s}$ and $I_{s,r}$, respectively.

2.3 Color Correction

Here a gamma correction that matches the luminance content of neighboring frames within the area of overlap, and a linear correction for the chrominance components are conducted sequentially in YUV color space.

1) Gamma and Linear Correction Coefficients Computation

For K pairwise matching regions $S^i_{r,s}$ and $S^i_{s,r}$ $(i=1,2,...,K)$, we match the luminance in the corresponding regions with gamma correction and construct an error function,

$$\min_{\gamma_i} E_1 = \frac{1}{2}\left(\sum_{i=1}^{K}\left(\gamma_i B^i_{r,s} - \gamma_i B^i_{s,r}\right)^2 / \sigma_N^2 + \sum_{i=1}^{K}\left(1-\gamma_i\right)^2 / \sigma_g^2\right), \quad (1)$$

where σ_N and σ_g are the standard deviations of the normalized color and luminance errors and gamma coefficients. ($\sigma_N = 2.0/255$ and $\sigma_g = 0.5/255$ when the image value range is normalized to [0, 1]).

$$B_{r,s}^i = \ln\left(\frac{1}{N_{r,s}^i}\sum_{p\in S_{r,s}^i} Y_{r,s}^i(p)\right),$$
$$B_{s,r}^i = \ln\left(\frac{1}{N_{r,s}^i}\sum_{p\in S_{r,s}^i} Y_{s,r}^i(p)\right), \quad (2)$$

$Y_{r,s}(p)$ is the luminance value of pixel p in the region $S_{r,s}^i$ (linearized from the sRGB luminance by raising to the power of $\gamma = 2.2$); $Y_{s,r}(p)$ is the luminance value of the corresponding pixel p in the region $S_{s,r}^i$; γ_i are gamma correction coefficients for the region $S_{s,r}^i$; $N_{r,s}^i$ is the number of pixels in the region $S_{r,s}^i$.

By minimizing the error function E_1, we can obtain the gamma coefficients $\gamma_i (i = 1,2,...,K)$. In a similar way, we can match the chrominance in K pairwise matching regions $S_{r,s}^i$ and $S_{s,r}^i$ $(i = 1,2,...,K)$ with linear correction and construct an error function,

$$\min_{\alpha_i} E_2 = \frac{1}{2}\left(\sum_{i=1}^{K}\left(\alpha_i \bar{S}_{r,s}^i - \alpha_i \bar{S}_{s,r}^i\right)^2 / \sigma_N^2 + \sum_{i=1}^{K}(1-\alpha_i)^2 / \sigma_g^2\right), \quad (3)$$

where $\bar{S}_{r,s}^i$ and $\bar{S}_{s,r}^i$ is the chrominance mean value of the corresponding regions $S_{r,s}^i$ and $S_{s,r}^i$ respectively,

$$\bar{S}_{r,s}^i = \frac{1}{N_{r,s}^i} C_{r,s}^i(p), \quad \bar{S}_{s,r}^i = \frac{1}{N_{r,s}^i} C_{s,r}^i(p), \quad (4)$$

$C_{i-1,i}(p)$, $C_{i,i-1}(p)$ are the chrominance values of pixel p in the regions $S_{r,s}^i$ and $S_{s,r}^i$ $(i = 1,2,...,K)$. $\alpha_i (i = 1,2,...,K)$ are linear correction coefficients.

Solving this quadratic objective function, we can obtain the linear correction coefficients $\alpha_i (i = 1,2,...,K)$.

2) Weighted Color and Luminance Correction

Given K pairwise matching regions between the source and reference frames, the color correction is a combination of K local color transfer. In addition, in order to ensure smooth color shading across the color-corrected frame, each local color transfer is weighted by an influence mask IM, which means the percentage of the number of pixels in the each corresponding region from the total overlapping area. IM^i is the percentage of the number of pixels in the region $S_{r,s}^i$ from the total overlapping area.

$$IM^i = \frac{N_{r,s}^i}{\sum_{i=1}^{K} N_{r,s}^i}. \quad (5)$$

$$\gamma_c = \sum_{i=1}^{K}(\gamma_i \times IM^i), \alpha_c = \sum_{i=1}^{K}(\alpha_i \times IM^i), \quad (6)$$

where γ_c is the weighted gamma coefficient, and α_c is the weighted linear correction coefficient.

For each source frame, we perform gamma correction for the luminance component,

$$Y_s(p) \leftarrow Y_s(p)^{\frac{\gamma_c}{\gamma}}, \quad (7)$$

where γ is the gamma coefficient used above for linearization of the sRGB color space. $Y_s(p)$ is the luminance component at pixel p in the source frame I_s. Finally, we can perform linear correction for the chrominance components for all source frames.

$$C_s(p) \leftarrow \alpha_c \times C_s(p), \quad (8)$$

where $C_s(p)$ is the color value at pixel p in the source frame I_s.

2.4 Lookup Table and Conversion

With these correction coefficients, the color values of the source view are converted. However, since the corrected values have to be calculated for every pixel and every channel, this process takes a long time. To reduce the computational complexity, we generate three lookup tables for the luminance and chrominance components. The lookup tables contain pixel values to be corrected in the source view and their corrected values. This process is conducted for all pixels and channels. After that, we can get the corrected frame having similar color distribution to the reference frame's one.

III. EXPERIMENTAL RESULTS

In this section, the proposed approach is evaluated with a variety of surveillance frames. We uses Hikvision network camera for video surveillance. We run C++ implementation on a workstation with Intel i5 3.10 GHz CPU and 4 GB memory. The dataset for evaluating the proposed timestamp localization and recognition algorithm consists of 300 video clips (704×576) and 300 video clips (1280×720) cropped from the surveillance videos. Each clip is about 20 second long with a working digital video timestamp. The frame rate of videos in our test is 25Fps. The dataset is available at "http://pan.baidu.com/s/1o6DvTwe".

The proposed color correction method in this paper is compared with Xiong's method in [5] in their performances under different lighting conditions. There are five lighting conditions as follows: sunny (morning) in Figure 2(a), sunny (noon) in Figure 2 (b), evening in Figure 2 (c), night in Figure 2 (d) and cloudy in Figure 2 (e), and. In Figure 2 (a) to (e), column 1 is source frames (Reference frames); column 2 is source frames; column 3 is color corrected frames by approach in [5]; column 4 is color corrected frames by our approach. Panorama frames produced by different approaches are shown from Figure 2 (f) to (h). Although the approach in [5] uses color correction and blending, the color transition is not smooth enough to make the seams invisible on the final panorama as Figure 2 (g) shows. The proposed approach produces visually consistent panoramas, on which the color transitions are natural and the seams are invisible as Figure 2 (h) shows.

The color similarity measure proposed in [12] can be used as the evaluation metric. The color similarity (CS) between two frames A and B is defined as their peak-signal-to-noise-ratio $(PSNR)$. A higher $(PSNR)$ generally indicates that the color between two frames is closer.

$$CS(A, B) = PSNR(\hat{A}, \hat{B}) = 20\log_{10}\frac{\max I}{RMSE(\hat{A}, \hat{B})}. \quad (9)$$

where $\hat{A}$ and $\hat{B}$ are the overlapping areas between A and B, $\max I$ is the highest possible pixel value of the frame. Since each pixel is represented by 8 bits, $\max I = 255$. $RMSE$ stands for the root mean square error. In this case, it is computed from all pixels of $\hat{A}$ and $\hat{B}$ in RGB channels.

The source frames in column 1 from Figure 2 (a) to (e) is used as ground-truth frames C_{gt} to do objective evaluation of the approach in [5] and the proposed approach. We measure the color similarity between the ground-truth frame C_{gt} and (i) the input frame C_{input} in column 2 from Figure 2 (a) to (e), (ii) the frame C_{other} after the color correction by the method in [5] and (iii) the frame C_{our} after the color correction by the proposed method. It can be seen that both approaches of color correction improve the color of the input frame, and the proposed method performs better than the method in [5]. The reason may be that the reference and input frames contain very similar regions.The evaluation results of the color correction are given in Table 1.

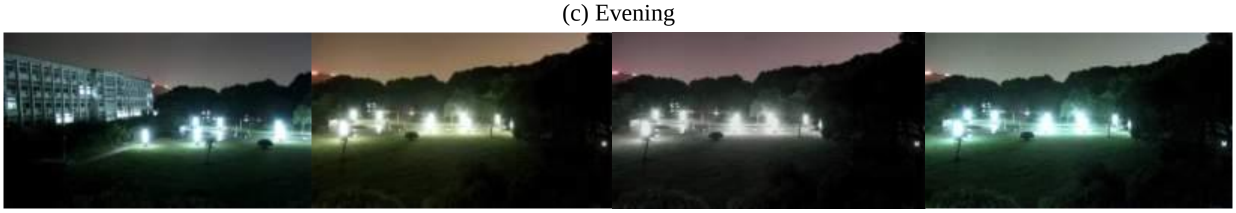
Table1. Comparison of color similarity by different approaches with respect to different lighting conditions.

method	$CS(C_{rf}, C_{input})$	$CS(C_{rf}, C_{other})$	$CS(C_{rf}, C_{our})$
Sunny1 (Morning)	18.662	22.926	24.391
Sunny2 (Noon)	20.597	23.743	24.265
Evening	19.635	21.562	23.256
Night	17.182	20.238	22.851
Cloudy	18.258	21.526	23.826

(a)Sunny1 (Morning)

(b) Sunny2 (Noon)

(c) Evening



(d) Night

(e) Cloudy

(f)

(g)

(h)

Fig.2. Example frames of color correction by the proposed method and Xiong's method in [5] with respect to the five lighting conditions (sunny1, sunny2, evening, night and cloudy). From (a) to (e): column 1 is source frames (reference frames) from camera1; column 2 is source frames from camera2; column 3 is the result frames after color correction by approach in [5]; column 4 is the result frames after color correction by our approach. (f) Panorama frame with (e) by source frames. (g) Panorama frame with (e) corrected frame by approach in [5]. (h) Panorama frame with (e) corrected frame by proposed approach.

IV. Conclusions and Future Work

In this study, we proposed a novel hybrid method consisting of two color correction schemes to deal with the photometric inconsistency problem that commonly exists in panorama video surveillance. The method includes four major steps. First, the overlapping areas are decom-posed into regions using watershed transformation between every pair of adjacent frames. Second, regions are paired using point correspondences which are invariant to geometric transformation and illumination variations. Third, we proposed to use the combination of gamma correction for the luminance component and linear correction for the chrominance components of a source frames in the YUV color space. Finally, the look table is used to reduce the time cost of color correction. This method can be used in panorama video surveillance to correct the color of video streams from various cameras, which may have different internal settings and external illumination conditions.

According to the experimental results, the method has advantages over traditional approaches. The proposed approach aims at panorama surveillance video and it improves the color correction process proposed in [5]. The proposed method is able to handle frames under different acquisition conditions. The results of color correction for panorama video have shown that color transition is natural and smooth.

This method can be improved the market competitiveness of panoramic video surveillance products. This technology can not only improve the economic ability of the enterprise, but also support the innovation and development of the enterprise.

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