Study on Small Target Extraction Algorithm Based on Deconvolution Normalization

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Abstract: To improve the problem of small target information extraction in linear CCD detection system, the method of deconvolution is put forward to extract and analyze small target’s image information under complex background. Through establishing a mathematical model to extract target information, the pure white template with the original background images that without target was deconvoluted, the complex background was transformed into a white plate template image, and then obtains the transfer function at the same time. After processing, the result shows that the background mainly becomes a piece of white board. While the target can be displayed clearly, a large number of gray-scale information of the target point can be retained at the same time. And the target can also recover the actual gray value of the point by using the reserved gray values, which has considerable research value for the judgment of small target and recovery of original target shape.

Keywords: Linear CCD, Image processing, Small target extraction, Transfer function, Deconvolution, Complex background.

1. Introduction

Binocular linear CCD intersection measurable technology is an advanced non-contact measurement technology. It is used to test the gesture of high-speed weak target in the large target surface testing system, which has high measurement accuracy, strong instantaneity, simple structure and many other advantages. It’s a very effective measurement method that has already been widely used in the coordinate location of dynamic target and shows its unique superiority in the application [1].

By using linear CCD camera to capture high-speed moving target, it just scans only one or several pixels width, and it is difficult to pick up the weak target. In addition, there are some factors to influence the target extraction, such as the brightness of light background, the stability of that, the uniformity of that and the interference points existing in natural environment [2]. Due to the edge of the target in the image is a fuzzy concept, and it is generally considered to be part of the dramatic changes, accurately identify the target edge information directly concerns the target extraction accuracy [3]. For small dim target under complex background, the image usually contains more noise, it is necessary to improve the image SNR and suppress background by preprocessing for the real time requirements of image processing system, and the quality of the preprocessing of image will directly affect the target feature extraction [4]. In a general way, image processing methods could mainly divide into two kinds, i.e. spatial domain method and frequency domain method. Spatial domain method is, mainly in
space domain, to directly calculate the pixel gray value, such as median filter, high-pass filtering, etc. [5]. Frequency domain method is, mainly in some transform domain of the image, to manipulate the transform coefficients of the pixels. For example, the image is processed by Fourier transform first, then filter the original image in frequency domain, finally inverse transform filtered image into spatial domain, so that noises are filtered, the background is suppressed. Meanwhile, from the practical point of view, the extracting algorithm should not only has good processing result, but also be easy to implement in practice [6]. However, high-performance and instantaneous is a pair of mutual restrictive factors. Therefore, finding an effective target extraction method is the focal and difficult point of the research [7].

The rest of the paper is organized as follows. Section 2 introduces the target image features under a complex background, analyses the extraction principle of the small and weak targets and derivation the formula that used in small target extraction. Section 3 analyses the experiment data, compare the image parameter before and after process, proved that deconvolution method has a strong applicability in different background. Section 4 analysis the experimental results and comparison with other methods proved that deconvolution method in target extraction, especially in weak and small target extraction under the complex background have high accuracy and Easy to implement. Conclusions are drawn in Section 5.

2. The Extraction Principle of the Small and Weak Targets

2.1. The Target Image Features Under a Complex Background

To the small dim target, there are some obvious characters.

1) The image background has a change of rolling, it relates to the intensity of the background light.

2) The background of image has noise, especially during the measurement in a dynamic and complicated environment, the noise is random.

3) The edge of target is curve, fuzzy, and asymmetric. So it requires an algorithm to search the edge.

4) The signal-to-noise ratio of the target and the background is very low, so it is easy to filter out part of the target information during filtering [8-10].

2.2. The Deconvolution Algorithm Process

Firstly, we take the target as a signal. Secondly, the working principle of linear camera is to scan a same position many times, record the signal on the same location at different moment [11]. So the process of linear CCD capturing high-speed flying target can be regarded as the process of gathering target signal. When linear camera scans, the one-dimensional image that forms at different moments is taken as a signal of the moment. Due to the fast-speed of linear CCD camera (20000-40000/SEC), the scanning information is roughly the same [12]. When the target signal rapidly goes through the position where linear CCD camera scans, the original information will be changed. Because the target signal passed quickly, so the signal change is not a smoothing process, but is a very sudden change. Finding the abruptly changing point can get the target point [13].

Fig. 1 shows the flow chart of the deconvolution method. From the speed of the target and the camera position, it is known that the target will not appear in the former fifty lines. Averaging the second row of the image to be detected to the eleventh row of that, the no target one-dimensional image $D_1$ can be got. Deconvoluting the structured single color smooth template $W$ with $D_1$, we can receive the transfer function $T$. And then to convolute each line of $D$ with $T$ in turn can obtain the result of each line. If the each line’s result is put according to the line order, the position of the target point can be found.

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Fig. 1. The flow chart of deconvolution process.
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2.2. The Algorithm of Small Target Extraction Based on the Deconvolution

In the continuous-time system, the convolution of the two known signals, $f(x), h(x)$ can be expressed as [14]:

$$y(k) = f(k) * h(k) = \sum_{i=-\infty}^{\infty} f(i) * h(k-i). \quad (1)$$

The deconvolution can be expressed as:

$$h(k) = [y(k) - \sum_{i=0}^{k-1} f(i) * h(k-i)] / f(0). \quad (2)$$

For the image to be detected, it can be considered as a two-dimensional matrix $M$, which is composed of different gray values:
\[ M = \begin{bmatrix} x_{i1} & x_{i2} & x_{i3} & \ldots & x_{ij} \\ x_{i1} & x_{i2} & x_{i3} & \ldots & x_{ij} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ x_{i1} & x_{i2} & x_{i3} & \ldots & x_{ij} \end{bmatrix}, \]  
(3)

where \( x_{ij} \) is the gray value of \( M \), \( D \) is any line of \( M \)
\[ D = \begin{bmatrix} x_{i1} & x_{i2} & x_{i3} & \ldots & x_{ij} \end{bmatrix}, \]  
(4)

\( T \) is the transfer function to be computed
\[ T = \begin{bmatrix} y_1 & y_2 & y_3 & \ldots & y_j \end{bmatrix}, \]  
(5)

where \( y_1, y_2, y_3, \ldots, y_j \) is the unknown, \( W \) is the constructed template function
\[ W = \begin{bmatrix} a_1 & a_2 & a_3 & \ldots & a_{2j-1} \end{bmatrix}, \]  
(6)

where \( a_n \) \((0 \leq a_n \leq 1, 1 \leq n \leq 2j-1)\), by the properties of convolution, both \( D \) and \( T \) have \( j \) columns, according to formula (1), \( W \) has \( 2j-1 \) columns.

According to the formula (1), the process of convolution can be expressed as follows:
\[ D \times T = W, \]  
(7)

According to the formula (2), the process of deconvolution can be expressed as follows:
\[ T = D' \times W, \]  
(8)

where \( D' \) is the pseudo inverse matrix of \( D \). \( D \) Can be expressed as:
\[ D = x_{i1} + x_{i2}x + x_{i3}x^2 + \ldots + x_{ij}x^{j-1}, \]  
(9)

Another form of \( D \):
\[ D = \begin{bmatrix} x_{i1} & x_{i2} & x_{i3} & \ldots & x_{ij} \end{bmatrix} \begin{bmatrix} 1 \\ x \\ x^2 \\ \vdots \\ x^{j-1} \end{bmatrix}, \]  
(10)

\( T \) Can be expressed as:
\[ T = \begin{bmatrix} y_1 & y_2 & y_3 & \ldots & y_j \end{bmatrix} \begin{bmatrix} 1 \\ x \\ x^2 \\ \vdots \\ x^{j-1} \end{bmatrix}, \]  
(11)

The template function \( W \) can be expressed as:
\[ W = \begin{bmatrix} a_1 & a_2 & a_3 & \ldots & a_{2j-1} \end{bmatrix} \begin{bmatrix} 1 \\ x \\ x^2 \\ \vdots \\ x^{2j-1} \end{bmatrix}, \]  
(12)

Taking formula (10), (12) into formula (8), there is:
\[ y_1 = a_1x_{i1}, \]  
(13)
\[ y_2 = a_2x^{-1}x_{i2} - y_1, \]  
(14)
\[ y_3 = (a_3x^{-2} - x_{i2}y_2 - x_{i1}y_1)/x_{i1}, \]  
(15)
\[ \ldots \]  
(16)

When \( W \) selects single color template, after calculating, the background of the new image is also the same color.
\[ a_1 = a_2 = a_3 = \ldots = a_{2j-1} = a, \]  
(17)

where \( a \) is the background gray value \((0 \leq a \leq 1)\).

If \( M \) has the target point, taking formula (10), (12), (17) into formula (7), there is:
\[ M' = \begin{bmatrix} a & a & a & \ldots & a \\ a & a & a & \ldots & a \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ a & a & a & \ldots & a \end{bmatrix}, \]  
(18)

In formula (13) \( d \) is the target location.

2.4. The Principle of Deconvolution

Line processing

In most of the traditional target extraction methods, the image is considered as a two-dimensional image to be disposed, but in practice, the two-dimensional image is composed of line image
scanned by linear CCD camera in time order [15]. Therefore, deconvolution arithmetic method is considered to process the image line by line according to the time order. Linear camera acquisition speed is very fast (one picture needs 0.033-0.05 ms). So the image gray value of each line is roughly the same. By using the formula (8) to convolute transfer function $T$ and single color template $W$, after calculation the gray value of each line in the new image is very close, thus the complex background can be transformed into a single color background in this way, as the formula (18) shows. Because the gray value of target point is smaller than that of other points which stay in the same column. If gray value has obvious changed by convoluting, that’s the target point. Separating the target from background in this way can find the target points accurately. So the deconvolution method is also called ‘Change background method’.

2.5. Selection of Template Function

The selection of the template function is the key part of the whole algorithm. The template is equivalent to the processed image’s background. If the template selected inappropriately, the contrast of target and background is very weak, which will bring difficulty in extracting target, and the interferential points will be difficult to remove, Table.1 is the gray value of ten different gray scale templates, the gray value of target chooses 0.4, because most of the gray value of target is under 0.6, according to formula (7), $X$ is the gray value of the selected template, $Y$ means the processed target’s gray value.

From Table 1, we know when $X$ increase, $Y$ will increase. When the $X$ is ‘1’, there is the biggest difference between $X$ and $Y$. The result shows that when the template’s gray value is ‘1’, the difference between the target and the background is the biggest, and the target is the easiest to be found.

![Table 1. Gray values of different template after processing.](image)

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3. Simulation and Parametric Analysis

3.1. Simulation Analysis

Fig. 2(a) shows a picture shot by linear CCD camera which shoots the moving target outdoor. Due to the shortage of light conditions, the background of the image is more complex, it is hard to find out the location of the object in the picture. Fig. 2(b) and Fig. 2(c) are shot from moving target indoor.

![Fig. 2(b) is indoor close shot. Fig. 2(c) is indoor long-distant shot.](image)

Fig. 3 shows the image of the Fig. 2(a) after amplifying 16 times, through the picture we can find a weak target point.

In Fig. 3, it shows that the camera just get three lines of the target, and each line only has three pixels points. And the targets’ gray value is very close to the background, so it’s hard to find out the location of the target.

Firstly, by the conclusion of 2.2, averaging gray levels of the 2nd to the 11th lines, we can get a no target image. Fig. 4 shows the frequency spectrogram of no target images.

Fig. 4 shows the no target Spectrum of Fig. 3, horizontal coordinate axis represents columns, and vertical coordinate axis represents the gray value. For Fig. 4(a), between the lines of 600 to that of 800, this area belongs to the light source area, and its gray value is 0.25-0.5. If the camera gets the target, it’ll be showed in this area, and the target’s gray value is
under 0.5. Between 0 and 600 lines the gray value is less than 0.25, and from 800 and 1000 lines the gray value is less than 0.18, especially at the line of 390, it's about 0.05. This means that the gray value of the image is small, color is more deep, close to black. The gray curve is not steady, it has a wide range, so the target is very easy to hide in the background and hardly to find out.

Fig. 3. Target amplified 16 times.

Fig. 4 (a). No target spectrum before processing – no target line spectrum in outdoor.

Fig. 4 (b). No target spectrum before processing – no target line spectrum in indoor.

Fig. 4 (c). No target spectrum before processing – no target line spectrum in indoor.

Fig. 5 (a). Transfer function T – outdoor image transfer function.

Fig. 5 (b). Transfer function T – indoor close shot image transfer function.

From the conclusion of Table 1, constructs a white template function $W$. Taking $W$ and $D$ into formula (8), we can get the transfer function $T$. Fig. 5 shows the spectrum of transfer function $T$:
After calculating transfer function $T$, as the flow chat shows, taking $D$ and $T$ into formula (7), we can get the line frequency spectrogram. Fig. 6(a), Fig. 6(b), Fig. 6(c) shows the spectrum without target, Fig. 6(d), Fig. 6(e), Fig. 6(f) shows the spectrum with target.

Fig. 6(a) to Fig. 6(f) are the spectrum curves. After computer simulation, Fig. 6 (a), Fig. 6 (b), Fig. 6 (c) are the curves without target, all of the background are around 1, close to white. The spectrum of the row with target, as show in Fig. 6(d), Fig. 6(e), Fig. 6(f), it has some prominent change which is significantly different from both sides of the
curve. Fig. 6(d), Fig. 6(f), just has a few pixels width, because it is long-distant shot. Fig. 6(e) has a very wide image and the difference between target and background is smaller than that of Fig. 6(d) and Fig. 6(f). Because Fig. 6(e) is closes shot, the target has a big image on camera and the gray value is small.

![Fig. 6 (f). The processed spectrum – indoor long-distant shot target spectrum.](image)

Table 2 shows the target and it's around points before processing. Table 3 is the target and it's around points after processing. The central nine points is the target. According to the analysis between these two different tables, we can get the change of the image.

### Table 2. The center of the target and its surroundings' gray value before processing.

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### Table 3. The center of the target and its surroundings' gray value after processing.

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### 3.2. Data Analysis

Table 2, before processing the target center’s gray value is 0.3922, and its surrounding background’s gray value is about 0.494, the difference of them is about 0.1018, just like Fig. 4, the target and background is difficult to distinguish. After dealing with the deconvolution method, Table 3 shows the result, the target central point of the gray value become 0.6, most of the background and the inferential points are weakened to white or close to a white background, so the difference of them is about 0.4. Compared with Table 2, the new result has great improvement. Not only improve the difference between target and background, but also transfer complex background into white, makes the target easier to distinguish. From Table 3, it shows that the gray value of the eight pixels around the target center point is different from the white template. That means the surrounding eight points are part of the target, but just weaker than the target center. In Table 2, the gray values of surrounding eight points and the background have small disparity, after processing, the contrast between them increases and it’s also easy to find the boundary.

### 4. Results Analysis

#### 4.1 The Simulation Results

According to the image of row order, arranging the processed image, Fig. 7 shows the result.

From Fig. 8, it can clearly distinguish the target and background, and other inferential points are weakened on images, which will not have impact on the target's judgment. After processing, the target can also retain some gray value. The gray value of the target is known, and the original gray value is unknown, through the formula (2), (4), the initial gray value of target can be calculated. Using the obtained gray information will be very helpful for further research in the study of flight gesture.

In Fig. 2(a), treating the gray value as the Z axis, row and column as X axis, Y axis, we can set up a three-dimensional rendering, as shown in Fig. 8. Fig. 8(a) is the rendering of Fig. 2(a), while Fig. 8(b) is the rendering of Fig. 7(a).

From Fig. 7(a), the gray value of background has a very wide range and the target hides in background. Therefore, it is difficult to find out. After processing, as shows in Fig. 7(b), the image has a suddenly changing part which is obvious different from the other part, and the inferential point is very weak, it’ll not influence the judgment. We can find the target easily [16].

The experiment collects 30 different images, including complex background, simple background, big targets and small targets, close shot, and long-distant shot. These results show that the deconvolution method has greater accuracy and
better application in the target extraction. If we change the color of the template, or use a variety color combinations, the template that can acquire the different information of the whole image [17].

![Image](a) Target outdoor.

![Image](b) Indoor close shot target.

![Image](c) Indoor long-distant shot target.

**Fig. 7.** The final result after processing.

### 4.2. Comparison with Other Methods

Using two different methods for processing the Fig. 3 (a), Fig. 9 shows the result, Fig. 9 (a) uses Gradient method, and Fig. 9 (b) uses morphological processing combine with Threshold segmentation.

Fig. 9 (a), the Gradient method can only keep or remove the interferential point, but can not weaken the interferential point. Because the target’s gray value is very close to background, although the target has been found, but there are two interferential points exist which have impact on the judgment of the target [18].

From Table 3, showed that the camera capture 9 pixels of target. Fig. 9(b) uses morphological processing combine with Threshold segmentation. This method rules out the interferential point and finds the center of the target successfully, but it has 41 pixels which is much more than the actual number of pixels.

![Image](a) Gradient method processing

![Image](b) Morphological processing and threshold segmentation

**Fig. 9.** Gradient method and threshold segmentation dealing with the image.
Through a lot of experiments, we can find that in the processing of the target, especially in dealing with the small targets under complex background, the deconvolution method has showed its higher precision, can weaken some small and weak interference point, which is difficult to exclude. It'll be more conducive to the target's judgment.

5. Conclusion

With the machine vision systems more widely, moving target detection and extraction problems become a research hotspot.

In this paper, the author takes practical engineering as background, analyzes the traditional extraction method of high speed target, combines the theory of signal detection, and puts forward a new method of deconvolution normalization. Through the processing of actual collected target image and the comparison with the traditional image processing method, the results show that the method is more accurate, less sensitive to noise, more adaptable and spending less time on communications. Moreover, this method can be applied in some practical occasions with higher requirements, and it is a more prospect method.

References


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