Development and Implementation of Software for Multi-Algorithm Image Quality Enhancement

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Abstract: Different image defogging methods should be adopted for different degrees of low contrast and sharpness of images caused by different weather conditions. This paper builds a MATLAB-based image quality improvement and evaluation software that combines the global RGB histogram equalization algorithm, the global HSV histogram equalization algorithm, the restricted contrast adaptive histogram equalization algorithm, the single-scale Retinex algorithm, the multi-scale Retinex algorithm, the Multi-Scale Retinex with Color Restoration, and the dark channel a priori algorithms and their optimization algorithms for image quality improvement and evaluation software. Outdoor images of hazy days, rainy days and snowy days are selected and the best algorithms for different weather conditions are obtained through extensive experimental simulations, software processing and analysis.

Keywords: Defogging Methods; MATLAB; Multi-Algorithms

1. Introduction

With the booming development of image processing technology and computer vision technology, scene detection and image processing for special weather has become an important research direction in this field. The so-called special weather includes, but is not limited to, rain, snow, fog and the hazy weather caused by environmental degradation in recent years. When water droplets are present in the air, either in the form of larger liquid droplets or condensed snowflakes or in the form of fog with a smaller particle size, each drop is equivalent to a transmission mirror with an irregular shape and undetermined transmittance. In the air, countless tiny water molecules absorb and refract light with their different shapes and transmittance[1,2], resulting in a significant decrease in the clarity and contrast of images captured by outdoor image acquisition equipment and a large loss of details, thus making it impossible to obtain real image information, so it is extremely important to adopt different fast and efficient image defogging methods for different situations.

Image defogging algorithm is an image analysis and processing method that aims to meet the needs of specific scenes, highlight image details and enhance image quality. This paper is dedicated to designing a multi-algorithm defogging and clarification software with a wide range of applications, intuitive and simple operation, which can select different image quality improvement and evaluation methods for the phenomenon of image clarity and visibility degradation under different weather conditions.

2. Theoretical description

Due to the urgent demand for image defogging techniques, new image defogging methods have been developed rapidly, and these techniques can be classified into the following three types according to their basic principles: image enhancement algorithms based on image features[3,4], image restoration algorithms based on physical models[5], and deep learning model defogging methods[6]. Among them, the image enhancement algorithms represented by histogram equalization and Retinex algorithm enhance the contrast of the whole image, which can show high computational efficiency and high practicality. And the image restoration and defogging methods based on the dark channel a priori algorithm are based on certain a priori knowledge or hypothetical information to recover the target light according to the physical model of the image, which can also get more ideal defogging effect.

2.1 Histogram equalization

Histogram equalization techniques can be divided into global histogram equalization and local histogram equalization. Global histogram equalization is the same transformation method for the whole image. In practical applications, the captured images are mostly color images, which require histogram equalization for R, G, and B components separately, or conversion of R, G, and B to H, S, and V[7], followed by histogram equalization for V components, and the latter processed images have better color fidelity.

The Constrained Limited Adaptive Histogram Equalization algorithm (CLAHE)[8] based on the image local histogram equalization algorithm can redistribute the luminance to change the contrast of the image. Therefore, this algorithm can improve the local contrast of the image as well as obtain more image details. And the algorithm is effective in limiting the problem of having over-amplified noise in the same areas of the image.

2.2 Retinex algorithm

The simplest and basic Retinex algorithm is the single-scale Retinex algorithm (SSR)[9], which is based on the following principle: firstly, the incident and reflected light components of the light are separated by taking the logarithm, and the reflected component, which reflects the image detail information, is retained,i.e.

$$\ln R(x,y) = \ln S(x,y) - \ln L(x,y) \#$$

$S(x,y)$ is decomposed into incident image $L(x,y)$ and reflected image $R(x,y)$.

To obtain $R(x,y)$ it is sufficient to obtain $L(x,y)$, but according to the theory of mathematics, $L(x,y)$ cannot be obtained, but only approximated. $L(x,y)$ can be approximated by the convolution of $I(x,y)$ and a Gaussian kernel $G(x,y)$. So $R(x,y)$ can be expressed by the following equation.

$$\ln R(x,y) = \ln S(x,y) - \ln (S(x,y) * G(x,y))$$

In the above equation $*$ represents the convolution and $G(x,y)$ represents the Gaussian kernel. The final image we see is the result of mapping $R(x,y)$ onto [0,255], which is generally taken as a linear mapping, i.e.

$$R(x,y) = \frac{value - min}{max - min} \cdot (255 - 0)$$

The Multi-Scale Retinex algorithm (MSR) is developed on the basis of SSR and has the advantage of color enhancement and constancy. The principle is to perform a weighted average of the results of several SSR algorithms at different scales, i.e.

$$R_i(x,y) = \sum_{k=1}^{N} weight_k \cdot \{\ln S_i(x,y) - \ln[S_i(x,y) * G_k(x,y)]\}$$

In the above equation, i∈R,G,B three color channels, $weight_k$ denotes the weight factor, and k denotes the number of scales used.

However, in practice, single-scale Retinex and multiscale retinex are prone to color distortion. Jobson and Rahman et al [10] proposed a new algorithm, multiscale Retinex with color recovery, which scales the MSR results to recover the original scale values.

Starting directly from a quantitative approach, the concepts of mean and mean squared deviation are introduced, and the mean and mean squared deviation Var of the data for each channel of R、G、B in $log\ [R(x,y)]$ are calculated separately, together with a parameter to control the image dynamics to achieve a color-bias-free adjustment process, by calculating the Min and Max values for each channel as dynamic parameters via the formula ,as follows:

$$Min = Mean - Dynamic * Var;$$

$$Max = Mean + Dynamic * Var;$$

Then for each value of log [R(x,y)], a linear mapping is performed as follows.

$$R(x,y) = \frac{(Value - Min)}{(Max - Min)} * (255 - 0);\#$$

with the addition of an overflow judgment, i.e.

$$if\ (R(x,y) > 255) R(x,y) = 255;$$
$$else\ if\ (R(x,y) < 0) R(x,y) = 0;$$

2.3 Dark channel prior

In the vast majority of non-sky local areas, some pixels always have at least one color channel with a very low value, and the channel with this very small value is defined as the dark channel of that image [11], which is mathematically defined as.

$$J^{dark}(x) = \min_{y\in\Omega(x)} (\min_{c\in(r,g,b)} J^c(y))$$

where J^c denotes each channel of the color image and $\Omega(x)$ denotes a window centered on pixel X. It can be seen that obtaining the dark channel means obtaining the minimum value of each channel for all pixels within a window. The theory of dark channel a priori states that

$$J^{dark} \to 0$$

This algorithm is a typical image restoration algorithm, which is based on the principle of atmospheric scattering to construct a degradation model of the image as a way to perform the fog removal process. The atmospheric scattering model in hazy weather is as follows.

$$I(x) = J(x)t(x) + A(1 - t(x))$$

Where $I(x)$ refers to the brightness of the image we see in hazy weather, which is known, $J(x)$ is the image after the defogging process, which is the target we are trying to reach, $t(x)$ represents the transmittance of the medium, and A is the global atmospheric light component.

In practice, the value of the atmospheric light component value A can be obtained from a fogged image with the help of a dark channel map. To avoid image distortion, a parameter ω between [0,1] is introduced such that a certain amount of fog is retained in the defogged image, which leads to the equation for the initial transmittance $\tilde{t}(x)$.

$$\tilde{t}(x) = 1 - \omega \cdot min_{y\in\Omega(x)}[min_c \frac{I^c(y)}{A^c}]$$

and to prevent the transmittance from being too small and thus leading to a large J value, the threshold t_0 can be increased. Thus, the final image defogging equation is.

$$J(x) = \frac{I(x) - A}{\max{[t(x),t_0]}} + A$$

2.4 Dark channel a priori optimization

However, it is found in the dark channel a priori algorithm that when there are a large number of low contrast areas such as the sky or water in the picture, the dark channel a priori method will show block effect and halo effect, and the color will be dark. To solve this phenomenon, we can choose to use the split picture method to divide the low-contrast areas such as the sky from the colored objects, and then perform the defogging process separately. First, the Otsu algorithm is chosen as the image segmentation algorithm to extract the gradient, RGB and luminance of the image as the difference degree features. Because the Otsu algorithm based on adaptive threshold segmentation segments the image based on its grayscale features, which means the probability of incorrect segmentation is minimal.

Since the sky region seriously affects the accuracy of estimating the overall image transmittance, it is necessary to use different atmospheric transmittance operations for the separated foreground and background, and the authors choose to set the transmittance of the sky region to 1, while the foreground is calculated using the atmospheric transmittance formula. The image morphology expansion method is also used to extract the bright channel of the image and expand it to cover the original image to achieve the effect of obtaining defogging and brightening.

3. Multi-algorithm defogging software build

With the powerful interactive function of MATLAB, a multi-algorithm image defogging system is designed for the phenomenon of image clarity and visibility degradation under hazy weather. Firstly, the graphical user interface (GUI) is designed and visualized by calling the user interface controls and creating the corresponding menus. Eight kinds of defogging algorithms, namely RGB HE, HSV HE, CLAHE, SSR, MSR, MSRCR, and dark channel a priori algorithm and its optimization algorithm, are embedded into the system, and the function menus are called to realize the correlation between different algorithms. The figure 1 shows the structure of this flat.

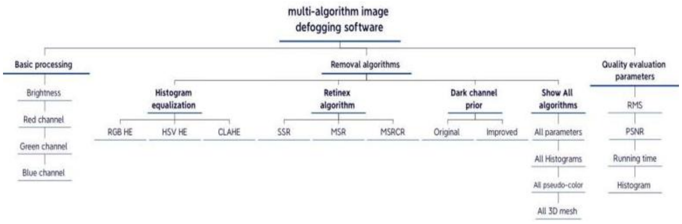

Figure 1 The structure of the multi-algorithm defogging software

Figure 2 shows the main window of the designed multi-algorithm de-fogging platform. The main interface contains two areas: the function area and the image display area. Four function buttons are embedded in the top left of the main window." Open", "Exit", "Save", and "Clear" are the four function buttons used to read, save, and exit the overall image. Also, a functional area is designed at the bottom of the main window for selecting different processing algorithms and displaying image quality evaluation parameters.

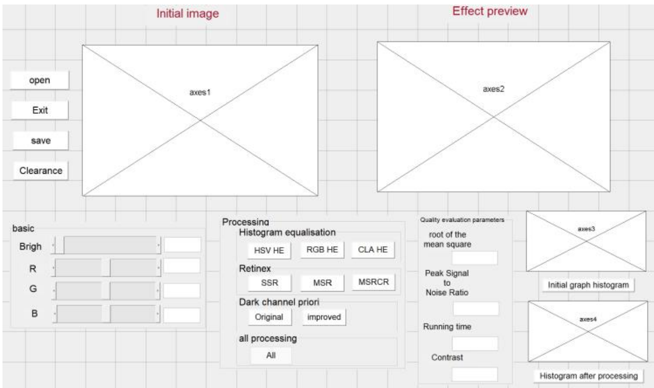

Figure 2 Multi-algorithm defogging software main window design

For better comparison and display, all images and parameters of the 8 defogging algorithms can be displayed in a sub-window by adding the "ALL" button in the main window. As shown in Figure 3.

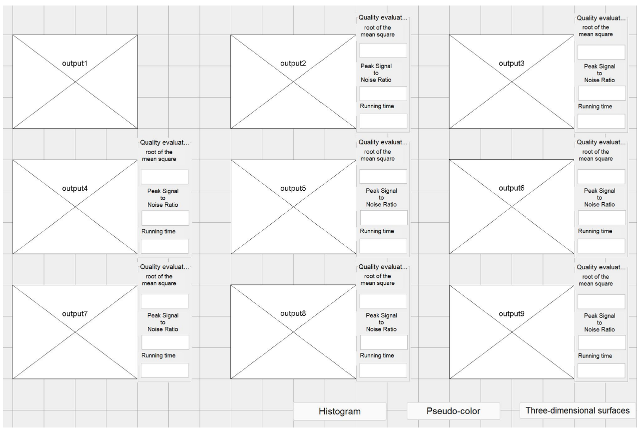

Figure 3 Multi-algorithm defogging software showing the sub-window design of all algorithm processing maps

4. Experimental comparison and data analysis

Image evaluation methods are divided into two categories: subjective evaluation methods and objective evaluation methods. Subjective evaluation is to evaluate the merits of an image by obtaining visual perception through observation of the image by the human eye as the evaluator. In this multi-algorithm image defogging platform, both the main window and the sub-windows can display multiple images at the same time, which makes it easy to visually compare the defogging effect of defogging algorithms and make a subjective evaluation.

The objective evaluation method is that the computer calculates the quality index of the image according to the algorithm. In this paper, root mean square error (RMS), peak signal to noise ratio (PSNR) and running time are selected as evaluation parameters. rms mainly evaluates the size of error between known image and degraded image, i.e. the difference between processed image and original image, the larger the value, the more obvious the processing effect. psnr reflects the degree of distortion of image, the larger the value, the smaller the distortion of image, i.e. the clearer the image. The running time reflects the efficiency of a certain algorithm to process the image, the shorter the running time, the higher the processing efficiency.

4.1 Hazy image clarification processing

Hazy weather as a frequent adverse weather conditions in recent years, seriously affects the acquisition of image information, with the subsequent processing of machine vision. Therefore, it is necessary to choose a suitable algorithm to process hazy weather images

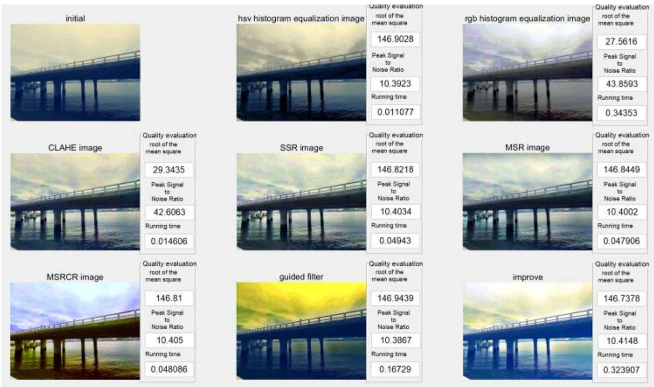

Figure 4 Experimental comparison chart of multi-algorithm defogging software in hazy weather

Get table 1.

	HSVHE	RGBHE	CLAHE	SSR	MSR	MSRCR	Dark channe	Dark channel improved
RMS	146.90	27.56	29.34	146.82	146.84	146.81	146.94	146.73
PSNR	10.39	43.8	42.60	10.40	10.40	10.40	10.38	10.41
Running time/second	0.01	0.34	0.02	0.05	0.05	0.05	0.17	0.32

Table 1 Experimental data sheet of multi-algorithm mist elimination software in hazy weather

From Figure 4 and Table 1, combining the subjective evaluation and objective evaluation indexes, it can be concluded that the above eight defogging algorithms have different processing effects. The three algorithms based on the histogram equalization algorithm process the image closest to the original image, and this algorithm operates efficiently, but the processed image is easy to be locally over-enhanced or blurred. The single-scale Retinex and multi-scale Retinex algorithms have low distortion and high definition, but the image after defogging sometimes appears white. the MSRCR algorithm can effectively improve the contrast and sharpness of the image, but the algorithm is prone to overexposure. The dark channel-based a priori algorithm can better recover the detail information and color degree of the fog-containing image, but it will cause the block effect of the image. The improved dark channel a priori method still has the problem of long running time even though it solves most of the shortcomings.

4.2 Rainy image clarification processing

The presence of a large number of water droplets in the air during rainy days and the constant refraction and reflection seriously affects the image quality and leads to difficulties in computer recognition. In order to select a better image rain removal algorithm, all eight algorithms were extended and observed as shown in Figure 5.

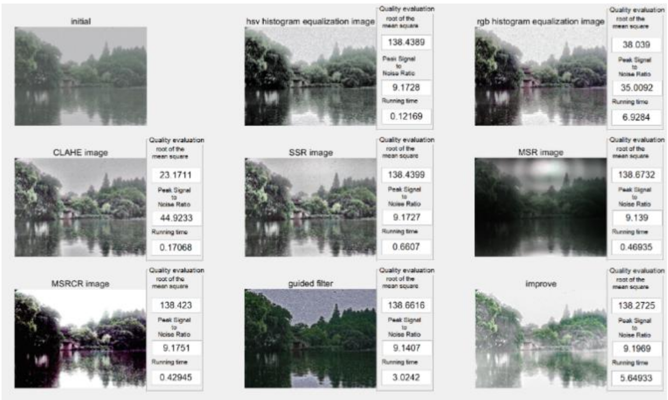

Figure 5 Experimental comparison chart of multi-algorithm defogging software in rainy weather

And get table 2

	HSV HE	RGB HE	CLAHE	SSR	MSR	MSRCR	Dark channel	Dark channel improved
RMS	138.44	38.04	23.17	138.44	138.67	138.4	138.66	138.27
PSNR	9.17	35.01	44.92	9.17	9.14	9.18	9.14	9.20
Running time/min	0.12	6.93	0.17	0.66	0.47	0.43	3.02	5.65

Table 2 Experimental data sheet of multi-algorithm mist elimination software in rainy weather

From the figure 5 and table 2, it is obvious that among the three algorithms based on histogram equalization, RGB histogram equalization has a longer computing time and lower efficiency. The signal-to-noise ratio is larger and the image is sharper. The remaining three Retinex algorithms and the two dark channel algorithms have very similar values of root mean square and peak signal-to-noise ratio, and it is easy to see that the five algorithms are not as effective as they should be by subjective evaluation methods.

4.3 Snowy image clarification processing

Snow scenes, as one of the common special weathers, also have an important impact on the collection and processing of image information. As shown in the figure 6 and table 3 different algorithms also have significant effect on the image sharpness and contrast degradation due to snowy weather.

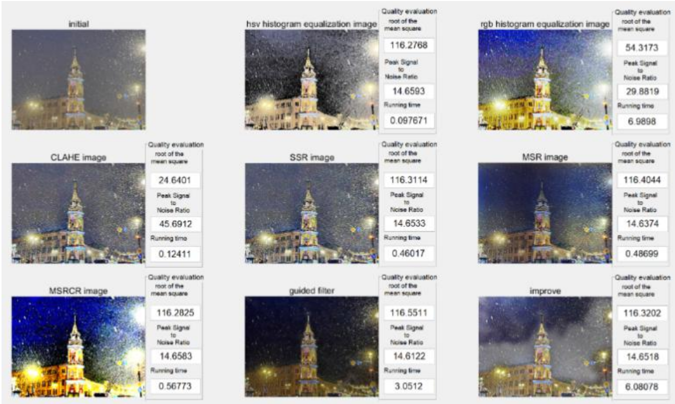

Figure 6 Experimental comparison chart of multi-algorithm defogging software in snow weather

	HSV HE	RGB HE	CLAHE	SSR	MSR	MSRCR	Dark channel	Dark channel improved
RMS	116.28	54.32	24.64	116.31	116.41	116.28	116.55	116.32
PSNR	14.66	29.88	45.69	14.65	14.64	14.66	14.61	14.65
Running time/min	0.10	6.99	0.12	0.46	0.49	0.57	3.05	6.08

Table 3 Experimental data sheet of multi-algorithm mist elimination software in snowy weather

As seen in Figure 6 and Table 6, for snowy days, the three algorithms based on histogram equalization improve the contrast of the image while maintaining the integrity of the image information, but also introduce a large amount of noise. the SSR algorithm in the Retinex algorithm can effectively improve the sharpness of the image. However, images processed by the MSR and MSRCR algorithms show color imbalance and overexposure. The two dark channel a priori algorithms for black backgrounds have good color contrast and sharpness, but have loss of image information and take longer time.

5. Summary

Based on the powerful interactive function of MATLAB, this paper designs a multi-algorithm defogging platform with simple pages, easy operation and intuitive results. Eight defogging algorithms with different advantages are integrated in the system: Global RGB Histogram Equalization algorithm, Global HSV Histogram Equalization algorithm, Restricted Contrast Adaptive Histogram Equalization algorithm, Single-Scale Retinex algorithm, Multi-Scale Retinex algorithm, Multi-Scale Retinex with Color Restoration, Dark channel a priori algorithm and its optimization algorithm. The root mean square, peak signal-to-noise ratio and runtime are also embedded as image quality evaluation parameters so that users can choose the best fogging algorithm to meet their needs.

The advantages and disadvantages of each algorithm are also validated by subjective and objective evaluations. The most appropriate defogging algorithm is also selected for images in different weather conditions. For example, the optimized dark channel a priori algorithm is found to be most suitable for hazy weather; the CLAHE algorithm is more suitable for rainy weather, The SSR could show more details for snowy weather. Finally, the usability, extensiveness and effectiveness of the platform are verified by a large number of image experiments, which realize the original intention of designing the software in this paper.

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