Available online at www.sciencedirect.com

ScienceDirect

Procedia Computer Science 154 (2019) 596–602

Procedia Computer Science

www.elsevier.com/locate/procedia

8th International Congress of Information and Communication Technology, ICICT 2019

Traffic Sign Image Enhancement in Low Light Environment

Yue Ya Qin[a], Wei Cui[a,]*, Qian Li[a], Wan Zhu[a], Xing Guang Li[a]

[a]*School of Electronic Information Engineering, Changchun University of Science and Technology, Changchun, China*

Abstract

In order to improve the contrast and sharpness of traffic sign images obtained under low light natural environment, we propose an improved enhancement method based on discrete wavelet transform to improve image contrast. We convert the original RGB image to the HSV color space, and use the discrete wavelet transform (DWT) to decompose the luminance component (V). In the low-frequency component use multi-scale Retinex algorithm estimate the illuminance to enhance the contrast of images, the high-frequency component enhances the detail information through the multi-scale detail boosting method. Finally, adjust the saturation component (S) by a piecewise exponential transformation method to make the image color more suitable for human observation. Experimental results demonstrate that our method can better display image details while reducing the halo effect, and effectively improve the contrast and sharpness of low-light images compared with existing algorithms through subjective and objective analysis.

© 2019 The Authors. Published by Elsevier Ltd.
This is an open access article under the CC BY-NC-ND license (https://creativecommons.org/licenses/by-nc-nd/4.0/)
Selection and peer-review under responsibility of the 8th International Congress of Information and Communication Technology, ICICT 2019.

Keywords: low-light environment; traffic sign image; image enhancement; discrete wavelet transform;

1. Introduction

As an important part of the Advanced Driver Assistance System (ADAS), Traffic Sign Recognition (TSR) can recognize the traffic sign information in real time and provide it to the driver, thus reducing driver's driving pressure, effectively ensuring driving safety, and avoiding traffic accidents [1]. However, the traffic sign images collected by

一 Corresponding author. Tel.: +0-000-000-0000 ; fax: +0-000-000-0000 .
E-mail address: 2572687097@qq.com

1877-0509 © 2019 The Authors. Published by Elsevier Ltd.
This is an open access article under the CC BY-NC-ND license (https://creativecommons.org/licenses/by-nc-nd/4.0/)
Selection and peer-review under responsibility of the 8th International Congress of Information and Communication Technology, ICICT 2019.
10.1016/j.procs.2019.06.094

the in-vehicle devices under low illumination conditions generally have problems such as a decrease in global contrast, content blurring, or loss of details [2]. This phenomenon has an adverse effect on the subsequent detection and recognition of traffic signs, Therefore, how to enhance the visual effect of traffic sign images under low light environment and highlight useful information of images has become an urgent problem to be solved.

Although recent vehicle-mounted imaging devices can adjust the self-parameters to obtain sharper images. However, the low sensitivity of imaging sensors is reduced in low light environment, causes the low signal-to-noise ratio (SNR). Therefore, enhanced images usually have noise amplification, color distortion and unnatural artifacts[3]. With the development of image enhancement technology, the researchers have proposed a variety of enhanced algorithms to improve low-light image quality. Han et al.[4] proposed an improved histogram equalization algorithm(HE), which effectively improved the loss of image detail caused by the over-combination of the traditional gray scale histograms. However, the color distortion is serious. Jung et al.[5] considered human visual attention, combined HE method with tone mapping to enhance images. This method can suppress over-enhancement of the smooth region, but the image edge details lost seriously. Jobson et al. simulated human vision systems and proposed enhancement methods based on Retinex theory (such as single-scale Retinex algorithm(SSR) [6] and multi-scale Retinex algorithm(MSR) [7]). They removed the illumination component by the Gaussian low-pass filter and logarithmic transformation. However, it frequently appears to be over-enhanced, and has high computational complexity and serious color distortion. Due to the excellent time-frequency analysis characteristics and strong robustness of wavelet transforms, Zhang et al.[8] combined the features of image wavelet domain decomposition with multi-scale Retinex theory(DWT-MSR) to enhance the contrast of images. However, this method is not effective in improving the details, and is prone to blooming, artifacts, and color distortions in color images.

We propose an improved low illumination image enhancement method based on discrete wavelet transform to improve images detail information and the contrast. The flow chart of the proposed method is shown in Figure 1.

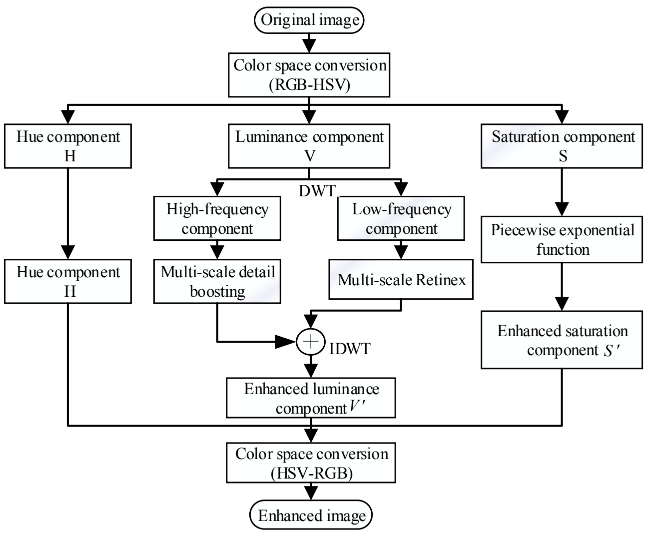

Figure 1. Flow chart of the proposed method

The discrete wavelet transform (DWT) decomposes the luminance component V into low-frequency and high-frequency components in the HSV color space. We utilize MSR method estimate illuminance components at low frequency sub-bands, and perform multi-scale detail boosting method on high-frequency components to enhance detail information. Then we stretch the saturation component S to ameliorate the overall visual effect of original images. Finally, we convert the image to RGB (Red, Green, Blue) space to acquire final enhanced images.

2. Enhancement Algorithm

The RGB model is sensitive to illumination changes and is not conducive to image enhancement processing. The HSV (Hue, Saturation, Value) color model is a non-linear transform of the RGB color model, which is consistent with human visual perception characteristics. The hue component H, the saturation component S, and the luminance component V can be processed independently of each other, which can better maintain the original color structure while improving the brightness and contrast of the image and without color distortion [9]. Therefore, we convert the acquired RGB images to the HSV color space. And obtain low-frequency sub-band and high-frequency sub-band though perform DWT decomposition on the luminance component V. Wavelet decomposition of the horizontal and vertical directions LL^1 results in:

$$LL^2(x,y) = f_0 * LL^1(x,y) \tag{1}$$

Where 错误！未找到引用源。represents the low-pass filter. The luminance component V undergoes the secondary wavelet decomposition can obtain a low frequency component LL^2 and three high frequency components in different directions $\{LH^2, HL^2, HH^2\}$. The low-frequency component concentrates the overall contour information of the image. and the detail information is included in each high-frequency component [10]. In this paper, We process the low-frequency and high-frequency sub-bands separately to improve the contrast and details of traffic sign images.

2.1 Illumination estimation and removal

For the low-frequency sub-band of wavelet domain, we use the MSR algorithm to estimate the illuminance component. Retinex-based image enhancement method is represented as:

$$I(x,y) = R(x,y) \times L(x,y) \tag{2}$$

Among them, $I(x,y)$ represents original image, $R(x,y)$ 错误！未找到引用源。is the reflection component, $L(x,y)$ is the illumination component. The standard MSR output is shown as:

$$R_M(x,y) = \sum_{n=1}^{N} \omega_n \cdot R(x,y) \tag{3}$$

Where $R(x,y) = \log I(x,y) - \log\left[F_n(x,y) * I(x,y)\right]$, Therefore simplify the substitution of $R(\cdot)$ into formula (3) to:

$$R_M(x,y) = \sum_{n=1}^{N} \omega_n \left\{\log I(x,y) - \log\left[F_n(x,y) * I(x,y)\right]\right\} \tag{4}$$

Where $*$ represents the convolution operation, $F_n(x,y)$ is the low-pass filter, The weight ω_n satisfies the condition $\sum_{n=1} \omega_n = 1$. Apply the MSR algorithm to the LL^2 sub-band, That is, $LL^2(x,y)$ is used as an input image to perform multi-scale enhancement according to equation (4) to obtain the low-frequency enhancement image R_{LL1}.

$$R_{LL1} = \sum_{n=1}^{N} \left\{\log LL^2(x,y) - \log\left[LL^2(x,y) * F_n(x,y)\right]\right\} \tag{5}$$

2.2 Multi-Scale detail boosting

We introduce a multi-scale detail boosting method in the high-frequency sub-band, use multi-scale differences of Gaussians (DoGs) to enhance details without halo, artifacts etc. We obtain three differently blurred images by applying Gaussian kernels to the high-frequency image: Using Gaussian kernel in the high-frequency sub-band I^* can acquire three different blurred images.

$$B_1 = G_1 * I^*, B_2 = G_2 * I^*, B_3 = G_3 * I^* \tag{6}$$

where G_1, G_2 and G_3 separately represent the Gaussian kernel of standard deviations σ_1=1.0, σ_2=2.0 and σ_3=3.0. Next, we abstract the subtle detail D_1, intermediate detail D_2 and coarse detail D_3, defined as follows:

$$D_1 = I^* - B_1, D_2 = B_1 - B_2, D_3 = B_2 - B_3 \tag{7}$$

Then we combine the three layers to generate the overall detail image

$$D^* = \left(1 - k_1 \times \operatorname{sgn}\left(D_1\right)\right) \times D_1 + k_2 \times D_2 + k_3 \times D_3 \tag{8}$$

Where k_1, k_2 and k_3 are adjustable parameters. Add subtle detail D_1 to the high-frequency image can enlarge the grayscale difference of image edges, which may cause image grayscale saturation due to excessive overshoot. To solve the problem, the average difference between the positive and negative components is maintained by reducing positive components of D_1 and amplifying its negative component in equation (8). Finally, adding the overall detail image D^* to the high-frequency image I^* to get a new enhanced image I^*_{new}.

$$I^*_{new} = I^* + D^* \tag{9}$$

2.3 Saturation enhancement

Stretching the saturation component can make the image more vivid and natural, produce visually pleasing images. We perform saturation adjustment in different regions through a piecewise exponential nonlinear enhancement method. According to the saturation of the image, we divid the saturation into high, intermediate and low parts. The low saturation region is exponentially transformed to amplified the saturation. Adjust the medium saturation area appropriately by exponential transformation, For regions of high saturation, saturation is reduced by exponential transformation. The piecewise exponential enhancement algorithm is expressed as follows:

$$S'(m,n) = \begin{cases} \alpha\left(e^{S(m,n)} - 1\right) & S(m,n) \le 0.2 \\ e^{S(m,n)} - 1 & 0.2 < S(m,n) \le 0.7 \\ \beta\left(e^{S(m,n)} - 1\right) & else \end{cases} \tag{10}$$

Where, S and S' respectively indicate the saturation before and after the enhancement; parameters α, β are used to adjust the transformation scale, Experiments show that when α is taken from 1.2 to 1.5 and β is from 0.7 to 0.9, the enhancement effect is best. In this paper, α takes 1.3 and β takes 0.8. Finally, the enhanced saturation component S', luminance component V' and the hue component H of the original image are synthesized and converted to the RGB space output the enhanced image.

3. Experimental Results

3.1 Subjective assessments

We perform experiments in MatlabR2016a by a series of low light traffic sign images in different environment, such as rainy days, dusk and night time. We compare the proposed method with the improved HE method[4], MSR method [7] and DWT-MSR[8] for the enhancement effect of the low-illumination traffic sign image. The enhancement effect comparison chart is shown in Figure 2 to Figure 6.

Analysis from subjective visual effects, The improved HE method has some improvement on the visual effect of low illumination images. But the effect is not obvious and the contrast is low (figure 3); As shown in figure 4, the image enhanced by the MSR method has poor visual effects, the edge details remain unsatisfactory, and there is a phenomenon of color distortion. DWT-MSR method can improve the sharpness and contrast of images, but, it often produces blurred details and halo artifacts in results (Figure 5). As shown in Figure 6, our method effectively improves the contrast and detail information of images, at the same time improves the halo and artifacts of the DWT-MSR method, and has a good visual effect. In addition, images are more natural and clear. In summary, the quality and visual effects of low-light images are superior to other methods.

Figure 2. (a) Rainy days, (b) Dusk, (c) Nights Original images

Figure 3.The effect of improved HE method

Figure 4. The processing effect of MSR algorithm

Figure 5. The effect of contrast enhancement method based on DWT-MSR

Figure 6. The effect of proposed algorithm processing (Multi-scale detail boosting adjustable parameters k1 = 0.5, k2 = 1.5, k3 = 2.5)

3.2 Objective assessents

In order to objectively evaluate the performance of the proposed algorithm, We analyze enhanced images though Lightness Order Error(LOE) [11] and Visual Information Fidelity (VIF) [12]. The LOE definition formula is:

$$LOE = \frac{1}{m}\sum_{x=1}^{m} RD(x) \tag{11}$$

In the above formula, $RD(x)$ represents the luminance step difference between I and I^* at pixel x, expressed as follows:

$$RD(x) = \sum_{y=1}^{m} U\left(L(x), L(y)\right) \oplus U\left(L'(x), L'(y)\right) \tag{12}$$

In the formula, represents the pixel number, $\oplus$ represents the exclusive-or operator, $L(x)$ and $L'(x)$ respectively represent the luminance component of original images and enhanced images at the location x. $U(p,q)$ is the unit step function, when $p \geq q$, $U(p,q)$ returns 1 ,otherwise it returns 0.

Visual Information Fidelity (VIF) is expressed as:

$$VIF = \frac{I(C;F)}{I(C;E)} \tag{13}$$

Where $I(C;E)$ and $I(C;F)$ is the mutual information that can be extracted from the original image and the test image. C,E is calculated to estimate the amount of the original image information that is transmitted to the brain via the human visual system (HVS)channel. C,F is also computed to estimate the amount of test image information. A number of low-light traffic sign images are used to construct the data set. We perform experimental analysis though reference algorithms and the improved algorithm respectively. The statistical curve is obtained by analysing the LOE and VIF values of the image in the overall dataset as shown in Figure 7.

From Figure 7. we can see that the improved algorithm in this paper has a smaller LOE. It shown that the improved algorithm can maintain the naturalness of the image better without over-enhancement and brightness distortion. At the same time, the improved algorithm provides a higher VIF, indicating that the algorithm keeps the visual information of the image well and makes the image appear more clear and natural. Therefore, the improved algorithm can enhance the contrast and sharpness of images while enhancing the detail information, effectively improve the visual effect of the low-illumination traffic sign image.

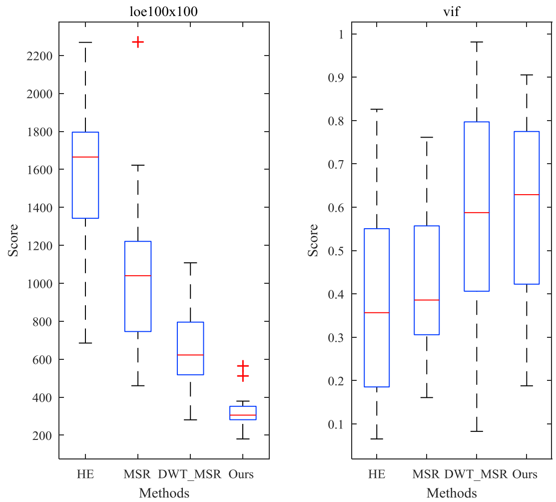

Figure 7. Comparison of LOE and VIF for improved algorithm and reference algorithm

4. Conclusion

We proposed an improved low-illumination traffic sign image enhancement method based on discrete wavelet transform. The DWT was used to decompose the luminance component in the HSV color space. In the low-pass sub-band utilized MSR to increase the contrast of images. And in the high-pass sub-band we performed a multi-scale detail boosting method to enhance image details. Furthermore, adjusted the saturation component by piecewise exponential function to ameliorate the visual effect of images. Experimental results shown that the traffic sign image processed by our method looks clear and natural, has richer information and better color fidelity than conventional methods. It laid the foundation for traffic sign recognition. In addition, the proposed algorithm can be applied to face recognition, video surveillance and pedestrian detection in low light conditions.

References

1. Kale A J, Mahajan R C. A road sign detection and the recognition for Driver Assistance Systems[C]// International Conference on Energy Systems and Applications. IEEE, 2016:69-74.
2. Yu S Y, Zhu H. Low-Illumination Image Enhancement Algorithm Based on a Physical Lighting Model[J]. IEEE Transactions on Circuits & Systems for Video Technology, 2017, PP(99):1-1.
3. Park S, Yu S, Moon B, et al. Low-light image enhancement using variational optimization-based retinex model[J]. IEEE Transactions on Consumer Electronics, 2017, 63(2):178-184.
4. Han D Y. Details Keeping Histogram Equalization Approach of Low-Illumination Video Image[J]. Computer Simulation, 2013, 30(8):233-232.
5. Jung C, Sun T. Optimized Perceptual Tone Mapping for Contrast Enhancement of Images[J]. IEEE Transactions on Circuits & Systems for Video Technology, 2017, PP(99):1-1.
6. Jobson D J, Rahman Z U, Woodell G A. Properties and performance of a center/surround retinex[J]. IEEE Transactions on Image Processing A Publication of the IEEE Signal Processing Society, 1997, 6(3):451-62.
7. Jobson D J, Rahman Z, Woodell G A. A multiscale retinex for bridging the gap between color images and the human observation of scenes[J]. IEEE Trans Image Process, 1997, 6(7):965-76.
8. Zhang M. CW-THz image contrast enhancement using wavelet transform and Retinex[J]. 2015.
9. Hou G, Pan Z, Huang B, et al. Hue preserving-based approach for underwater colour image enhancement[J]. Iet Image Processing, 2018, 12(2):292-298.
10. Sun T, Jung C. Readability enhancement of low light images based on dual-tree complex wavelet transform[C]// IEEE International Conference on Acoustics, Speech and Signal Processing. IEEE, 2016:1741-1745.
11. Wang S, Zheng J, Hu H M, et al. Naturalness Preserved Enhancement Algorithm for Non-Uniform Illumination Images[J]. IEEE Transactions on Image Processing, 2013, 22(9):3538.
12. Kuo T Y, Su P C, Tsai C M. Improved Visual Information Fidelity Based on Sensitivity Characteristics of Digital Images[J]. Journal of Visual Communication & Image Representation, 2016, 40:76-84