# Method to Enhance Degraded Image in Dust Environment

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*Abstract*—**Basically, the sharpness and contrast of the video images captured in dusty weather will be significantly degraded and diminished. This paper proposes a novel image enhancement method. First convert the degraded image into fuzzy domain to global PAL fuzzy enhancement; then band-limited histogram equalization is adopted for enhancing the local component in the spatial domain; finally POSHE algorithm is introduced to enhance the details. The experiment results show that this method not only can effectively improve the contrast of dust image, but also enhance the details of edge information and get a good visual effect of the image.**

*Index Terms*—**dust environment, image enhancement, PAL algorithm, band-limited histogram equalization, POSHE algorithm**

## I. Introduction

The total land area of Gobi desert and deserted land of our country is as much as $1.67\times10^{6}km^{2}$ , accounting for 17.38 percent of the land area. Xinjiang is located in the northwest border of China, with the Taklimakan Desert in the south and the Gurbantonggut Desert in the north, which is one of the major provinces that dust storms frequently occur [1]. According to the visibility of dust weather, there are floating dust, blowing sand, sandstorms and strong sandstorms. Dust will affect scattering and absorption of light, hence it will cause severe degradation of video images. Images obtained from sandstorms often have severe reddening phenomenon, and images under the backlight are whole slant black. Not only have such problems like blur, contrast reduction, but also have serious color image deviation and distortion. It causes tremendous negative impacts on public transport、production and living and even the social order of the edge areas of the Gobi desert. Therefore, enhancing the image obtained from dust condition is an inevitable task.

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The problems which affect the quality of video image can be divided into two major categories: dynamic and static [2]. Dynamic problem is such problem which appearing when objects fast-move such as motion tremors and motion blur; static problem is that always occur in a video sequence, and have no relation with object movement, such as various of noise, edge blur, poor contrast[3]. This article starts from the research on static problems, and analyzes the single degraded image enhancement algorithms. Currently the research results of image enhancement based on dust environment are rare, while the study of image enhancement based on bad weather is mainly concentrated in the fog and haze conditions [4-6]. Image defogging methods are mainly on two aspects: First, image restoration method which is based on image degradation reason and on atmospheric scattering law for establishing the degradation model [7-10], and make full use of a priori knowledge of the degradation to recover the degraded images. Although it has a significant effect on the image defogging in the experiment, it needs strong hardware if you want to get more deep information of image details; Second, image enhancement method[11-14], the common methods of image enhancement are histogram equalization algorithm, wavelet transform, curve-let transform, homomorphism filtering algorithm, and Retinex algorithm. But there are some shortages in traditional image enhancement methods of fog image enhancement. For example, these methods can not analyze the image comprehensively, it not only results in inevitably noise amplification during its enhancement, but also introduces new noises, even more may cause pseudo contour phenomenon.

Based on the image defogging method, this paper proposes a dust image enhancement method according to the second one mentioned above-image enhancement. The basic strategy is that combining the traditional method to solve different problems generated in dust image. First, the target image is converted into fuzzy domain and the PAL algorithm is adopted to process target image, for improving overall contrast; and then the processed image is handled with limited adaptive local histogram equalization algorithm, for modifying the local


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contrast; finally, it uses POSHE algorithm for the last step, and strengthens the local details further. Experimental results show that the proposed method can effectively improve the contrast of dust image and achieve better overall visual effect.

## II. The Main Idea Of The Proposed Method And Its Flow Chart:

In this section, we detail the process of our algorithm, there are two parts:

### A. *Steps of the Proposed Method*

1) First, in order to improve overall contrast, it converts the original image into fuzzy domain for PAL enhancement, as described in equation (3);
2) Second, the processed image is handled with limited adaptive local histogram equalization algorithm for modifying the local contrast;
3) Third, POSHE algorithm is used to enhance local details for strengthening the local details;
4) Finally, the enhanced image can be obtained after above steps.

### B. *The Specific Flow Chart:*

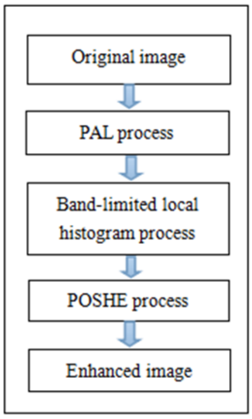


Figure1. Flow chart of the proposed algorithm

## III. Elementary Knowledge

Fuzzy set theory is an effective tool for the analysis of human systems such as judgment, perception, and identify all kinds of behaviors，thus it is being more and more widely applied to the image enhancement algorithm, and has achieved good results.

### A. *PAL Fuzzy Enhancement*

L. A .Zadeh proposed the concept of fuzzy sets in 1965, it extended the range of the subordinate relation signs function of set A from (0, 1) to [0, 1] for the element x in ordinary set theory, then got fuzzy set (fuzzy subsets) thought[15]. S.K.PAL proposed the fuzzy enhancement algorithm in 1980, fuzzy theory was introduced into the image enhancement techniques [16]. In accordance with the concept of fuzzy set theory, an M*N-dimensional image X with L gray-scale can be regarded as a fuzzy array, the array can be described as:

$$X = \bigcup_{i=1}^{M}\bigcup_{j=1}^{N}\frac{\mu_{ij}}{x_{ij}} \quad i = 1,2\cdots,M;\ j = 1,2\cdots,N \tag{1}$$

Where $x_{ij}$ stands for image gray values of the pixel (i, j), $\frac{\mu_{ij}}{x_{ij}}$ stands for extent $\mu_{ij}$ of the image pixel (i, j) with a certain degree of features. PAL method use transformation function (membership function) to extract fuzzy feature of the image firstly, the membership function is defined as follows:

$$\mu_{ij} = G(x_{ij}) = \left[1 + \frac{(L-1) - x_{ij}}{F_d}\right]^{-F_e} \tag{2}$$

Where $F_e$ and $F_d$ are exponential fuzzy factors and inverted index fuzzy factors, $F_e$ is usually set to 2, $F_d$ is artificially determined according to the transit point $x_c$, G ($x_c$) is set to 0.5. $\mu_{ij}$ ranges from $\alpha$ to 1, containing the boundary, and $\alpha$ is a positive number which forming the fuzzy feature plane of the image. The gray level is called the transit point when u is 0.5. Through transforming the membership function $\mu_{ij}$ to limit the transit point for increasing or decreasing the value $\mu_{ij}$, thus a new fuzzy feature plane {$\mu_{ij}{}'$} can be got, which is made up of $\mu_{ij}{}'$, that is to say, fuzzy enhancement operator can be defined as:

$$\mu_{ij}' = I(\mu_{ij}) = I_1(I_{r-1}(\mu_{ij})) \qquad r = 1,2,3\cdots(r\ is\quad iterations) \tag{3}$$

$$I_1(\mu_{ij}) = \begin{cases} 2\mu_{ij}^{\ 2} & 0 \le \mu_{ij} \le 0.5 \\ 1 - 2(1-\mu_{ij})^2 & 0.5 \le \mu_{ij} \le 1 \end{cases} \tag{4}$$

put the enhanced fuzzy features $\mu_{ij}'$ to inverse transform of G, and get the enhanced spatial image x’, the gray values of pixel (i, j) in X’ are as follows:

$$x_{ij}{}' = G^{-1}(\mu_{ij}{}') = x_{\max} - F_d\left[\left(\mu_{ij}{}'^{\frac{1}{F_e}}\right)\right], \alpha \le \mu_{ij}{}' \le 1 \tag{5}$$

Thus the gray values of the fuzzy enhanced image can be obtained.

From the above analysis, the fuzzy enhancement model proposed by PAL can be shown in Figure 2:

The key transform of fuzzy enhancement algorithm, in

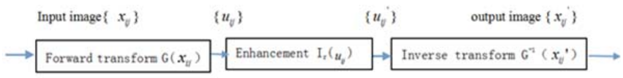


Figure2. Fuzzy enhancement model

other words, nonlinear variable function, has obvious flaws, due to the inverse function of the nonlinear function has no solution in local parts after the transform, lead to the loss of gray level information of the part of image, and thus affect the image enhancement effect. So we choose the band-limited local histogram equalization algorithm for next process.

### B. *Band-limited Local Histogram Equalization Algorithm*

Band-limited local histogram equalization is that control the range of the local contrast by limiting the height of local histogram, for reducing the amplification of noise and over-enhancement of the local contrast. Thus a better observed effect of image can be achieved. R. Cromartie proposed the local histogram equalization method with a limited band[17], the method not only consider the histogram within the window, and also contemplate outside the window, which is consist of two parts: within the rectangle window and outside the rectangle window.

$$h_l(r) = \alpha h_w(r) + (1-\alpha) h_B(r) \qquad (6)$$

Where $h_w(r)$ is a normalized histogram within the window, $h_B(r)$ is a normalized histogram outside the window, and $\alpha$ ranges from 0 to 1, containing the boundary. $s_w$ and $s_B$ stand for area W and area B respectively. Considering that $\alpha$ is a quotient that got from the ratio of $s_w$ and the sum of $s_w$ and $s_B$, then $h_l(r)$ is equal to $h(r)$, thus the local histogram is equal to global histogram. Supposing that $\alpha$ is bigger than the quotient got from the ratio of $s_w$ and the sum of $s_w$ and $s_B$, then the local histogram is more emphasized the local information. Therefore, local histogram can be adjusted according to $\alpha$, so it can simulate the influence of surrounding environment on the related areas [18].

### *C. The Principle of Band-Limited Local Histogram Equalization*

Main steps of the algorithm:

1) Block. Divide the image into Non-Overlapping Sub-blocks with the same size, each sub-block has M pixels. If the sub-block is large, its effect will be more obvious. While more image details will be lost.

2) Histogram calculation. $H_{i,j}(k)$ represents sub-block histogram, k represents the gray level, which ranges from 0 to N-1, and N is the number of gray levels.

3) The limited value calculations. The following formula can be used to calculate truncated limited value:

$$\beta = \frac{M}{N}\left[1 + \frac{\alpha}{100}(S_{\max} - 1)\right] \qquad (7)$$

Where the parameter is the maximum slope, which determines the magnitude of contrast enhancement, its value is an integer of 1 to 4. The parameter is called truncation coefficient, its value ranges from 0 to N-1. When the value is 1, it takes the minimum value of M/N; when the value is 100, it takes the maximum of $S_{\max}$ M/N, thus the corresponding contrast stretching effect is most obvious.

4) Pixel redistribution. For each sub-block, the corresponding value of $\beta$ is used to cut $H_{i,j}(k)$, and redistribute the number of pixels which have been cut down to the various gray levels of histogram. Repeat the above allocation process till all the sheared pixels are distributed and use $F_{i,j}(k)$ to represent the results which are re-allocated by $H_{i,j}(k)$.

5) Histogram equalization. Histogram equalization for $F_{i,j}(k)$, and the results can be represented by $C_{i,j}(k)$.

6) Reconstruction of the gray values of pixels. The gray values of the sub-blocks center pixels can be got according to $C_{i,j}(k)$, and use them as reference points, and calculate the gray values of each point in the output image by a bilinear interpolation.

After the above steps, image details are still not clear, so POSHE algorithm is chosen for further process.

### *D. Local Detail Enhancement Algorithm Based on POSHE Algorithm*

POSHE (partially overlapped sub-block histogram equalization) algorithm is a typically adaptive local histogram equalization algorithm, its effective pixel number to be calculated for histogram equalization extend from one to multiple, thus reducing the local computing times [19].

The detailed steps are as follows: divide the image into four sub-blocks, take the example as shown in Figure 3 that the step-length is half of sub-block, there are nine non-overlapping small areas (a-i) which is made up of four overlapping sub-blocks 1 (a b d e), 2 (b c e f), 3 (d e g h), 4 (e f h i). Four sub-blocks overlapping area is e. First, the first sub-block (a b d e) is equalized, and then the second sub-block, and next for loop process by row.

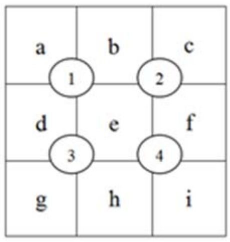

Figure 3. Non-Overlapping area

At last, the overlap sub-block regions can be weighted as the following formula:

$$s_k^{\ e} = \frac{1}{4}\left[T_1(r_k^{\ e}) + T_2(r_k^{\ e}) + T_3(r_k^{\ e}) + T_4(r_k^{\ e})\right] \qquad (8)$$

Where $s_k^{\ e}$ represents the gray values of K within area e after the POSHE algorithm, $T_j(r_k^{\ e})$ represents histogram transformation function of sub-block j, j is equal to 1,2,3,4; $r_k^{\ e}$ represents the pixels which the gray value is k within area e.

## IV. Algorithm In This Paper

The global histogram equalization algorithm can not overcome the problem of local degradation caused by different depth of field in dust image, thus PAL fuzzy algorithm can be adopted to enhance the local parts of image, but this method can result in a partial block effect, hence this paper adopts the global PAL fuzzy enhancement algorithm.

**Step1**. Global PAL fuzzy enhancement

The R, G, and B components are taken out of RGB color space in dust image respectively for making PAL fuzzy enhancement. To enhance the dust image adaptively, $X_C$ is used as a transit point in this paper.

$$X_c = k_1 * mean2(I) + k_2 * std2(I) \tag{9}$$

Where I represents the pixel values of the three components, mean2 (I) represents the mean value of a certain component of image, while std2 (I) represents standard deviation of image component [20]. And $k_1$ and $k_2$ can be adjusted according to the characteristics of image. After the repeated experiments, $k_1$ is 0.9 and $k_2$ is -1.4 in the method, thus a better enhancing effect can be got.

**Step2**. Band-limited local histogram equalization

After the global PAL fuzzy enhancement for dust degraded image, there are some disadvantages of globally fuzzy enhancement algorithm. Therefore, band-limited local histogram equalization in the space domain is used. The image that processed after step1 is converted from RGB color space into HSV color space, and component V is taken, which is processed by band-limited local histogram equalization, the algorithm steps are as follows:

(1) Take an arbitrary point out of V, and a 3 * 3 window size is taken to ensure its relevant area;

(2) In accordance with (5) to compute the size of the rectangular window, and $\alpha$ is 0.05;

(3) Equalization process for the histogram within rectangular window and the center pixel is processed;

(4) Move rectangular window to the next adjacent pixel, from step (1) to repeat the above process till the whole image.

**Step3**. Local detail enhancement method based on POSHE algorithm

In order to preserve image details as much as possible and make it more clearly in the visual effects, every sub-block of the image processed after step 2 is disposed by POSHE algorithm further.

## V. Experimental Results

To verify the effectiveness of the proposed algorithm, a memory of 2G Intel processors and MATLAB R2009a platform are taken for experiments. A number of images captured in dust environment are processed based on PAL algorithm, band-limited local histogram equalization algorithm, POSHE algorithm and the proposed algorithm. The simulation results show that the proposed method is significantly better than a single algorithm on these aspects: image clarity and detail enhancement. One-color photographs are taken for example as Figure 4:

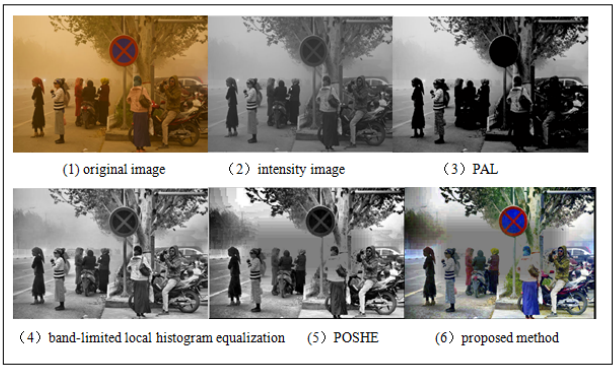


Figure4. Dust image processed by PAL algorithm, band limited histogram equalization, POSHE, and the proposed algorithm

Traditional methods only modify the degraded images on visual clarity, but the proposed method is more obvious. As can be seen from Figure.4 (3), after PAL algorithm process, the ambiguity of dust weather is eliminated to some extent, but the effect is not obvious; Figure.4 (4) band-limited adaptive histogram equalization algorithm is used, image dynamic range has a certain extension. In the picture, goal-oriented scenarios are effectively retained: the contrast of image maximize increase, and fence in the middle of the road as well as silhouette of house in the right side can be seen clearly; Figure.4 (5) POSHE algorithm is applied to improve the details of the image. Houses in the right and roadside trees are prominent obviously in the picture; Figure.4 (6) is obtained after the proposed algorithm, image quality has been greatly recovered. The clothing, fences in the middle of the road and trees have a significant recover in terms of color, and the clarity of picture has been greatly improved. Take another dust picture for example:

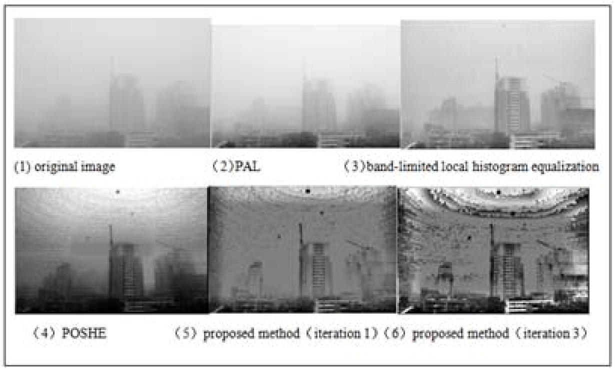


Figure5. Dust image processed by PAL algorithm, band-limited histogram equalization, POSHE, and the proposed algorithm

Seen from Figure.5(2), image is processed by PAL algorithm, the goal-oriented building is prominent in the picture, and its dynamic range of the pixel values are expanded; Figure.5(3) is conducted by band-limited local histogram equalization algorithm, the clarity of goal-oriented scenario is improved; Figure.5(4) is processed by POSHE algorithm, the outline of buildings is clear; Figure.5(5) is processed by the proposed algorithm, its iteration times is 1, compared to other images, the clarity of buildings has greatly improved; Figure.5(6) is disposed by the proposed algorithm, its iteration times is 3, compared to Figure.5(5), with the increase of the number of iteration times, the target scene has more complete information, and show a clearer details. Although the gray-scale values of the background area (sky area) decrease, it has little effect on the target scene.

However, it is too subjective to evaluate on visual aspect, this paper use the mean value, and information entropy and average gradient to evaluate these algorithms objectively. These methods are defined as follows:

(1) Mean value:

$$\overline{G}(x)=\frac{1}{M\times N}\sum_{i=0}^{M-1}\sum_{j=0}^{N-1}G(X_{ij}) \quad (10)$$

(2) Information entropy:

$$H[g(x,y)]=-\sum_{i=0}^{A-1}p_i\cdot\log_2(P_i) \quad (11)$$

(3) Average gradient:

$$g=\frac{1}{(M-1)\times(N-1)}\cdot\sum_{x=1}^{M-1}\sum_{y=1}^{N-1}\sqrt{\frac{1}{2}\cdot[(\frac{\partial g(x,y)}{\partial x})^2+(\frac{\partial g(x,y)}{\partial y})^2]} \quad (12)$$

As can be seen from Table I, the mean value of the proposed algorithm is close to 128, because the human vision is the best when the image gray value is in the vicinity of 128. Image entropy of the proposed algorithm is larger than the other conventional entropy algorithm, image entropy represents the number of image information, that is to say, the greater the entropy, the larger the amount of information it contained in the image[21], so the amount of information of the image can be significantly increased after the proposed method. In this paper, the average gradient of the proposed algorithm is also greater than the traditional methods. Average gradient reflects the change rate of small image details, namely, the change rate of density of the multi-dimensional direction represents the clarity of image [22]. If the average gradient is large and image level is high, the image will be more clearly.

TABLE I.
THE OBJECTIVE EVALUATION OF EACH ALGORITHM OF IMAGE IN FIGURE.4

| Fig.4 / Index | The original image | intensity image | PAL algorithm | Band-limited local histogram equalization | POSHE algorithm | The Proposed method |
|---|---|---|---|---|---|---|
| Mean value | 99.3812 | 110.9127 | 89.2517 | 129.2953 | 118.7516 | 118.8138 |
| Information entropy | 7.7347 | 7.2445 | 5.5975 | 7.6916 | 7.4468 | 7.5835 |
| average gradient | 4.1455 | 4.3769 | 7.3312 | 9.6243 | 11.7588 | 11.9264 |

As can be seen from TABLE II, it has the same change trend like TABLE 1, and with the increase of iteration times, its mean value is close to 128, information entropy is relatively high and average gradient is the biggest of other algorithms.

## VI. CONCLUSION

In this paper, PAL fuzzy enhancement method is used to process the whole degraded image firstly, for changing the overall contrast of image, then in the spatial domain, the band-limited local histogram adaptive equalization algorithm is adopted to enhance the local component, finally POSHE algorithm is applied to enhance the local details for improving the details further. Seeing from simulation results, the proposed method can effectively improve the contrast of dust images and better highlight the image details. Meanwhile, on the objective aspects: mean value、information entropy and average gradient, the proposed method is superior than traditional methods. Though it has a good effect on closer image, the distant view is not obvious, so make the panorama clear is the next key step to study. In addition, the time complexity is high in the proposed method, so the next step will be in the direction of improving the time complexity.

TABLE II.
THE OBJECTIVE EVALUATION OF EACH ALGORITHM OF IMAGE IN FIGURE.5

| Fig.5 / index | The original image | PAL algorithm | Band-limited local histogram equalization | POSHE algorithm | The Proposed method（iterate once） | The Proposed method（iterate three times） |
|---|---|---|---|---|---|---|
| Mean value | 190.8905 | 199.1140 | 184.4133 | 118.6244 | 114.0323 | 129.7041 |
| Information entropy | 6.4615 | 6.2754 | 6.7496 | 7.7551 | 6.6213 | 7.5997 |
| average gradient | 1.4563 | 2.0988 | 2.4796 | 3.0302 | 7.5323 | 10.5451 |


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