Scratches Detection of Optical Fiber Connector Based on Wavelet Packet and Machine Vision

Zhen Zhang

Zhengzhou Institute of Aeronautical Industry Management, Zhengzhou 450015, Henan, China

Fang Liu

Henan Medical College, Zhengzhou 451191, Henan, China

Abstract
The important meaning of the optical fiber connector scratches detection was introduced based on wavelet packet and machine vision. To detect the optical fiber connector scratches by using the UltraPAC system, aiming at the scratches feature, the method of analyzing and extracting the scratches eigenvalue by using wavelet packet analysis and pattern recognition by making use of the wavelet neural network is discussed. This method can realize to extract the interrelated information which can reflect optical fiber connector scratches feature from the ultrasonic information being detected and analysis it by the information. Construct the network model for realizing the qualitative scratches detection. The results of experiment show that the wavelet packet analysis adequately make use of the information in time-domain and in frequency-domain of the optical fiber connector scratches echo signal, multi-level partition the frequency bands and analyze the high-frequency part further which don't been subdivided by multi-resolution analysis, and choose the interrelated frequency bands to make it suited with signal spectrum. Thus, the time-frequency resolution is risen, the good local amplificatory property of the wavelet neural network and the study characteristic of multi-resolution analysis can achieve the higher accuracy rate of the qualitative classification of optical fiber connector scratches detection. Finally, the studies are described about detection method of the optical fiber connector scratches based on machine vision.
Key words: MACHINE VISION, OPTICAL FIBER CONNECTOR, SCRATCHES DETECTION, WAVELET PACKET

1. Introduction

Optical fiber connector, as the necessary equipment which connects two optical fibers, its surface scratches can make a head high loss when light signal that transmit in optical fiber through optical fiber connector and affect the performance of the optical fiber network. The traditional method of optical fiber connector surface scratches detection, mainly completed by artificially responsible for, has been unable to meet demand. In recent years, the system of product surface scratches detection based on machine vision technology by its fast detection speed, high precision, no damage, and many other advantages plays a more and more important role in the modern industrial automation production.

Optical fiber communication technology is a new technology with rapid development in recent 20 years, which is an important symbol of globe new technology revolution. With incessant perfecting technique and sharply falling price, the application of optical fiber become wide increasingly in communication field. The method of pattern recognition to optical fiber scratches based on machine vision will be analyzed and discussed in this paper.

2. Scratches detection and detection method

2.1 Scratches detection of optical fiber connector

The evaluation parameters of optical fiber quality include reflection loss, curvature radius, connection loss, dip angle migration, etc[1]. The connection loss is constituted mainly by intrinsic loss and fusion loss, which influence directly the transmission quality of optical fiber communication system. According to standard of ANSI/EIA/TIA-455-59, the maximum of luminous decay must less than 0.3dB in the project of FTTx. So classification and recognition of the optical fiber connector scratches is a significant problem to engineers.

2.2 Detection method and system

A great deal of information related to scratches feature can be acquired from the echo signal of optical fiber connectors through the ultrasonic detection, and the key of the classification of scratches realization lies in whether it can extract the information which reflect the feature of scratches character effectively and give the correct explanation. Because the ultrasonic echo signals have time-varying feature, which can't fulfill with condition of Fourier analysis in mathematics, it is difficult to gain the better spectrum, and the spectrum can't reflect the scratches feature in time-domain. The wavelet packet has the more refined local analyzing ability and suited to analyze the ultrasonic echo signals[2]. The wavelet neural network has more powerful abilities of approximate and fault-tolerant and the realized process is simpler. So if using it in the classification of scratches can get the good result. Choosing ultrasonic detecting signal of optical fiber connectors as the research object, use wavelet packet to extract the scratches feature signals and input it into the wavelet neural network for realizing the classification of scratches. The results showed that this method has good effect in the scratches recognition of optical fiber connector scratches.

In this experiment the material for producing the scratches sample is 62.5/125μm single-mode fiber, and the scratches mode is operation by optical fiber connector. The hardware of the experiment system constitutes with computer system, ultrasonic detector, A/D sample card, etc. And under supporting of the application software, which can complete the missions, such as the echo signal acquisition, scratches wave feature extraction and pattern classification of wavelet neural network etc, as the Figure 1 show.

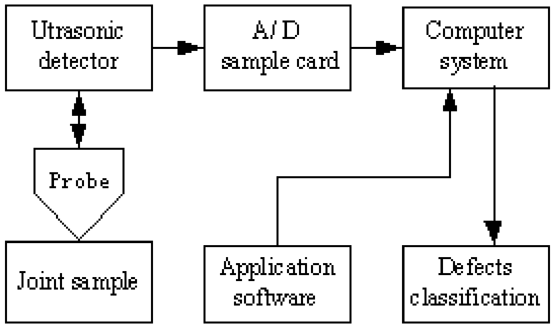

Figure 1. Detection system of scratches

3. Extraction of space feature by wavelet packet

The wavelet decomposition can only decompose further the low-frequency information and cannot decompose the high-frequency information, which make the high-frequency information cannot be use and information extracting cannot get enough. So the information decomposition is completed by wavelet packet in high-frequency bands. The differentia between wavelet packet decomposition and wavelet decomposition is that wavelet packet decomposition equal to use a low-pass filter and a high-pass filter at the same time.

The wavelet packet analysis can provide a more refined analysis method, which can multi-level partition the frequency bands and analyze the high-frequency part further which don't been subdivided by multi-resolution analysis, and choose the interrelated frequency bands to make it suited with signal spectrum. The time-frequency resolution is rising. Thus, discussing to this experiment, we can decompose the signal subtly by wavelet packet, and realize the recognition of the scratches. This paper use the pattern recognition method based on energy- defect [3].

Connector scratches signals in wavelet packet express with the distinct energy distributing changing in wavelet subspace. The signal j order wavelet packet transform can get wavelet packet coefficients $coef_{j,k}^{m}$, m=1, 2, … 2^j is the number of the wavelet tree nodes which getting after decomposing, and k is the location parameter under the wavelet packet subspace of 2^j scale. After decomposing the wavelet coefficients of N frequency bands constitute N subspaces, denoted as $A_{j,n}$, and the signal energy of each subspaces is

$$E_{j,m} = \sum_{k} (coef_{j,k}^{m})^2 \tag{1}$$

Constructing feature vector by using energy as element

$$F(m) = [E_{j,0}, E_{j,1}, E_{j,2}, \cdots, E_{j,m}] \quad (2)$$

Normalizing the eigenvector $E = \sum_m E_{j,m}$ is

$$F(m)' = [E_{j,0}/E, E_{j,1}/E, E_{j,2}/E, \cdots, E_{j,m}/E] \quad (3)$$

$F(m)'$ is feature space being extended after normalizing the eigenvector.

Researching from frequency-domain, if regard the highest frequency composition within original signal as 1, the wavelet packet decomposition is decomposing signal with different frequency bands evenly into several windows, and each decomposed results corresponds signal information in the frequency bands. Table1 express frequency bands partition of the 3 layers wavelet packet decomposition in the experiment. Because sample frequency of ultrasonic signal is 100 MHz, the scope of frequency band is 0~50 MHz in wavelet packet decomposition.

Table 1. Frequency band of wavelet package decomposition

Wavelet packet subspace	Frequency bands (MHz)
S(3,0)	0.000 ~ 6.250
S(3,1)	6.250 ~ 12.500
S(3,2)	12.500 ~ 18.750
S(3,3)	18.750 ~ 25.000
S(3,4)	25.000 ~ 31.250
S(3,5)	31.250 ~ 37.500
S(3,6)	37.500 ~ 43.750
S(3,7)	43.750 ~ 50.000

4. Pattern recognition based on wavelet neural network

Wavelet neural network is a kind of neural network based on wavelet analysis, which make use of the good local localized character of the wavelet transform and combine the self-learning function of neural network [4]. So wavelet neural network has more powerful abilities of approximate and fault-tolerant and the realized process is simpler. In this experiment we choose the discrete orthogonal wavelet network which is evolved from radial basis function, and its construction according to discrete wavelet transform theory as: select basis wavelet function $\varphi(x) = L^2(R)$, $\phi(\omega)$ is $\phi(x)$ Fourier transform, and suffice admissible condition:

$$\int_R \omega^{-1} \left|\phi(\omega)\right|^2 d\omega < \infty \quad (4)$$

The wavelet function system $\{\varphi_{a,b}(x)\}$ can be achieved after using scale transformation and translation transform to $\phi(x)$,

$$\psi_{a,b}(x) = a^{-1/2}\phi\left(\frac{x-b}{a}\right) \quad (a,b) \in Z^2 \quad (5)$$

In the formula, a is scale parameter, b is translation transform. To arbitrary function $f(x)$, its definition of continuous wavelet transform is

$$W_f(a,b) = \int_0^{+\infty} \psi_{a,b}(x) f(x) dx \quad (6)$$

Ordering $a = 2^j$, $b = 2^j k$, $j, k \in Z$, so binary discrete wavelet function is

$$\psi_{j,k} = 2^{-j/2}\psi(2^{-j}x - k) \quad (7)$$

The function $f(x)$ fits with coefficient $C_{i,j}$ as

$$f(x) = \sum_{j\in Z}\sum_{k\in Z} C_{i,j}\psi_{j,k}(x) \quad (8)$$

According to feature of optical fiber connector scratches signal, select Morlet decompose wavelet which used to detect the signal singularity at first, as

$$\varphi(x) = \exp(-x^2/2)\cos(1.75x) \quad (9)$$

For constructing the orthogonal basis of Hilbert space, the scale coefficient sequence $\{h_n\}$ and wavelet coefficient sequence $\{g_n\}$ are confirmed by the construction condition of compactly supported wavelet. Knowing from wavelet theory, when scale coefficient j is large enough, the feed-forward network, which includes one hidden layer can approximate a nonlinear mapping with arbitrary function. So we make use of three layers wavelet network in this experiment.

5. Recognition of defect wave characteristic

5.1 Ultrasonic detection of optical fiber connector

The ultrasonic flaw detector adopting in experiment is the ultrasonic feature and imaging system made in Physical Acoustics Corporation of USA. UltraPAC system is ultrasonic scanning imaging system of integrative computer and digitization, which is constituted by following few parts: the ultrasonic signal collecting hardware, dipping scanning support and actions control hardware, data collecting software, the system controller, ultrasonic sensor and attachments etc[5]. The signal of upper surface and nether surface, which are detected along the direction of ultrasonic detecting, are eliminated from the collecting signals. These signals are analyzed after its length change into 128 though symmetrical spread process. The wave-shape of scratches ultrasonic signal after processing showed as Figure 2, 3 and 4.

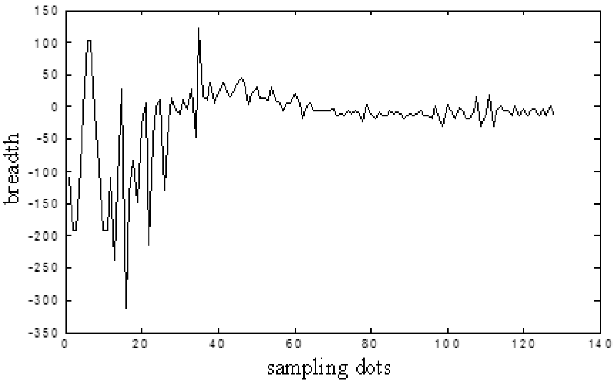

Figure 2. Waveshape of non-scratches signal

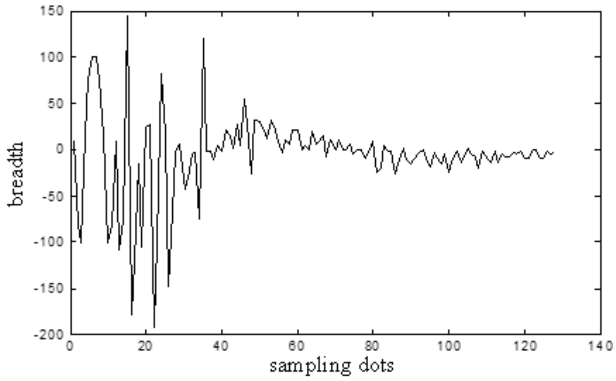

Figure 3. Waveshape of low scratches signal

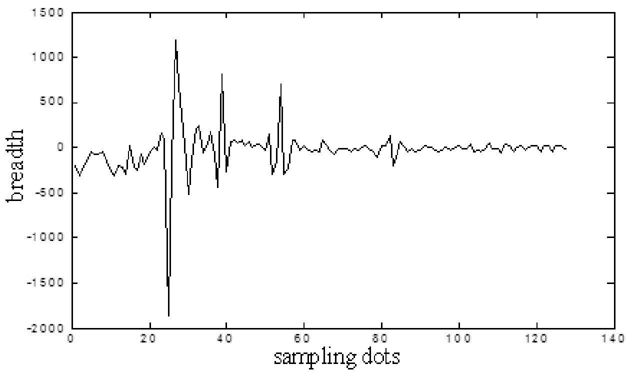

Figure 4. Waveshape of high scratches signal

5.2 Wavelet packet decomposing

According to the pattern recognition method of energy- defect, the scratches ultrasonic signals from detecting are carried on decomposing of 3 layers wavelet packet firstly, extracting respectively characteristic signals of the third layer is from 8 frequency bands between low frequency part and high frequency part. The characteristic extraction of scratches signal and non-scratches signal were shown as Figure 5, 6.

Reconstructing wavelet packet decomposition coefficient of the third frequency band, after extracting the time-domain signal, the total energy of the optical fiber connector can be gained and construct eigenvector finally. After wavelet transform, the reconstruction signals of each frequency parts, eigenvector of non-scratches, low scratches and high scratches were shown in Table 2, 3 and 4.

5.3 Pattern recognition result

Each scratches echo acquired by ultrasonic detecting was a sample, and total 36 samples. Extracting characters by using energy change of every frequency parts, which is input mode vector of wavelet neural network. In the 42 signals 14 signals are non-scratches signal, 14 signals are low scratches signal and the other 14 signals are high scratches signal. These signals are separated random two parts, one part of which with 21 samples makes use of exercising network and the other one part 21 signals make use of network capability testing. In this research, the input layer contains 8 neurons which represent 8 eigenvalues. The output layer contains 3 neurons which represent 3 output variables Y1, Y2 and Y3. Scale value of each output variable only can be 0 of 1, 3 output variables have 3 scale value combinations which represent 3 scratches conditions, such as (1,0,0) representing non-scratches, (0,1,0) representing low scratches and (0,0,1) representing high scratches. The number of hidden layer nodes is 15 after confirming finally.

Knowing from the upper figures, the error convergence curves can be approximated to 0.001 after 2200, 1300 and 1200 training cycles about, and rather approximate the ideal output mode, which have memory function and can use for testing. The recognition results of testing sample are 28 scratches samples being recognized all. Knowing from confirming result, the defeat network constructing in this research have good classification effect and can complete to test the type of unknown optical fiber scratches signals[6].

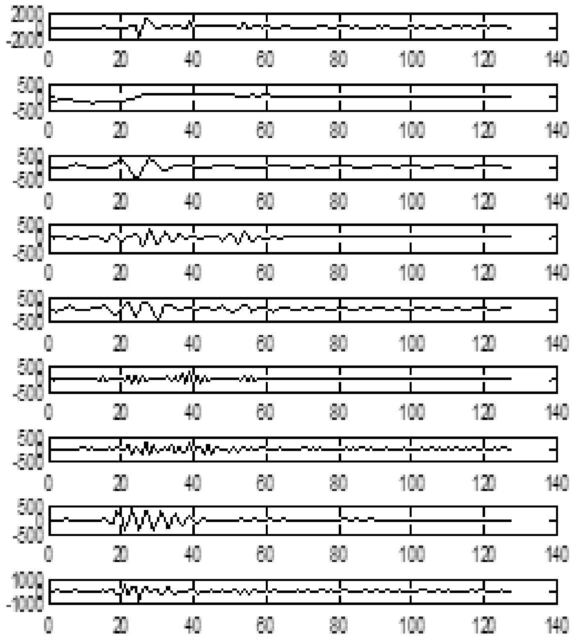

Figure 5. Characteristic extraction of scratches signal

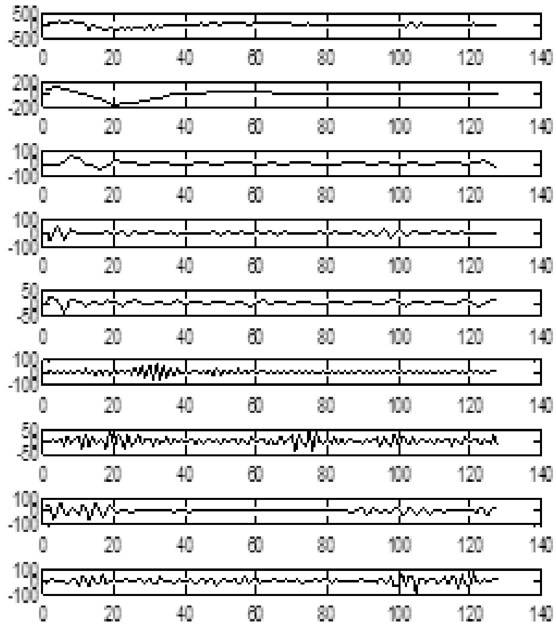

Figure 6. Characteristic extraction of non-scratches signal

Table 2. Testing signal eigenvector of non-scratches

Sample	1	2	…	8	9
E3,0	0.7537	0.8612	…	0.8246	0.7801
E3,1	0.1039	0.1442	…	0.1091	0.1225
E3,2	0.3323	0.3344	…	0.2372	0.3952
E3,3	0.1572	0.1367	…	0.0661	0.1017
E3,4	0.1423	0.0754	…	0.1309	0.2192
E3,5	0.1344	0.2209	…	0.0840	0.2817
E3,6	0.4035	0.1893	…	0.2821	0.1623
E3,7	0.2833	0.0964	…	0.3713	0.2328

Table 3. Testing signal eigenvector of low scratches

Sample	1	2	⋯	8	9
E3,0	0.4682	0.5743	⋯	0.3088	0.1907
E3,1	0.1151	0.1040	⋯	0.0789	0.1703
E3,2	0.2694	0.4352	⋯	0.2019	0.4286
E3,3	0.1939	0.2061	⋯	0.2127	0.4595
E3,4	0.3162	0.3138	⋯	0.3810	0.2734
E3,5	0.1210	0.4119	⋯	0.4605	0.2046
E3,6	0.5164	0.2743	⋯	0.5936	0.4471
E3,7	0.5212	0.2959	⋯	0.3223	0.4698

Table 4. Testing signal eigenvector of high scratches

Sample	1	2	⋯	8	9
E3,0	0.2173	0.1905	⋯	0.3198	0.2572
E3,1	0.2989	0.4030	⋯	0.1157	0.2465
E3,2	0.5842	0.5471	⋯	0.6316	0.5269
E3,3	0.3402	0.3135	⋯	0.3937	0.2418
E3,4	0.2827	0.2411	⋯	0.1334	0.3041
E3,5	0.2791	0.1843	⋯	0.1562	0.2376
E3,6	0.2326	0.4320	⋯	0.2921	0.5833
E3,7	0.4344	0.3472	⋯	0.4545	0.1841

6. Simulation

6.1 Influence of learning rate

In the learning process of fuzzy neural network, the variety of the learning rate will have great influence on the network training. The training scratches and subsequent verification scratches in this paper are all calculated according to the following formula. The influence of network training convergence circumstance with the different η was listed in the Table 5.

$$E=\frac{1}{2N}\sum_{k=1}^{N}E_k \tag{11}$$

In this formula,

$$E_k=\frac{1}{2}(f\eta(x_1^k,\cdots,x_n^k)-y^k)^2 \tag{12}$$

Table 5. Training times for expected precision

Learning rate	Sample quantity	Training quantity	Expected value	Final value
0.01	27	214	0.005	0.00494
0.02	27	111	0.005	0.00493
0.03	27	114	0.005	0.00490

From Table 5 can get, with different learning rate, the training times of network is also different when it attains same scratches. The mainly reason is the revising range of network parameter will get smaller when η value is small [7]. As a result attained the certain precision will increase the training times. When the η value is big, the revising ranges of the network parameter will also getting bigger along with the reducing of the training times. The curve of net training rate in Figure7 also explains same result [8]. Certainly, if value demand can be satisfied, we should choose the bigger learning rate as far as possible to improve the network training speeds. If η value is so big, the network will appear shakes and the scratches curve will become not smooth, therefore confirm the learning rate is 0.02 based on this cause.

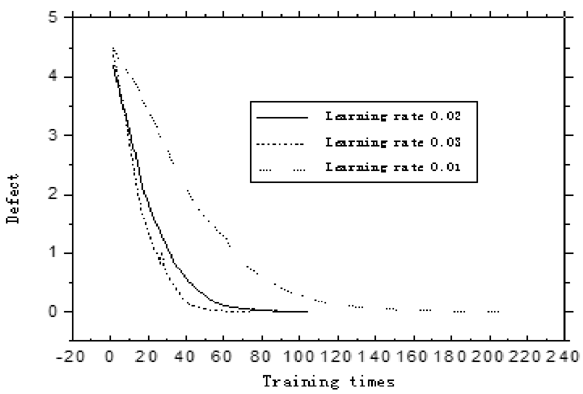

Figure 7. The curve of net training

6.2 Simulation result

To select 32 samples within the training samples to train the nerve network model of optical fiber connector scratches, among them including 10 non-scratches signals, 8 weak bounding scratches signals and 14 lack of bounding scratches signals. After training can get the verification result showed as the Figure 8, 9 and 10.

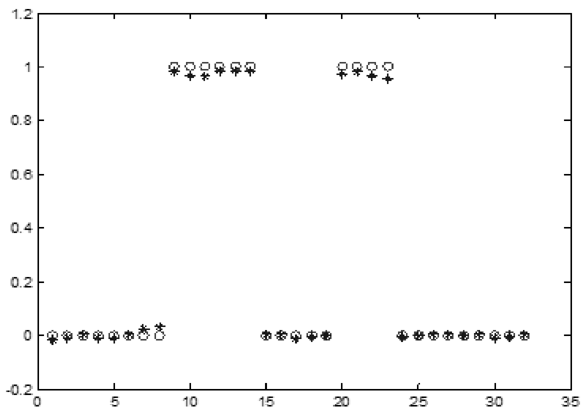

Figure 8. Contrast between expected output to the actual output of variable 1

Figure 8, 9 and 10 are the three type contrast diagrams which between the expected output to the actual output, among them "o" represent the expected output, "*" represent the actual output. It's easy to see from figures, the effect of the network integrating the training samples is quite ideal, and the actual output tallies the expected output mainly. The opposite scratches of signal test sample between the expected output to the actual output is also smaller, which express the network model satisfied with the request and can realize the classification recognizing to the scratches of friction welding. Corresponding recognizing result is shown as Table 6.

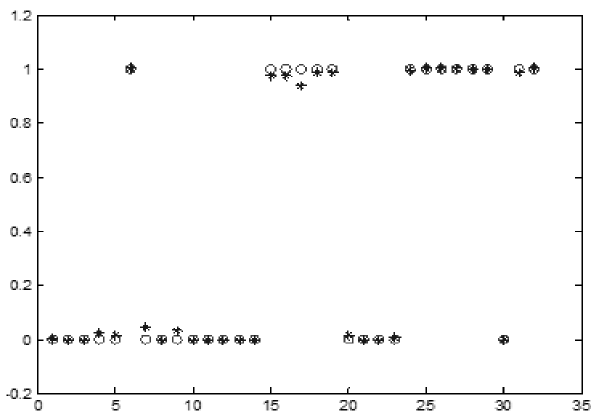

Figure 9. Contrast between expected output to the actual output of variable 2

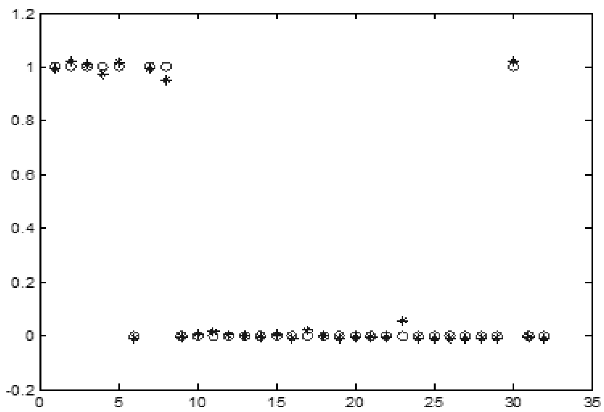

Figure 10. Contrast between expected output to the actual output of variable 3

Table 6. Validated recognize results of fuzzy neural network

Expected output	Type of sample	Actual output
(1,0,0)	Non-scratches signal	(0.9857, -0.0039, 0.0005)
(1,0,0)	Non-scratches signal	(0.9747,0.0149, -0.0055)
(0,0,1)	Low scratches signal	(-0.0174, 0.0015, 0.9946)
(0,0,1)	Low scratches signal	(0.0248, 0.0429, 0.9915)
(0,1,0)	High scratches signal	(0.0007,1.0062, -0.0089)
(0,1,0)	High scratches signal	(0.0014, 0.9775, -0.0086)

7. Machine vision application in scratches detection

Machine vision is an advanced technique of scratches detection. It brings great important to manufacturing industry such as optical fiber communication and can improve sustainable development of manufacturing industry [9].

Project team mainly studies the surface scratches detection method of optical fiber connector, which based on machine vision technology, including concentricity detection and scratches detection two aspects. In surface concentricity detection of optical fiber connector, the paper fit the surface concentricity of optical fiber connector by position of the center of internal circle in many surface images of optical fiber connector which are obtained through the microscope when the optical fiber connector is rotated. In order to accurately find out the position of the center of internal circle in each surface image of optical fiber connector, project team first get edge mask of internal circle by binary, internal circle contour extraction and morphological processing, and then combine Canny edge detection to obtain candidate edge pixels of the internal circle, then select pixels which can best show the edge of the internal circle from the candidate edge pixels through random sampling consensus estimation, further fit edge sub-pixel positions of the internal circle through three Facet model, finally fit the position of the center of the internal circle by the edge sub-pixel positions of it.

In surface scratches detection of optical fiber connector, the project team first grow to line-support regions according to feature of gradient of pixels which are in the scratches in surface gray image of optical fiber connector. Then each line-support region can be approximated by a proper rectangular. In order to reducing by mistake detection and accurate positioning scratches, this research verified each rectangular approximating line-support region. Finally, according to the distance and direction angle of scratches, combine the scratches belonging to the same scratches into one scratch. According to the studies of surface concentricity detection and scratches detection of optical fiber connector, the surface concentricity detection experiment and surface scratches detection experiment are implemented. And then the experiment results are carefully analyzed. The experiment results show that the surface scratches detection method of optical fiber connector studied which based on machine vision technology, can rapidly and accurately detect the surface concentricity and scratches of optical fiber connector, and can be applied to practical projects of the surface scratches detection of optical fiber connector. Therefore, the expected purpose is reached.

8. Conclusions

Extracting characteristic value of scratches signal based on wavelet packet transform and machine vision can keep high-frequency feature of the original data petty well and make the uneasily scratches signal feature can discovered in time domain with different resolutions. Some local feature of ultrasonic signal will not disappear after wavelet transform, so the wavelet packet transform can be used an effective method for extracting feature of scratches signals.

In classification of the optical fiber connector scratches, wavelet neural network not only have very quick learning speed, but also can realize the accurate scratches recognition. The results of experiment improve this wavelet neural network have high accuracy rate for the scratches predicting and can satisfy the requirements of, so which can provide the powerful technical assurance for realizing optical fiber connector quality detecting system further.

Acknowledgements

This work was supported by the Youth Science Research Fund of Zhengzhou Institute of Aeronautical Industry Management (Grant No. 2014133001).

References

1. Gioi G R, Jeremie J, Morel J M. (2010) LSD: A Fast Line Segment Detector with a False Detection Control. *IEEE Transactions on Pattern Analysis and Machine Intelligence*, 32(4) , p.p.722-732.
2. Brian J, Allen R, Edward M. Riseman (1986) Extracting straight lines. *IEEE Trans. PAMI*, 8(4) , p.p.425-455.
3. Ballard D H. (1981) Generalizing the hough transform to detect arbitrary shapes. *PR*, 13(2), p.p. 111 -122.
4. Desolneux A, Ladjal S, Moisan L, et al. (2002) Dequantizing image orientation. *IEEE Transactions on Image Processing*, 11(10) , p.p.1129-1140.
5. Gioi G R, Jakubowicz J, Morel J M,et al. (2008) Lsd: A line segment detector. *Technical report*, CMLA, ENS-CACHAN.
6. Gioi G R, Jakubowicz J, Randall G. (2007) *Multisegment detection*. Proc. of ICIP 2007.
7. Ji C X, Zhang Z P. (1988) Stereo match based on linear feature. *In ICPR88*, p.p.875–878.
8. Kahn P, Kitchen L, Riseman E M. (1987) Real-time feature extraction: A fast line finder for vision-guided robot navigation. *COINS*, Technical Report, p.p.57-87.
9. P. Kahn, L.Kitchen, E. M. (1990) Riseman.A fast line finder for vision-guided robot navigation. *IEEE Transactions on Pattern Analysis and Machine Intelligence*, 12(11), p.p.1098-1102.