Research and analysis of infrared image enhancement algorithm based on fractional differentiation

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Abstract. Due to the inherent defects of infrared imaging systems and the influence of the external complex environment, infrared images have low contrast, blurred edge details, low signal-to-noise ratio and poor visual effects compared with visible images, which have a great impact on the subsequent feature extraction, detection and identification and target tracking, and cannot meet the requirements in military, medical and civilian fields. The current technical deficiencies of infrared imaging devices at the hardware level cannot fundamentally solve these problems, so it is especially necessary to enhance infrared images from the perspective of algorithms. We propose an improved fractional differentiation algorithm that enhances the contrast of infrared images and the contrast of the images is controlled by the fractional order. Experiments and analysis show that the proposed method has good feedback for enhancing the contrast of dark images, and it can effectively enhance the edge information and detail information.

1. Introduction

Infrared imaging systems play an extremely important role in reconnaissance and early warning, public security and other fields because of their unique advantages such as round-the-clock operation, passive type and strong anti-interference capability. Infrared imaging system mainly uses the infrared radiation emitted by the target object itself for imaging, due to the different characteristics of infrared radiation of different types of objects, making infrared imaging system can distinguish different targets. Infrared imaging system breaks through the illumination and spectral response range of the human eye's visual limitations, enhancing the visual function of the human eye. Due to the characteristics of infrared imaging technology, infrared images generally have the problems of low contrast, blurred edges and inconspicuous detail highlighting [1,2]. This has a great impact on the accuracy of subsequent image segmentation, edge detection, image alignment and pattern recognition [3]. Images obtained directly from various sensors usually cannot meet the requirements of subsequent processing and applications, so the acquired infrared images must undergo an image enhancement step to improve the image quality.

The primary goal of image enhancement is to be able to highlight the main information of an image effectively, and a visually better image can be obtained by means of image enhancement. Image detail enhancement is usually achieved from two aspects, one of which is the stretching process of contrast...
and the other is the maintenance and reproduction of image details. There are many methods of image enhancement, which can be divided into two categories, spatial domain and frequency domain, according to the difference of space in the enhancement process. Commonly used spatial domain [4,5] image enhancement methods mainly include grayscale transformation, histogram equalization, image sharpening and other methods. The frequency domain [6,7] image enhancement methods mainly include low-pass filtering, high-pass filtering and homomorphic filtering.

In general, the detail information in images is highly self-similar fractal information, and the mathematical basis of fractal theory is fractional order calculus, so the fractional calculus processing can be considered to enhance the complex texture detail features with fractal characteristics in two-dimensional image signals. Fractional-order calculus is a generalized extension of integer-order calculus in terms of order. Commonly used differentials are of integer order, while the order differential can be false fraction or true fraction, and if its order if approximately divisible, the fractional order differential can be degraded to integer order differential. Fractional differentiation has the advantages of nonlinearity, weak derivativity and memory, and Fractional differentiation has made rapid progress in the field of image processing. Due to the advantages of weak derivatives of fractional differentiation, it can enhance the high frequency components of an image while nonlinearly preserving the low frequency components of the image. In the field of image enhancement, the differential operator can not only obtain a good enhancement effect relative to the integer-order differential operator, but also suppress the noise while enhancing the details, thus obtaining better visual effects.

In this paper, an adaptive fractional differentiation based IR target enhancement method is proposed. The algorithm not only enhances the edge details of the target, but also increases the contrast of the target and avoids the increase of background noise, which has a good visual effect of infrared target enhancement.

2. Fractional Differentiation

2.1. Definition of Fractional Differentiation

The vth order forward differentiation of the function \( f(x) \) under the Grumwald-Letnikov (G-L) definition is shown in Equation 1.

\[
D_v f(x) = \lim_{h \to 0} \frac{1}{h^v} \sum_{k=0}^{(x/a) / h} (-1)^k k^v (x - kh)
\]

Where \( (x/a + h) \) is rounded and \( D_v f(x) \) denotes the a-order forward derivative.

Fractional differentiation is an extension of integer order differentiation, and fractional differentiation degenerates to integer differentiation in the case where the order can be approximately differentiated. Therefore, when analyzing the action of fractional differentiation operators on signals, one can start with integer differentiation and then extend it to fractional differentiation. For an arbitrary energy signal \( f(t) \), the signal must be squarely productable. If the nth-order derivative of the energy signal \( f(t) \) is \( f^n(t) \), where order n is a positive integer, then the nth-order derivative \( f^n(t) \) of the energy signal \( f(t) \) can be expressed as Equation 2.

\[
f^n(t) = D^n f(t) = \frac{d^n f(t)}{d^n t}
\]

From the properties of the Fourier transform, we can get Equation 3.

\[
D^n f(t) \leftrightarrow (\hat{D} f)^n(w) = (iw)^n \hat{f}(w) = \hat{a}^n(w) f(w)
\]

Where \( (iw)^n = \hat{a}^n(w) \) is the multiplier function of the nth order differential. Since fractional differentiation is regarded as an extension of integer differentiation in order, the integer order n in the above equation can be extended to the fractional order \( v \) when analyzing the action of fractional order differentiation operator on the signal, and the fractional order v derivative of \( f(t) \) can be obtained as \( f^v(t) \). After the fractional differential conversion to the frequency domain, the strength of the signal can be reflected by the amplitude information therein, which changes exponentially in fractional order curtain when the frequency of the signal changes.
2.2. Improved Tiansi algorithm
The fractional differentiation operator Tiansi has good differentiation characteristics and can enhance the high frequency components of the image while nonlinearly preserving the low and medium frequency components of the image. Some pixels with Tiansi operator for image detail enhancement cannot detect the texture region, but will treat the texture region as a smooth region, which will result in the enhancement of detail information of individual regions not reaching the desired effect. To solve this problem, we decompose the Tiansi operator into four small 3×3 templates, and use each small template to enhance the pixel points to be processed, as shown in Figure 1.

![Figure 1 Template decomposition](image)

In the process, the pixel point \( m(x, y) \) to be processed is the location of the constant coefficient \( 2a_0 \). Each pixel point in the image is convolved with the above four 3×3 templates to obtain the four convolution values \( M_1, M_2, M_3, M_4 \) corresponding to the direction of the coordinate axis, respectively. Assume that the result of the convolution operation is \( M \), if \( M < 0 \), then directly let \( M = 0 \), if \( M > 255 \), then let \( M = 255 \).

2.3. Feature fusion
In order to better obtain the local feature information of the infrared target, the gradient of the image and the local information entropy are used to jointly obtain the target features, which leads to the dynamic parameters of the whole image. We use a 5×5 template for rectangular local area feature calculation. The gradient of the target region is obtained using the horizontal gradient, vertical gradient, primary diagonal gradient and secondary diagonal gradient of the image jointly, so the target contains gradient features in 8 directions. The gradient \( K(i) \) of the image is calculated as shown in Equation 4.

$$K(i) = \frac{k_h(i)}{4} + \frac{k_v(i)}{4} + \frac{k_p(i)}{4} + \frac{k_d(i)}{4}$$  (4)

Where \( k_h(i) \) is the horizontal gradient of the pixel at point \( i \) of the image, \( k_v(i) \) is the vertical gradient of the pixel at point \( i \) of the image, \( k_p(i) \) is the primary diagonal gradient of the pixel at point \( i \) of the image and \( k_d(i) \) is the secondary diagonal gradient of the pixel at point \( i \) of the image. The local entropy \( S(i) \) of the image is shown in Equation 5.

$$S(i) = -\sum_j Q_j \log_2 Q_j$$  (5)

Where \( Q_j = \frac{H_j}{M \times M} \), \( 1 \leq j \leq 256 \), \( j \) is the pixel value, \( M \) is the template size, \( Q_j \) is the number of pixel values of size \( j \) obtained by local histogram statistics of the template image centered on the pixel at point \( i \).

The magnitude of the adaptive feature parameter value of an image corresponds to the degree of enhancement of each pixel of the image, which is mainly expressed as a value in the range of 0 to 1. The larger the value, the stronger the enhancement. In order to map the feature parameter values into the range of 0 to 1, the above two feature parameters are normalized separately to obtain Equation 6.

$$Y(i) = \frac{Y(i) - \min(Y(i))}{\max(Y(i)) - \min(Y(i))}$$  (6)
Where $T(i)$ is a feature parameter of the $i$th pixel point of the image, $\text{Max}(T(i))$ is the maximum value of the feature parameter $T(i)$, $\text{Min}(T(i))$ is the minimum value of the feature parameter $T(i)$. Finally, the fusion of the two feature parameters is performed. Since the size of the weights occupied by the two features is not very different, we use the summation average method of fusion, and the calculation formula is as follows.

$$C(i) = \frac{K(i)}{2} + \frac{S(i)}{2}$$

Where $K(i)$ and $S(i)$ are the gradient and local entropy of the image, respectively, and $C(i)$ is the local fusion feature value of each pixel point of the image, which mainly highlights the edge detail part of the image target.

3. Results and Discussion

To prove the effectiveness of the method in this paper, four different infrared image enhancement methods were selected for comparison with the proposed method. These four methods are GHE [8], CLAHE [9], wavelet transform [10] and BPDHE [11]. Images are selected from street images taken by IR cameras and run on Matlab2018 platform. The images after processing by various methods are shown in Figure 2.

![Figure 2](image)

Figure 2 Visual comparison of different methods, (a) Original image, (b) GHE, (c) CLAHE, (d) Wavelet transform, (e) BPDHE, (f) Our method

Fig. 2(a) shows the original image, which is dark and the target is blurred. The image is obviously enhanced after GHE processing, the street and part of the car are bright and prominent, but the background of the image is over-enhanced resulting in too much brightness and obvious distortion. The background noise of the image is well suppressed by CLAHE and the background is kept intact and undistorted, but the edge of the target and the overall enhancement are not good. wavelet transform and BPDHE are too small, and cars, streets and trees are still blurred. After the processing of the proposed method, the image target is bright and the target edges are clear, and the street, tree and car outlines are clearly distinguished, and the features of the target are well preserved, in addition, the image noise is well suppressed and there is no distortion. This shows that the infrared image enhancement effect of this method is better than the above four algorithms.
4. Conclusions
In this paper, an infrared image enhancement algorithm based on fractional differentiation is proposed, which mainly solves the problems of unclear target edge details and low contrast of infrared images. This paper uses the gradient of the image and the local information entropy jointly to get the new target edge feature, and uses it as the order to adjust the fractional order differentiation, so as to realize the fractional differentiation-based infrared image enhancement. The experimental results show that the contrast of the image is significantly improved after image enhancement, and the image background is clearer. Therefore, the algorithm in this paper can effectively improve the contrast and edge detail clarity of infrared images, and is suitable for the enhancement of infrared targets.

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