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Mechanical Part Recognition based on Moment Invariant and BP Neural Network

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***Abstract* – This paper solves the problem of mechanical parts identification based on MTALAB software using the moment invariants theory first proposed by Hu. M.K. In order to simulate the identification of mechanical parts, we added different degrees of noise to the randomly selected three mechanical parts pictures. Firstly, the images of mechanical parts are processed by median filtering, binarization and Canny operator edge detection algorithm. Then, the images are rotated at equal intervals and scaled at different multiples. Some images are selected from the rotated and scaled images as training sample images. The number of input and output nodes and the number of hidden layer neurons of BP neural network are determined by the moment invariants of samples and the number of selected mechanical parts. The 7-13-3 BP neural network structure with a single hidden layer was established to identify the selected mechanical parts. Using the Levenberg-Marquardt training algorithm, the BP neural network is trained with the moment invariants of the training sample images. The minimum training error is 0.001, the learning rate is 0.01, and epochs are 3000. Using the remaining images and noise-processed images as the test sample of the neural network, the test accuracy rate is close to 90%, solving the problem of mechanical parts identification.**

***Keywords* – BP Neural Network, Image Preprocessing, Mechanical Part Identification and Moment Invariant.**

I. Introduction

The application of mechanical parts identification technology in industrial production and other fields is more and more extensive, and it is also very important in production automation. So far, there are many similar studies in China.

In China, Tianjin University Key Laboratory of Precision Testing Technology and Instruments Jincai Zhao and Shugui Liu proposed a method for automatic recognition of part pose based on image moment invariants [1]. Ken Chen, Shenzhen University, made a key technology research on machine vision-based material sorting industrial robots [2]. Caihua Li, Xin Wang and Xueying Wang of Harbin Institute of Technology also developed edge detection technology to identify work pieces [3]; Cong Zhang of Tianjin University of Technology and Education studied the mechanical part recognition technology based on machine vision, and proposed a part recognition algorithm based on ICP algorithm to optimize template matching [4]; Long He et al. of Beijing Information Science and Technology University proposed a cooperative target scheme and proposed an identification and feature point localization algorithm for cooperative targets [5].

In recent years, automatic identification technology is still developing at a high speed, but the recognition speed needs to be improved. The problem of image quality and interference of recognition environment remains to be solved. In this paper, image preprocessing avoids the interference of image quality and recognition environment, and noise processing of different degrees of image is closer to reality, so that recognition is more accurate and efficient. In addition, seven image invariant moments are used as input of BP neural network, which greatly improves the recognition accuracy and speed.

II. Model Establishment

According to many literatures and materials, it is known that the artificial neural network model is used to solve the problem of pattern and behavior recognition and control. It is a system composed of many simple units that can process each other. It can output and judge the result by mapping the input feature values or feature points to the network. Taking BP neural network as an example, this kind of mathematical model is suitable for identifying the shape of special parts. BP neural network is filled with a large number of neurons that can learn efficiently, so we choose it as the model of mechanical parts recognition. Fig. 1 shows a schematic diagram of the topology of a three-layer BP neural network [6].

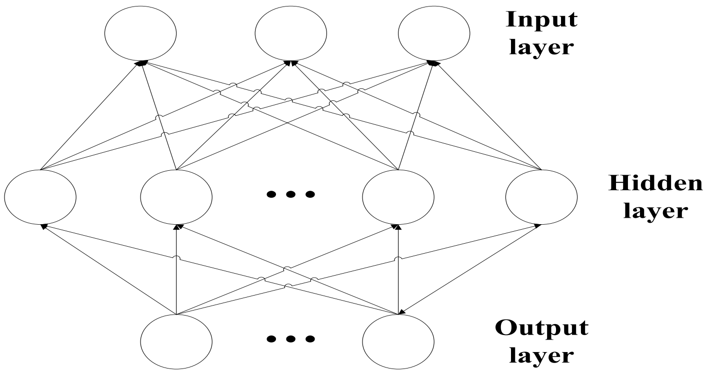

Fig. 1. Three-layer BP neural network.

The mathematical model of BP neural network is established. The algorithm flow is shown in Fig. 2.

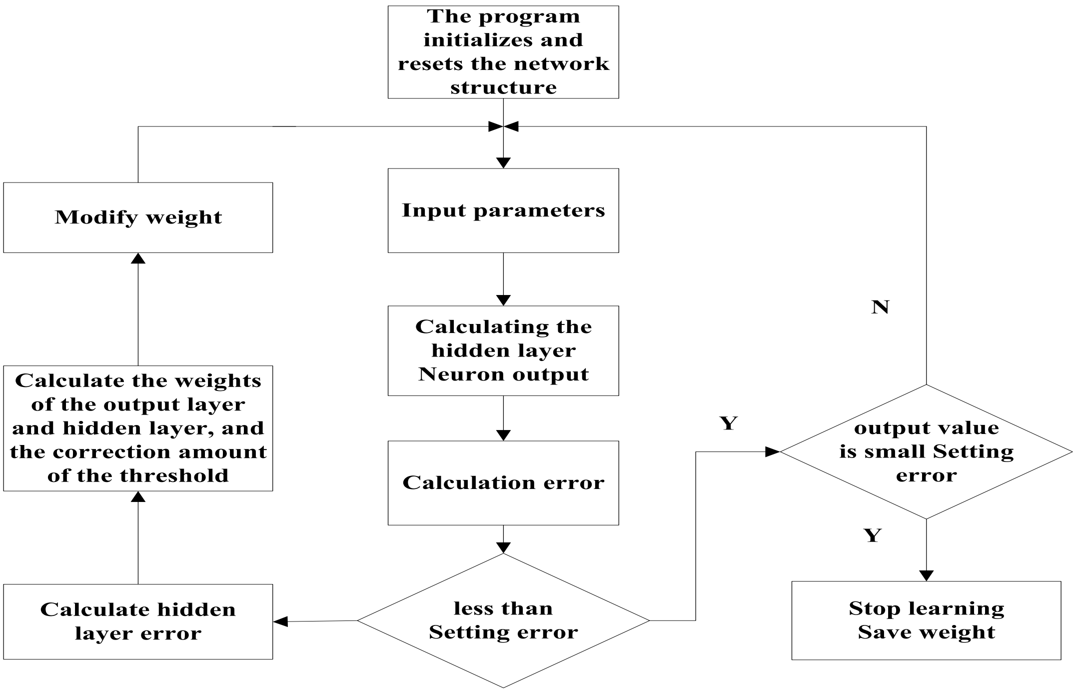

Fig. 2. BP neural network model flow chart

III. Model Solution

In this paper, three randomly selected mechanical parts are taken as identification objects.

(1) *Select Parts*

Randomly selected mechanical parts are shown in Fig. 3.

Fig. 3. Three randomly selected parts.

(2) *Noise Processing*

In the original picture, 0.02-0.12 different degrees of Gaussian noise are added to simulate the actual captured image.

(3) *Image Preprocessing*

The MATLAB function is used to perform grayscale conversion, median filtering and image binarization of images to eliminate the interference of external factors on recognition.

(4) *Edge Detection*

After comparing the result graphs obtained by various operators, finally, the canny operator is selected for edge detection of parts. As shown in Fig. 4.

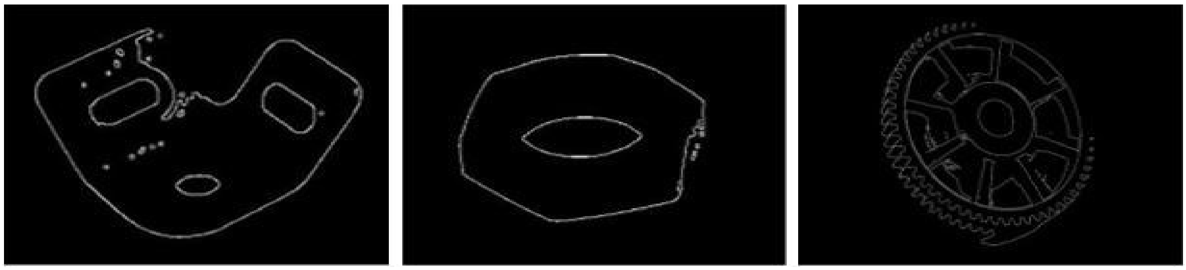

Fig. 4. Mechanical parts edge detection diagram.

(5) *Calculation of Moment Invariants of Images*

The moment invariants proposed by Hu. M.K refer to the feature quantity of the moment that the image remains unchanged after translation, rotation, etc. As shown in Formula (1-7).

$$\Phi_1 = \eta_{20} + \eta_{02} \tag{1}$$

$$\Phi_2 = (\eta_{20} - \eta_{02})^2 + 4\eta^2 \tag{2}$$

$$\Phi_3 = (\eta_{30} - 3\eta_{12})^2 + (3\eta_{21} - \eta_{03})^2 \tag{3}$$

$$\Phi_4 = (\eta_{30} + \eta_{12})^2 + (\eta_{21} + \eta_{03})^2 \tag{4}$$

$$\begin{aligned}\Phi_5 = {} & (\eta_{30} - 3\eta_{12})(\eta_{30} + \eta_{12})[(\eta_{30} + \eta_{12})^2 - 3(\eta_{21} + \eta_{03})^2] \\ & + (3\eta_{21} - \eta_{03})(\eta_{21} + \eta_{03})[3(\eta_{30} + \eta_{12})^2 - (\eta_{21} + \eta_{03})^2]\end{aligned} \tag{5}$$

$$\Phi_6 = (\eta_{20} - \eta_{02})[(\eta_{30} + \eta_{12})^2 - (\eta_{21} + \eta_{03})^2] + 4\eta_{11}(\eta_{30} + \eta_{12})(\eta_{21} + \eta_{03})^2 \tag{6}$$

$$\begin{aligned}\Phi_7 = {} & (3\eta_{21} - \eta_{03})(\eta_{30} + \eta_{12})[(\eta_{30} + \eta_{12})^2 - 3(\eta_{21} + \eta_{03})^2] \\ & + (3\eta_{21} - \eta_{03})(\eta_{21} + \eta_{03})[3(\eta_{30} + \eta_{12})^2 - (\eta_{21} + \eta_{03})^2]\end{aligned} \tag{7}$$

(6) *Image Rotation Invariance*

According to the invariance of rotation of image features, 24 pictures can be obtained by rotating them every 45 degrees, and the invariant moment of each picture can be calculated. Fig. 5 is a picture obtained by rotating 45 degrees.

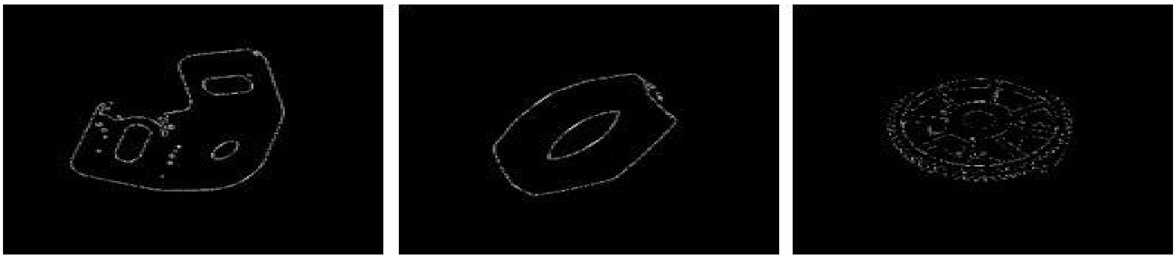

Fig. 5 Image of a mechanical part rotated 45°

(7) *Image Scaling Invariance*

Using the feature that the feature quantity of the image has the property of scaling invariance, we scale the three pictures at a magnification of 0.5, 0.8, 1.2, 1.5, and 2.0 to obtain 15 pictures and the invariant moment of each picture can be calculated. Fig. 6 shows an image of a mechanical part obtained by magnifying 0.8 times.

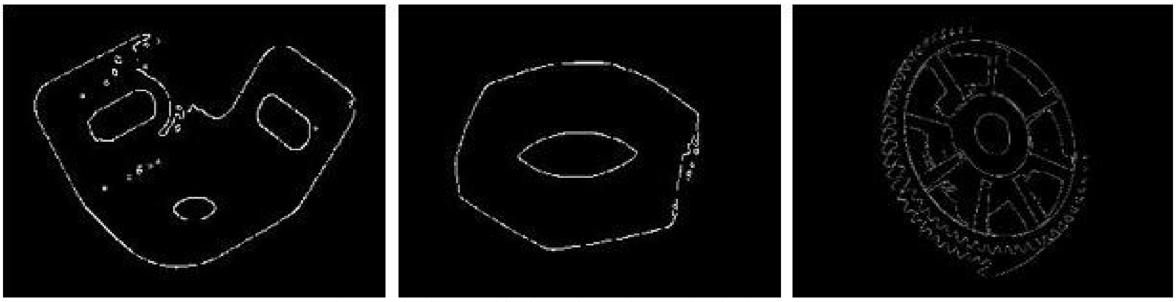

Fig. 6. (Pixel) magnified 0.8 times the mechanical part image.

(8) *Determine the Number of Input Nodes*

In order to ensure the accuracy and stability of the mechanical parts identification, the 7 moment invariants of each sample are used as the input of the BP neural network, so the number of input nodes is 7, namely m = 7.

(9) *Determine the Number of Output Nodes*

Since the output value of the neural network is between 0 and 1, and infinitely close to 0 or 1, the value of the output value less than 0.5 is set to 0, and the value greater than 0.5 is set to 1, thereby facilitating each identified part number. The number of parts identified in this paper is 3, and the output of the neural network is set to a one-dimensional array of 3 elements. If the sample image is identified as the first part, the first number of the array is set to 1, and the rest is set to 0, that is (0, 0, 1); similarly, when the recognition result is the second part, the output is (0, 1, 0), and the output is (0, 0, 1) when the recognition result is the third part.

According to the above, the number of output nodes is three, namely: n = 3.

(10) *Determination of the Number of Hidden Layers and Hidden Neurons* [7]

In general, the number of hidden nodes conforms to the following Formula (8)

$$n_1 = \sqrt{m + n} + a \tag{8}$$

a is an arbitrary constant between 1-10

According to Formula (8), the number of neurons in the hidden layer is selected to be 13. Finally, a single hidden layer BP neural network with 7 input nodes, 3 output nodes and 13 hidden layer neurons is determined. As shown in Fig. 7.

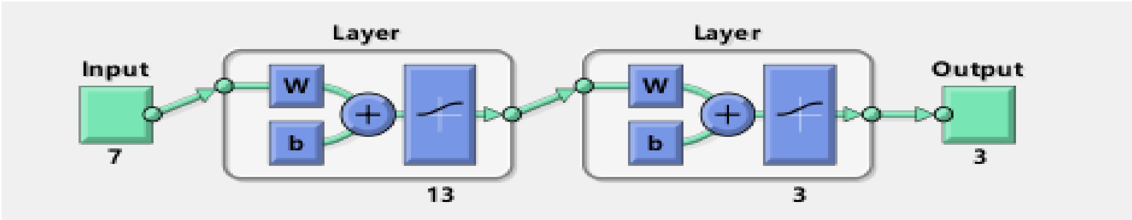

Fig. 7. 7-13-3 BP neural network structure.

(11) *Training and Testing*

According to the above, this paper has taken a total of 39 zoomed and rotated images, each sample image has seven moment invariants. Four groups are selected in the rotation images, and two groups are selected in the zoom images. The Levenberg-Marquardt algorithm is used to train the BP neural network by using the moment invariants of the six sets of training sample images. The seven moment invariants of the noise-processed images and the remaining seven sets of test sample images are used as test samples of the neural network, and the recognition results are tested. The training process is shown in TABLE 1.

Table 1. BP Neural Network Training Date.

Mechanical Parts	**operating**	**Training sample image moment invariant**							**Training goal**
		Φ1	**Φ2**	**Φ3**	**Φ4**	**Φ5**	**Φ6**	**Φ7**	
Part 1	Rotate 0°	3.9212	10.0319	13.8975	16.1198	32.2631	21.3712	31.3540	(1,0,0)
	Rotate 45°	3.9124	10.0510	13.7677	15.8737	34.9894	24.3572	30.8698	
	Rotate 90°	3.9198	10.0443	13.9045	16.1213	31.6906	21.3723	31.3538	
	Rotate 135°	3.9143	10.0593	13.7640	15.8856	32.7242	24.4989	30.8874	
	Magnify 0.5 times	3.4253	9.0394	12.4919	16.0993	31.6716	21.0205	30.6286	
	Magnify 0.8 times	3.9735	10.0859	14.1245	16.6535	33.2047	21.9331	32.2711	
Part 2	Rotate 0°	3.6467	9.2301	17.4116	15.7132	33.5105	20.3579	32.6772	(0,1,0)
	Rotate 45°	3.6948	9.3146	17.0617	16.0027	32.6782	25.5368	33.0767	
	Rotate 90°	3.6466	9.2306	17.3204	15.6967	33.2731	20.3434	32.6374	
	Rotate 135°	3.6993	9.3470	17.0055	15.9680	34.5876	25.4011	32.9444	
	Magnify 0.5 times	3.1406	8.2876	13.1995	13.5228	28.0771	17.8930	30.0894	
	Magnify 0.8 times	3.6816	9.3445	17.7422	15.8430	33.3884	20.5845	33.6499	
Part 3	Rotate 0°	4.1585	11.4253	17.7563	17.1256	36.8925	26.9740	35.2239	(0,0,1)
	Rotate 45°	4.1683	11.4724	17.7072	17.1391	38.8288	23.1511	35.3180	
	Rotate 90°	4.1578	11.4204	17.7561	17.1234	35.0083	26.9909	35.2141	
	Rotate 135°	4.1690	11.4780	17.7328	17.1482	34.8670	23.1602	35.3648	
	Magnify 0.5 times	3.6445	10.3948	15.8329	15.3262	32.2759	23.3607	31.0434	
	Magnify 0.8 times	4.2139	11.4761	17.8931	17.4170	37.2495	26.6370	35.5121	

IV. Test Results and Analysis

The Levenberg-Marquardt back propagation algorithm is used to train the network as described above, and the activation function selects logsig. The goal of the training setting is that the overall mean square error is less than or equal to 0.001, the learning rate is selected to be 0.01, and epochs are 3000. After the training is completed, the recognition results are shown in TABLE 2. The recognition rate of BP neural network to the sample is 89.74%. There are individual recognition errors in the image processed by Gaussian noise, which indicates that the neural network model has a good effect on parts identification, the algorithm is simple and the recognition is efficient.

Table 2. Test Sample Identification Results.

Mechanical Parts	operating	Test sample image moment invariant							Recognition result			Binary results
		Φ1	Φ2	Φ3	Φ4	Φ5	Φ6	Φ7				
	Rotate 180°	3.9203	10.0313	13.9067	16.1821	32.3226	21.4153	31.4421	0.9694	0.0147	0.0222	(1,0,0)
	Rotate 225°	3.9160	10.0775	13.7693	15.9035	35.4949	24.5474	30.9136	0.9737	0.0104	0.0301	(1,0,0)
	Rotate 270°	3.9252	10.0475	13.9105	16.0769	31.6310	21.3300	31.2886	0.9660	0.0123	0.0315	(1,0,0)
	Rotate 315°	3.9141	10.0725	13.7559	15.8631	32.7449	24.5532	30.8401	0.9716	0.0074	0.0507	(1,0,0)
	Magnify 1.2 times	3.9085	10.0438	13.8549	15.9548	32.0534	21.2334	31.1014	0.9639	0.0103	0.0432	(1,0,0)
	Magnify 1.5 times	4.0075	10.2391	14.1107	16.1898	32.4736	21.5391	31.5646	0.9681	0.0098	0.0395	(1,0,0)
Part 1	Magnify 2.0 times	3.8577	9.9197	13.7011	15.8809	31.8051	21.0813	30.8990	0.9639	0.0121	0.0349	(1,0,0)
	Adding noise 0.02	4.1374	10.4139	14.5151	15.3910	31.0386	20.7754	30.5062	0.9822	0.0007	0.0227	(1,0,0)
	Adding noise 0.04	4.1317	10.2410	14.4419	15.2426	30.7444	20.5200	30.2490	0.9778	0.0009	0.0277	(1,0,0)
	Adding noise 0.06	4.2720	10.3514	14.8055	14.9977	30.3558	20.2917	30.1045	0.8989	0.0028	0.1491	(1,0,0)
	Adding noise 0.08	4.4366	10.5896	15.2841	15.0647	30.5414	20.4259	30.5950	0.6372	0.0081	0.5285	(1,0,1)
	Adding noise 0.1	4.4423	10.5498	15.4269	15.0872	30.6310	20.4447	30.6754	0.5026	0.0119	0.6634	(1,0,1)
	Adding noise 0.12	4.5344	10.7669	15.5646	15.1500	30.7251	20.5786	31.0187	0.4608	0.0116	0.7084	(0,0,1)
	Rotate 180°	3.6493	9.2414	17.3713	15.7649	33.8313	20.4289	32.7415	0.0094	0.9843	0.0246	(0,1,0)
	Rotate 225°	3.7004	9.3394	17.1897	15.9844	32.7460	25.5670	33.0373	0.0038	0.9485	0.0553	(0,1,0)
	Rotate 270°	3.6509	9.2511	17.3814	15.7844	33.3093	20.4499	32.8018	0.0093	0.9852	0.0237	(0,1,0)
	Rotate 315°	3.7023	9.3635	16.9316	15.9526	34.5808	25.5189	32.9141	0.0048	0.9373	0.0547	(0,1,0)
	Magnify 1.2 times	3.6287	9.1828	17.2622	15.6293	33.8916	20.2355	32.3193	0.0089	0.9680	0.0559	(0,1,0)
	Magnify 1.5 times	3.7491	9.4501	17.9010	15.9649	34.0743	20.7112	33.2617	0.0103	0.9812	0.0352	(0,1,0)
Part 2	Magnify 2.0 times	3.5911	9.1248	16.9048	15.4895	33.0671	20.0940	32.1187	0.0077	0.9656	0.0545	(0,1,0)
	Adding noise 0.02	3.7144	9.2929	17.9895	15.3082	33.4610	19.9549	32.1423	0.0011	0.9833	0.0075	(0,1,0)
	Adding noise 0.04	3.7038	9.4376	19.6249	16.6959	37.0296	21.4488	35.1318	0.0001	0.9726	0.0212	(0,1,0)
	Adding noise 0.06	3.7131	9.7267	18.5043	17.6221	37.7847	23.0344	35.9313	0.0002	0.9444	0.0416	(0,1,0)
	Adding noise 0.08	3.7525	9.8237	18.4651	18.1428	36.4868	23.0580	37.7285	0.0001	0.9690	0.0238	(0,1,0)
	Adding noise 0.1	3.8367	10.2544	18.3640	19.8644	39.3222	27.0059	39.3538	0.0002	0.9049	0.0668	(0,1,0)

Mechanical Parts	operating	Test sample image moment invariant							Recognition result			Binary results
		Φ1	Φ2	Φ3	Φ4	Φ5	Φ6	Φ7				
	Adding noise 0.12	3.9396	10.6894	18.1202	18.7855	37.7925	24.6177	38.7644	0.0010	0.1447	0.7727	(0,0,1)
Part 3	Rotate 180°	4.1579	11.4241	17.7611	17.1334	36.9154	27.0261	35.1970	0.0290	0.0316	0.9595	(0,0,1)
	Rotate 225°	4.1696	11.4811	17.7805	17.1600	39.1631	23.1744	35.3858	0.0299	0.0375	0.9535	(0,0,1)
	Rotate 270°	4.1585	11.4294	17.7726	17.1316	35.0378	27.0291	35.2107	0.0245	0.0355	0.9610	(0,0,1)
	Rotate 315°	4.1681	11.4787	17.7391	17.1407	34.8543	23.1515	35.3389	0.0230	0.0443	0.9577	(0,0,1)
	Magnify 1.2 times	4.1388	11.4082	17.6786	16.9811	36.8591	29.8805	35.0995	0.0341	0.0281	0.9583	(0,0,1)
	Magnify 1.5 times	4.2597	11.6150	18.0925	17.4621	37.1802	27.7347	35.9270	0.0394	0.0326	0.9377	(0,0,1)
	Magnify 2.0 times	4.1036	11.3103	17.5923	16.9345	36.8438	26.6291	34.7553	0.0250	0.0316	0.9665	(0,0,1)
	Adding noise 0.02	4.3714	11.8398	19.1988	17.3873	37.8515	25.7806	36.2717	0.0039	0.0058	0.9883	(0,0,1)
	Adding noise 0.04	4.3799	11.8156	19.5200	17.5247	37.3576	24.7591	36.1545	0.0039	0.0059	0.9882	(0,0,1)
	Adding noise 0.06	4.4170	11.7098	20.6893	17.7535	38.2505	24.9687	37.0611	0.0034	0.0079	0.9844	(0,0,1)
	Adding noise 0.08	4.4370	11.8493	20.4313	17.7720	37.7495	25.0015	36.8749	0.0037	0.0065	0.9870	(0,0,1)
	Adding noise 0.1	4.4319	11.8463	19.7768	17.9688	40.4182	25.6943	36.8456	0.0039	0.0057	0.9885	(0,0,1)
	Adding noise 0.12	4.4222	12.1276	18.7483	18.0583	36.9386	28.9852	36.6280	0.0041	0.0056	0.9877	(0,0,1)

V. Conclusion

With the progress of the times, automation and intelligence will become the trend of the times. However, automatic identification of machinery is indispensable in the process of automated production. The content of this paper is an important part of the automatic identification of machinery. On the basis of the work of the predecessors, the following problems are mainly solved:

(1) Adding different degrees of Gaussian noise to the image to simulate the actual image and preprocessing the image solves the problem of blurring and distortion in the actual image, increases the reliability of the neural network recognition and solves the problem of interference caused by image quality to the recognition.

(2) Using seven moment invariants as the input of BP neural network, the standard BP neural network is trained and improved by using the algorithm. The recognition rate and speed of the BP neural network for mechanical parts are improved, and the stability of the recognition is increased. The recognition rate reaches 90%.

(3) The BP neural network model can recognize the contour shape of any part, which has good versatility, and does not require complicated mathematical operations, directly performs machine recognition and is more intelligent.

(4) Different scaling factors and rotation angles simulate the complexity of the position of actual mechanical parts, making the identification of mechanical parts more convincing and practical.

The BP neural network model has a wide application prospect. For example, it is suitable for machine learning in life, performs certain signal processing or pattern recognition functions, constructs expert systems, and manufactures robots. It has high promotion value.

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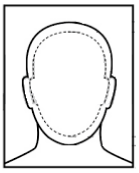

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