Multi exposure image fusion algorithm based on YCbCr space

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Abstract. To solve the problem that scene details and visual effects are difficult to be optimized in high dynamic image synthesis, we propose a multi exposure image fusion algorithm for processing low dynamic range images in YCbCr space, and weighted blending of luminance and chromatic aberration components respectively. The experimental results show that the method can retain color effect of the fused image while balancing details of the bright and dark regions of the high dynamic image.

1. Introduction

In real life, the intensity of the daily scenes is far greater than the dynamic range recorded by image acquisition device. Generally, when the intensity of the scene changes too much, it is inevitable that some details will be lost due to overexposure and underexposure. By adjusting the exposure time, the multiple exposure images of the same scene are processed to expand the dynamic range of low dynamic range images.Debevec[1] restores the camera response curve and tone mapping, which is complex and the fusion image produces a clear halo. Mertens[2] calculates contrast, saturation and exposure as fusion guidance indicators, and complete image fusion in Laplacian Pyramid. Due to the lack of considering the correlation of RGB color channels, fusion image color degradation and more details are lost in bright and dark areas. Paul[3-5] deals with the luminance and chromatic aberration domains of the image respectively in YCbCr color space. The fused image has higher saturation and the details of the darkness are promoted, but the overall image is darker and with a smaller contrast. This paper proposes a multi exposure image fusion algorithm based on YCbCr space, processing in luminance and chromatic aberration components respectively. Fusion image retains details in bright and dark areas, at the same time, obtains good color expression.

The rest of the paper is organized as follows. In Sec. 2, the proposed multi exposure image fusion algorithm is presented. In Sec. 3, the high dynamic images synthesized by three methods are evaluated and compared. Finally, In Sec. 4, the main conclusions are drawn.

2. Multi exposure image fusion algorithm in YCbCr space

In Mertens and Paul methods, the details and saturation of the image cannot be optimized at the same time when dealing with the multi exposure images. We propose to transform the low dynamic range images into YCbCr space. In luminance component Y, Firstly, the weight map W is calculated according to the contrast, saturation, and proper exposure. Then, W and Y are decomposed in Laplacian pyramid and weighted blending on multiresolution scale. Finally, operating the gamma correction and histogram equalization for the fused luminance component Y'. In chromatic aberration
components \( C_b \) and \( C_r \), take the offset maximum absolute values corresponding to the chromatic aberration value as \( C_b' \) and \( C_r' \).

### 2.1 YCbCr color space.

The YCbCr color space is the offset version of YUV color space, where Y is the luminance component, \( C_b \) and \( C_r \) are chromatic components. \( C_b \) and \( C_r \) reflect the difference between the blue and red part of the RGB input signal and the intensity value. The advantage of YCbCr color space is that its luminance components Y and chromatic components \( C_b \) and \( C_r \) are separated. It can be operated separately in each channel without mutual effect. The conversions between YCbCr color space and RGB color space is as follows:

\[
\begin{align*}
Y' &= 128Y + 128B + 16C_r + 16C_b \\
Y &= 0.299B + 0.587G + 0.114R \\
C_b &= -0.148B - 0.291G + 0.439R \\
C_r &= 0.439B - 0.368G - 0.714R \\
R &= 1.164Y - 0.392G - 2.017B \\
G &= 1.164Y + 0.392G + 2.017B \\
B &= 1.164Y - 0.813G - 2.017B
\end{align*}
\]

Where \( Y' \)=[16 235], \( C_b \)、\( C_r \)=[16 240].

### 2.2 Luminance domain processing.

#### 2.2.1. Weight map.

The fused luminance component is obtained by weighting the corresponding position luminance value of source images. The weight coefficient determines the quality of the fusion image. The weight map for each luminance image is determined by three factors: contrast, saturation, and exposure.

- Contrast \( C_k(i, j) \). There are distinctions in details at the same scene with different exposure times in which the area with a larger contrast remains more edges and outlines. In the process of calculating contrast, \( Y \) is convolved by Laplacian operator. After convolution, the absolute value of coefficient is used as the contrast weight of corresponding image pixels.
• Saturation $S_k (i, j)$. Under the appropriate exposure, the color expression of the fusion image is the strongest, which should be given a greater weight. When the chromatic components $Cb$ and $Cr$ are all 128, this image loses color and becomes a grayscale map. The larger the deviation from 128, the more colorful the color is. The standard deviation of $|Cb-128|/240$ and $|Cr-128|/240$ is taken as the saturation weight.

• Exposure $E_k (i, j)$. Overexposure and underexposure will lose the details of the scene, which is not consistent with the visual characteristics of the human eye, and should be given a smaller weight. When the exposure is moderate, the intensity is mostly distributed in the middle region, so more weights are expected to be allocated to the pixels in the middle brightness area. Using the method of Mertens[2], we calculate how close each intensity is to 0.5 with a Gauss curve, and the result coefficient is used as the saturation weight. Its calculation is shown in the following formula:

$$E_k (i, j) = \exp\left(-\frac{(I_k(i,j)-0.5)^2}{2\sigma^2}\right)$$

$I_k (i, j)$ is the pixel value at the position of $(i, j)$ in the $k$-th image; $\sigma$ refers to the variance, which equals 0.2 in our implementation.

2.2.2. Gamma correction. Converting luminance component blended at multiresolution scale to uint8 type, $Y \in [0, 255]$ exceeds the luminance range in the $YCbCr$ color space. Thus the $Y$ is corrected by the following gamma correction, after correction $Y' \in [16, 235]$:

$$Y'(i, j) = \left(\frac{Y(i, j) - Y_{\min}(i, j)}{Y_{\max}(i, j) - Y_{\min}(i, j)}\right)^\gamma \times R_c + L$$

Where $\gamma = \log_{\gamma_c}(R_c) / \log_{\gamma}(R_f)$, $R_f$ is the range of luminance threshold to be corrected, $R_c$ is the $Y$ channel luminance range. $H$ and $L$ are the maximum and minimum values of the $Y$ channel, $R_c = H - L$, $H = 235$, $L = 16$.

2.2.3. The processing steps of the luminance component $Y$.

• Compute the weight of contrast, saturation, and exposure.

• Fusion weight map $W$ is obtained according to the following formula:

$$W_k(i, j) = C_k(i, j) \times S_k(i, j) \times E_k(i, j)$$

• The fusion weight map $W$ and the luminance component $Y$ are weighted blending on the multiresolution scale in Laplacian Pyramid which is given in paper[2].

• Fusion brightness is converted to uint8 type and performed gamma correction.

• The corrected luminance is balanced by histogram equalization to $Y'$.

2.3 Chromatic aberration domains processing. When the value of $Cb$ and $Cr$ are all equal 128, the image loses color and is a grayscale map. The higher the degree of deviation from 128, the more obvious the color effect is, and the more suitable for human visual system to observe. Therefore, The chromatic value of the corresponding position of the maximum absolute value of deviation from 128 is used as the chromatic component of the fused image:

$$Cb' = C_{b, \max}^n \leq k \leq n \leq \max [C_{b, n} - 128]$$

$$Cr' = C_{r, \max}^n \leq k \leq n \leq \max [C_{r, n} - 128]$$

$k$ represents the number of fused low dynamic images.

3. Analysis of experimental results
In this paper, we select two groups of multi exposure images. The fused results are compared with the methods proposed by Mertens[2] and Paul[3]. The experiment is verified by MATLAB R2013a, and the experimental system is windows7 64bits.

3.1 Subjective evaluation. We can see the "Floor" and "Table" series of fusion images. The Mertens[2] method shows color degradation and details loss in the light and dark areas, such as "Floor" to the right window and the lamp filament of "Table". The method of Paul[3] shows the best performance of the details of the scene, but the integrated image is dark and not conducive to visual observation. The result images of our method can see more scene details than Mertens and better color expressiveness than Paul.

3.2 Objective evaluation. The entropy, mean variance contrast and saturation of the two groups of high dynamic images in figure 2 and figure 3 are respectively evaluated. Entropy is calculated on the corresponding grayscale map. The larger the entropy is, the more information is contained in the image. Its calculation formula is as follows:

$$H = - \sum p(x_i) \log p(x_i)$$

where \( p(x_i) \) is the frequency of greyscale \( x_i \).

Evaluation methods in literature[6] are used to calculate the mean variance contrast and saturation. The high dynamic range image is transferred to HSI space, and the mean value of S component represents the global saturation of the image. The mean variance contrast refers to the dynamic range of the image, which is computed in the I component:

$$C = \frac{1}{r \times c} \sum_{x=0}^{r-1} \sum_{y=0}^{c-1} \left[ I(x,y) - I_{\text{mean}} \right]^{1/2}$$

Where \( I_{\text{mean}} \) is the mean value of the I component in a \( r \times c \) sizes image. The larger the value of the three evaluation criteria, the more information, color, and details the fusion image has.

![Figure 2. Comparison of Floor scenes in different methods.](image)
Figure 3. Comparison of Table scenes in different methods.

(a) Mertens method  (b) Paul method  (c) Our method

Table 1. Fusion image evaluation indicators.

| Image sequence | Mean variance contrast | Entropy | Saturation |
|----------------|------------------------|---------|------------|
|                | Mertens | Paul | Ours | Mertens | Paul | Ours | Mertens | Paul | Ours |
| Floor          | 0.1359  | 0.1116 | 0.1361 | 6.7170 | 6.6135 | 6.8807 | 0.5129 | 0.5587 | 0.6250 |
| Table          | 0.2095  | 0.1737 | 0.2136 | 7.5651 | 7.3228 | 7.5950 | 0.1931 | 0.2219 | 0.2823 |

From Table 1, we can see that the three evaluation indicators of our algorithm are better than those of the other two methods. The mean variance contrast is slightly improved than Mertens, and the saturation is larger than Paul. It shows that the proposed method has been improved in both image details and color expressiveness compared with the existing methods.

4. Conclusion
For Mertens and Paul methods, the details of light and dark areas and image saturation cannot be simultaneously optimized when expanding the dynamic range of low dynamic images. This paper deals with luminance and chromatic aberration components in YCbCr space respectively. The experiment shows that our method can achieve better visual effect while balancing the light and dark area details of low dynamic images.

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