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Application of Wavelet Analysis in Detecting Runway Foreign Object Debris

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Abstrak

Foreign Object Debris (FOD) berbahaya bagi keselamatan pesawat. Dan adalah disarankan untuk menggunakan teknologi pemrosesan citra pada deteksi FOD. Tergantung pada sistem pengolahan citra, sebuah sub-sistem utama dalam sistem deteksi FOD di landasan pacu, citra FOD akan diamati secara efisien dan cepat dengan biaya ekonomis dan sangat akurasi dan reliabilitas. Makalah ini menganalisis karakteristik dan prinsip-prinsip algoritma transformasi wavelet dan menerapkan teori wavelet pada identifikasi dan deteksi FOD. Pengidentifikasian bentuk dan titik karakteristik penandaan FOD di landasan pacu pada kondisi latar visual yang buruk akan dicapai dengan pemrograman MATLAB menggunakan algoritma wavelet. Hasil penelitian menunjukkan bahwa skenario yang diusulkan dapat diterapkan. Itu juga secara signifikan untuk mewujudkan deteksi waktu-nyata pada FOD dan pengujian dengan fisibilitas dan efektifitas yang lebih.

***Keywords**: analisi Wavelet, Foreign Object Debris (FOD), penghilangan derau citra, deteksi batas, pengolahan citra*

Abstract

Foreign Object Debris (FOD) is dangerous for aircraft safety. And it can be suggested to use image processing technology on the FOD's detection. Depending on image processing system, a major sub-system in FOD detecting system on the runway, FOD image will be observed efficiently and rapidly with few economy costs and highly accuracy and reliability. The paper analyses the characteristics and principles of wavelet transformation algorithm and applies wavelet theory on FOD's identification and detection. Identifying the FOD's shape and marking characteristic point on the runway under poor visual background would be accomplished by programming in MATLAB using wavelet algorithm. The results show that the plan is applicable. Besides that, it brings about profound significance for realizing the real-time detecting on the FOD and testing with more feasibility and efficiency.

***Keywords**: Wavelet analysis, Foreign Object Debris (FOD), image de-noising, border detection, image processing*

1. Introduction

Foreign object debris (FOD) on the runway would damage aircrafts' engine, landing gear and many other components which will cause a lot of injury of people and huge loss for maintenance or flight-delay costs about 40 billion dollars (Figure 1). So, detection for FOD is a most significant aspect for flight safety. Effective and applicable methods about FOD clearing are gradually making the subject in aviation fields.

Popular Detection methods on FOD could be classified two categories: manual or intelligent. Traditional method in detecting FOD, especially small size things like rugby, depending on the humanity is inefficient and unbelievable under the worse weather or at night. Besides that, high density flight numbers degrades the possibility of human detection. Cameras and video systems used in modern FOD detecting devices are sensible to the weather environment and unavailable in low visibility. And also, interferences from series of noises in the image sampling and transmitting process increase the noises in the original image.So the paper gives an intelligent method for identifying the FOD using wavelet algrithm. Compared with the other methods, it could be more effective.

De-noising is necessary for bettering the original image. Algorithms of image de-noising are various in quantity but unsatisfing in application. Nowadays, a wavelet analysis method is

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coming on the scene which supplies a new way of image processing as its properties of multi-resolution in time domain and application in frequency domain. As a result, it will make an image of FOD identified better.

Figure 1. FOD's damage on aircraft

The paper makes full use of advantages of wavelets in image processing to transfer detected original image into a better one by programming in MATLAB tools to determine the type of the object, under normal or severe weather such as rain, snow or at night. FOD can be cleared easily combining image processing and object's positioning, and also, the method from the theory will be helpful for eliminating latent danger and ensuring landing safely by providing FODs' feature to ground maintenance workers.

2. The Proposed Method of Image Processing Model on the Runway

Runway Debris is an important form of Foreign Object Debris which contains several types such as damaged road and devices; components or units from aircraft; missed tools after maintenance; debris brought about from carriage and luggage of passenger, and sundries at turning corner of narrow runway, and so on.

The paper takes collected image under different environments as examples to determine debris' type after selecting suitable wavelet or wavelet packet to process original positioned image.

As is shown in the Figure2, procedure of FOD's image processing is similar to that of other images processing [1]. In the figure, image acquisition is used for pre-treatment of original. Image enhancement is for enhancing interested zone in Fourier transform, a mathematics algorithm in frequency domain. Image reconstruction is an objective handling method for a better image effect [2]. Colored image processing is the base of picking out image characteristics. Wavelet is the fundament of describing image under different resolutions. Image depressing will reduce storage space. Morphology can be used in extracting basic characteristics of image. Segmentation is helpful to identify the objects. The section of description and expression outputs the processed image by computer. Identification is the ultimate destination. With these segments, results can be matched with typical parameters of FOD in the database and FOD's identification and clearance can be realized.

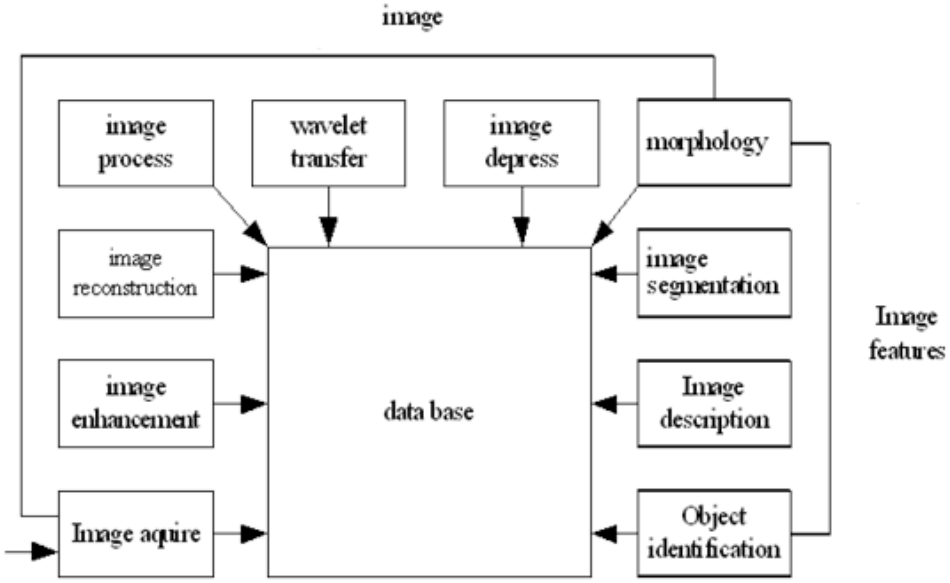

Figure 2. FOD image process procedure

3. Methods of Wavelet Analysis Algorithms

Wavelet has properties of multi-resolution and describes signals in both time domain and frequency domain as a tool of time-frequency analysis method [3]. That is to say, it has higher frequency resolution and lower time resolution in low frequency range, while it has opposite characteristics in high frequency range.

So, the wavelet method, like a microscope, is suitable to detect and display instant abnormal contains carried by original signals. In Figure 1, we can see that wavelet analysis is widely used in all links.

According to its function, wavelet transformation can be used in three main aspects: image depressing, image de-noising and features extraction [4].

3.1 2-Dimensional (2-D) Wavelet Transform

Coordinate of a point in an image can be described as (x,y) ,corresponding with a gray scale value f(x,y) of image. So, points' coordinate change continuously with a 2-D continuous signals f(x,y) and wavelet of one dimensional wavelet should be transformed into two dimensional wavelet [5].

Imagine that a 2-D basic wavelet can be defined as $\varphi(x_1, x_2)$. Scale factor, a, and displacement, from b1 to b2, can be stated as the following formula.

$$\varphi_{a;b1,b2}(x_1, x_2) = \frac{1}{a}\varphi(\frac{x_1 - b_1}{a}, \frac{x_2 - b_2}{a}) \tag{1}$$

Continuous wavelet transform formula:

$$WT_f(a; b_1, b_2) = \left\langle f(x_1, x_2), \varphi_{a;b1,b2}(x_1, x_2) \right\rangle = \frac{1}{a}\iint f(x_1, x_2)\varphi^*(\frac{x_1 - b_1}{a}, \frac{x_2 - b_2}{a})dx_1 dx_2 \tag{2}$$

2-D image scale flexibility is companied with image rotation, so a, the scale factor, can be transformed a Matrix, A, calculated in the following Matrix equation:

$$A = a r_0 \tag{3}$$

In the equation , r_0 can be called as rotation coefficient relavant to the image rotation angle θ , that is:

$$r_0 = \begin{bmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{bmatrix} \quad (4)$$

3.2 Image De-noising

Wavelet threshold can be used as an effective de-noising method. Comparing constants of different levels from decomposed wavelet, threshold will be a reference modifying these constants to reconstruct de-noised image [6].

Following equation can be built in 2-D multi-resolution:

$$V_{j-1}(x_1, x_2) = V_j(x_1, x_2) \oplus W_j(x_1, x_2) \quad (4)$$

In the above equation, $V_j(x_1, x_2)$ stands for 2-D space and $W_j(x_1, x_2)$ is for complementary subspace.

It can be supposed that $V_j(x_1,x_2)$ might be separated into two 1-D space, $V_j(x_1)$ and $V_j(x_2)$. It can be seen as the product of these two vectors.

$$V_{j-1}(x_1, x_2) = V_{j-1}(x_1) \otimes V_{j-1}(x_2) \quad (5)$$

And then:

$$W_{j-1}(x_1, x_2) = \left[V_j(x_1) \otimes W_j(x2)\right] \oplus \left[W_j(x_1) \otimes V_j(x2)\right] \oplus \left[W_j(x_1) \otimes W_j(x2)\right] \quad (6)$$

As is seen in (Eq. 6), $V_j(x_1, x_2)$ is a low scale space of image with smooth proximity and the three parts from $W_j(x_1, x_2)$ reflect the details of high pass or high frequency.

Therefore, image de-noising follows the three steps:

(1) 2-D signal decomposition in wavelet

Select a wavelet and its level number, j, after decomposition, if the image might be separated, to decompose original image f (x1, x2) into j levels.

(2) Threshold quantization of high-frequency coefficient

Select a threshold for every level (from 1 to j) to process the high-frequency coefficient of a certain level in soft threshold method.

(3) 2-D wavelet reconstruction

According to low-frequency coefficients and modified high-frequency coefficients (from 1 to j), image reconstruction can be realized.

As is shown in the Figure 3, the key of de-noising is to select right threshold to quantify.

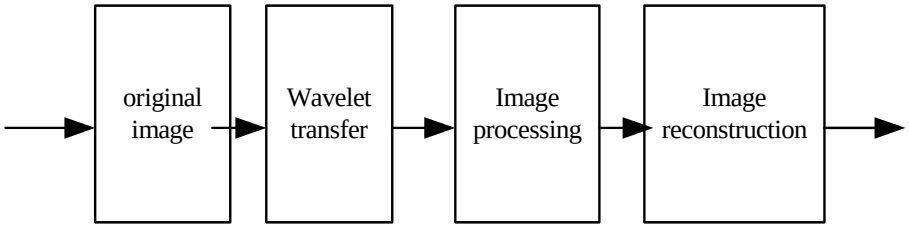

Figure 3. image de-noising procedure

Threshold function reflects typical processing and estimating method of wavelet decomposition in threshold de-noising.

It consists of soft threshold and hard threshold functions. Hard threshold function demonstrates characteristics of image border well but visual distortion phenomenon maybe inevitable, just like fake Gibbs effect. While soft threshold function is good at image smoothening but border effect might be disturbed obviously.

3.3 Image Edge Detection and Feature Extraction

Image border detection assists in determining differences between object and background, such as grey scale, color and veins to pick out FOD [7].

Multi-scale features of images after wavelet transfer can be obtained, and with these characters, image edge of different scales will be demonstrated using high-frequency product of decomposed wavelet [8]. It may be a newer idea to make border detection with multi-scale wavelet.

Image ,detailed as f (x1, x2) ,can be decomposed twice along different arises, x1 and x2.

At the first decomposition, 1-D scale function $\phi(x_1)$ and wavelet function $\varphi(x_1)$ is decomposed in x1 direction. So image generates two components. One is for smooth approximation and the other is details correspondently.

After the second decomposition of the smooth part and detail part, the two items are transformed into function $\phi(x_2)$ and $\varphi(x_2)$ along x2 direction. One is for scale and the other is for wavelet. As is shown in Figure 4.

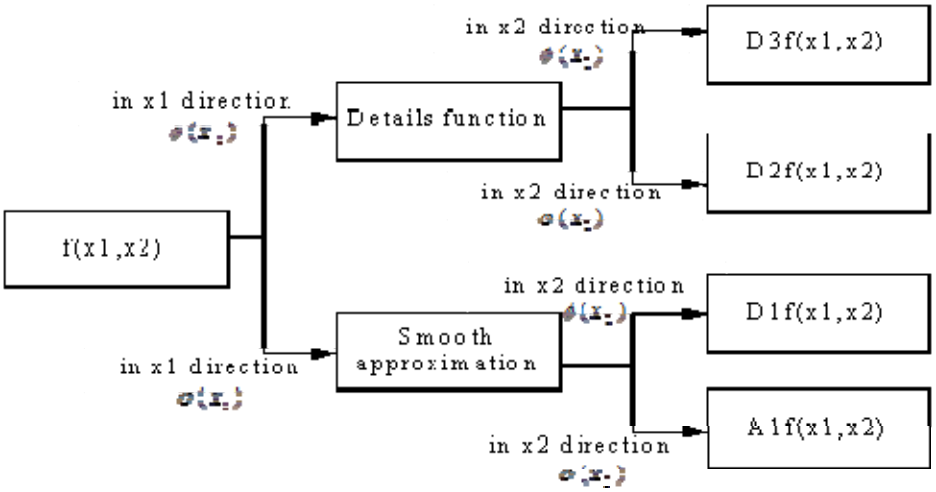

Figure 4. Edge Detection of Image and Feature Extraction

In this figure, $A1f(x1,x2)$ is for low frequency component and $D1f(x1,x2)$ is for horizontal low frequency component and vertical high frequency component. In the similar meaning, $D2f(x1,x2)$ is for horizontal high frequency component and vertical low frequency and $D3f(x1,x2)$ is for horizontal high frequency component and vertical high frequency component. So, image edge is detected by the four units.

Feature extraction follows wavelet transfer. Pick out image features in frequency domain by twice wavelet transfer and apply them into classifying the FOD image [9].

4. Results and Discussion

After de-noising and edge detecting with wavelet on a certain FOD on the runway, features of FOD can be drawn and simulated in MATLAB. Here is the simulation results about images acquired under poor visual background.

4.1 Image Processing Results in the Night

Visibility is poor in bad weather, such as in the rain, snow or at night, so FOD detection on the ground becomes important. Because problems of image clarity and edge are hard to solve in ordinary method [10], wavelet can be adopted to improve visual effect of image after decomposed into several levels. Original image at night and processed image are shown individually Firstly, load the original image, as shown in the Figure 5.

Secondly, apply smoothing filtering on image to reduce noises existing in high frequency band normally to make the image smooth [11], and then, utilize wavelet decomposition and extract the low frequency image from second level to reconstruct image according to the image edge. So, de-noising process is completed, just like that in Figure 6.

Figure 5. original image

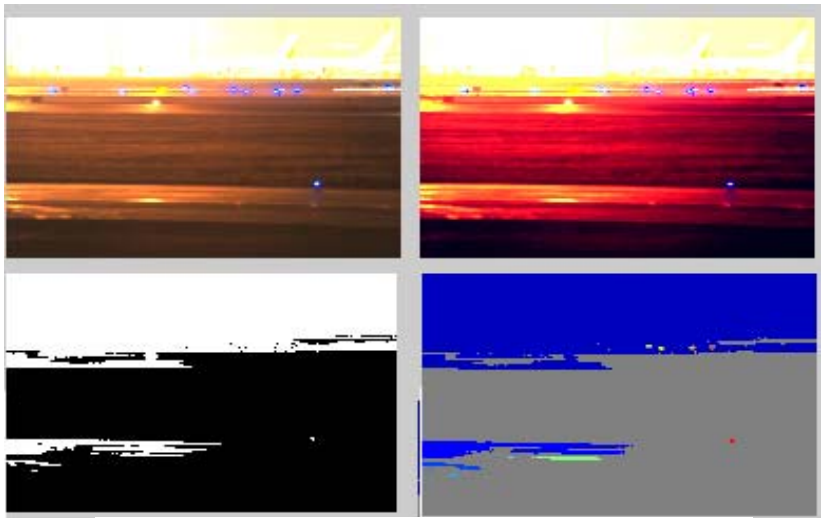

Figure 6. de-noised image and edge

Obviously, wavelet is applicable for image de-noising, especially big size objects under fine weather in the day though it is not more effective obviously than ordinary method of image processing [12].

4.2 Simulation Results Analysis

Besides the above image processing, we can mark edge line in white or any other color in original image. Using mathematic algorithm on metrics of round object, NAV-aid light and its' relative position to the runway edge could be determined in the image. The result details about the algorithm can be seen in Figure 7.

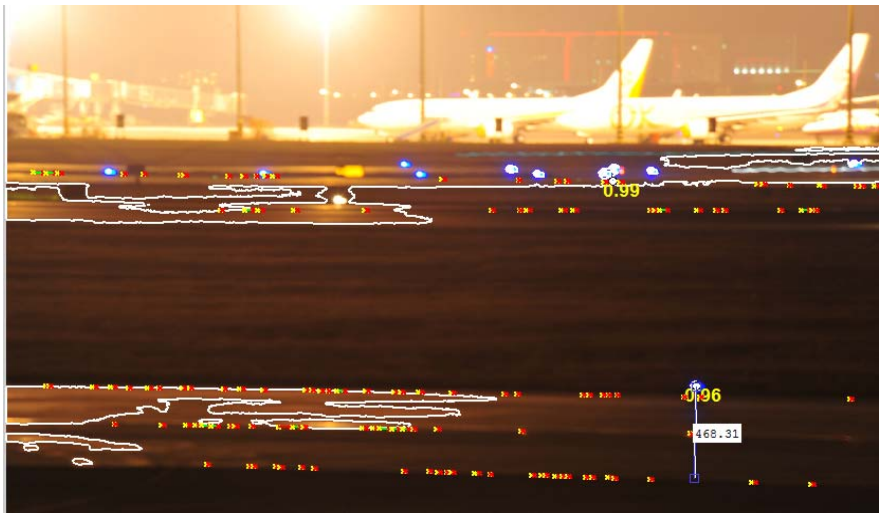

Figure 7. Result Details

As is shown in Figures 5-7, image contrast ratio is magnified and edge is distinguished clearly. Contrasting with original image, processed image is more helpful for maintenance finding and clearing debris.

In a word, processed images with wavelet verify that wavelet method has more extensive application whether in the severe environment, rainy or snowy, or not. Suitable wavelet and programs will improve image effect by de-noising, edge extraction and image reconstruction [13].

5. Conclusion

FOD detection on the runway consists of positioning and acquiring of debris. The paper describes local image processing method after FOD is positioned. But it will be more successful with selecting best wavelet and combined with experience to real image features [14]. Programming to an image with a certain background noise is another point to improve.

According to the experimental result recently, wavelet theory realizes realtime detection of FOD, especially in bad weather. And also, it is convenient and economical in use than any other methods and worthy to spread.

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