The HMM-based banknote recognition system

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\textbf{Keywords:} Features extraction, HMM, ERM, Banknote recognition.

\textbf{Abstract.} In order to satisfy the fast, accurate and high reliability of banknote image recognition, a banknote image recognition method based on hidden Markov models (MHH) is proposed in this paper. The grid method is used to extract banknote image features and the process of image preprocessing. By analysing the experimental data, the number of Markov model states, the number of iterations and the number of Gaussian models is finally determined. This method can be used to identify any currency. In this paper, 16000 pieces of RMB were collected by the self-developed banknote cleaner as experimental samples. Experimental results show that the proposed method achieves higher recognition rate than using neural network and support vector function.

1 Introduction

With the development of science and technology, the paper money recognition system becomes more and more important. The ability to automatically identify banknotes according to their denomination and face is the goal of this system. The automatic recognition of banknotes by machines is a new technology in recent years. Among them, high speed and high reliability are the most important requirements of a banknote recognition system. There are many kinds of classifiers in banknote recognition system, among which neural network and support vector machine are used frequently. The advantage of neural network classifier is that it can be classified in complex feature Spaces without too much knowledge of the problem. Its disadvantage is that it requires a large number of samples for training. In contrast, support vector machines do not require many samples to train. For the training system, it can directly construct the optimal classification plane. For nonlinear systems, samples are transformed from low-dimensional space to high-dimensional space by nonlinear transformation. Markov model is a probabilistic method to model data, which has been successfully applied to voice and handwriting recognition systems.

The selection of feature extraction method should be based on the characteristics of banknote image and banknote recognition system. As the banknote runs through the system, its image is seen as a data series. When banknote is running in a high-speed system, the

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changes in the sequence are different. Therefore, a complex model needs to be constructed
to describe this pattern over time. Markov models are able to describe the properties of
these patterns. It is an effective method in the banknote recognition system. The method of
this paper includes two contents, one is the banknote feature extraction, that is, the
banknote image is converted into feature vector. Another method is to use Markov model to
classify these feature vectors.

Through the study of Markov architecture, we know that the evaluation problem is
solved by Forward-Back-ward algorithm, the decoding problem is solved by Viterbi
algorithm, and the sample training problem is solved by Baum-Welch algorithm. The
maximum likelihood estimation criterion is used in the training process, and the
classification accuracy is gradually improved through each iteration. The number of states
of Markov model, the number of training times, the number of Gaussian model and the
number of iterations are obtained through the empirical data.

2 Banknote feature extraction

Feature extraction is an important step in banknote recognition, and many scholars have
made great efforts in the research of banknote feature extraction. Takeda and Nishikage
proposed a mask method to extract banknote features. Then they applied genetic algorithm
to it and proposed an optimized mask extraction technique. Hassanpour et al. characterized
the shape, background color, and texture of banknotes. How to extract the features that
reflect the main information of banknotes is crucial for identification. The original banknote
image acquired by 25dpi sensor is preprocessed. Due to the difference in the horizontal
direction of banknote images in the process of collection, it is necessary to carry out
brightness equalization processing for banknote images. The process of collecting banknote
images is carried out in high-speed equipment, so the banknote images have geometric
inevitably. Therefore, it is necessary to perform tilt correction for banknotes, and the pre-
processing process is shown in Figure 1.

![Fig. 1. Image preprocessing.](image-url)

In this paper, grid is used to extract the features of banknotes. Firstly, the banknote
image after preprocessing is analysed. Because the calculation amount of selecting the
whole banknote image is very large, the region that can most reflect the main information
of the banknote image should be selected. The selected areas are then divided into 16×6
grids. Then the selected area will have 6 rows and 16 columns. Finally, the gray mean of
each grid is calculated and normalized into the 96-dimensional feature vector of the
banknote image. This is denoted by \( X^T = (x_1, x_2, \ldots, x_{96}) \). The feature vector is
normalized according to formula \( \bar{X} = X^T / \| X^T \| \). Using grid method to extract features has
the advantages of simple calculation and suitable for high-speed equipment. Figure 2
shows the process of banknote feature extraction.

![Fig. 2. Banknote image feature selection.](image-url)
3 Hidden markov model (MHH)

Statistical learning theory can effectively analyse the variability and similarity of patterns, it is based on the principle of risk minimization, and it is also the simplest inductive decision criterion. Markov model is a double stochastic process, which is defined by Markov chain with fixed state. Compared with the classifiers such as neural network and support vector machine, Markov model has faster convergence rate and easily reaches the local minimum. It is able to express the sequence of vectors that change over time very clearly. In view of the advantages of Markov model, this paper applies it as a classifier to the face value and denomination recognition of banknotes.

The training process is to find the best model parameters by analysing the known sample data. This paper builds a model for each banknote and selects the parameters of the model by optimizing the training data. The Baum-Welch algorithm was applied in the training process, and the Forward-Backward algorithm was used to evaluate the effectiveness of the training data. The Markov model training process is calculated as follows:

\[
\bar{\lambda} = \text{argmax}(P(\lambda_i|O_i, i = 1, \cdots, t))
\]

where \(\bar{\lambda}\) is the optimal Markov model, \(O_i\) is the observation sequence in the training database, and \(P(\lambda_i|O_i)\) is the observation sequence \(O\) and the probability under model \(\lambda\). Suppose the input vector \(X\) is represented by \(O = O_1, O_2, \cdots, O_T\). The optimal classifier will calculate the model \(\lambda^*\) with the highest probability.

\[
P(\lambda^*|O) = \max_{\lambda_m} P(\lambda_m|O)
\]

\[
P(\lambda_m|O) = \frac{P(O_m|\lambda_m)P(\lambda_m)}{P(O)}
\]

Formula (3) is Bayes criterion. Maximizing the prior probability \(P(\lambda_m|O)\) is equivalent to maximizing the likelihood probability \(P(\lambda_m|O) = P(\lambda_m)P(O|\lambda_m)\). Here \(P(\lambda_m)\) is the prior probability and \(P(O|\lambda_m)\) is the conditional probability for a particular currency. So, maximizing \(P(\lambda_m|O)\) is the same as maximizing \(P(O|\lambda_m)\). Given HMM model \(\lambda\), the selection of model state number, training iterations and Gaussian number is determined experimentally.

4 Experimental results

4.1 Experimental database construction

It is very important to build a database for the banknote recognition system. The sample in this paper adopts the 2005 version of RMB. RMB has 5 main currencies, each of which has four faces, so there are 20 categories for RMB recognition system. 800 samples were collected for each category, so that is a total of 16,000 samples. All samples are collected by sensors, and the samples are divided into two data sets. The first data set is the training set, including the sample number of 6000 banknotes. The second data set is the test set,
including the sample number of 10,000 banknotes. In Figure 3, \(X\)(\(X=5,10,20,50,100\)) represents the face value of the banknote and \(Y(Y=1,2,3,4)\) represents the face direction of the banknote.

4.2 Analysis of experimental results

HMM model parameters include state, Gaussian function, and the number of training iterations. Table 1 shows that when the number of model states is 4 and the number of Gaussian functions is 5, the banknote recognition rate reaches the highest value. The number of iterations has little influence on the recognition rate.

<table>
<thead>
<tr>
<th>Gauss number</th>
<th>Recognition rate (%)</th>
<th>The number of states</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>4</td>
</tr>
<tr>
<td>1</td>
<td>72.38</td>
<td>82.76</td>
</tr>
<tr>
<td>2</td>
<td>77.49</td>
<td>90.34</td>
</tr>
<tr>
<td>3</td>
<td>91.54</td>
<td>90.68</td>
</tr>
<tr>
<td>4</td>
<td>90.32</td>
<td>89.08</td>
</tr>
<tr>
<td>5</td>
<td>93.54</td>
<td>92.04</td>
</tr>
</tbody>
</table>

Figure 3 shows that the recognition rate increases when the number of iterations exceeds 40, whereas the recognition rate decreases. Figure 4 shows the recognition rates with different classifiers. The average recognition rate of HMM is 93.9%, which is higher than that of neural network and support vector machine. This paper analyses the causes of sample errors as follows:

1. The defacement of banknote images is one of the reasons for misclassification. Banknote in circulation will cause defilement inevitably, especially in the main areas of banknote.

2. Because the collecting process is carried out at high speed, the tilt of the banknote image is also one of the reasons for misclassification.

3. The pattern of RMB with the same face value and facing is very similar, which is also the reason for misclassification.

Fig. 3. Recognition rate of each denomination (number of states :4, Gauss number:5).

Fig. 4. Comparison of recognition rates of different classifiers
5 Conclusion

This paper presents a banknote recognition system based on Markov model and evaluates its performance. Grid technology is used to extract banknote image features, which can satisfy the high speed and high reliability of the banknote recognition system. The number of states, the number of Gaussian functions and the number of iterations of Markov model are determined by the experimental data. The sample of this paper is the 2005 version of RMB, and a total of 16,000 samples are collected for the test. The experimental results show that Markov classifier can achieve higher recognition rate than neural network and support vector.

This work was financially supported by Higher Education 2023 Heilongjiang Provincial Education Science "14th Five-Year Plan" Key projects (GJB1423136)

References