Visual Enhancement Method for Intelligent Vehicle Based on Brightness Guide Filtering Algorithm

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Abstract: - In order to improve the low visibility and poor contrast of video, in this study, we propose a haze video enhancement algorithm based on guide filtering method. In the paper, firstly, we simplified the atmospheric attenuation model. Then, the current concentration of haze is estimated based on dark channel priori theory. After that, a guide filter of brightness channel was used to obtain current haze coverage. Videos are recovered based on the results of estimation of haze concentration and coverage. To improve the efficiency of the algorithm, highly time-consuming stage of haze concentration is implemented in initialization phase, and an indicator of video definition is used to control the procedure of subsequent module. Experimental results show that the algorithm can effectively improve the contrast and sharpness of video while with highly computational efficiency. The proposed method can meet the needs of video haze removing.

Key-Words: - Intelligence vehicle, haze removal, brightness guide filtering, dark channel estimation.

1 Introduction

Massive expansion of industrial production and overuse of vehicle in modern society are resulting in large amounts of energy consumption and serious environmental pollution, which directly led to frequent fog and haze in recent years, and gives tremendous threat to traffic safety. In the fog and haze conditions, atmospheric particle scattering of light not only makes the energy and strength attenuation of reflected light but also make a part of natural light attached to the target object, causing a substantial decline in image clarity[1].

Currently, researchers mainly focus on the study of single image defogging algorithm, and have proposed a variety of defogging methods[2]. Most of them, In general, need a bit long operation time and cannot meet the application requirements of intelligent vehicle. Meanwhile, until now, there are few studies focus on the video defogging algorithm, and does not reach maturity stage[3].

In order to improve the low visibility and poor contrast of video, in this study, we propose a haze removal algorithm for intelligent vehicle based on guide filtering method.

2 Simplified model of atmospheric attenuation

Under fog and haze environment, suspended particles surge dramatically in the air, which will bring two effects:

(1)The intensity of reflected light would be reduced, because of the absorption and attenuation effect of the atmospheric aerosol during the dissemination process;

(2)There are a lot of suspended particles in the haze environment, which contain strong scattering effect. In the end, both partial reflected light and scattered light superimpose together and enter the camera, resulting in large-scale degradation of image.

Thus, atmospheric color scattering theory was proposed by McCartney in 1975, which sets up the haze of degraded physical model[4], as described in the follows:

$$E = I_{\infty}\rho(x)e^{-\beta d(x)} + I_{\infty}(1 - e^{-\beta d(x)}) \qquad (1)$$

Where, I_{∞} is atmosphere coverage. ρ is standard radiation intensity. E is the degraded image captured by the camera under the influence of mist. Assume that the reflected light from the surface of objects is R. From the radiation theory, we know that $R = I_{\infty}\rho$ and can convert the formula (1) into the following form:

$$R = e^{\beta d(x)}(E - I_{\infty}) + I_{\infty} \qquad (2)$$

Where, R is the clear image after the restoration. β is haze concentration factor. $d(x)$ is distance factor describing the distance from environment points to the camera.

It can be assumed that the distance factor of each point in the image to be a setting value, with respect to the long-distance transmission of light. Then, the formula (2) can be simplified as the following form:

$$R = f_{\beta}(E - I_{\infty}) + I_{\infty} \qquad (3)$$

Where, the parameter $e^{\beta d(x)}$ can be simplified as the haze concentration factor $f(\beta)$.

The haze concentration factor would not change significantly during a short time. It means that there is no need for real-time computing of the haze concentration factor. Then, in order to save the processing time, this paper only estimate the current environment haze concentration in the initial stages of video demisting algorithm using the dark colors principle method.

3 Environment haze concentration estimation based on the principle of dark colors theory

Dark colors priori theory was proposed by Dr. He in 2009[5]. The principle indicates that, in clear images, at least one of the three RGB color channels has low pixel value, which can be expressed as:

$$J^{dark}(x) = \min(\min(J^{c}(y))) \quad c \in \{r, g, b\}, y \in \Omega(x) \qquad (4)$$

Where, J^{c} is any color channel of RGB image J. $\Omega(x)$ is a statistical area with as its center.

It has been confirmed that is always very small and even close to zero in clear images apart from the sky area with the statistical analysis of a large number of clear images. Dark color images under different haze concentration degree are shown in figure 1.

From the dark color comparison image, it can be found that the average pixel gray of the dark color image can be used to evaluate the haze concentrations of the current environment. Then, the evaluation factor of haze concentration is defined as follows:

$$D_{dark} = \frac{sum(v_{dark}(x, y))}{u \times v} \qquad (5)$$

Where, v_{dark} is the normalized pixel gray of each pixel in dark color image. u is the width of dark color image. v is the height of dark color image. sum is the accumulation value of each pixel gray in the dark color image.

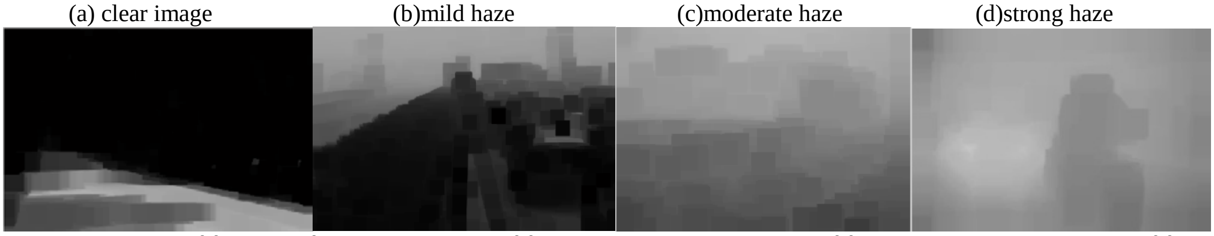
Utilizing ` (5), the D_{dark} value of the figure(e) can be calculated as 0.1135. D_{dark} value of the figure(f) is 0.2158. D_{dark} value of the figure(g) is 0.4824. And the D_{dark} value of the figure(e) is 0.5900. It means that with the increase of the haze concentration, the D_{dark} value of the image is increasing.

Meanwhile, from the formula (3), it can be known that the haze concentration factor determines the degree of enhancement of the foreground image and the haze image restoration results are not sensitive to this parameter. Therefore, in order to simplify the solution process and improve the algorithm speed, a linear relationship is defined between the parameter f_{β} and D_{dark}, which can be described as follows:

$$f_{\beta} = k \times D_{dark} \qquad (6)$$

Where, k is linear scaling factor. In order to ensure the non-distortion of the image during process, the parameter f_β is limited to the range of $[2,8]$. The test results showed that the linear hypothesis of algorithm can effectively improve the algorithm speed and has little effect on the accuracy of the result.

(a) clear image (b)mild haze (c)moderate haze (d)strong haze



(e)dark color image of figure(a) (f) dark color image of figure(b) (g) dark color image of figure(c) (h) dark color image of figure(d)

Figure 1: Dark color images under different haze concentration degree

4 Atmosphere coverage estimation based on brightness guide Filtering algorithm

Image guide filter is a kind of local linear filter, which was proposed by Dr. He in 2010[6]. Compared with traditional methods, this algorithm has a clear advantage in computational efficiency and in removing artifact images. Using this feature, this article apply it to the visual enhancement to get the current atmospheric parameters with the filtering process of foggy image luminance channel.

4.1 Color space conversion

As is well know that real-time performance is critical for video processing algorithms, which directly determines the safety of the system[7]. Dislike traditional algorithms of dealing with the images in separate RGB channels, this paper convert the haze images into the brightness independent HSV space. And only deal with the brightness channel with brightness guide Filtering algorithm. With the proposed method, about 2/3 processing time and computational cost can be saved.

4.2 Image procession using guide filtering algorithm

Image guide filter is a kind of linear shift-variable filter and the kernel can be described in the following formula:

$$q_i = a_k I_i + b_k \qquad \forall i \in w_k \tag{7}$$

Where, w_k is the k-th kernel window. (a_k, b_k) is the linear transform coefficients within a given unit window w_k. i is the pixel index within the window.

For the guide filtering system, in order to ensure the small different between the input image and the output image , the following formula (8) can be obtained.

$$\min_{(a,b)} \sum_{i \in w_k} ((q_i - p_i)^2 + \varepsilon a_k^{\ 2}) \tag{8}$$

Using formula (8) as the objective function, the solution of equation (7) can be obtained by linear regression method, which can be shown in the following:

$$a_k = \frac{\mathrm{cov}_k(I,p)}{\mathrm{var}_k(I)+\varepsilon} \qquad b_k = \overline{p}_k - a_k \overline{I}_k \tag{9}$$

Where, ε is regularization smoothing factor. $\mathrm{cov}_k(I,p)$ is covariance matrix of the guide image I and the input image p. $\mathrm{var}_k(I)$ is the variance matrix of the guide image I. $\overline{p}_k$ is the means of the image p and $\overline{I}_k$ are the means of the image I.

In this paper, we take the guide image I equal to the input image p, and take formula (9) into formula (7), then we can obtain the following equation:

$$q_i = a_k(p_i - \overline{p}_k) + \overline{p}_k \tag{10}$$

Where, $\mathrm{cov}_k(I,p) = \mathrm{var}_k(I)$, $\overline{I}_k = \overline{p}_k$. Therefore, the formula (9) can be rewritten in the following:

$$a_k = \frac{1}{1+\varepsilon / \mathrm{var}_k(I)} \qquad b_k = (1-a_k)\overline{p}_k \tag{11}$$

The formula shows that with the increasing of the value of smoothing factor ε, the value of a_k would become smaller and smaller. When a_k close to 0, q_i will be close to $\overline{p}_k$; On the contrary, with the decreasing of the value of smoothing factor ε, the value of a_k would become bigger and bigger, until its value close to 1. At this time, the value of q_i will close to $a_k p_i$. It means that when a reasonable choice of smoothing factor ε, the guide filter not only has the ability of cascade smoothing, but also has the ability of linear shift-variable processing.

Applying the guide filter to the whole image area, then, the hierarchy relationship of the original image can be preserved and the current value of atmosphere coverage can be obtained, as described in the following:

$$I_\infty \triangleq \Re((\frac{1}{|w|}\sum_{k:w_m} a_k) p_m + \frac{1}{|w|}\sum_{k\in w_m} b_k) \tag{12}$$

Where, $|w|$ is the number of pixels in the kernel window. m is index number of pixels. p_m are the pixels of input image. w_m is the kernel window with the center of p_m pixel. $\Re$ indicates the processing step for each pixel.

In this paper, the smoothing factor ε is set to 0.3 and the kernel window width r is set to 30 pixels.

4.3 Enhancement of single image

The enhancement process of the single image based on the guide filtering algorithm can be summarized as the following steps:

(1) Convert an image from RGB color space to the HSV color space;

(2) Estimate the current atmosphere coverage parameter based on the guild filtering algorithm;

(3) Obtain the foreground image $I_{vis}(x)$:

$$I_{vis}(x) = E - I_\infty \tag{13}$$

(4) Use Gaussian filter to remove image noise and add the atmosphere coverage parameter to foreground image. Then, the enhanced haze image can be obtained, as shown in the figure 2.

$$R = f_\beta \times I_{vis}(x) + I_\infty \tag{14}$$

Figure 2(a) original image Figure 2(b) atmosphere coverage

Figure 2(c) foreground image Figure 2(d) Enhancement result

Figure 2 Process of haze image enhancement

4.4 Video enhancement and quality assessment

Entropy is a kind of evaluation methods which can be used to measure the content of information involved in an image. According to Shannon's information evaluation theory, the bigger of the value of entropy, the more of the information contained in the image and the better clarity of the image. The calculation method of entropy within images is given below:

$$I(E) = \log\frac{1}{P(E)} = -\log_2(P(E)) \tag{15}$$

Where, $P(E)$ is the probability of the event E.

From the view of entropy, the image can also be seen as a random information source. The clarity degree of an image can be described by the entropy contained in it. The formula is as follows:

$$H = \sum_{i=1}^{L} P(b_i)\bullet I(P(b_i)) = -\sum_{i=1}^{L} P(b_i)\bullet\log_2 P(b_i) \tag{16}$$

Where, $P(b_i)$ is the probability of each pixel.

For the video system of intelligent vehicles, there are temporal relevance between video frames. The objective laws determine that the value of atmosphere coverage would not mutated. Therefore, in this paper, the conditional starting method is used to improve the algorithm efficiency. A new estimation round of atmosphere coverage would be aroused only when the clarity evaluation of haze image beyond the given threshold value. Haze video enchantment process is shown in Figure 3.

5 Experiment and Analysis

Take the Youku video library[8] as the test video source. Road traffic videos colleceted at different times, places and haze concentration were downloaded for the test sets, which includes 7 video clips and 21,180 frames. Test algorithm is developed based on the matlab platform and the operating environment is windows 7 with the processor of 2.3 GHz.

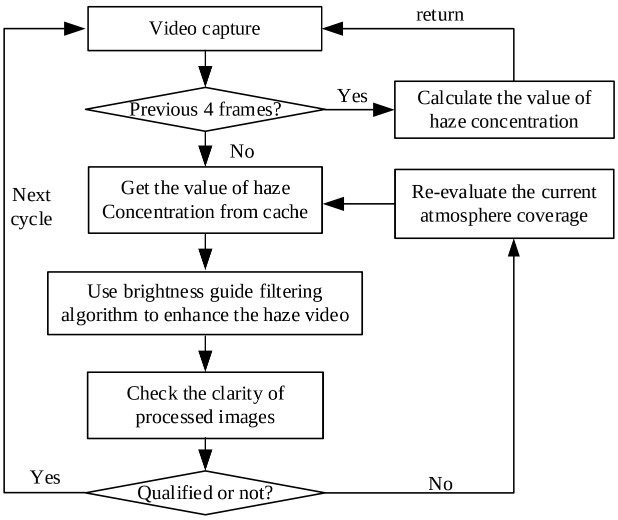


Figure 3. The process of visual enhancement for haze video

4.1 Comparative experiment and analysis

The proposed method was compared with two classic algorithms in this study using the same test video, which includes color histogram equalization method and multi-dimensional retinex algorithm. The processing results are shown in the following figure:

Figure 4(a) Figure 4(b)

Figure 4(c) Figure 4(d)

Figure 4 Comparative experiment

(Figure 4(a)original image; Figure 4(b)Output result using color histogram equalization method; Figure 4(c)Output result using multi-dimensional retinex algorithm; 4(d)Output result using the method proposed in this paper)

During the image process with the histogram equalization method, sub-channel equalization method was used and the number of histogram bin was set to 255. And during the image process with the multi-dimensional retinex algorithm, the scaling coefficients were taken as the low, middle and high types.

From the subjective point of view, some conclusions can be obtained:

(1) With the processing of the color histogram equalization method, image contrast can be improved by stretching the RGB channels, but resulting in severe color distortion.

(2) Multi-dimensional retinex algorithm has good enhancement effect. After the processing, most of the image area shows a fine clarity and sharpness performance, while some area prone to emerging halo, such as the area around the fog lamps.

(3) Compared to the two classic algorithms the proposed algorithm in this paper performs a better results in terms of improving image contrast and Sharpness. Meanwhile, using a linear enhancement method, the proposed algorithm can also eliminate the halo phenomenon around the brightness mutation image area.

From the quantitative point of view, 3 kinds of statistical methods including standard deviation, entropy and spatial frequency were chose in this study to conduct a comparative assessment of the above haze enhancement methods. The results and corresponding time-consuming are shown in the table below:

Table 1 comparative assessment with 3 kinds of statistical methods

-	standard deviation	spatial frequency	entropy	Time consuming(s)
Original image	18.964	5.235	5.891	-
color histogram equalization method	74.437	12.185	7.419	0.1227
multi-dimensional retinex algorithm	71.428	12.939	7.602	2.7405
the method proposed in this paper	45.224	33.682	7.118	0.0442

As can be seen from the table that, the proposed algorithm has the maximum efficiency among the whole algorithms and get a good result in the aspect of image contrast improvement, image noise suppression and image information enhancement.

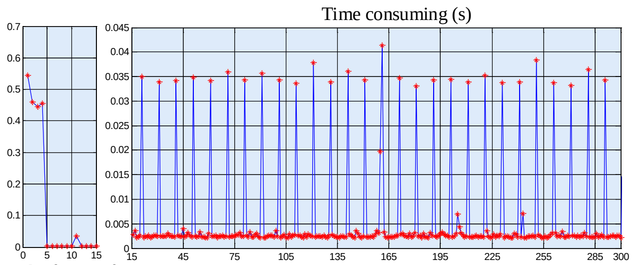
4.2 Performance under different haze visibility degree

In order to verify the algorithm performance within different haze visibility degree, this paper test the proposed algorithm off-line using mild haze, moderate haze and strong haze respectively. The results is shown in the following:

(a) mild haze (b) moderate haze (c) strong haze

(d) result of mild haze (b) result of moderate haze (c) result of strong haze

Figure 5: Performance within different haze visibility degree



(a)the first 15 frames (b)the subsequent image frames

Figure 6: time consuming of the proposed algorithm

4.3 efficiency analysis

It is crucial for visual enhancement algorithm has a real time performance. Therefore, in order to reduce the computational load, this paper takes the high time-consuming procedure of atmosphere concentration estimation task to the initial stage. As shown in the figure 6(a), in the first 4 frames, the principle of dark colors theory is used to obtain the current atmosphere concentration and the stage will cost about 500ms each frame.

In the normal identification stage, algorithm update the value of atmosphere concentration based on the output image clarity and sharpness. As shown in the figure 6(b), the atmosphere concentration estimation task would start on the condition that the image resolution is below a given threshold value 5.0 or 200ms timing cycle expired. On the average, time consuming of each frame will up to 35ms when the atmosphere concentration estimation task start and down to 5ms during normal visual enhancement process, as shown in figure 6

6 Conclusion

In order to improve the low visibility and poor contrast of video, in this study, we propose a haze video enhancement algorithm based on guide filtering method.

Firstly, we simplified the atmospheric attenuation model. Then, the current concentration of haze is estimated based on dark channel priori theory. After that, a guide filter of brightness channel was used to obtain current haze coverage. Videos are recovered based on the results of estimation of haze concentration and coverage. To improve the efficiency of the algorithm, highly time-consuming stage of haze concentration is implemented in initialization phase, and an indicator of video definition is used to control the procedure of subsequent module.

Experimental results show that the algorithm can effectively improve the contrast and sharpness of video while with highly computational efficiency. The proposed method can meet the needs of video haze removing.

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