RECOGNITION OF OPTICAL IMAGES BASED ON THE FEATURE SPECTRUM ENTROPY IN WAVELET DOMAIN

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ABSTRACT

Under the certain circumstances of the low and unacceptable accuracy on image recognition, the feature extraction method for optical images based on the wavelet space feature spectrum entropy is recently studied. With this method, the principle that the energy is constant before and after the wavelet transformation is employed to construct the wavelet energy pattern matrices, and the feature spectrum entropy of singular value is extracted as the image features by singular value decomposition of the matrix. At the same time, BP neural network is also applied in image recognition. The experimental results show that high image recognition accuracy can be acquired by using the feature extraction method for optical images proposed in this paper, which proves the validity of the method.

KEYWORDS

Image Recognition, Wavelet Domain, Feature Extraction, Spectrum Entropy

1.INTRODUCTION

With the development of the science technology, the image recognition technology in daily production and life has become increasingly common, and has been widely used in the field of aerospace, medical and health, industrial control, transportation and logistics [1-3]. Due to the human visual properties, the images acquired by optical sensors are most likely to be accepted and identified by our eyes. So optical sensors are used to acquire images as the core device of many products, including the high-end digital cameras, camcorders, etc. As is well known, the principle of optical imaging is the light transmission and refraction, thus the optical images are liable to be influenced by clouds, the weather and other natural factors. Especially the turbulence will cause the lightwave distortion from the original plane wave front into a random surface when the light waves spread in the atmosphere, which can induce the blurred image. In addition, some features of optical sensor and its related devices such as temperature drift, edge nonlinearity, will further affect the imaging results of the optical image.

In order to reduce the impact produced by the natural conditions on the optical images and improve the recognition accuracy, two methods are employed in the current research: the first method is to use physical measures, that is, to improve the quality of the images by adding lenses and other devices, and then the visible light correlator (VLC) or joint transform correlator (JTC) is used for image recognition. VLC is simple in principle with a high signal-to-noise ratio, but is not suitable for the real-time target recognition because of its complex machining process. In addition, JTC cannot get a good picture because of its high intensity zero-order spectrum. In literature [4], an improvement of edge adjusting JTC by wavelet transform method was researched, and the image displacement problem with joint scores transform technology based on

phase encoding was studied in [5]. In literature [6], the image encryption and authentication technologies using non-traditional fractional joint transform method were investigated comparatively. The second method is the image processing using the software system, and the keys to the study are the feature extraction and the optical image recognition algorithms. An improved Hu matrix for image object recognition was proposed in [7], and the application of computer vision and pattern recognition techniques in image processing was studied in [8]. In literature [9], the image metric learning algorithm with adaptive iterative restoration for asymmetric optical images was made a thorough study. These researches have provided a theoretical basis for the development of the optical image recognition technology.

Among the previous research results, the study focused on image recognition algorithms and image recovery technologies. According to the study of plenty of literatures, we argue that the feature extraction of optical image exerts a tremendous influence on the image recognition accuracy. The special emphasis has been put on the feature extraction technology of optical image in this paper. The main innovations of this paper is that the wavelet transform technology is introduced into the optical image processing, and spectrum entropy is considered as the features of the image for image recognition using BP neural network.

2.THE RECOGNITION PROCESS OF OPTICAL IMAGE

The image recognition is a complicated process, which can be divided into four major stages: image acquisition, image preprocessing, image feature extraction and image recognition. Image acquisition is the first step in the whole process, which is the procedure of acquiring the image using optical sensors. The second step is image preprocessing, that is, the original image is transformed preliminary to lay the foundation for the feature extraction. Image preprocessing is also a complicated process with a lot complex algorithms, which is not the key of our research work. Feature extraction is the important part of image recognition and is the emphasis in this paper, because top-quality feature extraction can largely improve the image recognition accuracy. Image recognition has already been an important branch of pattern recognition, and there are many recognition algorithms applied to image recognition. The neural network algorithm is applied for image classification and recognition in this work.

Optical image is often heavily contaminated by sophisticated background noise in the image acquisition, recording and transmission process, so that an image often contains some noise. Therefore, in image processing, image preprocessing is necessary to restrain the noise, including grayscale, binary, edge detection and filtering of optical image, etc. The optical image grayscale is the process of converting a color image into a grayscale image, which has the great advantage of not only retaining the structural features such as chromaticity and luminance distribution of the image objects but improving efficiency by reducing the amount of data processed. In this paper, the image grayscale method is the weighted average method. Binarization algorithm is a conventional image segmentation algorithm based on threshold, which is used to turn the gray values of pixels within a specified threshold into black pixels (0), and turn the other pixels into white pixels (255). It is crucial to select segmentation threshold for the Binarization algorithm, and the method of maximum class square error is used in this paper. Image filtering is to remove the noise produced by external signal interference in the shooting or transferring phase, and is beneficial to succeeding process. However, the process will lower the quality of the original image more or less, and the algorithm should be appropriate. The Gaussian filtering method has been chosen in this paper.

3.FEATURE EXTRACTION OF IMAGES

The process of digitizing and extracting some features of the image is called feature extraction. As the difference of an image with the other image increases, the image becomes easier to be correctly recognized. The common methods used in image feature extraction involve the region segmentation matrix method and the moment invariants algorithm [10][13][14] etc. According to the feature of the optical image, wavelet space feature spectrum entropy of image is used as the features for image recognition in this paper.

3.1. Wavelet Analysis Theory

The basic theory of wavelet analysis was first proposed by French scientists in the early 1980s, which has become a mature branch of mathematics, and the theory developed continuously. Wavelet analysis is similar to a mathematical microscope with zoom, shrink and shift function, analyzing the dynamic properties of the signal by examining the signal variances in different magnifications. Therefore, wavelet analysis is widely used in many fields [11]. Wavelet function is obtained by the translation and dilation of a wavelet basic function. Wavelet analysis is that the signal is decomposed to be the superposition of a series of wavelet function. Wavelet transformation is that a basic wavelet functiondoes inner product with signalin the different scales a after shifting, as follows:

$$f_x(a,\tau)=\frac{1}{\sqrt{a}}\int_{-\infty}^{+\infty}x(t)\varphi\left(\frac{t-\tau}{a}\right)dt, \qquad a>0, \tag{1}$$

the equivalent time-domain expression is:

$$f_x(a,\tau)=\frac{1}{\sqrt{a}}\int_{-\infty}^{+\infty}x(t)\varphi(a\omega)e^{jw}dt, \qquad a>0, \tag{2}$$

where the parameter τ is the distance the lens moved in parallel relative to the target, a is the distance the lens close to or away from the target. From equation (1) and (2), we can see that the wavelet analysis is a good analysis tool, which can analyze the local features of signals by the transformation of wavelet basis function with the characteristic of signal direction selectivity in the two-dimensional case.

3.2. The Wavelet Space Feature Spectrum Entropy Of The Image

The image feature extraction methods commonly are extracting the regional feature or time-domain feature, but this feature is not obvious when the image nature is similar to that of the shooting environment. Therefore, we propose to study the wavelet space feature spectrum entropy based on wavelet transformation in the time-frequency domain. Obviously, the energy of the function $f(t)$ with limited energy before and after the wavelet transformation must be constant, that is:

$$\int_{-\infty}^{+\infty}|f(t)|^2dt=\frac{1}{C_\Psi}\int_0^a a^{-2}E(a)da, \tag{3}$$

in the equation (3), $C_v=\int_{-\infty}^{+\infty}\frac{|\hat{\varphi}(\omega)|^2}{\varpi}d\varpi$, $E(a)=\int_{-\infty}^{+\infty}|W_f(a,b)|^2db.$ $W_f(a,b)$is the amplitude of the wavelet transformation; $C_v$is the admissible condition of the wavelet function; $E(a)$is the energy value of function $f(t)$when the scale is *a*.

From equation (3), the wavelet transformation is that the one dimensional signal is mapped into the two-dimensional wavelet space. Matrix $W = \left[\frac{\left| W_f(a,b) \right|^2}{C_\varphi a^2} \right]$ is called the wavelet energy distribution matrix of the two-dimensional wavelet space, which may serve as the pattern matrix of signals, and singular value decomposition for matrix *W* is given. $\delta_1 \geq \delta_2 \geq \cdots \geq \delta_n$ is selected as the singular values of matrix *W*. Singular value spectrum $\{\delta_i\}$ is the efficient partition of the original signal $\{x_i\}$ in time-frequency domain, and the wavelet space feature spectrum entropy of the image in time-frequency domain can be defined as:

$$H_{ws} = -\sum_{i=1}^{n} p_i \log p_i, \tag{4}$$

Where in $p_i = \delta_i / \sum_{i=1}^{n} \delta_i$ is the proportion of the *i* singular value in the singular value spectrum. Wavelet space feature spectrum entropy reflects the energy distribution of the image in the time-frequency domain. Wavelet space feature spectrum entropy decreases when images features become simple because the energy is concentrated in a small number of modes. Conversely, wavelet space feature spectrum entropy increases as the images features become more complicated, because the energy begin to disperse. Thus, we can recognize image correctly by comparing the wavelet space feature spectrum entropy.

4.IMAGE RECOGNITION

Image recognition is a classification process according to the image features. The selection of the recognition algorithm is of great importance, because the image recognition should be accurate and fast. In this paper, BP neural network method serves as the recognition algorithm.

4.1. Overview Of BP Neural Network

The core content of the BP neural network is the feed forward of signals and the back-propagation of error. During the feed forward of signals, the signals are processed layer-by-layer, and each neuron in input layer has an influence on the neurons in output layer. If the error between the actual output and the expected output does not meet the requirement, back propagation will be used for training neural network, and the weights and threshold values of the network are adjusted to reduce the error according to the optimal target. This process will not stop until the error meets the accuracy requirement [12]. The structure of BP neural network often used in engineering is shown in Fig. 1.

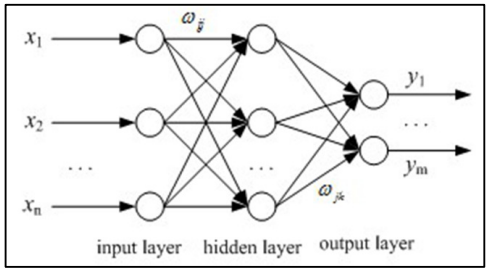

Figure 1. The topology structure of BP neutral network

4.2. The Training Process Of BP Neutral Network

BP neural network must be trained to have the functions of associative memory and predictability before being used. The training process of BP neural network includes the following steps:
Step1: network initialization. The number of input layer node *n*, the number of hidden layer node *l*, the number of output layer node *m* is determined by the input and output sequence data (X, Y) in the system. The connection weight ω_{ij} of neurons between the input layer and hidden layer, the connection weight ω_{jk} of neurons between the hidden layer and output layer, the threshold of hidden layer *a* and the threshold of output layer *b* are initialized. The learning rate and neuronal excitation function are given.

Step2: the calculation of the hidden layer output. Calculating the output of hidden layer H according to the input vector X, ω_{ij} and a:

$$H_i = f\left(\sum_{i=1}^{n} \omega_{ij} x_i - a_i\right), \qquad j = 1,2,\cdots l, \tag{5}$$

Step3: the calculation of the output layer output. Calculating the predicted network output O according to H, ω_{jk} and b:

$$O_k = \sum_{j=1}^{l} H_j \omega_{jk} - b_k, \qquad k = 1,2,\cdots m, \tag{6}$$

Step4: error calculation. Calculating the prediction error *e* according to the predicted network output *O* and the desired network output *Y*:

$$e_k = Y_k - O_k \quad k = 1,2,\cdots,m \qquad e_k = Y_k - O_k, \tag{7}$$

Step5: weights update. Updating ω_{ij} and ω_{jk} according to e:

$$\omega_{ij} = \omega_{ij} + \eta H_j (1 - H_j) x(i) \sum_{k=1}^{m} \omega_{jk} e_k, \qquad j = 1,2,\cdots l, \tag{8}$$

$$\omega_{jk} = \omega_{jk} + \eta H_j e_k, \qquad j = 1,2,\cdots,l, \qquad k = 1,2,\cdots m, \tag{9}$$

Step6: thresholds update. Updating *a* and *b* according to *e*:

$$a_j = a_j + \eta H_j (1 - H_j) \sum_{k=1}^{m} \omega_{jk} e_k, \qquad j = 1,2,\cdots l, \tag{10}$$

$$b_k = b_k + e_k, \qquad k = 1,2,\cdots m, \tag{11}$$

Step7: Determine whether the iterative algorithm end or whether the prediction error meets the desired requirement. If not, return Step2, otherwise end.

5.EXPERIMENTAL ANALYSIS

Here we analyze and investigate the face orientation recognition. Facial image recognition has been a complex pattern recognition problem, and face orientation recognition is becoming a hotspot of resent research, which is widely used in the field of guard against burglary, tracking and identification, etc. The main purpose of the experiment is to verify the validity of the method of image feature extraction based on the wavelet space feature spectrum entropy.

Firstly, the facial images towards different orientations are collected by using a high-speed digital camera equipped with optical lens sensor. The images are shot by 10 different persons, and each person shoots five images. The face orientations are as follows: left, left front, front, front right

and right. After the preprocessing of grayscale, Binarization and filtering, the images are shown in Fig. 2.

Fig. 2 The face recognition images

From the Fig.2, we can see the images show good effects after preprocessing, and then we begin to extract the feature. Firstly, these 50 images are distributed into five groups for ease of distinction. Number 11, 12, 13, 14, 15 represent the images of being left, front left, front, right front, and right in the first group, respectively. After that, these 50 images are wavelet transformed. DB6 is the mother wavelet in this paper, and the pattern matrix is constructed to attain the singular value according to the process introduced in 4.2. Finally, the wavelet space feature spectrum entropy of the image is calculated in accordance with the formula (4), and the results are classified by left, left front, front, front right and right, as shown in table 1 below.

In Table 1, there is significant difference in the wavelet space feature spectrum entropy of facial images towards different orientations. It can make a preliminary decision that the method considering the wavelet space feature spectrum entropy as the feature of the image is efficiency. However, the ranges of wavelet space feature spectrum entropy in the left front and front right directions overlap, so BP neural network will be used for image recognition finally.

In order to ensure the randomness of the network training, the features of 30 images are selected randomly from 50 images as the training data volume, and the features of the remaining 20 images serve as the testing data volume. The next step will be the determination of the network structure. In this paper, a typical three-layer network is selected relying on the actual demand of the experiment. The input values are the wavelet space feature spectrum entropy of the image, so there is only one node in the input layer of the neural network. The output of the network should be the image recognition results, so there is also one node in the output layer. We should encode the output status of the network because the mode of the BP neural network output is binary data. The coding available here are three binary numbers, specifically as shown in Table 2. The number of hidden layer node is selected as 7 based on experience. Ultimately, the network structure is determined as 1x7x1.

Table1.The features of images towards different orientations

	Left	Left front	Front	Front right	Right
Wavelet space feature spectrum entropy	0.812~0.778	0.527~0.496	0.251~0.235	0.545~0.519	0.745~0.761

Table 2 Neural network output status table

	Left	Left front	Front	Front rignt	Right
Coding	100	110	010	011	001

Table 3 Image recognition results

No.	Predictive value	Expected value	No.	Predictive value	Expected value
1	010	010	11	001	001
2	110	110	12	100	100
3	001	001	13	011	110
4	010	010	14	010	010
5	100	100	15	011	011
6	110	011	16	100	100
7	011	011	17	100	100
8	001	001	18	001	001
9	010	010	19	010	010
10	100	100	20	110	110

In our analysis, the training step number is set to be 3000, and training goal is 0.01. The training procedure is shown in Fig. 3. We can see it would take only 1746 steps to finish the training under the training goal of 0.01, and the training time is short. Then the features of remaining 20 images are inputted into the network for testing network, and the image recognition results are shown in Table 3.

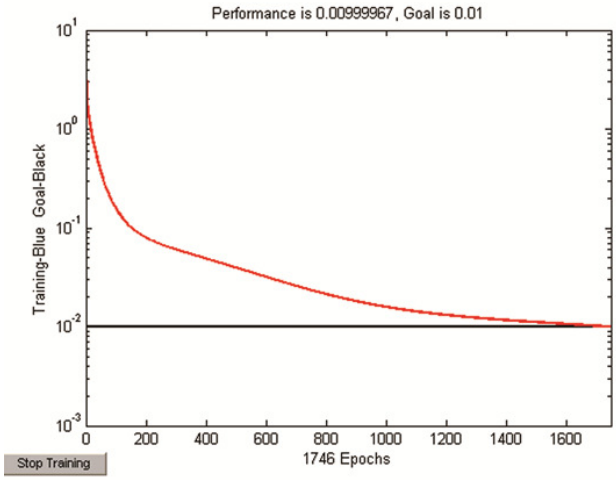

Fig. 3 Network training curve

It can be found from Table 3 that the recognition results of 18 images are correct except for the image No. 6 and No. 13, of which the accuracy is 90%. To further verify the validity of the proposed method, 100 repeated experiments are carried out under the same conditions, and 30 images are selected randomly from 50 images for recognition in each experiment. The recognition results are shown in Fig. 4. The repeated experiments results indicate that the recognition accuracy is high as an average accuracy of 93.13% in the total 100 experiments. The highest accuracy can reach 100%, while the lowest accuracy is 86.7%. The accuracy can come up to the requirements of use even though the accuracy in practical situations differs from that in experiments, which reinforces the fact that the image feature extraction method based on wavelet

space feature spectrum entropy is efficient. And then transversal comparison is conducted for research, which shows the superiority of this method.

The image segmentation method and grayscale entropy method are the most common feature extraction methods for face orientation recognition based on the current study. The image segmentation method is to determine the position where the eyes are by matrix partitioning images, and then to determine the face orientation in accordance with the characteristics of the sub-matrix on which the eyes are. During extracting the features by using this method, the image is divided into 6 rows and 8 columns of 48 sub-matrix blocks according to the size of the image, and the eyes are located in the second row, so the face orientation can be determined according to number and location of "1" pixel point on the 8 sub-matrix blocks in the second row. The grayscale entropy method is to calculate the gray percentage of the image, then to extract the grayscale entropy. We can compute the grayscale entropy directly because the image has been preprocessed. The image features of 50 images are extracted by using these two methods, respectively. The comparisons of recognition accuracy and recognition time between the wavelet method and the two image feature extraction methods are shown in Fig. 5 and Fig.6, respectively.

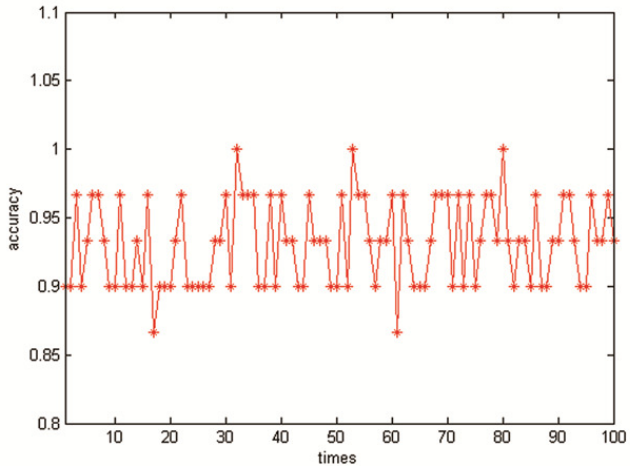

Fig. 4 Comparison of multiple recognition results

From the comparison results in Fig. 5, we can see that the average recognition accuracy of matrix method is only about 80%, similar to the result of grayscale entropy method, which is lower than that of the wavelet method (about 90%). In Fig. 6, the average time of the wavelet method is about 88 seconds, while the average time of the grayscale entropy method is about 84 seconds and the time the matrix method speed is about 78 seconds. Although the wavelet method spends more time than the other two methods, the average time can also meet the requirements of practical engineering because the difference is small. In addition, the recognition result "000" appears when using the matrix method, which cannot give the image orientation result because "000" is not in accordance with any kind of encoding shown in Table 2. However, the wavelet method is the most effective method to overcome the defect.

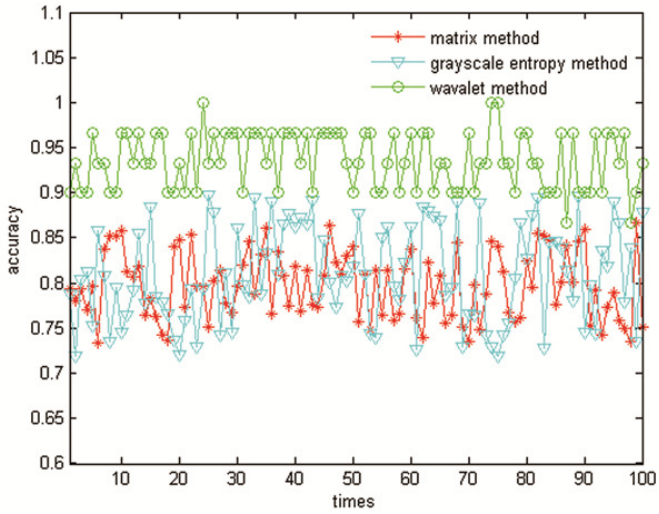

Fig. 5 Comparison of recognition accuracy

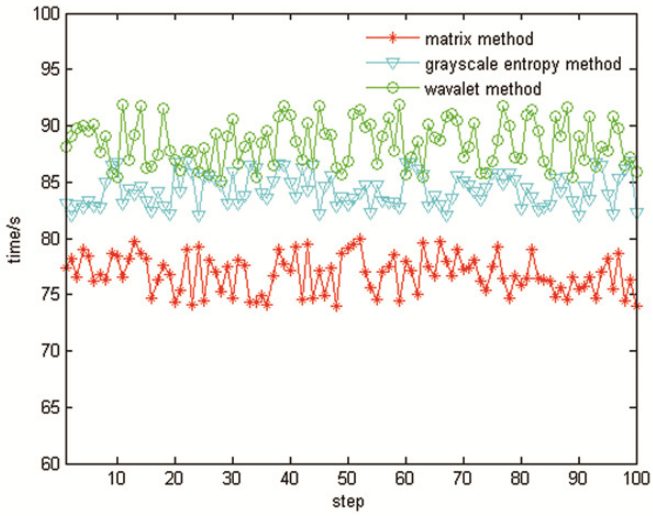

Fig. 6 Comparison of recognition time

6. CONCLUSIONS

Because the optical images are liable to be influenced by the natural factors, the image feature extraction method is important to determine whether the image can be identified correctly. This paper focuses on the image feature extraction method based on the wavelet space feature spectrum entropy. In this method, the principle that the energy is constant before and after the wavelet transformation is employed to construct the wavelet energy pattern matrices, and the feature spectrum entropy of singular value is extracted as the image features by singular value decomposition of the matrix. Finally, BP neural network is applied in image recognition according to the image feature. The experimental results show that the image features extracted by using the wavelet space spectrum entropy method are representative and separable, and a high image recognition accuracy of up to 90% can be acquired. Compared with the current image feature extraction methods, the proposed method has great advantages. But the experiment result also shows that the time this method spends is slightly longer than that of the other two methods,

and the future research will focus on how to reduce the complexity of the method, and how to improve the efficiency. In the future, we decide to use some mathematical[15] and related method to optimize our algorithm[16][17].

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