The Third Israeli Conference for Conveying and Handling of Particulate Solids
Joined with the Tenth International Freight Pipeline Society Symposium
Dead Sea, Israel, May 2000

PARTICLE SURFACE INSPECTION WITH FOURIER-WAVELETS TRANSFORM

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Abstract Defective parts between two particle surface images have been clearly extracted by means of Fourier-wavelets transform method without threshold values even though the two particles are differently located on a two-dimensional space. This concept is applicable to inferior products classification of a complicated image such as IC pattern. The method consists of two steps; the first is to acquire the difference between the two particle surface images in Fourier space. The second is to extract the feature of the difference image by means of wavelets transform and multiresolution. The low wavelets level indicates the whole image of the defective parts. The high level indicates the position and size of the defective parts. This technique contributes to automation of products classification.

1. INTRODUNCTION

Products surface inspection has been needed for inferior products classification in for example pharmaceutical industry, agriculture and semiconductor industry. Mainly, the inferior particles are produced as chipping, scratching and sticking tablets in the pharmaceutical process[1]. The normal system is only able to classify the inferior particles by means of image processing such as a threshold value method. A future system should be demanded extraction of the detailed defective position and size in pharmaceutical industry. Also, the system is better to be able to extract the defective position and size not only on the surface but also inside by a tomography method in order to multi-coated effective tablets and fragile sublingual tablet for old people. In the other field such as semiconductor industry, a system to extract the detailed defects is put to practical use. The basic concept of the system is a comparison between the standard image and the test image captured by a CCD camera on a two-dimensionally same location. In the case that the surface inspection system is applied to pharmaceutical products, there are two drawbacks to overcome, which are center fitting and extracting technique. In terms of center fitting, the software method is considered to fit the two particles to each center on the image; however, the method is only available to simple shaped particles. The hardware method is to fit both particle centers by a mechanical guide before capturing the images; however, this method is so hard to fit the two particles to the exact position. In terms of extracting technique, generally, after fitting to the center position, image processing such as magnification-reduction method and differential method with threshold values is carried out to extract the defective feature. But, the binarization by threshold needs many techniques[2] and is dependable on individuals.

This study focus on a development of a system to extract the defective position and size without threshold technique even though they have complicated images on a different location. The basic concept to achieve that is a combination of Fourier transform and wavelets transform.

Recently, wavelets transform has been popular for image processing instead of Fourier transform in computer graphics[3]. The analysis enables to decompose simultaneously time and frequency to extract peculiar points[4]. Our research group has been studying wavelets transform and industrial application. With regard to fluid engineering, Li displayed very different scale eddies, the breakdown of a large eddy and the successive branching of a large eddy structure in a plane turbulent jet [5]. The author applied the wavelet transform to analyzing eddy structure in a turbulent jet[6]. Saito applied this idea to analyzing the electromagnetic wave[7].

The originality of this paper lies in applying a combination of Fourier and wavelets transform to a surface inspection system. In this paper, pseudo particle images are processed by Fourier-wavelets transform to extract the defective feature to classify the inferior particles as a first step. Also, IEEE standard image is analyzed with the method.

2. FOURIER-WAVELETS TRANSFORM

The basic concept of Fourier-wavelets transform is composed of two steps which are a different part extraction by Fourier transform and a clarification by wavelets transform as shown in Fig.1. At the first step, a two-dimensional standard image matrix $\mathbf{X}_S$ and a test image matrix $\mathbf{X}_T$ are transformed to Fourier space images as,

$$\mathbf{S}_F = \mathbf{F}\mathbf{X}_S \qquad \mathbf{S}_{FT} = \mathbf{F}\mathbf{X}_T \qquad (1).$$

Where, **F** is Fourier transform matrix, $\mathbf{S}_F$ and $\mathbf{S}_{FT}$ are the absolute values of Fourier spectrum. The difference between $\mathbf{S}_F$ and $\mathbf{S}_{FT}$ are elementally multiplied to the test image in Fourier spectrum (* symbol in Eq.(2)). Next, the difference part in Fourier space changes to the real space **D** by inverse Fourier transform as

$$\mathbf{D} = \mathbf{F}^{-1}[(\mathbf{S}_F - \mathbf{S}_{FT}) * \mathbf{S}_{FT}] \qquad (2).$$

D indicates the difference part between the standard image and the test image in the real space; however, it is usually ambiguous in the case that the two images are differently located in the real space. The previous method to clarify the ambiguous difference image is to carry out the threshold value that is dependable on individuals and needs know-how to determine the exact value. The characteristic of this study's concept is to transform the ambiguous image with wavelets transform that is not dependable on individuals.

Two dimensional wavelets transform to **D** is expressed by

$$\mathbf{S} = \mathbf{W}\mathbf{D}\mathbf{W}^T \qquad (3).$$

S is a wavelets spectrum, **W** is an analyzing wavelets matrix, $\mathbf{W}^T$ is a transpose matrix of **W**. Because the wavelets transform is an orthonormal transform, the inverse wavelets transform and its multiresolution is expressed by

$$\mathbf{D} = \mathbf{W}^T\mathbf{S}\mathbf{W} = \mathbf{W}^T\mathbf{S}_0\mathbf{W} + \mathbf{W}^T\mathbf{S}_1\mathbf{W} + \mathbf{W}^T\mathbf{S}_2\mathbf{W} + \mathbf{W}^T\mathbf{S}_3\mathbf{W} + \mathbf{W}^T\mathbf{S}_4\mathbf{W} \qquad (4).$$

In the case of 30th Coifman function as the analyzing wavelets **W** and 256 X 256 pixel image, the difference image **D** is decomposed to five wavelets levels. In Eq.(4), the first term $\mathbf{W}^T\mathbf{S}_0\mathbf{W}$ is called Level 0 which shows the lowest space frequency, and the last term $\mathbf{W}^T\mathbf{S}_4\mathbf{W}$ is called Level 4 which shows the highest space frequency. The low level indicates the whole information of **D**, and the high level indicates the peculiar information of **D**. Fourier spectrum of the analyzing wavelets **W** is shown in Fig.2. The each level operates a kind of band pass filter.

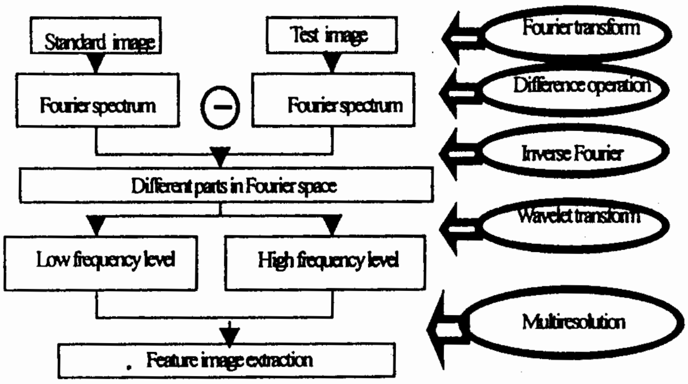


Fig. 1 Fourier-Wavelets Transform

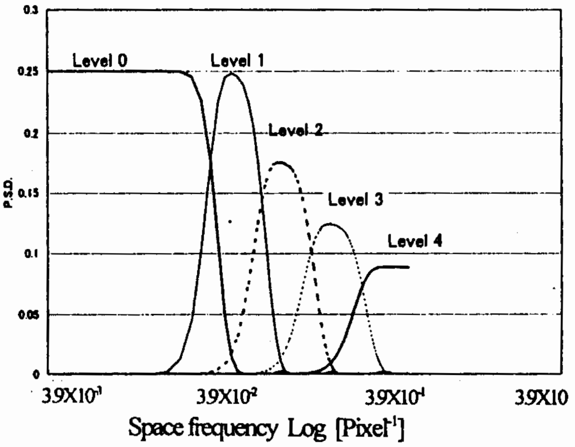


Fig. 2 Fourier spectrum on each level of 30th Coifman wavelets

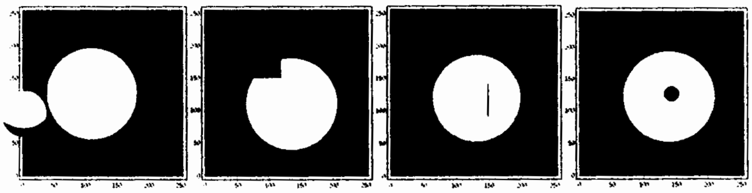
3. STANDARD IMAGE DATA & TEST IMAGE DATA

3.1 Simple Image

The concept is applied to simple images imitating particles and complicated images corresponding to IC patterns to test the feasibility. The pseudo particles images which are chipping, scratching and sticking are used as shown in Fig.3. All pseudo particles are located at the different place. Of course, it is easy to fit the centers between the standard image and the test image; however, these image is directly processed in order to apply the concept to complicated images. The whole images are 256 pixels X 256 pixels, and the diameter of the pseudo particles is 140 pixels The scratching is 2 pixels X 60 pixels, and the sticking is 20 pixels diameter. The white part is one and black part is zero in the digital image.

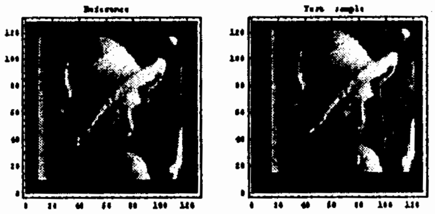
3.2 Complicated Image

Lena of IEEE standard image is used as the complicated image. The standard image has 10 blank pixels around the frame as shown in Fig.4 (a). The test image is moved to 5 pixels toward right up and it has a white small defective part at her shoulder as shown in Fig.4(b). Both images are normalized with a maximum value one and a minimum value zero. The defective part is found in the next section.



(a)Standard (b)Chipping (c)Scratching (d)Sticking

Fig.3 Standard image & test images of pseudo particles



(a)Standard image (b)Test image

Fig.4 Standard image & test image of complicated images

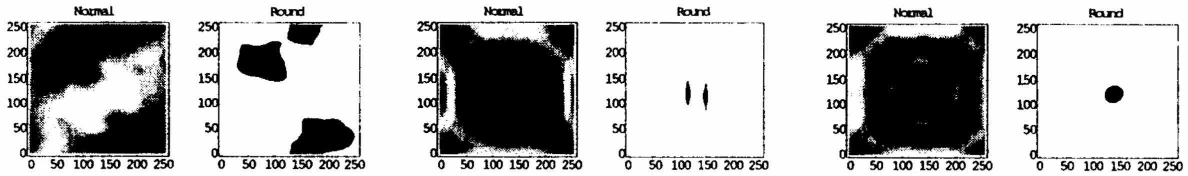
4. ANALYSIS & DISCUSSION

4.1 Simple Image

At the first step, Fourier transform are carried out between the test image and the standard image by Eqs.(1) and (2). Fig.5 (1) shows the difference image **D**, and Fig.5 (2) shows the round image binarizing Fig.5 (1) with a threshold value 0.5. The difference image **D** is normalized with a maximum value one and a minimum value zero. The round image less than 0.5 is black and that over 0.5 is white. From the Fourier image in Fig.5 (1), the defective points are so ambiguous. Even, the defective point on the binary image can not be accurately obtained except for the sticking. In Fig5 (a), the chipping point is extremely magnified. The two black specific parts at right and left sides are inevitable because of the absolute value of Fourier transform. Also, the width of scratching is thick and short as compared with the original image. The binary image of sticking is relatively accurate. It is realized that it is difficult to classify the defective point and size from the results of Fourier transform even though the image is processed with binarization..

At the second step, the difference image by Fourier transform in Fig.5 (1) is decomposed with the wavelets multiresolution. Fig.6 shows the lowest and the highest levels representatively. In Fig.6, the outside of the center circle area is painted with black as a window operation to make it clear. Level 0 is the lowest space frequency of **D** that shows a whole image, Level 4 is the highest space frequency that shows the sharp outline of the defective parts. The summation from Level 0 to Level 4 recovers completely to the original test image in Fig.3 because of the orthonormal transform. It is realized that the highest wavelets level indicates the edge of the Fourier transformed image. Then, this concept has the possibility to classify the defective point without threshold values.

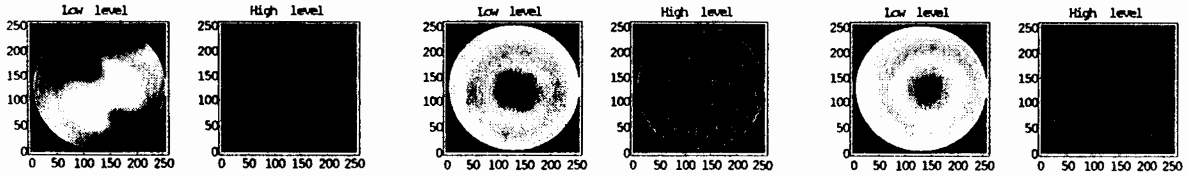
As a reference, the binary operation is carried out after normalizing Level 0 and Level 4 to clarify the different parts more as shown in Fig.7. In Fig.7 (a) and (b), the highest Level 4 shows more accurately the defective point and size. In Fig.7(c), the sticking is also indicate the defective point.



(1)Difference (2) Round (1) Difference (2)Round (1)Difference (2)Round

(a)Chipping (b)Scratching (c)Sticking

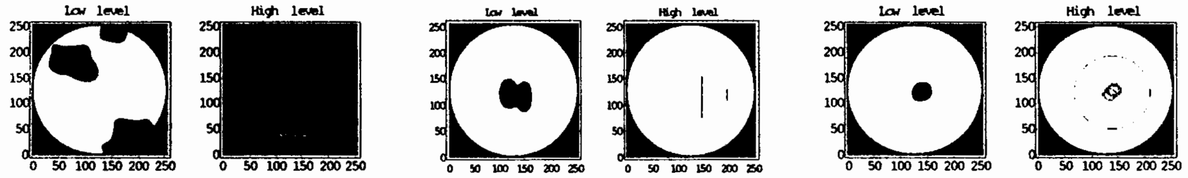
Fig.5 Difference of standard image and test image after Fourier transform



(1)Level 0 (2) Level 4 (1)Level 0 (2) Level 4 (1)Level 0 (2) Level 4

(a)Chipping (b)Scratching (c)Sticking

Fig.6 Multiresolution analysis of Wavelets transform



(1)Level 0 (2)Level 4 (1)Level 0 (2)Level 4 (1)Level 0 (2)Level 4

(a)Chipping (b)Scratching (c)Sticking

Fig.7 Binary image of Wavelets Levels 0 & 4

4.2 Complicated image

According to the analysis of the simple image, it has possibility to classify the defective point without threshold values by means of wavelets transform. The lowest level shows the whole defective part image and the highest level indicates the edge. The original image is transformed with Fourier-wavelets transform. Fig.8 shows the Fourier image of the original Lena image. It is possible to realize the defective part; however, that is so ambiguous. From the figure, the upper parts seems to be a defective parts. Next, the image is decomposed with wavelets multiresolution to show the lowest and highest levels as shown in Fig.9. The defective point is clearly realized without any binary operation in Fig.9(b). It means the it is possible to realize the different point without threshold values.

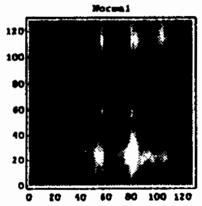
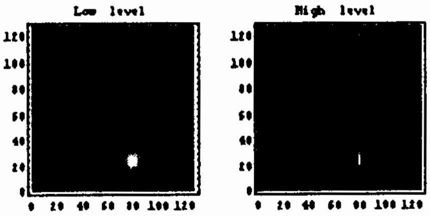


Fig.8 Defective parts of Lena by Fourier transform



(a)Lowest level (b)Highest level

Fig.9 Wavelets levels of Lena

4. CONCLUSIONS

Fourier-wavelets transform method is applied to obtain defective parts between two particle surface images. The followings are becomes clear.

1) It is possible to obtain the point and size clearly without threshold values even though the two particles are differently located on a two dimensional space. This is caused by the combination of Fourier transform and wavelets transform.
2) The defective part in a complicated image of IEEE standard image Lena is able to be realized clearly on a highest wavelet level. This concept is applicable to a complicated image such as IC pattern. This technique contributes to automation of surface inspection.

5. REFERENCES

[1]K.Toyoshima, Y.Ueda, Quantitative Evaluation of Tablet Sticking by Surface Roughness Measurement, *Int.J.Pharm.*, 46,211-215 (1988)

[2]Weszka,J.S., A Survey of Threshold Selection Techniques, *Comput. graph. image process.*, 7, 259- (1978)

[3]E.J.Stollnitz, T.D.DeRose, D.H.Salesin, Wavelets for Computer Graphics — Theory and applications, Morgan Kaufmann publishers Inc., San Francisco (1996)

[4]Molet,F., Wavelets Propagation and Sampling Theory, *Geophysics*, Vol.47,pp203-236 (1982)

[5]Li,H. and Nozaki,T., Wavelet Analysis for the Plane Turbulence Jet (Analysis of large eddy structure), *JSME International Journal Fluids and Thermal Engineering*, Vol.38, No.4 pp525-531 (1995)

[6]Li,H, Takei, M., Ochi, M., Saito, Y. and Horii, K., Application of Two-dimensional Orthogonal Wavelets to Multiresolution Image Analysis of a Turbulent Jet, Transactions of the Japan Society for Aeronautical and Space Sciences, Vol.42, No.137, pp120-127 (1999)

[7]Saito,Y., Wavelet Analysis for Computational Electromagnetics, (in Japanese), *Trans. IEE of Japan*, Vol. 116A, No10, pp833-839(1996)

6. ACKNOWLEDGMENT

The authors wish to thank Mr. Hiroshi UEDA of Taiho Pharmaceutical Co., Ltd in Japan for useful advice.