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Vehicle Bottom Image Enhancement Method Based on Improved PM Equation

Yingfu Cai[1, 2*], Xiaoyang Yu[1]
[1]The Higher Educational Key Laboratory for Measuring & Control Technology and Instrumentation of Heilongjiang Province, Harbin University of Science and Technology, Harbin 150080, Heilongjiang, China
[2]China Coal Construction Engineering Group Co., Ltd., Beijing, China
*Corresponding Author

Abstract:

Aiming at the fuzzy effect caused by filtering in neighborhood enhancement algorithm, this paper improves the PM equation and proposes a new enhancement method by using improved PM equation. The anisotropic diffusion characteristic of PM equation is particularly conducive to the preservation of edges and details in the process of image enhancement. Firstly, an improved PM equation based on fractional order is constructed, which has better anisotropic diffusion characteristics. Secondly, aiming at the improved PM equation, reasonably configuring parameters and setting new boundary conditions, an effective accurate solution method of the equation is designed. Finally, the enhancement effect of the new method is experimentally studied. The final results show that after image enhancement method based on the improved PM equation, the contrast is significantly promoted, image details are clear and complete, and PSNR of the enhanced image is also significantly improved.

***Keywords**: Underbody image, image enhancement, PM equation, contrast, definition, Peak signal-to-noise ratio*

I. INTRODUCTION

Vehicle bottom inspection is of great significance to public safety. However, the underbody light is not good, and the underbody image needs to be enhanced before it can be used for further analysis. Image enhancement is a key technology for image processin [1-3]. It has very important applications in fog hidden image processing, night vision image processing, weak texture region extraction, contrast enhancement, fingerprint image recognition and other fields [4-5].

From the implementation approach of image enhancement algorithm, it includes four categories: image enhancement by using neighborhood information, neighborhood enhancement based on color information, image enhancement based on histogram correction and image enhancement based on depth learning [6-8]. Among them, the image enhancement algorithm based on neighborhood information is widely used for image enhancement because of its good visual effect [9].

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Image smoothing algorithm and image sharpening algorithm are commonly used in neighborhood operation [10]. The image is continuous, that is, the gray values of adjacent pixels are similar, and the existence of noise makes the local gray jump at noise points, and image smoothing is an enhancement algorithm that can reduce and suppress noise [11-12].

Park proposed a gradient minimization algorithm based on gradient filtering, which reduces ladder effect caused by image smoothing technology based on partial differential. Before image smoothing, filter is used to process image gradient, which not only has robustness to noise, but also improves image edge protection performance [13].

Ravisankar proposed an image smoothing algorithm based on high-frequency gradient information and joint bilateral filtering. The algorithm has good smoothing effect for the smoothing problem of texture image. It can not only remove redundant texture, but also retain the main structure information in the image [14].

Yamakawa uses the neighborhood mean of the minimum variance as the gray value of the target area, and selects the minimum and maximum correlation areas disturbed by noise by controlling the size of the smoothing area and the mean square deviation threshold, realizing a relatively good smoothing effect [15].

Fu proposed a general image model with the filter kernel as the variable. This model uses different filter outputs as the base output, and then determines the object boundary by the interpolation of the edge preserving filter and the smoothing filter, which can effectively suppress the noise and have a good edge enhancement effect [16].

Musa introduces a graph based local pixel image representation algorithm, which can distinguish different regions in the pixel neighborhood, making it possible to synchronize the smoothing and sharpening of the image. The algorithm overcomes the shortcomings of sequential smoothing and sharpening, enhances the details of the image, reduces the noise and retains the key information [17].

Sandeepa decomposes the infrared image by using edge preserving smooth filtering, and uses different enhancement strategies to process the decomposed components, which effectively expands the local contrast of the infrared image [18].

Saifullah proposed an smoothing method by using anisotropy to describe anisotropy of the local gradient of edge pixels. The pixels with large anisotropy are edge pixels. The measurement of anisotropy is embedded into the regularization objective function, and the objective function is optimized by training the depth neural network. The algorithm can sharpen the edge of the image while maintaining the smoothness of the image, and eliminate trivial useless details [19].

Toaar smoothes the image by improving the elastica model commonly used in image processing, and applies the time discretization method based on operator decomposition to the calculation direction of the

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relevant initial value of the optimal system, so as to obtain the result of operator decomposition faster and simplify the calculation steps of the model. This method can obtain the result of image smoothing faster, improved image processing efficiency [20].

In conclusion, filtering and denoising plays a very important role in image enhancement algorithms based on neighborhood information. However, while filtering noise, noise filtering algorithm may damage some high-frequency information in the image more or less, resulting in fuzzy edge and texture effects, especially for the very sensitive signal such as fingerprint texture. Based on this, this paper adopts the anisotropic diffusion partial differential equation filtering algorithm based on PM equation, and improves it to complete the enhancement solution, in order to obtain better vehicle bottom image enhancement effect.

II. PROPOSED METHOD

2.1 Improved PM Equation Design

In order to remove noise, various filtering algorithms are widely used. However, filtering will produce smoothing effect while denoising, resulting in magic effect in the image.

The image enhancement method based on partial differential equation can effectively avoid the smoothing effect and highlight the edge and detail features of the image because of its anisotropic diffusion characteristics. PM equation is a typical partial differential equation in the form of:

$$\begin{cases} \frac{\partial I(x,y;t)}{\partial t} = div(d(x,y)\nabla I(x,y;t)) \\ I(x,y;0) = I_0 \end{cases} \quad (1)$$

Here, parameter I_0 denotes original image, parameter t denotes time, parameter $d(x,y)$ denotes diffusion factor.

There is an inverse correlation between diffusion factor and image gradient. The larger the gradient, the smaller the corresponding diffusion factor. The calculation rules of gradient are as follows:

$$g(I) = \frac{1}{\sqrt{1+c|\nabla G_\gamma * I|}} \quad or \quad g(I) = \frac{1}{1+|\nabla I|/\lambda} \quad (2)$$

Here, $(*)$ denotes convolution operation, G_γ denotes Gaussian filtering operation.

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With the further study of partial differential equations, the expression based on fractional form has better anisotropic diffusion properties. Give a new equation as follows:

$$ {}_{a}^{G-L}D_{t}^{\alpha} f(t) = \lim_{h\to 0} \frac{1}{h^{\alpha}} \sum_{i=0}^{\left[\frac{t-a}{h}\right]} (-1)^{i} \binom{\alpha}{i} f(t-ih) \tag{3} $$

Here, parameter α denotes derivative order.

So far, an improved expression of PM equation based on fractional order can be obtained, specifically:

$$ \begin{cases} {}_{a}^{G-L}D_{t}^{\alpha} I(x,y;t) = div(g(I)\nabla I), (x,y,t) \in (0,a)\times(0,b)\times(0,T) \\ I(x,y;0) = I_0, 0 < x < a, 0 < y < b \\ I(0,y;t) = I(a,y;t) = 0, 0 < y < b, 0 < t < T \\ I(x,0;t) = I(x,b;t) = 0, 0 < x < a, 0 < t < T \end{cases} \tag{4} $$

Here, parameter a is changed in the section of (0, 1), parameter ∇I denotes image gradient, $g(I)$ represents the edge locking function. When x or y tends to infinity, $g(I)$ tends 0.

2.2 Design of Solving Method for PM Equation

To enhance image, it is necessary to obtain the accurate solution of PM equation.

In this paper, formula (3) is rewritten:

$$ {}_{a}^{G-L}D_{t}^{\alpha} I(x,y;t) = \frac{1}{\Delta t^{\alpha}} \sum_{i=0}^{\left[\frac{t}{\Delta t}\right]} (-1)^{i} \binom{\alpha}{i} I(x,y;t-i\Delta t) + O(\Delta t) \tag{5} $$

Based on this new expression, according to the calculation method of the central difference of the first derivative, it can be seen that PM equation will turn at the position of (x_j, y_k, t_n):

$$ I_{j,k}^{n} = I(x_j, y_k; t_n)\ ,\ \ g_{j\pm\frac{1}{2},k}^{n} = g(I(x_j \pm \frac{\Delta x}{2}, y_k; t_n)) $$

$$ I(x_j \pm \frac{\Delta x}{2}, y_k; t_n) = \frac{I(x_j, y_k; t_n) + I(x_{j\pm\Delta x}, y_k; t_n)}{2} \tag{6} $$

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$$g^{n}_{j,k\pm\frac{1}{2}}=g(I(x_j,y_k\pm\frac{\Delta y}{2};t_n))$$

In order to meet the requirements of image enhancement, set $\Delta x=\Delta y=1$. Further, the difference solution of formula (9) can be obtained:

$$\begin{aligned}\sum_{i=0}^{n}(-1)^i\alpha_i\tilde{I}^{n-i}_{j,k}=(\Delta t)^{\alpha}\Big[&g^{n}_{j+\frac{1}{2},k}(\tilde{I}^{n}_{j+1,k}-\tilde{I}^{n}_{j,k})-g^{n}_{j-\frac{1}{2},k}(\tilde{I}^{n}_{j,k}-\tilde{I}^{n}_{j-1,k})\\&+g^{n}_{j,k+\frac{1}{2}}(\tilde{I}^{n}_{j,k+1}-\tilde{I}^{n}_{j,k})-g^{n}_{j,k-\frac{1}{2}}(\tilde{I}^{n}_{j,k}-\tilde{I}^{n}_{j,k-1})\Big]\end{aligned} \quad (7)$$

Here, the boundary conditions to be noted are:

$$\begin{cases}\tilde{I}^{0}_{j,k}=I_0(x_j,y_k;0) & 1\le j\le N_1, 1\le k\le N_2\\ \tilde{I}^{n}_{0,k}=\tilde{I}^{n}_{N_1,k}=0 & 1\le k\le N_2, n=1,2,\cdots\\ \tilde{I}^{n}_{j,0}=\tilde{I}^{n}_{j,N_2}=0 & 1\le j\le N_1, n=1,2,\cdots\end{cases} \quad (8)$$

III. EXPERIMENTAL RESULTS AND ANALYSIS OF UNDERBODY IMAGE ENHANCEMENT

3.1 Determination of Optimal Parameters

To verify the effect of our algorithm on scanned image of underbody, the enhancement experiment of the actual underbody image is processed to observe contrast before and after enhancement. Through the numerical solution based on the fractional PM equation, the enhancement results of the underbody image can be obtained like Fig 1.

(a) original vehicle bottom

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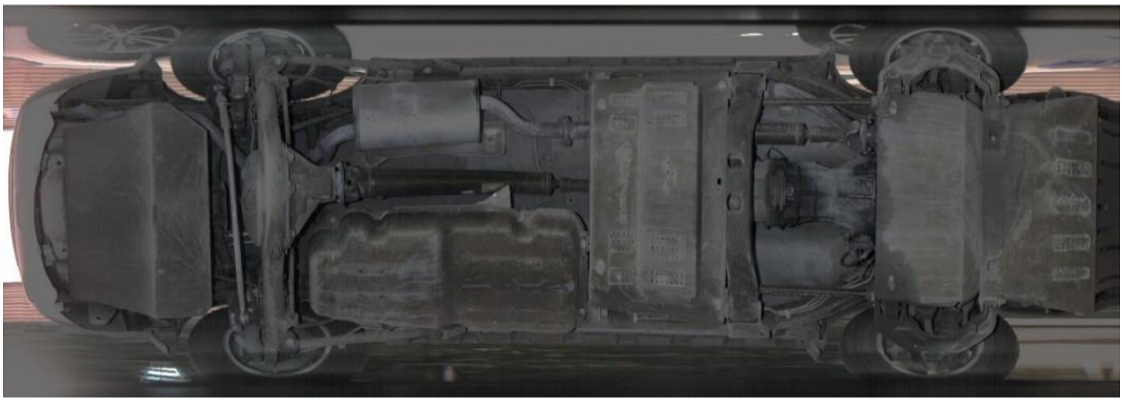

(b) vehicle bottom image with α of 0.4

(c) vehicle bottom image with α of 0.8

Fig 1: results by using our method

In Figure 1, figure (b) and figure (c) show the coefficients respectively α. When it is 0.4 and 0.8 respectively, results can be obtained by running the algorithm. We can see the visual effect shown in Fig 1 that effect of the underbody image is better and obvious when $\alpha = 0.4$.

Further compare PSNR of the three images in Fig 1, which are 8.353, 14.083 and 10.043 respectively, indicating that the image quality of the underbody image has been improved after being processed by the algorithm in this paper.

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3.2 Enhancement Experiment of Multiple Groups of Vehicle Bottom Images

To show universal effect of our algorithm in the vehicle bottom image, this paper carries out the enhancement processing experiment of multiple groups of vehicle images under the configuration $\alpha = 0.4$ of the algorithm, and the results are shown in Fig 2.

(a) first image

(b) first enhancement results

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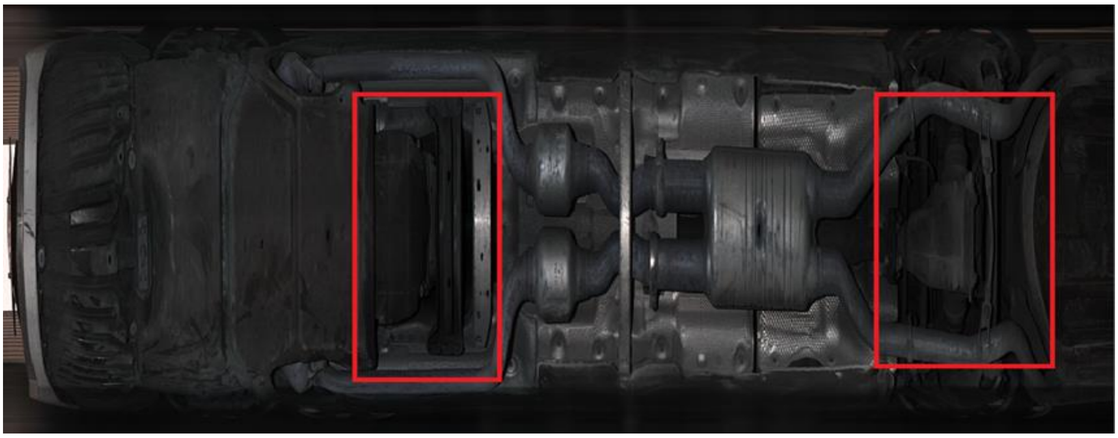
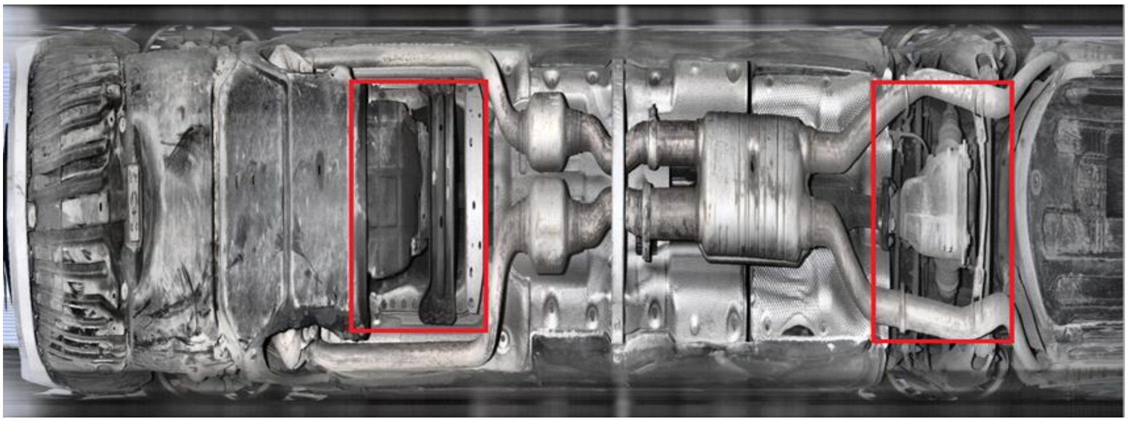
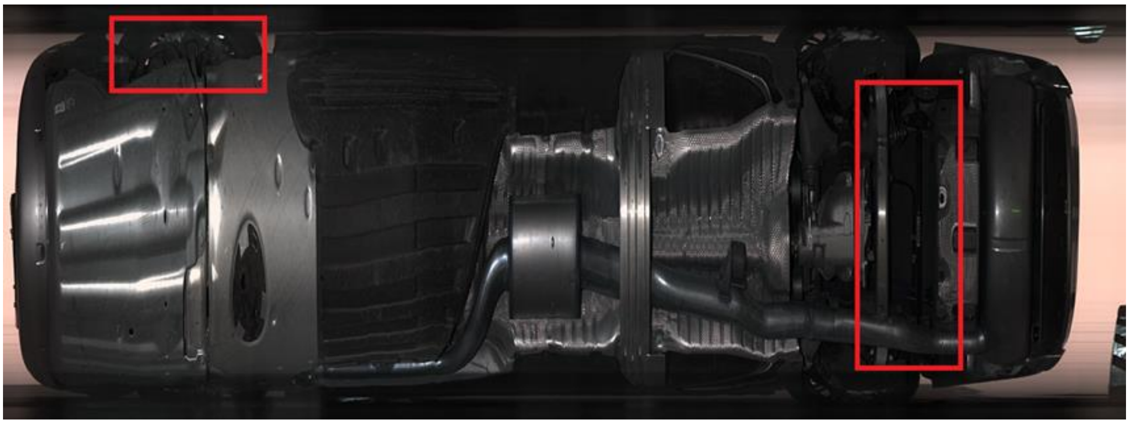


(c) second image



(d) second enhancement results



(e) third image

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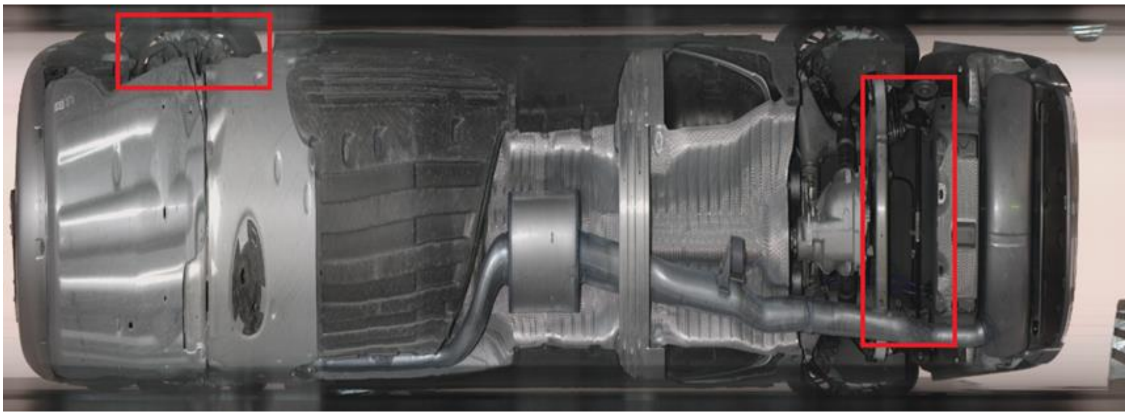

(f) enhancement results of third image

Fig 2: enhancement results of three groups of different vehicle bottom images

We can see in Fig 2:

First, although three groups underbody images are different, the original images are dark and the contrast is not obvious. After the processing of the enhancement algorithm in this paper, the contrast of the three groups of underbody images is significantly enhanced, showing a good visual effect.

Second, in the three groups of underbody images and their enhancement results, there are marked areas with red boxes. In this area, the detail features cannot be seen clearly on the original image. After the enhancement processing in this paper, the detail features in the red box become clear and recognizable.

3.3 Comparison of Various Enhancement Algorithms

In order to form an intuitive comparison between the effects of this method and other enhancement methods, histogram equalization enhancement method (HE) and nonlocal mean enhancement method (NLM) are selected as reference methods to enhance the image in Fig 2 (1), and the results are shown in Fig 3.

(a) vehicle bottom image

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(b) results obtained by HE enhancement method

(c) results obtained by NLM enhancement method

(d) results obtained by our enhancement method

Fig 3: Comparison of enhancement results of three different methods

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Results in Fig 3 show that complete enhancement effect obtained by enhancement method based on the improved PM equation is indeed better than HE method and NLM method.

Further compare PSNR ratio obtained by three methods after thorough image enhancement processing for the three groups in Fig 2, as shown in the table below:

TABLE I. Comparison of Peak Signal-to-Noise Ratio of Three Methods

Method	**HE**	**NLM**	**Our Method**
vehicle bottom 1	12.708	9.071	14.592
vehicle bottom 2	12.335	8.558	14.041
vehicle bottom 3	13.001	9.839	17.150

It can be seen from the comparison in TABLE I that for the three groups of different underbody images in Fig 2, PSNR obtained by our method is higher than other two methods.

IV. CONCLUSION

New enhancement method of improved PM equation is used to enhance the underbody image. During the verification experiment, three groups of underbody images are selected, which have obvious differences in image brightness, contrast and details. Results show that three groups of underbody images enhanced by the improved PM equation method are better than he method and NLM method. The contrast of results obtained by using our method is more obvious, and detailed features are clearer and complete. Further PSNR results also show that PSNR of the enhanced image obtained by the improved PM equation method is higher than HE method and NLM method.

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