An automatic target detection algorithm based on wavelet analysis for infrared image small target in background of sea and sky

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ABSTRACT

An automatic target detection algorithm is developed for infrared image small target in complicate background of sea and sky. Wavelet multiresolution edge detection algorithm is adopted to detect the sea-level line from coarse to fine. A strip can be decided accordingly as the potential area where the naval vessel targets in infrared images usually appear. We realized target detection by defining an energy function that integrated the results of horizontal wavelet transform. We complete the detection by marking the position where the energy is assumed the maximum and improving the target location precision by comparing the dissimilarity between a couple of windows. Experiment results indicate that the method can detect and locate small targets precisely in an infrared image with high detection probability.

Keywords: image recognition ; automatic target detection ; wavelet multiresolution analysis ; edge detection ; sea-level line

1. INTRODUCTION

Target detection and location in infrared clutter background is very important to Infrared Search and Track (IRST) system. For small target detection in infrared image in background of sea and sky, there is no geometric and structure character to use. We notice that targets such as ships and naval vessels sailing at long distance always appear around the sea-level line, and they are mixed with clouds and waves clutter. It is difficult to segmentation and location precisely, and high false alarm rate would be gotten if general approaches were adopted at this circumstance.

In this paper, an automatic target detection algorithm is developed for infrared image small target in complex background of sea and sky. Making use of the prior knowledge that targets always appear around the sea-level line, we first detect the sea-level line and then set up the line equation to locate it. Here wavelet multiresolution edge detection algorithm is adopted to detect the sea-level line from coarse to fine. A strip can be decided accordingly as the potential area where the naval vessel targets in infrared images usually appear. The target detection is restricted in the potential area, which occupies a relatively small area compared with the whole image, so the searching area is reduced and the speed of detection can be increased markedly. On the other hand, the smaller searching area can reduced the disturbance of the background of clouds and waves clutter efficiently, As a result, high detection probability can be achieved.

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2. WAVELET MULTIRESOLUTION EDGE DETECTION ALGORITHM

The basic idea of the small target detection algorithm is from the location of the sea-level line, and then the row region in the image can be decided which is called potential target area. To find the sea-level line is through edge detection of the image. Edge detection is an important low-level vision problem. In a general way, edges can be considered as transients in image, they occur at the location where there is a large variation in intensity between adjacent pixels. In mathematical terms, the edges are located at the points with the highest first derivative and zero-crossing second derivative. However, significant intensity change in an image generally occur at different resolution just as the brain processes visual information at various scales.

The wavelet transform has the advantages of local analysis in spatial and frequency domain Mallat proposed the multiscale edge detection method[1, 2], R.Rifaat[3] and other researcher[4,5,6,7] showed that using wavelet transform in edge detection had advantages of multiscale resolution, improved noise handling and edge direction information over other edge detection techniques. We realize edge detection by adopting wavelet transform, through choosing appropriate wavelet mother function, and searching for the local maximum to get the optimal edge.

Defining two wavelets which are the partial derivatives along x and y of a two-dimensional smoothing function $\theta(x,y)$ respectively:

$$\psi^1(x,y)=\frac{\partial\theta(x,y)}{\partial x} \quad \text{and} \quad \psi^2(x,y)=\frac{\partial\theta(x,y)}{\partial y} \tag{1}$$

Using $\psi^1(x,y)$ and $\psi^2(x,y)$ to construct two-dimensional wavelet function as:

$$\psi^1{}_{2^j}(x,y)=\frac{1}{2^{2j}}\psi^1\left(\frac{x}{2^j},\frac{y}{2^j}\right) \quad , \quad \psi^2{}_{2^j}(x,y)=\frac{1}{2^{2j}}\psi^2\left(\frac{x}{2^j},\frac{y}{2^j}\right) \tag{2}$$

a two dimensional discrete wavelet transform (DWT) is given as:

$$w^1{}_{2^j}f(x,y)=f*\psi^1{}_{2^j}(x,y) \quad , \quad w^2{}_{2^j}f(x,y)=f*\psi^2{}_{2^j}(x,y) \tag{3}$$

where $f(x,y)$ represents the image and $*$ indicates convolution. $\left[w^1{}_{2^j}f(x,y),w^2{}_{2^j}f(x,y)\right]_{j\in z}$ is a dyadic two-dimensional wavelet transform of image $f(x,y)$. One can easily prove that:

$$\begin{aligned} w^1{}_{2^j}f(x,y)&=2^j\frac{\partial}{\partial x}\left(f*\theta_{2^j}\right)(x,y) \\ w^2{}_{2^j}f(x,y)&=2^j\frac{\partial}{\partial y}\left(f*\theta_{2^j}\right)(x,y) \end{aligned} \tag{4}$$

So the two components of the wavelet transform can be interpreted as the corresponding edge information of the image in horizontal and vertical direction at scale 2^j. In order to combine the components, a modulus of the wavelet transform at scale 2^j is defined as:

$$M_{2^j} f(x,y) = \sqrt{\left|w^1{}_{2^j} f(x,y)\right|^2 + \left|w^2{}_{2^j} f(x,y)\right|^2} \tag{5}$$

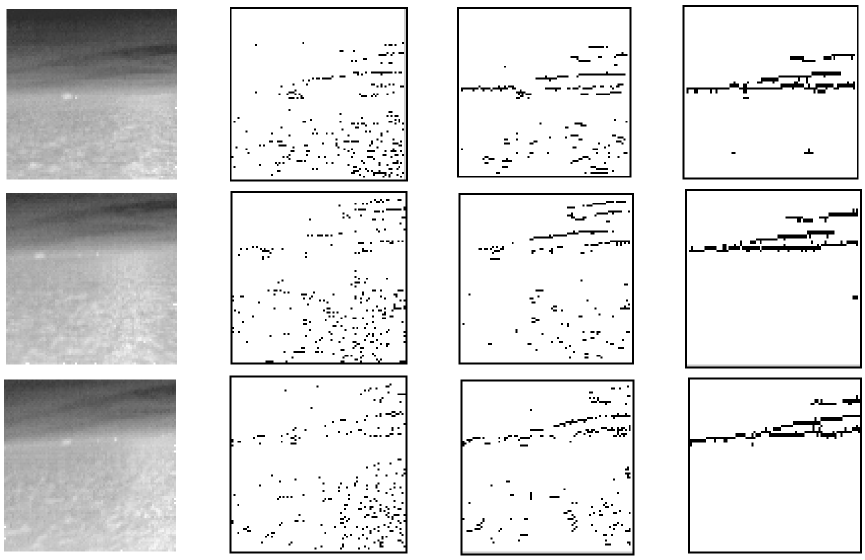
The angle of the edges can be determined by:

$$A_{2^j} f(x,y) = \arctan\left[\frac{w^2{}_{2^j} f(x,y)}{w^1{}_{2^j} f(x,y)}\right] \tag{6}$$

The gray transients of $f * \theta_{2^j}(x,y)$ is corresponding to the local maximum of the modulus $M_{2^j} f(x,y)$ along the gradient direction given by $A_{2^j} f(x,y)$. The positions of these maximum points buildup the edge of the image at 2^j scales.

According Mallat algorithm, a digital image can be decomposed into several approximations and details at different directions through two *quadrature mirror* filters which include a low-pass filter *H* and high-pass filter *G*, so the process of wavelet decomposition have the effect of denoising. On the other hand, the subband decomposition obtained by wavelets transformation allows for the more modification of edge details at various scales.

A low contrast infrared image usually shows blurring edges and severe noise. The influence of the noise would result in the discontinuity and branching out of detected edges. So it is difficult to detect true edges accurately by using single scale through general edge detection techniques. However, the wavelet transform has the advantage for edge detection that the edges are not distorted in decomposed images at large scales while the discontinuities caused by the noise avoided.



(a) (b) (c) (d)

(a) Original image (b) Edge images at 2^1 scale (c) Edge images at 2^2 scale (c) Edge images at 2^2 scale (d) Edge images at 2^3 scale

Fig.1 Edge detection at different scales

An edge detection result of three infrared images using wavelet multiresolution algorithm at three scales is shown in Fig.1. It can be seen that the edges are the clearest with least noise at 2^3 scale, and the detection of the sea-level line is feasible.

There are several kinds of wavelet functions, such as Dubble wavelet, Daubecies wavelet and Mordrlet wavelet etc, and they have different shapes and peculiarities. For edge detection, the result would be better if the change tendency is similar to the shape of the wavelet function which is chosen. Here Battle-Lemarie wavelet is adopted, and the coefficients of corresponding low-pass filter *H* and high-pass filter *G* is shown in Tab.1.

Tab.1 Coefficients of wavelet filters

n	-3	-2	-1	0	1	2	3	4
H	0.0000	0.0625	0.2500	0.3750	0.2500	0.0625	0.0000	0.0000
G	-0.00008	-0.01643	-0.10872	-0.59261	0.59261	0.10872	0.01643	0.00008

3. THE TARGET DETECTION ALGORITHM

The flow chart of the target detection algorithm is shown in Fig.2. After preprocessing such as cropping in dimension to make the image is appropriate in size, the image is decomposed into several approximations and details at different directions channels using Mallat algorithm. Wavelet multiresolution edge detection algorithm is adopted to find the sea-level line as description in section 2. Meanwhile, a new image is produced by defining energy function that integrated the results of horizontal wavelet transform which is called mutual wavelet energy combination. Then the line equation of the sea-level line is set up and a strip can be decided accordingly. Target detection is completed by marking the position where the energy is assumed the maximum and improving the target location precision by comparing the dissimilarity between a couple of windows in the strip of the mutual wavelet energy combination image.

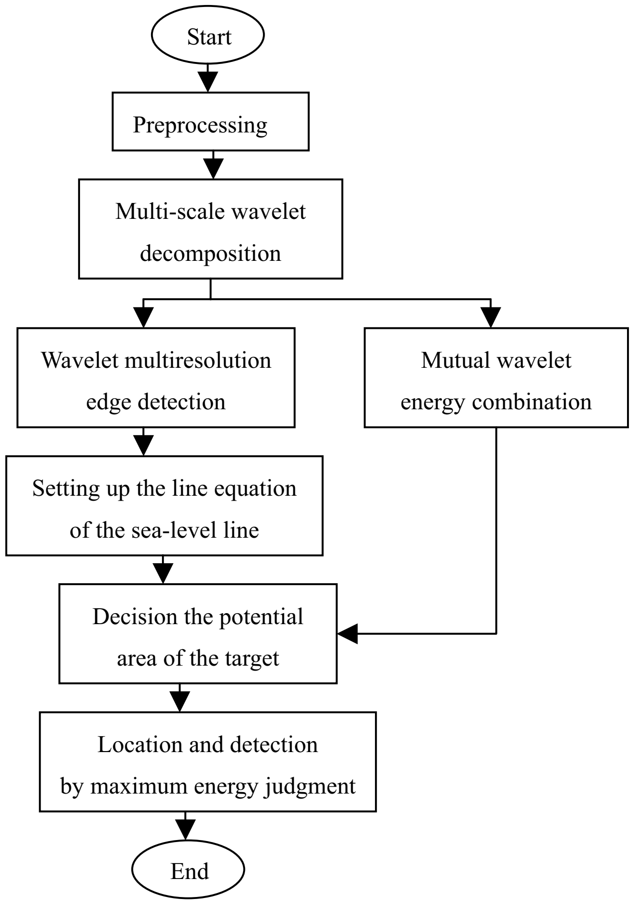


Fig.2 The flow chart of the detection algorithm

3.1 The line equation establishment of the sea-level line

The analysis of section 2 indicates that it is difficult to find the sea-level line in the original image through general edge detection techniques, so wavelet multiresolution edge detection algorithm is adopted. The reliability of edge recognition is enhanced at large scale, but the precision of edge location is debased. However, the aim of edge detection here is to find the location of the sea-level line, and some fine edge details is not needed. So the edges is detected at large scales to decide the approximate position of the sea-level line, then from large to small scale also called from coarse to fine, the sea-level line is detected precisely in the original image.

As shown in Fig.1, the sea-level line is comparatively clear in the edge image at scale of 2^3, but the edge may be a part of the sea-level line and not a whole one. Sometimes there are several edges, and we should decide which one is the sea-level line. Here we proposed a method by measuring the maximum connection to find the longest line which is regarded as the sea-level line. In the binary edge image at scale of 2^3 (2^j), all the pixels are sorted into groups by a proper gathering rule of 8-neighbor connection. The pixels in the group who possesses the maximum size can be considered as points of the sea-level line at scale of 2^3 (2^j). According to the duplation between scales of 2^j and 2^{j-1}, getting coordinates of a series points of the sea-level line in the image at scale of 2^{j-1}. Finally, coordinates of a series point of the sea-level line can be obtained in the original image. We adopt the least-square fitting method to set up the line equation of the sea-level line using these points. Suppose the coordinates of the series point are $(x_1, y_1),(x_2, y_2),\ldots,(x_n, y_n)$, and using the formula of $y = ax + b$ to fit the line. According to the principle of the least-square error, the fitting error of each point is e_i $(i = 1,2,\cdots,n)$, and $e_i = ax_i + b - y_i$. The square sum of the error E is: $E = \sum_{i=1}^{n}(ax_i + b - y_i)^2$. In order to make E the minimum, the following formula should come into existence:

$$\frac{\partial E}{\partial a} = \frac{\partial E}{\partial b} = 0 \tag{7}$$

so

$$\begin{aligned} \frac{\partial E}{\partial a} &= 2\sum_{i=1}^{n}(ax_i + b - y_i)\cdot x_i = 0 \\ \frac{\partial E}{\partial b} &= 2\sum_{i=1}^{n}(ax_i + b - y_i) = 0 \end{aligned} \tag{8}$$

It is easy to get the solution of formula (8):

$$\begin{aligned} a &= \frac{\sum_{i=1}^{n} x_i y_i - \sum_{i=1}^{n} x_i \sum_{i=1}^{n} y_i}{\sum_{i=1}^{n} x_i^2 - \frac{1}{n}\left(\sum_{i=1}^{n} x_i\right)^2} \\ b &= \frac{\sum_{i=1}^{n} y_i - a\sum_{i=1}^{n} x_i}{n} \end{aligned} \tag{9}$$

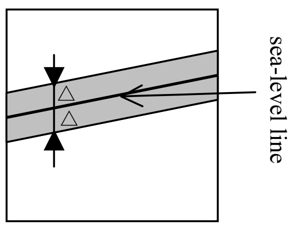


Fig.3 Sketch map of the potential target area
Note: The gray color area is the potential target area

So far, the line equation of the sea-level line has been set up.

Two parallel lines in the distance of Δ from the sea-level line respectively can be drawn as shown in Fig.3, and location of the potential target area is decided as the strip between the two lines.

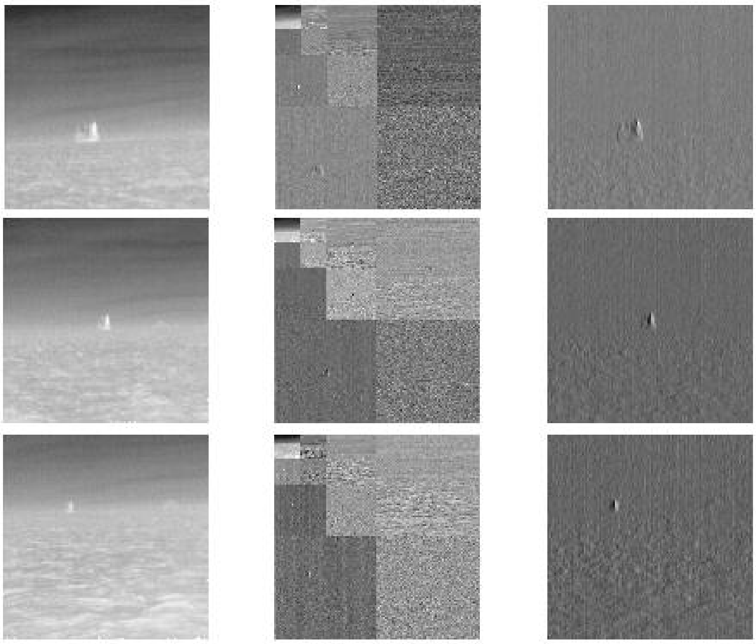
3.2 Mutual Wavelet Energy Combination (*MWEC*)

In the image of small target in background of sea and sky, the sea-level line is generally a bright area with direction of horizon, and the target is in the area which is called potential target area. The location of target is within the potential target area. Simple method is using the accumulation of gray-level of all pixels in a slide window, but the false alarm rate is relatively high because of the influence of the background. In order to eliminate the influence of the gray-level distribution of the background, it is important to define a special function to stand out the target from the background. Here we make use the direction of wavelet decomposition, and define an energy function called Mutual Wavelet Energy Combination (*MWEC*) to integrate the results of horizontal wavelet transform.

The wavelet decompositions are realized using Mallat algorithm. The D_{j+1}^h, D_{j+1}^v and D_{j+1}^d are the detail of the original image in horizontal, vertical and diagonal directions respectively. Mutual Wavelet Energy Combination (*MWEC*) is defined as follows:

$$D_e = \mathrm{sgn}\{D_j\} \times \left|D_j^h\right| \times \left|D_{j+1}^h\right| \tag{10}$$

$\mathrm{sgn}\{\ \}$ is the sign of the function, $\left|D_j^h\right|$ is the detail image of horizontal direction. *MWEC* can remove the non-correlative noise in the clutter, and make use of the direction to intensify the edge of target. The effect of *MWEC* is shown in Fig.4.



(a) (b) (c)

(a) Original image (b) Three times decomposition images using Mallat algorithm (c) *MWEC* image

Fig.4 Effect of *MWEC*

3.3 Location and detection by maximum energy judgment

A maximum energy method is utilized to detect a target in the potential area in a *MWEC* image. In a slide window of size $M \times N$ for every pixel in the potential target area, the judgment energy function is constructed as follows:

$$E = \frac{1}{M \times N} \sum_{i,j \in (M \times N)} \left| D_e(i,j) \right| \tag{11}$$

$\left| D_e(i,j) \right|$ is the gray value of pixel (i,j) in the potential target area of *MWEC* image. The position of pixel with maximum E is assumed as the center point of the target.

We use a couple of windows to find the maximum dissimilarity to decide the size of the target. The outer window and inner one indicate the target and the clutter respectively, as shown in Fig.5. Suppose that the size of outer window is the maximum dimension of the targets, it is a changeless value. The size of inner window is changed, the dissimilarity function to decide the size of target is defined as follows:

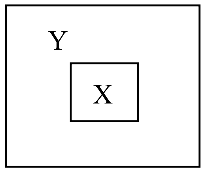


Fig.5 A couple of windows

$$\Delta E_{\max} = \max \left\{ \Delta E \middle| \Delta E = \frac{1}{N_Y} \sum_{(i,j) \in Y} \left| D_e(i,j) \right| - \frac{1}{N_X} \sum_{(i,j) \in X} \left| D_e(i,j) \right| \right\} \tag{12}$$

Where N_Y and N_X are the number of pixels in the outer window and the inner window respectively, N_X is considered as the size of the target when $\Delta E = \Delta E_{\max}$. So far, both the location and the size decision of the target can be obtained.

4. EXPERIMENTAL RESULTS

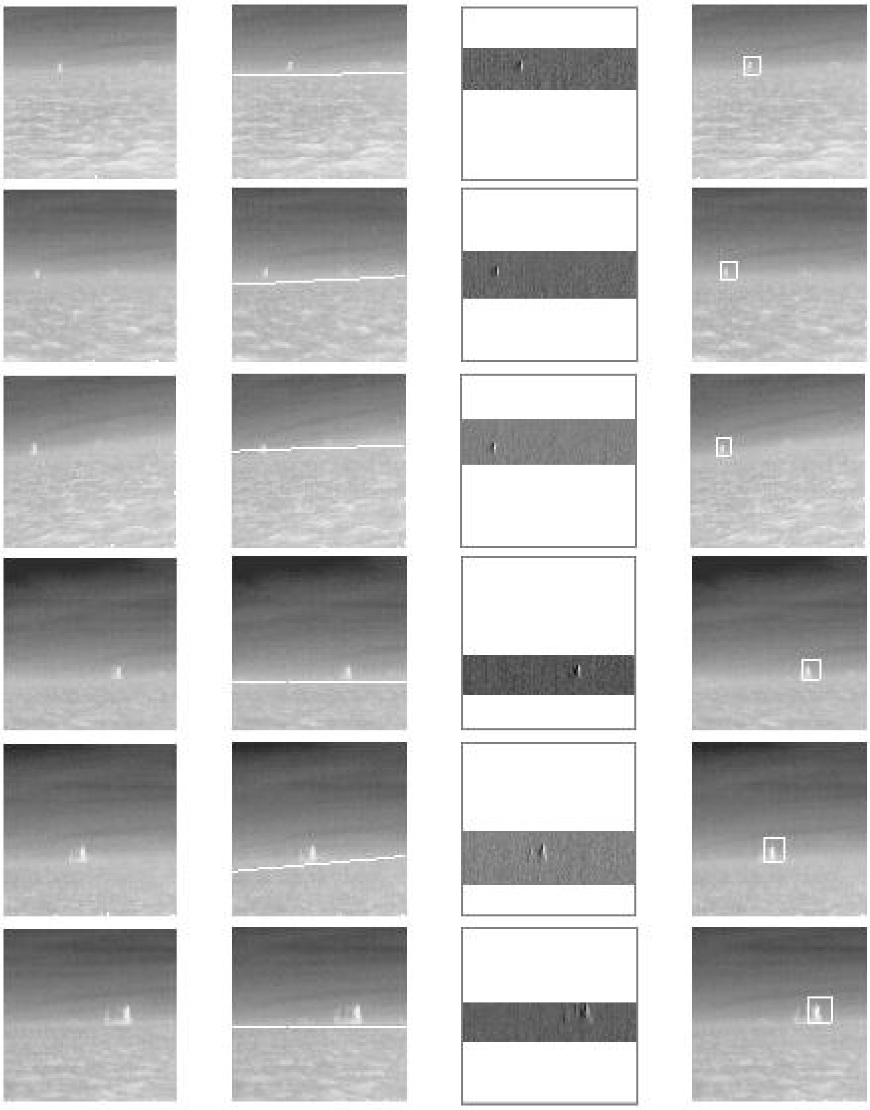
In this section, we present results of small targets detection in infrared images of sea and sky background using the target detection algorithm proposed above. Targets are naval vessels sailing at long distances in cluttered clouds and waves, the sizes of targets vary from 3×3 to 40×40 pixels in the image, with the original size 576×768. 600 images were used to verify the algorithm.

4.1 Location of the sea-level line and potential target area

Location of sea-level line is very important because it decides the potential target area. If the location of sea-level line is a wrong position in the image, it would cause a false detection result. In an infrared image in low contrast between targets and background with blurring edges and severe noise, it is difficult to detect the sea-level line correctly by other general edge detection algorithms, however, wavelet multiresolution edge detection algorithm is very effective. As shown in Fig.6 (b)(c), the sea-level line is located correctly in most occasions. When a slant line occurs, the width of the strip of potential target area is enlarged correspondingly to ensure the target is included in it. In the all 600 experimental images, there are only 5 trials whose sea-level line were wrongly located and the potential target areas failed to include the targets.

4.2 Position and size of the target

In the potential target area of *MWEC* image, as shown in Fig.6(c), the clutter of sea-wave can be eliminated efficiently and the target is distinct from the background. The position of the target is detected using maximum energy method. In the 600 images, success probability is above 97% for single frame, and target sizes are approximately true. As shown in Fig.6(d), white rectangles indicate positions and sizes of targets in images.



(a) (b) (c) (d)

(a) Original image (b) Location of the sea-level line (c) Potential target area in *MWEC* image (d) Target label in image

Fig.6 Part images of experimental result

5. SUMMARY

In this paper we have presented an automatic target detection algorithm for small target in background of sea and sky. Wavelet multiresolution edge detection algorithm with ability of noise handling is adopted to detect the sea-level line. We propose a method of measuring the maximum connection to find the longest line, and the least-square fitting method are used to establish the line equation. The result shows that the method can detect and location the sea-level line effectively and correctly in a low contrast infrared image.

We also propose a method for eliminating the disturbing of clutter, through defining an energy function called Mutual Wavelet Energy Combination (*MWEC*). According to the location of sea-level line in *MWEC* image, potential target area is decided. As the area only occupies a small part of original image, searching area is reduced and the detection speed can be advanced. We complete the detection by marking the position where the energy is assumed the maximum and calculating the size of a target by comparing the dissimilarity between a couple of windows. Experiment results indicate that the method can detect and locate a small target precisely for single frame with high detection probability.

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