A Novel Visual Perception Enhancement Algorithm for High-speed Railway in the Low Light Condition

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Abstract—With the rapid development of high-speed railway, the safety of railway becomes extremely important. Video is a direct and effective manner for monitoring railway environment, but it is easily affected by weather condition and ambient light. Therefore the security risks are hidden in the low light condition and difficult to identify. In this paper, we propose a new visual perception enhancement algorithm VPEA based on Illuminance-Reflectance Model for low light image, and it can be used to produce a clear image from the train-borne video in the low light condition. The experimental results show that VPEA has better practical effect on image enhancement, and VPEA will be used in railway safety check and railway facility inspection in the future.

Keywords—Retinex; Low Light Image; Visual Perception Enhancement; High-speed Railway;

I. INTRODUCTION

The high speed railway is growing rapidly all over the world in recent years. High speed trains run in closed environments fenced by guardrails for safety assurance, and any unexpected matters may lead to disastrous consequences, such as missing communication units and bolts on the track, broken fences, unpredictable objects falling into the rail area or hanging on wires on top of the train. It is an extremely urgent task to ensure the high speed trains free from accidents. The moving camera installed in the font of a high-speed patrol train[1][2][3] is used for railway inspection tasks, as shown in Fig.1. The camera above is more economic, easier to implement, and more comprehensive in data acquisition, but this video is easily affected by weather condition and ambient light. It means that the potential safety risks are hidden in the low light condition and difficult to identify, as shown in Fig.2.

In this paper, we propose a visual perception enhancement algorithm VPEA based on Illuminance-Reflectance Model for low light image, and it can be used to produce a clear image from the train-borne video in the low light condition.

The rest of the paper is organized as follows. Related works on Illuminance-Reflectance Model are described in Section 2. Section 3 formulates VPEA based on Illuminance-Reflectance Model for low light image. Experimental results are demonstrated in Section 4. Section 5 concludes the paper and gives the further work.

II. RELATED WORKS ON ILLUMINANCE-REFLECTANCE MODEL

In low light condition, the HSV (Human Vision System) is able to generate visual images of the environment or the object. That means human have the ability to perceive the surrounding environment and color no matter what the light condition is. It is difficult to pinpoint exactly that which parts of HSV cause this phenomenon. In 1971 Land et al proposed Retinex theory[4] in order to simulate the process of perceiving peripheral vision of HSV. The word Retinex is a compound word of cortex and retina. Some scholars have applied this theory to image enhancement and obtained some good results.

The enhancement algorithms based on Retinex theory take the enhanced image as the product of reflectance and illuminance. The reflectance corresponds to the essential attribute of the image, the illuminance corresponds to the outside influence of the image. The algorithms aim at getting reflectance in some ways and then recover the original characteristic of the image by further removing the influence of illuminance in the image. According to the Retinex theory, Jobson et al.[5][6] proposed the center/surround Retinex algorithm to get reflectance of the image. In the center/surround Retinex algorithm, the convolution between an original image and a low-pass filter is proposed to obtain illuminance. Further the reflectance can be obtained by division or subtraction in the logarithm domain[5]. Many researches on the selection of low
pass filter have been done, such as inverse square function, Gaussian function[5], [6], [7], [9], bilateral filter[10] and NL filter[11].

As one single filter, namely SSR (Single Scale Retinex)[5], cannot estimate the illumination accurately, Jobson proposed to use the weighted form of the multiple filters to estimate the illumination, namely MSR (Multi Scale Retinex)[6]. But MSR easily leads to the halo phenomenon. Meylan et al.[8] used the adaptive filtering method to estimate illumination, firstly they detected the high contrast edge of the image, and then changed the shape of the filter in the edge to reduce diffusion. In this way, the halo phenomenon can be eliminated more effectively. Litao et al. successively proposed LDME algorithm (Luma Dependent Nonlinear Enhancement) [7], IRME algorithm (Illuminance-reflectance Model for Enhancement)[9] and these algorithms are implemented by FPGA. Medioni et al. proposed an active perception of adaptive Retinex image enhancement algorithm by using NL (Nonocal Mean) Filter[11][12]. It makes Retinex algorithm applies to both unexposed images and exposed images. From the above discussion, center/surround Retinex algorithm can be divided into two types:

1. Only keeping reflectance and remove illuminance, such as SSR and MSR.
2. Processing illuminance, and synthesize the new image with the processed illuminance and the original reflectance, such as LDME and IRME.

In this paper, we propose a new image enhancement algorithm based on Illuminance-Reflectance Model, and it can process illuminance to achieve dynamic range compression while still retaining or even enhancing the visual key features. In addition, the proposed method only processes the luminance/intensity information of images so the incorrect color rendition can be avoided and the halo phenomenon is also eliminated.

III. VISUAL PERCEPTION ENHANCEMENT ALGORITHM FOR LOW LIGHT IMAGE

According to the illumiance-reflectance model mentioned in the above section, a visual perception enhancement algorithm for low light image called VPEA is proposed in this section. The flow chart of VPEA is shown in Fig.3.

The detail information of VPEA is as follows:

A. Color transformation and Illuminate estimation

In order to reduce color cast of the image enhancement result and increase the processing speed, color image should be transformed into gray image by using Eq(1)

\[ i_0 = 0.30i_r + 0.59i_g + 0.11i_b \]

where \(0.30i_r, 0.59i_g, 0.11i_b\) are the three primary colors of RGB in the original image \(i_0\).

There are a lot of researches[4]-[8][12] on how to accurately get illuminate estimation \(l\), and we choose the simpler but more effective one among them

\[ l(x, y) = i_0(x, y) * w(x, y) \]

where \(w(x, y) = P \cdot e^{-\frac{(x^2 + y^2)}{2\sigma^2}}\) is Gaussian function and \(P\) is normalized parameter which makes \(\int \int P \cdot e^{-\frac{(x^2 + y^2)}{2\sigma^2}} \, dx \, dy = 1\), where \(\sigma\) controls the size of the Gaussian convolution kernels.

B. Illuminance processing

For illuminance, we use gamma correction to adjust the dynamic range, which is expressed as Eq(3):

\[ L = \left( \frac{l}{255} \right)^\gamma \times 255 \]

(3)

Where \(l\) is illuminance, \(L\) is the dynamic range adjustment result of illuminance. \(\gamma\) is exponential coefficient, can be got by the following equation:

\[
\gamma = \begin{cases} 
\gamma_l & I_m \leq Th_1 \\
(\gamma_b - \gamma_l) \cdot \frac{I_m - Th_1}{Th_2 - Th_1} + \gamma_l & Th_1 \leq I_m \leq Th_2 \\
\gamma_b & I_m \geq Th_2 
\end{cases}
\]

(4)

Where \(I_m\) is the mean of the intensity image \(I_0\), \(\gamma\) is a piecewise linear function with \(\gamma_l, \gamma_b, Th_1, Th_2\) as empirical parameters, as shown in Fig.4. \(\gamma = \gamma_l\) is for the bright image, \(\gamma = \gamma_b\) is for the dark image, and \(\gamma\) is adaptively adjusted according to the mean of image for other images. A set of the curve shapes of \(\gamma\) is provided in Fig.5.

Although illuminance has made a lot of improvement in global visual effect by adjusting its dynamic range, the local contrast of illuminance is reduced because of the gamma correction stretching or compressing effect. Therefore, the image visual quality is degraded. In order to improve the image contrast, Eq(5) is proposed for contrast adjustment,

\[ L_E = L + \frac{L - \bar{L}}{L_{Max} - L_{Min}} L \]

(5)
image bias towards this primary color, so the color needs to be reduced to $\text{mid}_i$; if the value of $(1 - \bar{I}_i/ar{I})$ is positive, it means the primary color is too small, and the overall image bias towards the other two primaries, so the color needs to be increased to $\text{mid}_i$.

Considering the color restored image should satisfy the grey world hypothesis, we should further adjust the color image with Eq(10) based on the result of Eq(8),

$$f_{\text{inal}}_i = \text{mid}_i \cdot \text{avgGray}/\text{avg}_i \quad i = [R, G, B]$$  \hspace{1cm} (10)

where $\text{avg}_i$ is the mean of one primary color of RGB in image $\text{mid}$ and $\text{avgGray}$ is the mean of image $\text{mid}$ given by Eq(11):

$$\text{avgGray} = (\text{avg}_R + \text{avg}_G + \text{avg}_B)/3$$  \hspace{1cm} (11)

IV. Experiment and Discussion

In this section, we compare VPEA with Histogram Equalization, MSRCR and IRME on HSRI high speed railway inspection image dataset in the low light condition (images collected by us). The HSRI dataset contains 2000 images captured in the evening or in the tunnels. Histogram Equalization is performed using the basic function in Matlab. A commercial software PhotoFlair@ is used to implement MSRCR. IRME is performed using the Matlab code according to Reference[9]. In our experiments, a PC with 2.13GHz dual-core CPU 2GB RAM is used as the experimental platform and VPEA in Matlab takes about 0.23s to process an 800×600 image.

A. Qualitative evaluation

Fig.6 presents some results of VPEA, Histogram Equalization, MSRCR and IRME on HSRI high speed railway inspection image dataset. The results of Histogram Equalization are the worst. The results of MSRCR expose much more halo artifacts, especially in enhanced images taken in tunnels. IRME performs better than MSRCR with much more natural look. However, both MSRCR and IRME create incorrect color in some areas. For VPEA, it performs the best in the four enhancement methods with much more natural look and its color adjustment method can effectively remove the color cast.

B. Quantitative evaluation

Image enhancement method is usually difficult due to the subjectivity of human sense. In this paper, we evaluate VPEA by a quantitative method based on the visually optimal region[13]. In this method, a region of 2D space of the mean of an image in [100; 200] and the standard deviation of an image in [35; 80] are expressed as Visually Optimal Region(VOR). In this method, a region of 2D space of the mean of an image in [100; 200] and the standard deviation of an image in [35; 80] are expressed as Visually Optimal Region(VOR).

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make the enhanced image less natural. IRME works better than MSRCR but worse than VPEA. This shows the advantage of higher adaptability of our method. The parameters of IRME are constant and cannot be changed with different images, while VPEA modifies its parameters adaptively according to the global characteristics of different images. Moreover, the color adjustment method in VPEA makes the color of enhanced image more natural and more close to the true color. That is why the all visibility indicators of VPEA are better than Histogram Equalization, MSRCR and IRME.

V. CONCLUSION

Considering the influence of low light condition, we propose a visual perception enhancement algorithm (VPEA) based on illumination-reflection model. The experimental results demonstrate that VPEA has the good practical effect in image enhancement. We will focus on the further efficiency improvement of the enhancement algorithm to realize the real-time image processing in the future.

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REFERENCES