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A Review of Research on Handwritten Chinese Character Recognition with Multi-Feature Fusion

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Abstract: This paper analyzes the progress of handwritten Chinese character recognition technology, from two perspectives: traditional recognition methods and deep learning-based recognition methods. Firstly, the complexity of Chinese character recognition is pointed out, including its numerous categories, complex structure, and the problem of similar characters, especially the variability of handwritten Chinese characters. Subsequently, recognition methods based on feature optimization, model optimization, and fusion techniques are highlighted. The fusion studies between feature optimization and model improvement are further explored, and these studies further enhance the recognition effect through complementary advantages. Finally, the article summarizes the current challenges of Chinese character recognition technology, including accuracy improvement, model complexity, and real-time problems, and looks forward to future research directions.

Keywords: Chinese character recognition; Multi-feature fusion; Machine learning

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1. Introduction

Chinese characters have been inherited as a treasure of history and civilization for thousands of years. In continuous inheritance and development, they have become one of the most widely used languages in the world today, occupying an indispensable place in many fields such as license plate recognition, automatic driving, intelligent security, drug identification, etc. However, Chinese characters themselves have the characteristics of a wide range of categories, complex structures, and more similar characters, which lead to greater difficulties in Chinese character recognition [1]. Especially for handwritten Chinese characters, the phenomenon of "multiple characters" is caused by individual writing habits, which greatly aggravates the difficulty of the task of Chinese character recognition and evaluation, and thus the recognition of handwritten Chinese characters has always been difficult and is a hot topic in research.

Currently, the recognition of handwritten Chinese characters is divided into two categories: offline recognition and online recognition, in which online recognition is less difficult and more accurate due to the real-time collection of data on stroke order, writing speed, strength, angle, and other characteristics of Chinese characters

[2]. Offline recognition, on the other hand, can only extract image features by studying the two-dimensional image information of the Chinese characters themselves because of the lack of time series information, so the recognition is more difficult and the accuracy rate is difficult to guarantee [3]. According to the current research on the recognition of offline handwritten Chinese characters, the research direction can be divided into two main categories. The first category is based on traditional Chinese character recognition methods, which usually focus on image preprocessing to enhance the effective features of the image, provide high-quality inputs for the subsequent feature extraction and classification of Chinese characters, and rely highly on the effective extraction of features.

Traditional recognition methods mainly start from structural and statistical features (e.g., Gabor features, Gradient features, HOG features, etc.) for feature extraction and information recognition of Chinese characters, including discriminative feature learning (DFE), discriminative learning quadratic judgment function (DLQJF), and discriminative learning quadratic judgment function (DLQF) [4]. Discriminative learning quadratic discriminant function (DLQDF) classifier and Support Vector Machine (SVM) are widely used, but traditional methods heavily depend on data quality, leading to significant bottlenecks. Their best recognition accuracy on DB1.1 of CASIA-HWDB has not exceeded 93%, which is comparable to human performance [5]. With the enhancement of arithmetic power and the concept of neural network, the Swiss Dalle Molle Institute for Artificial Intelligence Research (IDSIA) applied Convolutional Neural Network (CNN) for the first time to the task of recognizing offline handwritten Chinese characters in the dataset of the International Conference on Document Analysis and Recognition (ICDAR) competition in 2011, and the accuracy reached 94.77%, which has surpassed the bottleneck of the traditional algorithms [6].

Since then, the research of Chinese character recognition based on deep learning algorithms has become the focus of scholars. According to previous research, offline Chinese character recognition based on deep learning algorithms can be divided into three categories: Chinese character recognition based on feature optimization, Chinese character recognition based on model optimization, and Chinese character recognition based on fusion technology.

2. Overview of Chinese character recognition based on non-fusion ideas

The usual process of handwritten Chinese character recognition based on machine learning is data preprocessing, feature extraction, model training, model testing and validation, and the optimization of each link has the potential to improve the effectiveness of Chinese character recognition and reduce the complexity and requirements of the model.

2.1. Handwritten Chinese character recognition based on feature optimization

Since Chinese characters have a more complex structure and a larger number of characters than numbers and letters, many researchers have analyzed their own structure and composition and extracted a variety of features such as center of gravity features, grid features, etc. to strengthen the quality of the data and improve the recognition efficiency. Ren and Li proposed to use the parameters of binary character image projection to construct feature vectors of characters, and the constructed feature vectors are used as inputs to the support vector machine model, and experimentally verified the feasibility of this idea, but the dependence on preprocessing is too strong, thus the recognition effect is unstable [7].

Jia *et al.* proposed a two-dimensional Principal Component Analysis network for the task of classifying the images, and the original data are projected into two-dimensional space to retain as much as possible of the original data [8]. In a two-dimensional space, the main information is retained as much as possible while reducing the

data's dimensionality. This simplifies the model by enhancing the key features, thereby reducing computational complexity. Although this leads to improved recognition efficiency, there is a slight corresponding decrease in accuracy. Zhou and their team proposed a multi-feature handwritten Chinese character recognition technique based on SVM, which added the center of gravity feature and stroke feature in addition to the single grid feature and achieved a higher correct rate than the traditional recognition methods [9].

Yu extracted the inflection features in the stroke sequence of Chinese characters and segmented them to form the stroke segments, then classified the segments with the help of SVM, and finally formed the coding sequence of the segments, combined with the statistical analysis of Hidden Markov Model (HMM), and finally accomplished the task of recognizing Chinese characters, which is mainly focused on the structural characteristics of Chinese characters themselves [10]. This idea mainly analyzes the structural characteristics of the Chinese characters themselves, disassembles the Chinese characters, and finally compares and analyzes the results of the statistical analysis to arrive at the classification results, which is a kind of optimal use of the feature sequences. Tao and Lu proposed an improved Speeded-Up Robust Features (SSURF) feature based on the fast Scale-Invariant Feature Transform (SIFT) implementation algorithm, Speeded-Up Robust Features (SURF). By combining the advantages of the SURF algorithm in region matching and the structural characteristics of Chinese characters, they fused global and local features to form the SSURF feature. Through fuzzy reasoning, they derived fuzzy matches for key points in the text to be recognized, arriving at classification results despite image deformation and variations in brightness and darkness [11]. This results in better recognition in the case of image distortion and brightness difference.

Gan *et al.* proposed a coarse classification based on wavelet decomposition of density features, combined with a binary tree SVM for similarity optimization, by wavelet decomposition of the data and the formation of integrated features, effectively improving the recognition speed and recognition rate [12]. Zhu and their team proposed a method that combines stroke node feature recognition with the original stroke characterization, improving recognition for more complex Chinese characters by enhancing the depth of stroke feature extraction [13]. Tang and others proposed the extraction of graph features for the problem that image pixels are difficult to express the characteristics of Chinese characters, which can more effectively represent the essential characteristics of Chinese characters, and lays the foundation of feature optimization for better Chinese character recognition [14].

Overall, although the single-feature optimization-based Chinese character recognition method has fully exploited the features of Chinese characters, there is still a bottleneck because of the limitation of classification technology.

2.2. Handwritten Chinese character recognition based on model optimization

With the first application of CNN to the Chinese character recognition task in 2013 and obtaining a high accuracy rate, many researchers began to explore the great potential of neural network models in the Chinese character recognition task. Wu *et al.* proposed to integrate the Alternately Trained Relaxation Convolutional Neural Network (ATR-CNN) idea for model improvement, which improved the accuracy by 1.29% and provided theoretical ideas for later researchers to conduct model fusion studies [15]. Li *et al.* proposed to utilize the higher-order difference method for data enhancement and replace the last 2 layers with the increase in the number of neurons based on the original LeNet-5, which reduces the size of the model and improves the effect by reducing the layers and improving the image quality [16].

Chen *et al.* proposed an improvement of the Inception module, which simplified the module structure, strengthened the scalability of the Inception structure, reduced the difficulty of fusion application with other models, and provided great convenience [17]. Cui *et al.* enhanced the input of the model by incorporating the

similarity comparison algorithm using the characteristics of associative memory of the Hopfield neural network, and verified the feasibility of the improved model, providing a new research direction for handwritten Chinese character recognition [18]. Wang *et al.* proposed using a batch normalization processing layer and the Root Mean Square Propagation (RMSprop) gradient optimizer incorporated into the CNN. This approach helps reduce the impact of the vanishing gradient problem to some extent [19].

Recent research on model optimization has shown that the overall performance of Chinese character recognition tasks is improving. This advancement has been achieved through multi-dimensional and multi-model approaches, providing a foundation and direction for research on model characteristic fusion.

3. Handwritten Chinese character recognition with multi-feature fusion

Single-model Chinese character recognition is typically improved by enhancing the model's depth, increasing the number of parameters, and refining features. However, due to the inherent limitations of the mode itself, the extent of improvement is constrained. By fusing multiple features to complement each other, it may be possible to push the recognition performance of the model to its upper limits. Recent research suggests that current approaches can be categorized into three major directions: feature-based fusion, "feature + model" fusion, and "model + model" fusion.

3.1. Character recognition based on feature fusion

With the in-depth study of neural networks and the development of various special mechanisms, such as attention mechanisms and confidence measures, new ideas have emerged for the study of Chinese character recognition. Yue proposed a Particle Swarm Optimization (PSO)-Backpropagation Neural Network (BPNN) model optimized using the Particle Swarm Optimization algorithm. This model leverages the global optimization capabilities of the PSO algorithm and enhances convergence, demonstrating the feasibility of optimizing neural network models through the integration of other algorithmic features [20].

Qin *et al.*, using a modified quadratic function and a Deep Boltzmann Machine fusion model, improved the accuracy and efficiency of recognition by incorporating confidence measures to coordinate the model. This approach successfully integrated the two models to achieve complementary advantages, providing a basis for the idea of synergizing technologies for Chinese character recognition [21]. Xu proposed a Convolutional Neural Network (CNN) based on Attention (ATT-CNN) that utilizes the Convolutional Block Attention Module (CBAM), a two-way attention mechanism. The model extracts features using the Inception module, accelerates convergence with the Batch Normalization layer, and enhances the importance of key information through the bidirectional attention mechanism. This approach achieves better detection accuracy than AlexNet and GoogleNet and represents an initial fusion of "mechanism + features" [22].

Cheng and their team proposed to use the attention mechanism to fuse the global and local features under the multi-scale channel, to speed up the training speed of the model with more effective feature extraction, and completed a "mechanism + feature" fusion model optimization [23]. Guo and others proposed a fused full convolutional layer classifier structure and fused deep image features with spatial features, taking advantage of deep convolutional feature extraction, improving recognition accuracy, reducing model size, and demonstrating the desirability of combining feature fusion in the fusion of classifiers [24].

3.2. Chinese character recognition based on "feature + model" fusion

In the field of deep learning and pattern recognition, feature extraction and model fusion are key techniques for improving recognition accuracy. In recent years, numerous researchers have been exploring how to combine

feature extraction techniques and different model architectures more effectively through innovative approaches to achieve higher recognition performance. Mao and others proposed to fuse the feature output of the previous layer with the feature map of the current layer as the input of the next layer each time, which can preserve more effective information, and attempted to perform feature fusion with superposition, which improved the classification accuracy but sacrificed the space and efficiency of the model accordingly [25].

Wei and colleagues proposed a sparse hypergraph plus pairwise constraint technique to form a new multi-model hypergraph, which has some improvement effect compared to a single technique, but the overall recognition rate is still to be improved [26]. Li and the team proposed to carry out multi-level grouping feature extraction for the problem of insufficient or redundant feature extraction, and fusion of features, which effectively refines the feature information, has a certain enhancement effect on the recognition rate, and provides a new idea for feature fusion [27]. Zheng *et al.* proposed combining Two-Dimensional Principal Component Analysis (2DPCA) with a convolutional neural network (CNN) by image information screening from 2DPCA and then input to CNN and successfully reduce the training time of the model without losing high correctness, providing the idea of the fusion of feature extraction techniques and neural networks [28].

Wu and the research team proposed to fuse the attention layer with the convolutional layer based on the AlexNet model, which reduces the impact of the loss of information in the convolutional layer and improves the recall of the model and is a fusion application of "mechanism + model" [29]. Yang proposed using a weighted fusion of features in the fully connected layer and combined with the multilevel features of LeNet-5 to reduce the error rate of recognition, which is an idea of feature fusion + model feature fusion [30]. Ren *et al.* proposed an algorithm to combine the suppression noise mechanism with CNN, through which the algorithm can effectively remove the random noise of the data and improve the training speed and efficiency of the model, which is a better attempt at the preprocessing mechanism + model fusion [31].

Huang and others proposed to use 8-direction features to replace the traditional image input into the CNN and experimentally proved that although 8-direction features and the original image have a similar recognition rate, 8-direction features have a more stable performance, which is a practice of improving the features + model [32]. Zhou and Zhang proposed adding the weighting feature on top of the convolutional layer based on the original LeNet-5 network, to improve the problem that the network does not treat different words differently, and there is a certain improvement in the recognition rate, which is a kind of fusion of the region weighting mechanism + model [33]. Zhu and colleagues proposed an algorithm based on feedback knowledge migration, by decomposing the convolutional neural network into the main network and sub-network, passing the learning task to the sub-network, and then converging the learning results through knowledge migration, which reduces the phenomenon of gradient dispersion to a certain extent, guarantees the accuracy of recognition, and provides a new idea for the fusion of the Chinese character recognition model [34].

Zhou *et al.* proposed the idea of incorporating dynamic network surgery based on the SqueezeNet model, which ensures the accuracy as much as possible with parameter reduction, and finally compresses the model size and improves the convergence speed at the expense of partial accuracy, which is a kind of fusion attempt of technology + model [35]. The team of Tu proposed to fuse the shallow details and high-level semantics of Chinese characters to obtain features with high differentiation, which combined with the deep residual network to improve the recognition ability of Chinese characters, and it is a practical application of deep fusion of features + model [36]. Chen and others proposed to fuse spatial information (spatial relationship of pen shapes, etc.) into deep residual networks, which reduces the dependence on feature information and is an attempt at the fusion of features + models [37].

3.3. Chinese character recognition based on "model + model" fusion

In the task of Chinese character recognition, the fusion of multiple models and the innovative design of models are important ways to improve the recognition performance. Researchers have continuously explored new fusion strategies and model architectures intending to improve recognition accuracy while maintaining algorithmic efficiency. Chen and Huang proposed a coarse and fine granularity classification model, in which the coarse classification is performed first and then the fine classification of similar words is performed, forming a joint classifier, which slightly improves the recognition accuracy over a single classifier, but the overall accuracy is still insufficient, which side-steps the fact that the fusion of a single classifier cannot bring about a significant improvement in effectiveness, and it is best to be used as a back-up idea to improve the recognition performance [38].

Zhang *et al.* proposed the idea of multi-channel cross-fertilization and used it to improve the Inception module of the deep residual network, which demonstrated a better classification performance and showed an idea of in-model fusion optimization [39]. Hou and Ni proposed an improved HCCR-IncBN model based on GoogLeNet, which combines the advantages of the Inception module, resulting in a model that occupies less space, converges faster and has a certain guarantee of recognition accuracy, which provides a practical basis for the fusion of the Inception module with other models [40]. Wang proposed to incorporate the Inception module in dense neural networks, experimentally verified the feasibility of this optimization, and proved the portability of the Inception module [41]. Guan and Ding proposed a fusion model based on a capsule network and deep confidence network for the problem of difficulty in Chinese character feature extraction, which can capture the relationship between attributes such as feature position, feature direction, etc., and obtain better initial weights, and has a better recognition rate in experimental performance, which is a fusion attempt of model + model [42].

Yang and Huang proposed a method to address the suboptimal classification effects of traditional RBF and K-means algorithms. They proposed first-class reduction and then model fusion, with an improved K-means algorithm to construct the nodes of the RBF model and improve the training speed of the model, which is the deep practice of model + model [43]. Zhang and Zhang proposed to fuse Deep Belief Network (DBN) and You Only Look Once (YOLO) with the help of the maximum entropy feature, which improves the generalization ability and recognition rate of the model, which is an ingenious fusion of model + model [44]. Li *et al.* proposed to fuse a convolutional neural network with a deep belief network by using a fusion factor, and experimentally verified that the fused CNN-DBN model possesses higher accuracy than a single model, which realizes the preliminary fusion of model + model [2]. Ma and Xu proposed the stacked model idea, by superimposing the training model with a subset of similar words after the pre-training model, which fits the idea of coarse classification + fine classification, and can better accomplish the task of recognizing multiple shapes of a word [45].

4. Summary and prospects

To summarize, the handwritten Chinese character recognition technology is constantly progressing, and researchers have explored the fusion strategies in various cases through various innovative methods, including the mutual fusion among features, models, and technological mechanisms, which have significantly improved the accuracy and efficiency of recognition. From feature optimization based on traditional machine learning to the innovation of deep learning models to the fusion application of multiple models and techniques, each step has brought new breakthroughs in the field of Chinese character recognition. However, there are still some challenges, such as room for accuracy improvement, model complexity, real-time performance, etc., in the future through the fusion of technologies.

Disclosure statement

The authors declare no conflict of interest.

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