A Novel Dual-band Video Fusion Algorithm Using Fast Lookup-Tables: Toward Naturalistic Color

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Abstract. This paper presents an algorithm for fast dual-band video fusion with good naturalistic color using lookup tables. We establish a color lookup table based on the methods of frame extraction, pseudo-color mapping and color transfer; then we fill up the missing values of the lookup table using the Euclidean distance among its elements. From this lookup table, the luminance value and chromatic values of each pixel in the output frames are retrieved, and consequently the final color fused video is attained. Experiments show that the algorithm is a fast and practical approach to fuse dual-channel videos with stable color appearance and perceived high naturalness.

1. Introduction
The technique of image fusion makes it possible to take advantage from different sensors, not a single sensor. Color fusion images are considered more efficient than gray fusion images in helping people for tasks especially based on human eye observation. This is because human eyes are very much more (hundreds of times) sensitive to the levels of color scale than to the levels of gray scale. To put it another way, human is more likely to remember the details within a color image than within a gray-scale image. Considering humans’ physiological characteristics, color images, compared to the gray scale images, have the advantage of enabling better memory of the scenes, faster response to the scenes, and higher impression of the scene by human beings. Many researchers have studied multi-band natural color fusion imaging algorithms. Waxman et al. [1-3] enhanced the in-band image contrast and the inter-band color contrast based on the biological vision characteristics, and continuously proposed many low-light level and infrared image fusion methods. Toet et al. [4-6] put forward many natural color fusion algorithms, such as by using the local minimum operators, by drawing on the photo color cast correction processing method introduced by Reinhard et al. [7], and so on. Toet’s algorithms transferred color from natural daytime images to the fusion images with high contrast but less naturalistic colors, and improved fusion images’ color naturalness. Other color fusion algorithms based on color transfer were also developed later [8-10].

However, most of the prior color fusion algorithms for attaining naturalistic color requires very large amount of computation, which is not time efficient and not applicable to the real tasks. In recent years we developed the multi-band and the single-band image fusion algorithms to attain perceived naturalistic colors based on color transfer. The purpose of this study is to explore a new method for fast processing of video fusion with enhanced naturalness.
2. Dual-Band Image Color Fusion

We captured optical registered infrared image (denoted by IIR) and grayscale television image (denoted by Ivis), and then these images were mapped to RGB color space (IIR→R channel, Ivis→G channel, 0→B channel), so we got a source image (denoted by Isource), as is shown in Figure 1. Figure 1 showed that Isource had low color saturation and poor color hues, negatively affecting target’s recognition capability and scene’s perceived depth. We transformed IIR and Ivis from most commonly used color space RGB to opponent color space $l\alpha\beta$.

Three natural daytime color images with different scenes were chosen as the reference images (denoted by Iref, as is shown in Figure 1(a)~1(c)). In $l\alpha\beta$ space, we transferred color effects from Iref to Isource using color space channels’ mean and standard deviation which is shown in equation (1):

$$
\mu_C = \frac{1}{mn} \sum_{i=0}^{m-1} \sum_{j=0}^{n-1} C(i, j), \quad \sigma_C = \sqrt{\frac{1}{mn} \sum_{i=0}^{m-1} \sum_{j=0}^{n-1} [C(i, j) - \mu_C]^2}
$$

where $C$ represented $l$, $\alpha$ or $\beta$ channel. $m$ and $n$ denoted the numbers of image rows and columns. Images’ origin coordinates were $(0, 0)$. Means and standard deviations of Iref’s three channels were separately transferred to Isource so that Isource gets similar color effects as Iref, by operating

$$
C_{\text{trans}} = \mu_{\text{trans}}^{\text{source}} + \frac{\sigma_{\text{trans}}^{\text{source}}}{\sigma_{\text{source}}} (C_{\text{source}} - \mu_{\text{source}}^{\text{source}})
$$

where $C_{\text{trans}}$ represented $l$, $\alpha$ or $\beta$ channel of resulting image of color transfer. $\mu_{\text{source}}^{\text{source}}$, $\mu_{\text{ref}}$, $\sigma_{\text{source}}^{\text{source}}$ and $\sigma_{\text{ref}}$ denoted means and standard deviations of source image and reference image. After this operation, mean and standard deviation of $C_{\text{trans}}$ were the same as those of reference images. However, the operation in $l\alpha\beta$ space led to some loss of image details. $I_{\text{trans}}$ was a 24-bit image, but the RGB values of some of the pixels were likely to overflow the range of $[0, 255]$ when doing color space reverse conversion. Therefore, when doing data type conversion, we compressed the values of the high and low ends of each channel while preserving the range of $[26, 229]$: \[C_{\text{trans}}^* = \begin{cases} \text{round}(25(C'_{\text{trans}} - \min(C'_{\text{trans}}))/[25 - \min(C'_{\text{trans}})]), & C'_{\text{trans}} \in [\min(C'_{\text{trans}}), 25] \\ \text{round}(230 + 25(C'_{\text{trans}} - 230)/[\max(C'_{\text{trans}}) - 230]), & C'_{\text{trans}} \in [230, \max(C'_{\text{trans}})] \end{cases} \]

where $C'_{\text{trans}}$ and $C_{\text{trans}}^*$ were the data of $I_{\text{trans}}$’s R, G or B channel before and after the compression.

Ref images’ colors were separately transferred into Isource to get the result images (denoted by $I_{\text{trans}}$, as shown in Figure 1(d)–1(f)), which were more colorful than Isource. The natural sense and color saturation of result images were remarkably improved.

Because of the individual differences in terms of the physiological and psychological vision, people’s color effect evaluations on three result images are not fully consistent. We recruited 8 trained subjects to subjectively evaluate the color naturalness of Figure 1(d)–1(f)). The result (see Table 1) showed that most of the subjects (6 out of 8) ranked Figure 1(f) as the best one, and there was no obvious pattern for the ranks of the other two figures (Figure 1(d), Figure 1(e)). This result provided us with the basis for choosing reference images in connection with specific scenes; meanwhile, the diversity of the ranking orders from the subjects showed the need to provide observers with different reference images.
Hardware implementation of video color transfer needs to store only the means and standard deviations of three color-channels (6 scalars in total) of reference image selected by observers not the whole reference image. Therefore, a lot of storage space can be saved. However, each individual source video frame performs division operations in addition to calculating the mean and standard deviation, so the amount of computation is still large.

Table 1. Ranking order of the color naturalness on three color transfer results (Figure.1(d)~1(f))

| Observer Number | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|------------------|---|---|---|---|---|---|---|---|
| Order of color naturalness | f>d>e | f>e>d | d>f>e | f>e>d | f>d>e | f>e>d | d>f>e | f>d>e |

3. A Novel Dual-band Video Fusion Algorithm Using Fast Lookup-Tables

3.1. Two-dimensional color look-up table

The color look-up table (LUT) is a commonly used data structure to store and display color images among the multi-media technologies. We colorized dual-band images $I_{IR}$ and $I_{vis}$ by color space mapping and color transfer to obtain a resulting image $I_{trans}$. Then we established a two-dimensional color look-up table $L_0$. The method is to set the grayscale values of each pixel in $I_{IR}$ and $I_{vis}$ to be the horizontal and vertical coordinates in $L_0$ and set the chromatic values (RGB values) of $I_{trans}$’s pixel, whose locations is the same as the pixels in $I_{IR}$ and $I_{vis}$, to be the value of $L_0$ (see Figure.2(a)). The expressions were as follows:
where \( x \in \{0, 1, 2, \ldots, m-1\}, \ y \in \{0, 1, 2, \ldots, n-1\} \). \( m \) and \( n \) denoted the numbers of image rows and columns respectively. The value ranges of image \( I_{IR}, I_{vis}, \) and each color channels in \( I_{trans} \) were all \([0, 255]\). Accordingly, the color look-up table \( L_0 \)'s horizontal and vertical coordinates’ ranges were \([0, 255]\), and \( L_0 \) can index up to 65536 colors.

Because the actual dual-channel video frames do not commonly comprise all the grayscale values \(([0, 255])\), we cannot get a complete LUT. Put it more clearly, on one hand, the sets of grayscale values from \( I_{IR} \) and \( I_{vis} \) are included in the sets of coordinate values in \( L_0 \), namely

\[
\{I_{IR}(x, y), I_{vis}(x, y)\} \subseteq \{(x_0, y_0) | x_0, y_0 \in \{0, 1, 2, \cdots, 255\}\}
\]

(5)

On the other hand, the data provided by the color fusion image \( I_{source} \) cannot cover the whole color look-up table. Therefore, in the look-up table \( L_0 \) (see Figure.2(a)), there are a certain number of vertical lines and break points. Therefore, \( L_0 \) only provides part of the mapping relationships between grayscale and chromatic values. If this is directly applied to video fusion, part of the pixels of some frames cannot be colorized.

So, we assigned the chromatic values of the nearest pixels to the pixels without color in \( L_0 \), according to the principle that the closer the pixels’ Euclidean distances is, the closer the chromatic values will be. Thus, complete color look-up table is established. The specific implementation method is to take the pixel whose \( R + G + B = 0 \) as center, and draw a smallest circle containing chromatic pixels. Take the mean of chromatic values on the circle as the chromatic values of the center (see Figure.2(a)). After traversing over the whole image of \( L_0 \), we obtained the complete color look-up table \( L \) (see Figure.2(b)).
3.2. Fast algorithm based on two-dimensional color look-up table

The flowchart shown in Figure 3 described the procedure we followed to get the color look-up tables base on dual-band color fusion and color transfer. The fusion effect of an actual scene was shown in Figure 4. In the next, the algorithm processing procedure will be explained via the color transfer procedure of these images.

![Flowchart](image)

Figure 3. The flowchart for getting color look-up table base on dual-band color fusion and color transfer

![Images](image)

Figure 4. The pseudo-color fusion image derived from single-band grayscale images

Multiple images were used as reference images to transfer color to source image separately, so we obtained different resulting images accordingly. Only the mean and standard deviation of each channel of de-correlated opponent color space Iαβ were used when we transferred reference image’s color (as table 2), so we can just pre-store these statistics in the system hardware. Thus, a certain number of selected reference images (such as hills and woods, shrubs, deserts, towns, sea and blue sky, white clouds, etc.) don’t take up much storage space, guaranteeing the application requirements in different environments. Figure 5 shows 6 result images obtained by transferring the color of 15 reference images in Table 1 to Figure 4(c). As Figure 5 showed, the resulting images have different naturalistic color. According to observer’s visual preference, one of them was chosen to establish two-dimensional color look-up table following the methods in the previous section. Figure 6 showed the two-dimensional color look-up table corresponding to Figure 5(d).

Inputted dual-channel videos can be colorized directly with the help of two-dimensional color look-up table. That is to determine corresponding pixel’s chromatic values after natural color fusion from indexing the grayscale values, which belong to pixels with the same coordinates of simultaneous frames extracted from dual-channel videos, in two-dimensional color look-up table. Figure 7 showed 4 frames of the actual resulting video transferred. Fusion images have good color stability and avoid the same object’s inter-frame color changing with the camera’s movement. In traditional methods,
camera’s movement may cause the mean and standard deviation of source image channels changing. As this two-dimensional color-lookup-table based method saves a lot of procedures for processing each frame, such as color space transformation, \( l \alpha \beta \) channels’ mean/standard deviation computation, and color transfer operation, the overall computational amount is significantly reduced. This advantage makes it possible to naturally color fuse dual-channel videos in real-time.

| Reference image number | \( \mu \)  | \( \mu_\alpha \) | \( \mu_\beta \) | \( \sigma \)  | \( \sigma_\alpha \) | \( \sigma_\beta \) |
|------------------------|---------|----------------|----------------|---------|----------------|----------------|
| 1                      | 3.0279  | -0.1221       | -0.0455        | 0.6649  | 0.2004         | 0.0396         |
| 2                      | 3.7828  | 0.0085        | -0.0252        | 0.3800  | 0.2805         | 0.0442         |
| 3                      | 2.8324  | 0.2030        | 0.0210         | 0.9783  | 0.2865         | 0.0376         |
| 4                      | 3.2456  | 0.1491        | -0.0378        | 0.4725  | 0.1488         | 0.0249         |
| 5                      | 3.0740  | 0.2515        | 0.0504         | 0.7478  | 0.2267         | 0.0447         |
| ……                     | ……     | ……            | ……             | ……     | ……             | ……             |
| 15                     | 3.2625  | 0.2693        | 0.0019         | 0.5952  | 0.1928         | 0.0231         |

Figure 5. Get different color appearances according to a set of reference image

4. Conclusion
This paper proposed an algorithm which establishes complete two-dimensional color look-up tables via color space mapping and color transfer and implements fast processing dual-channel video fusion using the look-up tables. Experiment results showed that this algorithm can significantly improve the speed of image fusion with good naturalistic color, which needs very complicated calculation. The obtained color video had good natural senses, rich color hues, and high color saturation. Meanwhile, the details and features of each video channel were well maintained. The color of look-up table in accordance with certain observer’s subjective judgment and selection was of benefit to current observer’s perception of scene. This operation mode was in line with the further practical application. The same set of grayscale values inputted to color look-up table will index to the same chromatic values. So, if a certain object’s reflection and radiation remain unchanged in different frames, its color
will maintain stability, excluding the impact of image sensor’s automatic gain. The application of look-up tables provides a new way of thinking for other complex image processing methods.

Figure 6. Set up two-dimensional color look-up table according to observer’s choice

Figure 7. Frames of fused video using natural color look-up table

References

[1] A M, Waxman A N, Gove M C, Seibert, et al 1996 Progress on color night vision: visible/IR fusion, perception & search, and low-light CCD imaging SPIE Enhanced and Synthetic Vision pp 96-107

[2] A M, Waxman M, Aguilar D A, Fay, et al 1998 Solid-state color night vision: fusion of low-light visible and thermal infrared imagery Lincoln Laboratory Journal 11(1) pp 41-60

[3] Waxman A M , Aguilar M , Baxter R.A, Fay D A , Ireland D B , Racamoto JP and Ross W D 2017 Opponent-Color Fusion of Multi-Sensor Imagery: Visible, IR and SAR Available online: http://www.dtic.mil/docs/citations/ADA400557 (accessed on 28 August)

[4] Toet A and Walraven J 1996 New false color mapping for image fusion Optical Engineering 35(3) pp 650-658

[5] Toet A and Hogervorst M A 2008 Portable real-time color night vision SPIE Multisensor, Multisource Information Fusion: Architectures, Algorithms, and Applications pp 697402-1-697402-12

[6] Maarten H and Toet A 2017 Improved Color Mapping Methods for Multiband Nighttime Image Fusion Journal of Imaging 3.3: 36

[7] Reinhard E, Adhikhmin M, Gooch B, et al 2001 Color transfer between images IEEE Computer Graphics and Applications 21(5) pp 34-41

[8] Rabin J, Ferradans S and Papadakis N 2014, October Adaptive color transfer with relaxed optimal transport. In Image Processing (ICIP) IEEE International Conference pp 4852-4856

[9] Yu X, Ren J, Chen Q and Sui, X 2014 A false color image fusion method based on multi-resolution color transfer in normalization YCBCR space Optik-International Journal for Light and Electron Optics 125(20) pp 6010-6016

[10] Ancuti C, Ancuti C O, De Vleeschouwer C and Bovik A C 2016 September Night-time dehazing by fusion. In Image Processing (ICIP), 2016 IEEE International Conference pp 2256-2260